water

Ethiopian Journal of Water Science and Technology

AWTI

volume 3 no 1 July 2000

Special Issue

ARBA MINCH WATER-TECHNOLOGY INSTITUTE

Proceeding of the Symposium on Sustainable Water Resources Development

Arbaminch

5 - 6 July 1999

Special Issue

ARBA MINCH WATER-TECHNOLOGY INSTITUTE

Proceeding of the Symposium on Sustainable Water Resources Development

Arbaminch
5 - 6 July 1999

contents

water

Is a biannual published by the Arbaminch Water Technology Institute. Basically the journal entertains and / or supposed to entertain different approaches to the major issues and problems in the water sector; it is a forum which gives a great deal of access to various professional views and outlooks to be reflected and discussed.

It also makes possible for the rich experience and wisdom of outstanding personalities in water engineering to reach and be utilized by those concerned. Most of all, **water** encourages and gives much more opportunity to young engineers to introduce their works and eventually to cultivate the tradition of using a journal.

Finally, with the ultimate goal of bringing about basic changes and development in all aspects of the country's water sector, **water** calls for articles to be of the purpose.

editorial board

guide to authors

Manuscripts in water science and technology are considered for publication. Manuscripts must be in English. Scientific and research papers, review papers, technical notes, short reports, letters to the editors are well accepted in **water.** Papers already published, or in press elsewhere, will not be accepted. The total length of a manuscript including figures tables and references should not exceed 7000 word equivalents (10 pages). The original and three copies should be submitted.

The manuscript must be addressed to: Research and Publication Coordination Service, Arbaminch Water Technology Institute, P.O. Box 21, Arbaminch, Ethiopia. All copies should be carefully checked and error free.

Authors requiring the return of the manuscript or original material should make their request known as soon as possible, as they will normally be discarded one month after publication.

The first page should contain the full title of the manuscript, the name(s) of the author(s) including addresses and the institution(s) in which the research was carried out. If more than one author is involved, the author to whom all correspondence will be addressed should be indicated by an asterisk. The first page should also contain the ABSTRACT.

A desirable, though not strictly prescribed plan, for the organization of a research paper is to start with an INTRODUCTION giving a description of the problem and its relation to other works in the same field. The objective(s) of the investigation should also be stated in this section. Abbreviations (e.g. BAP,, 6-Benzlyaminopunne; GA3, gibberellic acid 3; etc.) should be put under the INTRODUCTION in a separate paragraph. The remaining sections can then cover MATERIALS AND METHODS, RESULTS AND DISCUSSION or CONCLUSIONS. Then follows ACKNOWLEDGMENTS, if any, and the last item would be a list of REFERENCES.

References in the text should have the following form:

-Darwin and Morgan (1993) or, if more than two authors, Andersson *et al.* (1993).

-(Hartmann and Kester, 1975; Andersson *et al.*, 1993; Darwin and Morgan, 1993) - chronologically-

Ethiopian names should be in direct order,, that is, the full first name followed by the father's name; e.g 'Solomon Kassa'and not Kassa, S.

Listing of references is alphabetical, and should have the form:

-Kalb, J.E. (1978). Miocene to Pleistocene deposits in the Afar depression, Ethiopia. water.- *Ethio ,p. J. Sci.* 1:87-98.

-Hartmann, H.T. and Kester, D.E. (1975). *Plant Propagation: Principles and Practices.* Prentice-Hall, Inc., Engelwood Cliffs, New Jersey, pp. 53-66.

To cite some pages in a publication prepared by one or more editors, an recommended format is:

-Fraser, D.A.S. (1971). Events, information the structural model (with discussion). in: *Inference,* pp. 32-35, (Godame, V.P. and Rinehart, Toronto.

Tables, however small, should bear arabic numerals and be referred to in the text by their numbers, e.g. 'Table 4'. Each table must be typed on a separate sheet and should be placed at the end of the manuscript.

All illustrations should be given separately, not stuck on pages and not folded. They should be numbered as figures in sequence with arabic numerals. Each figure should have a descriptive legend. Black and white photographs can be submitted to **water**; they should be clearly numbered on the back in pencil.

Electronic Format

Authors of accepted papers will be asked to provide a copy on 3.5" disc to facilitate rapid processing of manuscripts. Discs should be labeled with information on the version of operating system, word-processing and drawing packages used, the authors' names and the short title of the article. In the text, hard returns should only be used at the end of paragraphs and automatic hyphenation should be turned off. When using symbols to denote special characters please supply a list of all codes used. Figures and diagrams produced in most of the popular Macintosh or PC drawing packages are acceptable, but should not be saved as Postscript files. All filenames should be listed. Authors must check their papers thoroughly before submission and ensure that the text on the disc matches the hard copy. If the disc differs from the hard copy, the saved file will be taken as definitive.

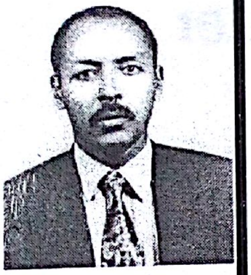
editorial office

Arbaminch Water Technology Institute, Research and Publication Coordination Service, P.O. Box 21, Arbaminch, Ethiopia.
Tel.: (00251) 06 / 810453 Fax: (00251) 06 / 810279
Chief Editor: Nigussie Teklie & Degefa Ayane
Assistent Editor: Feseha G/slassie
Printing: Addis Abeba
DTP: Feseha G/slassie

subscriptions

water will be distributed for free up to the end of 1999.

We would be very grateful should you send us names and addresses of individuals or institutions, if any, who are working in the water sector and interested in the contents of our journal. We very much like to send them free copies.



Dear Readers/ Contributors:

This issue of 'WATER', the fifth in the series and the third special issue, is dedicated to the proceedings of the third symposium on 'Sustainable Water Resources Development' organized from 5-6 July 1999 by Arbaminch Water Technology Institute.

In this symposium 24 paper presenters and 101 participants from within the country and abroad have taken part. As such, I can say it has given ample opportunity for sharing ideas among participants with different experiences.

I owe a particular debt of gratitude to contributors and the participants of this symposium. The success of the symposium was highly dependent on the efforts of the organizing committee and your contribution. Without your contribution and participation this proceeding would have not been so complete and nicely presented.

I am grateful too to the readers of the earlier issues who have stimulated us by their correspondence, and especially to those who, by bringing errors and obscurities to our notice, have helped us to achieve a better accuracy and clarity.

Finally, on behalf of the editorial board, I would like to invite all concerned experts in the water sector to contribute and publish in 'WATER' the latest developments in technology and the experiences they have gained in the development of water resources.

Nigussie Teklie
Editor -in-Chief

Third Symposium on 'Sustainable Water Resources Development'

5 - 6 July 1999
Arbaminch

Welcoming Address

by Nigussie Teklie,
Secretary,
Symposium organizing commitee

Invited Guests, Dear Participants
Ladies and Gentlemen:

It is a pleasure for me to have the opportunity to welcome you to the symposium organized for the third time on **"Sustainable Water Resources Development"**, on behalf of the organizing committee and myself. I hope and believe that your participation in this symposium will be a stimulating experience.

Invited guests, Dear participants
Ladies and Gentlemen:

The development of water resources involves the conception, planning, design, construction, and operation of facilities to control and utilize water. Basically, this is the responsibility of the water resources engineer. And this responsibility confronts him with the basic problem of man, namely to transform the natural world into a humane environment, an environment that we want to see providing a growing number of people with an increasingly better life, on the basis of sustainable growth. However, the services of other specialists such as economists, political and legal scientists, geologists, electrical and mechanical engineers, chemists, biologists, and other specialists in the natural and social sciences are also required to give solutions to water resources development and management problems. Thus, water resources development problems are of interdisciplinary nature and special conditions of each project must be met through an integrated application of the fundamental knowledge of the various disciplines. Therefore, the main objective of this symposium is to bring together engineers and other specialists involved in the water resources development activities in the country and abroad to share experiences and exchange scientific information.

The Arbaminch Water Technology Institute has organized such symposia in the last two years. The issues raised in the discussions and the opinions expressed by the participants of those two symposia were very useful and have given encouragement and inspiration to the sponsors and organizers to hold such symposia on a regular basis. This symposium is, therefore, the outcome of the combined efforts of the sponsors, the organizing committee, the participants of last symposia and your contribution to the present one.

During the two-day symposium, 24 papers are expected to be presented in the area of Hydrology & watershed management, Irrigation, Environment & Water, and Water Resources Development studies. An exhibition will also be held during the break time of the symposium.

I hope that this symposium will be of paramount importance in providing a chance for a wide exchange of ideas and experiences among the professionals in the water sector.

With this brief remark, I now have the honour to invite his excellency Ato Hailemariam Dessalegn, the dean, to the floor for his opening statement.

Thank you

Hailemariam Dessalegn, Dean

Opening Address

Distinguished Guests

Dear participants

Ladies and Gentlemen

On behalf of the Arbamich Water Technology Institute, I am very glad to have this opportunity to make an opening address to the third symposuim on Sustainable Water Resources Development.

My Country, Ethiopia, is a relatively large country with an area of about 1.1 million sq. km. and a population of about 62 million. It is a country emerging from long years of protracted civil war, political strife, and harsh economic and human calamities that culminated in recurrent draught and many years of economic mismanagement. Despite positive strides in Macro-economic reforms and encouraging performance in the last few years, Ethiopia still remains second to the bottom of the world's poorest countries with a per capita GNP of about US 100. Traditional rain fed subsistence agriculture accounts for the largest share of the GDP, making the country's economy vulnerable to the increasing erratic patterns of precipitation that ranges from as low as 50mm in the dry regions of the north-east to about 1,350mm in the wettest areas of the South West. The comparative degrees of food availability and poverty with in Ethiopia's regions are strongly linked with the amount of rainfall and the resulting quantity of soil moisture required to sustain farming and grazing.

When compared to neighboring countries, Ethiopia is endowed with significant amount of water resources, with a mean annual flow of about 110 Billion cubic meters (BCM) that drain into 11 river and lake basins. It's ground water resources are insignificant with an estimated annual renewable potential of only 2.6 BCM. When compared to surface water potential.

Ethiopia's seemingly abundant water resources are incompatible with the image the world has developed as a dry and famine-stricken country.

The paradox lies in the fact that these water resources are not properly harnessed: only 20% of the population has access to clean water, only 3% of the nations 3.5 mill. ha. of irrigable land is developed, and only 2.6% of its huge i.e. about 161,000 Gwh/yr hydro-electric power generation potential is harnessed. This potential probably makes the country next to Congo Kinshasa in Africa. These show extremely low levels of water resources development indictors indeed; even when compared to sub-Saharan African standards.

Distinguished Guests

Dear participants

Ladies and gentlemen

Sustainable water resources development, which is the focus of this sympothuim, is imperative for poverty alleviation, food self sufficiency and food security and for improving the quality of life for the impoverished majority of Ethiopians. While this fact is now widely recognized by the Government of the Federal Republic Democratic of Ethiopia, there exists a number of challenges and constraints that need to be addressed.

Eventhough there is an encouraging start from the side of regional governments in small-scale water resources development and comprehensive watershed management practices, and also National Water polices and River Basin Master plans studies are conducted at the central level, it should be supported by the Federal government Research & Training Institutions to solve some of the problems they face during their strive for development and implementation.

The fact that almost all of the country's river basins are transboundry water resources necessitate that Institutional capacities should be established to talk about sustainable water resources development in this country.

One of the bottlenecks for water resources development in this country is the non-existence of properly established water-resources Research Institutions when compared with our neighboring countries, which has got more than one Institutions of such type. The existence of such type of Institutions will extremely enhance the capacity of the country to take-up highly interlinked challenges in sustainable water resources development projects.

Distinguished Guests

Dear Participants

Ladies and gentlemen

The Arbminch Water Technology Institute, which has been engaged for almost a decade and half on training, education and small-scale research in water resources development, has now organized this sympothuim, which is the third in the series, to provide you-engineers and scientists-with the opportunity to meet and share information and experiences in the field of sustainable water resources development.

To my belief, this gathering will fill some of the gaps on information exchanges. I hope the deliberations during this few-days sympothuim will be successful both in the exchange of information and experience valuable for all the participants.

May I take this opportunity to extend my thanks to those who are prepared to present their papers and to those involved in the organization of the sympothuim.

With this brief remark, I now declare the sympothuim open.

Thank you !

Roughing Filtration of Water using Floating Plastic Media and Seeds of Moringa Tree

Ababu T/Mariam, *Lecturer, Arbaminch Water Technology Institute, P.O.Box.21,Arbaminch, Ethiopia*

Abstract

The design of water treatment plants that use surface water sources such as rivers, lakes and ponds call for an effective pre-treatment units to reduce the solids loading on subsequent units such as slow sand filters and rapid sand filters. Conventional pre-treatment units involving coagulation, flocculation and sedimentation are high cost and require higher levels of operational control. Roughing Filters are suitable alternatives. However, limited efficiency at high turbidity, cleaning difficulty and greater filter volume requirement particularly at high plant flow rates limit their suitability. An ideal alternative would be one that uses a compact filter volume, that can be run at higher rate, that is easier to clean and at the same time offers enhanced level of pre-treatment at higher turbidity. A pilot roughing treatment unit was set up that used gravel pipe flocculator followed by coarse size filter media of low specific gravity polyethlyene. To enhance the level of pre-treatment, seeds of the plant Moringa Stenopetala were used as coagulant. initial trials with kaolin and red clay suspension produced satisfactory results. The tests were followed by using sources of raw water from Lake Abaya and the "Kulfo" river. Higher level of pre-treatment was obtained at greater filtration rates and with a shallow depth of media. The pre-treatment was effective over a wider range of raw water turbidity. Cleaning was made easier because of the floating characteristics of the media. The cost of installation is estimated to be comparable with that of horizontal flow roughing filtration.

Scope of Application: Waste Water Treatment, Potable water treatment, Irrigation water treatment.

Background:

Surface water sources are invariably polluted with suspensions of silt, clay and organic matter. In tropical climates such as that of Ethiopia with rainy seasons concentrated in few months, erosion of the high intensity rain produces high levels of turbidities. An appropriate treatment alternative such as slow sand filter will call for an effective pre-treatment to reduce turbidities to a level required for slow sand filter treatment. In Ethiopia, many cities and small towns depend on surface water sources for potable water supply. Common problems reported from treatment plants are: Uneconomical rate of usage of chemicals for coagulation. Too much water required for washing of rapid sand filters; inefficiency in the washing process as a result of high silt load on rapid sand filters. Slow sand filters clog frequently requiring cleaning and sand replacement at uneconomic rate.

On the other hand, water supply development for rural communities mainly focuses on ground water sources. Surface water sources are excluded on account of poor water quality and the difficulty associated with running a treatment plant at rural level.

As a result of extensive research and development on the use of appropriate pre-treatment techniques for surface water treatment, there now exists well published volumes of literature on the design, technical functioning and operational experience of these pre-treatment techniques. Examples of such pre-treatment technologies include: plain sedimentation, up-flow roughing filtration, down flow roughing filtration, horizontal flow roughing filtration, river bank filtration, river bed filtration, modular subsurface sand abstraction, pebble-matrix filters, etc., (Smet, 1989).

Roughing filtration, either in the form of vertical up flow, down flow mode filtration or horizontal flow filtration are common alternatives. These filters use often coarse gravel or local media such crushed cocconut, rice husks, etc as filter media. The filters depend on the greater silt storage capacity of the coarse size media that minimizes the need for frequent cleaning. Low rate of filtration are prescribed for these filters as sedimentation is the dominant mode of solids removal. The reason being the chances for interception and straining are less with very coarse size media. At high plant flow rates, the volume requirement of such filters increases. Cleaning would require large labour force. At high raw water turbidity, the efficiency of roughing filtration decreases and together also the rate of clogging increases. Limited efficiency, large space requirement, absence of effective cleaning mechanism are,therefore, some of the inherent problems of roughing filters.

Objective of the Research

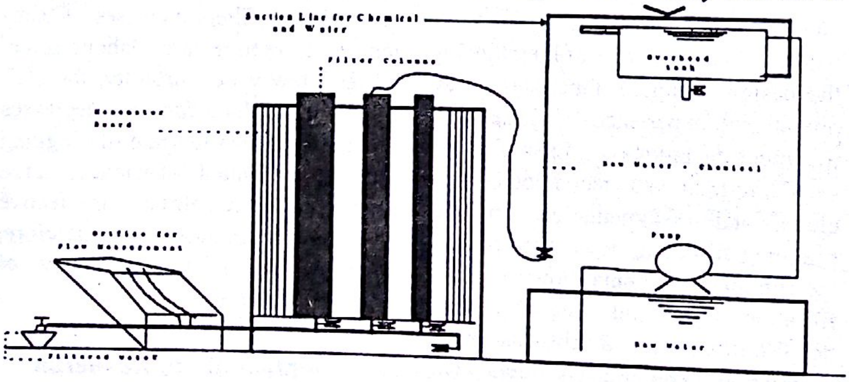
The objective of this research was to test the effectiveness of a roughing filtration set up that was thought to overcome some of the problems of roughing filtration stated above. The filter set up includes a gravel pipe flocculator, a coagulant addition using an indigenous plant seed, Moringa stenopetala for enhanced solids removal, a filter media using floating plastic, that is of finer size than the usual gravel roughing filter but that can be cleaned relatively easily.

Design variables, such as filter depth, filtration rate, head loss requirement, filter media size, range of raw water turbidity that can be treated, cleaning requirement were thought to be investigated. A preliminary design guideline using the above variables was also a possible target.

Pilot Setup and Test Procedure:

The pilot setup comprises the following:(see Fig.1)

1) A raw water tank on the ground, an over head tank in to which the raw water is pumped from the raw water tank and from which the water flows out to the filters by gravity.
2) A chemical dosing tank and dosing suction arrangement in which the coagulant enters the raw water pipe under negative pressure (suction).
3) A gravel pipe flocculator and two filter columns of 20 cm and 30 cm internal diameters. The coarser media (4.75mm size) is held in the 20cm filter column. The finer media (2.1 mm size) is held in the larger 30 cm filter column.
4) A filtered water collection tank and an outlet orifice meter for flow measurement.



5) A vertical manometer board for monitoring of head loss. Sampling points at depth intervals of 0.5m were provided connected by hoses to bottles for continuous sampling.

Test Procedure:

The raw water tank was filled with water from the different sources (Raw water sources used were from Lake Abaya, Kulfo river, and suspension made from kaolin and red clay.) These different sources of water have different settling characteristics. The water is pumped up from the raw water tank to the overhead tank from which it flowed to the gravel pipe flocculator by gravity. A coagulant was prepared and fed to the raw water through the suction line. The chemical dosing rate and solution concentration are pre-adjusted. The downstream valve is adjusted to correspond to the desired filtration rate and from then on a constant water level at the over head tank is maintained through recirculation by the pump. This maintains constant flow to the filters.

Monitoring of head loss and water quality was done at the several depths of both filter columns and at various times of filtration.

Several test were run using the different water sources, with varying rates of filtration and different levels of raw water turbidity. Different doses of coagulant were tried to investigate the effect of coagulant dosage on filtration.

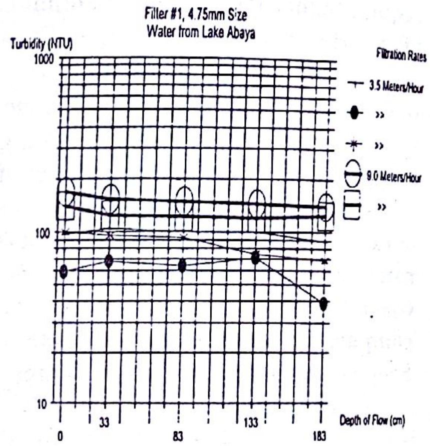
The coagulants used were mainly seeds of the plant type Moringa Stenopetala. This plant is indigenous to the Arbaminch region and has the local name "Aleko". Its leaves are eaten as vegetable while the roots are some times used for curing Malaria illnesses. the tree grows commonly over the region. A jar test was run to determine the optimum dose of coagulant for the various raw water tested.

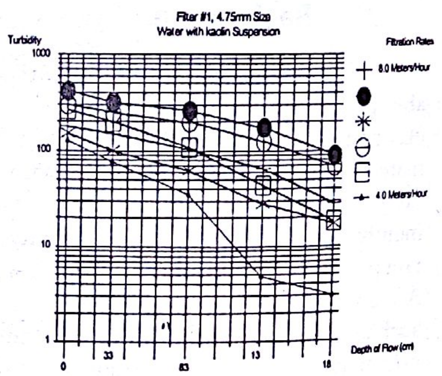
The dried moringa seeds were peeled and crushed using a coffee grinder. A solution of about 0.1% concentration was prepared by filtering the powder through a cloth to get rid of the coarse grain.

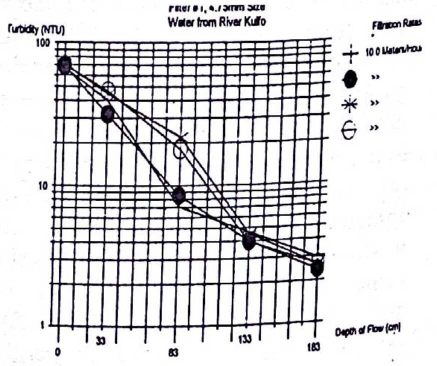
Apart from this natural plant, Aluminum Sulphate (Alum) was used for part of the test for comparison of the effectiveness of the Moringa seed with that Alum.

When the filter became dirty as is determined by head loss limit or water quality, filtration was stopped and cleaning was done by lifting the packing from above, floating the media and displacing the dirty water with raw or clean water from the top downwards. The quality of the wash water was being monitored with respect to time.

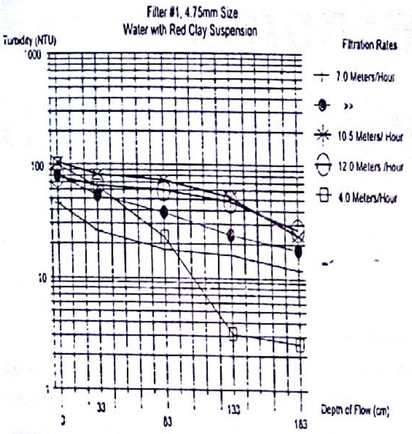
Test Results

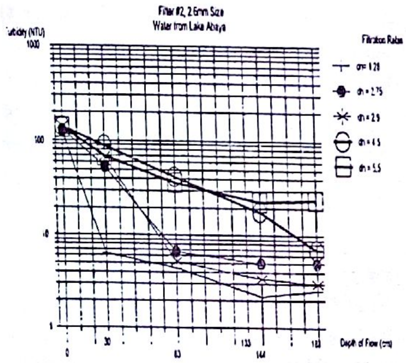


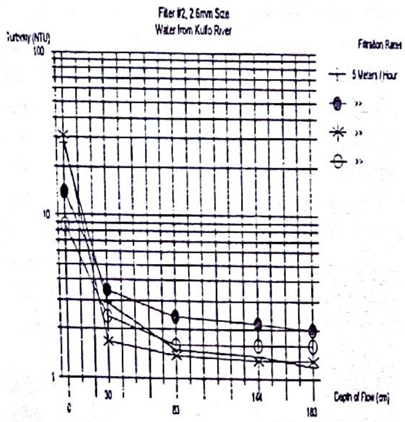


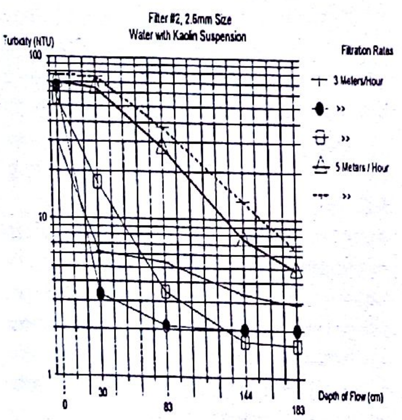


The figures below show the variation of water quality at several depths of filter column, at different filtration rate and for the different types of raw water used in the plot testing.

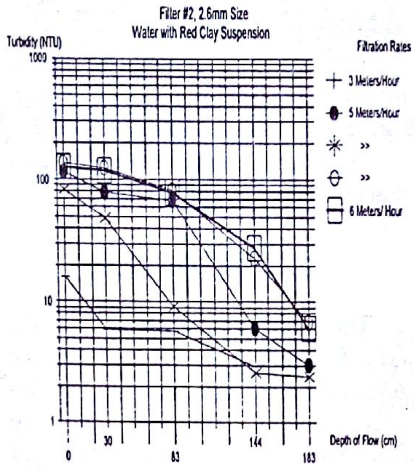








The quality of the filtered water is different for the different sources of water tried. For example, the water from river kulfo was the easiest to filter. With filtration ranges between 6-10



meters/ hour, it was possible to reduce turbidities to below 5 NTU using a depth of 1m of the coarse 4.75mm filter or only of 0.5m depth of the finer 2.2mm filter.

On the other hand, the raw water from Lake abaya contains very stable colloids. The coarser filter was effective at very low rate of filtration and over a larger depth of filter required. the finer filter of 2.2mm size was, however, effective at filtration rate between 5-10 m/hr and over filtration depth of up to 1.5 meters.

Similar results can be observed for raw water prepared using Kaolin and red clay.

Types and Characteristics of Raw water	Media Size Range Used	Range of Turbidity Tested	Effective Flow Rate	Effective Depth	Filtered Turbidity
I) River Water - Runoff from alluvial formations. Largely silt and little clay. Quick settling Characteistics	1.8 mm	< 500	6 - 10 m/h	> 0.5m	< 5 NTU
	5 mm	< 500	6 - 10 m/h	> 1.3 m	< 5 NTU
II) River water and Man made ponds. Runoff from Silt-clay formations. Intermediate rate of settlement.	1.8mm	<300	< 5 m/h	> 1.0 m	5 -10 NTU
	5 mm	< 300 NTU	< 4 m/h	> 1.5 m	5 - 20 NTU
III) Water from Natural lakes and runoff from clay formations. Stable colloidal suspensions.	1.8 mm	< 150 NTU	< 3.5 m/h	> 1.0 m	5 - 10 NTU
	5 mm	< 150 NTU	< 1 m/h	> 2 m	5- 10 NTU

Table 1. Design Variables According to Test Results.

Coagulant Dose

The use of coagulant (Seeds of the plant type Moringa stenopetala) was of great help in the removal of solids. The percentage removal in both filters without the use of coagulants is low at the high rates of filtration use. Otherwise, the filters have to be run at very low rates of filtration like the traditional roughing filter which may not be economical. Therefore, the use of coagulant is necessary for this type of filter.

Monitoring of flocs after the gravel pipe flocculator showed that macro size filtrable flocs are formed and the flocs have had good settling characteristics for all the types of water tested.

Media Cleaning

When the filter media became dirty, filtration was stopped and the media was made to float above while the dirty water was drained down. A greater volume of raw water was released from the top to displace the solids as the media floats again to the top. Draining the filter in this way 2 - 3 times will accomplish the cleaning. Stirring the media with rod while it is floated helps in further dislodging the solids.

Head Loss

The progression of head loss depended on the filtration rate and raw water quality. The initial head loss was low (3-10 cm) at higher filtration rate. This is expected as coarser size media have been used that have low head loss. the head loss is increased to about 10cm / 50cm of media depth after about 24-48 hours of filtration depending on the raw water quality.

Filtered Water Quality

The filtered water, over the range of effective filtration rates, is below 5 NTU. There was not much change in PH, conductivity as a result of adding the low doses of Moringa. The filtered water contained low chlorine demand. However, taste and odour problem started when filtration was stopped for few days and the filters were rerun again. Anaerobic condition was created in the filter that resulted in a constant odour problem. This finding suggests that the filters have to be run continuously. If there has to be stoppage for some reason, the filters have to be drained or possibly also cleaned.

Table.1 summarises the range of values for the common design variables that were used in the test and that gave good performance.

Conclusion

The pilot test results show that filtration rates as high as 6-10 m/hour can be allowed to remove solids using media size of 4.75mm and 2.mm. where as the depth requirement would not be more than 1.5 meters (Refer Table I above). Generally finer media size and smaller depth appear to be economical. With such type of choice, the filter run would be shorter. However, since the set up used in this research employed used less water for cleaning (or used raw water for cleaning), shorter filtr run causes less problem. The filtered water turbidity was 5 NTU in most cases. The use of Moringa seed was found to be effective for all of the types of water tested. Caglation with Mornga also gives an economic advantage, compared with plain filtration. However, for good flocculation the use of gravel pipe flocculator is recommended rather than direct in-line addition of coagulants on to the filters.

Cleaning of the media was facilitated by a lifting, draining and rinsing mechanism. the possibility of using raw water for cleaning have been tested and found to be working.

When Moringa is used as coagulant, taste and odour problem can possibly develop if the filters are run intermittently due to the Moringa deposited on to the filters.. Therefore, the filters have to run continuously.

The cost of acquiring the plastic media is estimated to be around 20 Birr / m^3/day of water treated. This cost is not expensive compared the benefits that are gained out of the filter.

Acknowledgement

The Author would like to thank the GTZ for funding this research and the AWTI for providing facilities. Particularly, thanks are due to Ato Hailemariam Desalegn, the Dean of AWTI and Professor G. Foerch of University of Siegen, Germany for their recommendation of the research proposal.

References

1. Boller M., "Filter Mechanisms in Roughing Filters," *Journal of Water SRT - Aqua,* Vol 42. No. 3 pp 174-185, 1993.

2.Ngo, H.H. and Vigneswarau, S.,"Application of Down flow Floating Medium flocculator-pre filter (DFF) - Coarse sand filter in Waste Water Nutrient removal," *Journal of Water Science and Technology*, 1996.

3. Shultz, etal. "Surface Water Treatment for Communities in Developing Countries", 1980.

4. Smet, J. and Visscher, J.T., "Pre-treatment Methods for Community Water Supply," IRC, Netherlands, 1989

Environmental Assessment in Water Resources Development Project Cycle

Haimanot Assefa , Environment Specialist, PSU/CIDA, Addis Ababa ,Ethiopia

Abstract

Integration of environmental concerns in each stage of a project cycle has become one of the pre-requisites for sustainable development. For each stage of the project cycle, there should be a matching environmental planning component. Most water resources projects require an environmental assessment to identify potential environmental impacts, thereby for mitigating the negative aspects and enhancing the positive aspects of the project. Environmental assessment should be regarded as an important tool, which brings sustainable development, and we should try to adopt it to our local situation to use its maximum benefits. The paper reviews the matching environmental components in each project cycle and the experience of environmental consideration in water resources projects undertaken by the Ministry of Water Resources (MWR). For this purpose three irrigation and three hydropower projects were analyzed and it has been evident that environment was considered as one component at each stage of the planning particularly in studies conducted in recent years.

1.Introduction

The inter-disciplinary nature of water resources planning demands the development of a new approach that integrates the technical, economic, environmental and social aspects into coherent management framework. In this respect environmental assessment integration in each stage of the project cycle, starting from the initial stage is vital more so in developing countries where technology has not yet been extensively employed to curb effects of inappropriate environmental management and where the economy is more stringent.

Environmental economists convey a message that environment and development are not conflicting elements in a zero sum game, in which progress in one is at the expense of the other. Rather, it is being emphasized that environment and development for the most part are elements of mutually reinforcing, positive sum game.

In Ethiopia, most recent large and medium scale water resource projects in one way or another exhibit environmental consideration in their project preparation documents. Integrating the concerns up to implementation and operation phase is yet to be seen. The concern for environment in the country has reached where an environmental policy is put in place and regulation, legislation and scetoral guidelines are being drafted. The critical area of concern however is enhancing the capacity and research on the EIA tool to make it more applicable to our local situation.

This paper provides reviews of environmental concerns corresponding the different stages of the conventional project cycle. Samples of water resources projects are analyzed for their environmental consideration in their planning process. It appears that most water resources projects conducted by the MWR had gone through an environmental assessment process. Whether environmental consideration is to be incorporated in the implementation and operation stages remains to be seen in the future. The paper also discusses the constraints of incorporating EIA in water resources development projects and suggests recommendations.

2.Development of EIA Concepts

2.1Definition of Basic Concepts

Some basic concepts in the area of environment are commonly used but are sometimes confusing and interchangeably applied. Definitions of the pertinent concepts as applied in this paper are given as follows for the purpose of creating a clear and common understandings while considering environmental management issues in water resources development.

Environment: Environment is defined as the surrounding zone, the specific zone to be affected by the project. All natural resources (physical, biological and human resources), people, economic development and quality of life values are basic components of the environment.

Environmental Impact Assessment (EIA): EIA is a systematic approach for identifying environmental effects of proposed projects. It is a way of making sure that we ask the right question, to pinpoint destructive effects early and look for alternative ways of doing things.

Initial Environmental Examination (IEE): An examination for estimating probable impacts in order to ascertain whether follow –up detailed studies are needed. It is a broad scoping of the potential environmental effects of a project, based on available data and knowledge, to identify key environmental issues.

Environmental Management (EM): It is a procedure which can be defined as a decision making mechanism that is used to ensure that environmental considerations are incorporated into development strategies, programs and projects. EM makes use of the information and analysis provided by environmental assessment and adds on element of dynamism by designing strategies to implement actions to protect and conserve the environment, and by focusing on the implementation of such strategies.

2.2 Development of EIA

In the 1970's, it became generally accepted by some of the leading development agencies that assessment should be made on the environmental impact of planned developments before they were implemented, with a view to taking some corrective action in the cause of environmental conservation. From these pioneering efforts a formal procedure known as Environmental Impact Assessment (EIA) emerged, to ensure that negative impacts were predicted and taken into account. The 1980's saw the scope of EIA being widened to incorporate, socio-economic impacts and mitigating measures, and EIA has developed progressively in its approach. It is still believed that further development in EIA procedure and application is needed.

The intangible and cross-cutting nature of many environmental issues and the negative connotation attached by many to the term "impact" has hindered EIA from becoming the comprehensive and integrated decision making tool. Some believe that EIA is not sufficiently geared towards the decision making and implementation process. It stops at attempting to quantify the positive and negative impacts of an intervention and fails in ensuring that the right decisions follow and that environmental concerns are carried through the entire project cycle. Today there is a shift from relying on a free standing planning tool and process, EIA, to adopting a planning procedure, EM, which has been introduced as a means of approaching sustainable development practices better than the EIA tool has managed in the past.

In the developing countries the overriding issue is to overcome the crippling and widespread poverty. What might be a normal environmental concern in the developed countries could be taken as hampering the development effort to overcome poverty in developing countries. The application of EIA concepts as developed in the more affluent society has given rise to the negative outlook that is being manifested today. To day this problem has been perceived and is under discussion in many forums on how to apply EIA in the right direction to the developing countries.

As in many developing countries, EIA in Ethiopia was limited to bankable projects. Such projects, however, incorporated environmental considerations faithfully at least at the project preparation stage. Some water resources experts, however, express their concern that EIA is a development constraining concept. This attitude emanates from the wrongly perceived outlook of EIA, and from the shortcoming of EIA in its application in the developing countries. In spite of this attitude, today, most water resources projects, even those, which do not require external assistance incorporate environmental consideration in their preparation.

3. EIA in the Context of the Project Cycle

A recent development in project preparation is the consideration of the impacts of a project that is not primarily of an engineering or cost nature. Environmental Impact Assessment among others is considered as one of the decision-making mechanisms in the project cycle. The purpose of EIA is to assist in ensuring that appropriate planning practices will be utilized whenever sensitive environmental resources or values are likely to be affected. (Asian Development Bank)

Environmental Assessment is, or should be an integral part of each stage of the cycle. For each stage of planning, there should be a matching environmental planning component. Each stage, however, is likely to involve a different depth of analysis for specific topics appropriate to the circumstances of the stage. In the early stages of the project cycle, everything that is known about the existing environment is documented. As the environmental assessment proceeds, however, documentation should become increasingly analytical, thereby spending time and resources on the issues of prime importance.

3.1 Water Resources Development Project Cycle

The project cycle is considered as a cycle because one stage leads to the next. At each stage, projects are investigated to a depth necessary for reaching a conclusion on their capability and suitability for the stated purpose. The depth of the study increases in each subsequent stage. The stages of project

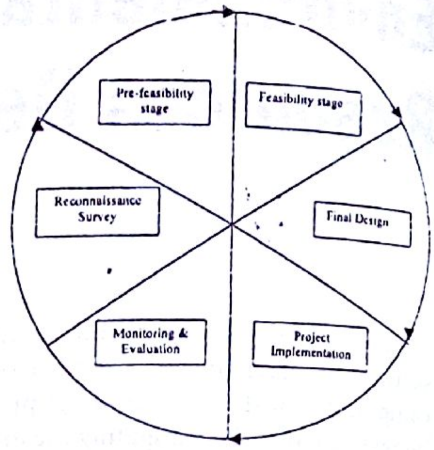


Figure 1: General Project Cycle

cycle generally frequented are shown in Figure 1 and the major features are given in subsequent paragraphs.

Reconnaissance Study: This is normally the first step of project oriented planning. Desk studies on the available data sometimes accompanied by field reconnaissance are the basis for this stage. The purpose of reconnaissance study is not to investigate projects in detail. However, the result of this study should be able to tell if there is a feasible project with approximate cost estimate and the additional studies needed for the subsequent stages of the project.

Pre-Feasibility Study: This is the second step in the project investigation and planning. In this phase one or more identified projects are brought one step further in the planning process. The pre-feasibility investigation justifies the project based on technical, economical and environmental practicability and make recommendations for further action.

Feasibility Study: At the feasibility stage technical studies more detailed than those required in the previous stage, financial and economic analysis are conducted. The output of this stage of the study should contain enough information to permit decision on whether or not to implement the project.

Final design: Contract documents including plans and specifications, which are sufficiently detailed, will be prepared at this stage. The drawings and specification are based on additional studies of the details of the project work.

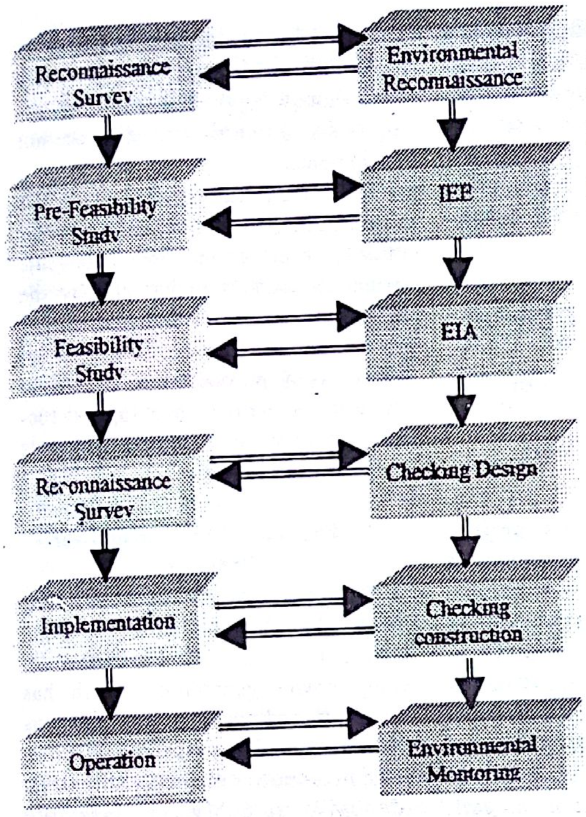


Figure 2: Stages of Project Cycle andtheCorresponding EnvironmentalProtection Activities

Implementation: Additional detailed drawings needed during construction are prepared at this stage. Supervision and inspection of construction activities are the major component of this stage.

Operation: At this stage of the project cycle, monitoring is done to see that targets are reached and a final evaluation is done to assess whether the expected development results have been achieved.

Financing agencies like the World Bank, African Development Bank, Asian Development Bank etc. and other donor agencies have slightly different approach/naming to the different stages of a project cycle. Some combine two stages together, others have different names for the same stage shown in the General project cycle. However, the concept remains the same. Financing agencies however, have an additional stage, appraisal-the decision on financing the project. Governments, also sometimes do appraisal.

3.2 Environmental Assessment in the Project Cycle

There is always a concern of the need for environmental assessment, if there is a good engineering in planning and designing. There is no clear delineation between mitigation prompted by environmental concerns and good engineering practice. Environmental assessment, however, is found to be an essential tool even in the presence of good engineering practice, as there are some other aspects which will not be covered by good engineering practice only. As the possible effects on environmental resources usually are of very little interest to the project proponent, conducting environmental assessment is essential to protect sensitive environmental resources.

Most water resources projects require an environmental assessment to identify potential environmental impacts. Environmental assessment should be an integral part of the project planning at every stage of the project cycle. The major features of environmental considerations at each stage of the project cycle are described in the subsequent sections. Figure 2 shows the environmental protection activities for each stage of the project cycle.

Some financing agencies refer terms as screening, scoping and preparation of EIA for the different stages of the project cycle. Screening is the process of determining whether or not a proposal requires further environmental assessment and scoping defines the boundaries of what is going to be done in the EIA. Both these issues are parts of the IEE described in this paper. Some financing agencies recommend screening for the identification phase, scoping for pre-feasibility and EIA for feasibility stage of the study.

Environmental Reconnaissance: It is important to integrate environmental issues at an early stage of the planning process. At the reconnaissance level, which is the first level of investigation, it is only necessary to determine the environmental disturbance, which the project is likely to bring about and to assess the environmental impact that can be attributed to its implementation. The study at this stage identifies the main environmental issue. As in the case with the other component of the study, the environment bases its data in the existing information. Supplementing it with field reconnaissance can attain better results. If reconnaissance and pre-feasibility studies are combined the assessment should be consistent to the IEE lelvel.

Initial Environmental Examination (IEE): The more effective environmental concerns are properly conceived at this stage of the project. The environmental study conducted at this stage is termed as Initial Environmental Examination (IEE) or Initial Environmental Assessment (IEA). The study makes use of a detailed checklist appropriate for the sector. Based on the checklists the study screens out all environmental impacts except those, which could have significantly adverse impacts. Potential impacts should be assessed within the sector of the proposed project and in terms of its cross-cutting, multi-sectoral aspects. In the IEE phase projects are categorized as those needing full EIA and those who do not require full EIA with limited environmental impact that can be routinely resolved through application of mitigation measures. If further detailed study is needed, then the IEE will require preparation of a brief TOR for the follow-up EIA. If there is no need for further study, the IEE itself becomes the completed EIA for the project and no follow-up EIA will be needed. (Asian Development Bank)

Environmental Impact Assessment (EIA): The main focus of the environmental review at this stage is to plan and implement environmental studies as part of, or in parallel with, the feasibility study. EIA is a more intensive examination which covers topics like project description, baseline data, environmental impacts, analysis of alternatives, mitigation plan, environmental management and training requirements, monitoring plan, interagency coordination and consultation with affected communities.

Checking Design: The environmental component at the final design stage is limited concentrating on checking designs for their environmental soundness and working out the detailed costs of mitigation measures.

Checking Construction: The major focus of the environmental activity during supervision will be to ensure that the environmental mitigation, monitoring and management measures identified during EIA are being implemented. Such measures may be incorporated into design and contract specifications for implementation.

Environmental Monitoring: The scope of environmental monitoring involves following the effect of the project on the natural, physical and human environment. The relevant parameters to be monitored will have been defined in the EIA report of the feasibility study.

3.3 Project Scale and Environmental Consideration

Magnitude of a project is sometimes a poor indicator of environmental effect particularly in water resources projects. Large scale run off river projects may have negligible environmental effects whereas small-scale irrigation projects if located in environmentally sensitive areas can imply significant environmental effects.

The World Bank environmental assessment guidelines provide an alternative to Environmental Assessment for small projects unless they are located in environmentally sensitive areas. The Asian Development Bank, however, recommends the preparation of IEE for all sizes of projects and projects that will not result in Significant Environmental Impact do not need to complete EIA.

There is no fixed rule on the significance of magnitude of projects in relation to environmental impacts, but it has to be recognized that large projects do have a greater propensity to cause environmental harm than do small ones. But this rule of thumb needs to be applied with greater caution.

Significant numbers of small-scale irrigation projects are not functional or have many problems. The paper is not suggesting that the problems arise from not undertaking environmental considerations or from lack of implementing environmental concerns as recommended by EIA. But it is to say that environmental assessment helps us to design better projects. By asking the right question, we can pinpoint destructive effects early and look for alternative ways of doing things.

4. Experience of EIA Application for Water Resources Projects

In Ethiopia water resources projects have been under development since the 1960's. Hydropower schemes and irrigation projects are the major activities in water resources in this sector. Compared to the country's potential, the resource is still untapped and a lot is expected to be done. For a water resource project to be sustainable, integration of environmental consideration at each development stage is found to be imperative. EIA concept in water resources projects planning in this country, has been applied starting the early eighty's on projects financed by UNDP and other major international sources. Beginning from the early sixties, large-scale water resources project planning were carried following the conventional project cycle approach and in this context some of the major environmental concerns were addressed. More recently EIA consideration are taken as part of the project planning activities even though legal mechanism enforcing this as a routine procedure are not yet in place.

To review the experience of EIA application in water resources sector three hydropower and three large-scale irrigation projects undertaken by the Ministry of Water Resources and its predecessor institutions have been selected. As the purpose of this paper is to show the experience and suggest recommendation, only few projects have been selected.

4.1 Experience in Hydropower Projects

In response to the urgent need for power the Government of Ethiopia launched an Emergency Program to develop power generation, which has identified medium scale hydropower as the most promising resource. Medium scale hydropower projects in the range of 40MW to 60MW capacities are given more attention rather than Large Scale Hydropower Developments.

The Ministry of Water Resources (MWR) with its responsibility for the development, protection and utilization of water resources has embarked on the planning of few hydropower projects. Among these, three projects whose studies and design have been completed are examined for analyzing the application of EIA concept at the various stages of the project cycle. The fol-

Table1: Sample of Medium Scale Hydropower Projects Studied by the MWR

No	Project/Environmental Consideration	Development Phase				
		Reconnaissance	Pre-Feasibility	Feasibility	Final Design	Implementation
1	Tekeze Medium Scale HP Project	✓	✓	✓	✓	×
	Environmental Component	Initial Screening	IEE	EIA	Quantification of mitigation measures	×
2	Gojeb Medium Scale HP Project	✓	✓	✓	✓	×
	Environmental Component	Initial Screening	IEE	EIA	Quantification of mitigation measures	×
3	Tis Abay Medium Scale HP Project	✓	×	✓	✓	Under Construction
	Environmental Component	Initial Screening	×	EIA	Quantification of mitigation measures	?

✓ - Conducted, × - Not conducted, ? -- No information lowing table shows the development cycle of the three medium hydropower projects and the associated environmental consideration at each stage.

As can be seen in the table, the preparation phase of the hydropower developments have taken the conventional project cycle. In each stage of the project cycle, pertinent environmental studies have been integral part of the study and have been used as a decision tool to move to the next stage. The feasibility studies of these projects have been conducted in the year 1996 and 1997. This explains the adoption of environmental consideration at each stage to the standard of international guidelines. The environmental considerations of all the three projects at each stage of the project cycle are briefly discussed.

4.1.1 *Reconnaissance Study*

For the Gojeb and Tekeze hydropower projects, the study results are presented in the form of comparative evaluation matrix based on a checklist relevant for the sector. The matrix presented significant environmental considerations and impacts associated with the proposed hydropower project. The matrix summarizes the study findings in a format that allows ranking of projects in terms of their environmental effects.

Examination of the comparative evaluation matrix indicates a number of important anticipated effects that should be carefully studied at pre-feasibility and feasibility level. As a result of these studies, a particular site was discarded, due to its environmental effect for the Gojeb hydropower project. In the case of Tis Abay project, unlike the above two studies, there is no matrix evaluation conducted and no detailed checklist used for the analysis. However, the study described the existing environment and listed potential negative and positive impacts of the project.

4.1.2 *Pre-Feasibility Study*

The pre-feasibility stage of the project cycle is conducted for Gojeb and Tekeze hydropower projects. The Tis Abay project, being an emergency project, skipped this stage and direct Feasibility and design were undertaken.

For the Gojeb and Tekeze projects, the pre-feasibility study stated that all environmental issues should be studied in depth at feasibility level during the course of the full environmental assessment. The preliminary environmental analysis focused on issues that could result, depending on the site and reservoir elevation selected in significant environmental mitigation costs. More detailed survey was conducted at this stage on the issues raised in the reconnaissance study.

In the case of Gojeb, environmental issues differentiated the two sites more than any other aspect, and were a critical factor in the site selection. The Tekeze case is different where the environmental impacts at both alternative sites had similar nature. Neither project alternatives in the Tekeze case, involves resettlement nor the reservoir would flood important social infrastructure. Therefore, environment was not taken as a factor to select between project alternatives.

4.1.3 *Feasibility Study*

The feasibility studies of both Gojeb and Tekeze projects have examined different dam height options for the sites selected at pre-feasibility level. The Environmental Impact Assessment considers the effects of these options. It is found out that the nature of the environmental impacts is similar for each dam height.

The potential environmental impacts, both positive and negative have been assessed and the mitigation measures required to enhance the benefits of the project, and to avoid or minimize the adverse impact have been stated. An appropriate monitoring program for each project is also recommended to verify the magnitude and scale of the predicted impacts and to detect any unforeseen impact at an early stage.

The project cycle and the related environmental study as mentioned earlier are different in the case of Tis Abbay hydropower project. Due to its emergency nature, after a reconnaissance study, which was conducted by the Ministry, the project was contracted to a consultancy service to undertake Feasibility and Detailed Design studies. The nature of the project is different from the above two in a way that, there is no dam to be constructed, and more data is available to undertake the feasibility study.

During this stage of the study the environmental component produced two reports for Tis Abay II project. A preliminary environmental study before the completion of the feasibility study which outlined the potential positive and negative impacts and mitigation measures and another report together with the feasibility study report having the same content with more depth as a result of further investigation. Both reports identified a critical issue which is the need to ensure an acceptable trade-off between the allocation of water for energy generation and the flow necessary to sustain the Tis Issat Fall which is an important natural heritage and tourism attraction. The later report however addressed this issue with additional model runs and outlined the significant impacts to be considered at full EIA.

4.1.4 *Final Design*

In the Final Design stages of these projects, the environmental component of the study quantified the mitigation measures. Detail compensation cost for each individual, other costs for mitigation measures such as construction of clinic and road have been quantified and submitted to the respective implementing organizations prior to implementation of the projects.

In the case of Tis Abay II, before the completion of the detailed design stage, a full EIA report was presented. This report provides an assessment of the environmental impacts of the development of Tis Abay II scheme. The effect of different release patterns for the Falls on energy generation has been examined from a hydrological simulation model of the lake and river system. The economic value of the Falls has been estimated from projected tourist growth rate and surveys undertaken during the study. Based on this a Cost-Benefit analysis has been undertaken and the benefits from production of electricity thus outweighed the ones that could be generated from tourism at the present time.

4.1.5 *Implementation*

Tis Abay II scheme is under construction, and EEPA is the owner of the project. No information could be made available on how environmental measures are being considered during construction. The other two projects are at the stage of preparation of contract documents and bids for the construction phase.

4.1.6 *Findings of EA Application in Hydropower Projects*

The environmental study at the initial level (reconnaissance) of the project cycle has been conducted satisfactorily for all the projects. Sites that could damage the environment were discarded from the alternatives.

At pre-feasibility stage, the environmental study should list all the possible environmental components based on the sector checklist and identify activities which will have significant impact for further detailed study at EIA during feasibility stage. The report, however, failed to do that and recommended all environmental issues to be studied in depth at EIA level. The purpose of conducting preliminary environmental study or IEE is to distinguish significant environmental impact so as to focus time and money on those relevant issues. The other important output of the environmental study at the pre-feasibility stage is preparation of TOR for the subsequent stage, where the study failed to do so.

In the case of Tis Abay, the EIA study should have been produced together with the Feasibility report to serve as one of the decision making tools as its purpose.

Environmental economics is exercised and clearly shows the benefit of the project, which is encouraging. The Tis Abay II project is located in the country's major cultural heritage site. This economic analysis clearly showed that projects located in an environmentally sensitive area, may not be automatically disqualified. The cost benefit analysis based on the environmental economics exercise was used as one of a decision parameter to proceed with the implementation of the project.

A number of local staff participated in the study, increasing the country's capacity in the field, which should be taken as a lesson in other projects.

In the absence of enforcing environmental regulation, such faithful consideration of environmental aspects into a project component needs to be encouraged and appreciated and is a great achievement to the country.

4.2 Experience in Irrigation Projects

Although water and land resources are plenty and the opportunity for irrigation development is vast in Ethiopia, very little has been done compared to the resources. Future development of this opportunity, however, should be planned and implemented with consideration of economic, social and environmental factors to achieve sustainable development.

In the following section, three large-scale projects are described in the context of their environmental considerations. Table shows three large-scale irrigation projects undertaken by the Ministry of Water Resources and its predecessors, and the environmental consideration at each stage of the project cycle.

Table 2: Sample of Large Scale Irrigation Projects Studied by the Water Sector

	Project/ Environmental consideration	Development Phase					
		Reconn.	Pre-Feasibility	Feasibility	Final Design	Implemen.	Monitoring & Operation
1	Birr and Koga Irrigation Project	✓	✓	✓			
	Environmental Consideration	×	✓	✓			
2	Weito Irrigation Project	✓	✓	✓	✓	✓	
	Environmental Consideration	×	✓	✓	✓	?	
3	Amibara Irrigation Project	✓	×	✓*	✓*	✓	✓**
	Environmental Consideration	×	×	?	✓	✓	✓

✓ - Conducted, × - Not Conducted, ? – Not Known

✓* Indicates studies followed by appraisal

✓** For the Amibara Project, after monitoring at the operation stage, additional design and implementation of a drainage project was undertaken.

4.2.1 *Reconnaissance Study*

The identification of irrigation projects for **Birr and Koga** was first conducted by USBR, 1964, and LAHMEYER, 1962 respectively. These studies in the early 1960's proposed the development of large-scale irrigation on both sites. The subsequent pre-feasibility studies of the projects considered these as reconnaissance studies to take over. As both the above studies were conducted as early as 1960's, and as they were not project specific, there was no environmental study component.

The report on Survey of the Awash River Basin produced in 1965 identified the **Amibara** Irrigation Project, which is located in the Middle Awash Valley. There is no as such environmental component in the report. However, the issue of incidence of bilharziasis in the basin was recognized and measures suggested and recommendation for future health studies was provided.

There was not reconnaissance study conducted for Weito Irrigation Project.

4.2.2 *Pre-Feasibility Study*

Birr and Koga Irrigation Project: The pre-feasibility studies for Birr and Koga were completed by WRDA/FAO in 1987. These studies were inclusive of a section on health and environmental aspects following the same procedure for both projects. The study regarding this issue was very well done and detailed enough. With the objective of identifying project specific major health and environmental problems associated with the planned irrigation scheme, the study outlined the findings and proposed mitigation measures in the area of health, water supply and sanitation for both Birr and Koga irrigation projects.

Weito Irrigation Project: The study output of the pre-feasibility stage study indicated that Weito would be economically viable and recommended it to be followed by feasibility study. The Public and Environmental Health Planning Department of the Water Resources Development Authority had studied the environmental health implications for the pre-feasibility study on March 1981 though the report was not made available for this review.

4.2.3 *Feasibility Study*

Birr and Koga Irrigation Project: The Health study identified the major health issues in the cathments and the available health facilities, water supply and basic sanitation. After analyzing the health situation and the potential health risks associated with the introduction of large-scale irrigation project, the study identified preventive and mitigating measures and their resource requirement.

The Environmental Impact Assessment report was mentioned to be arranged in the format suggested by the World Bank and the African Development Bank for large scale irrigation project. As these are the potential funding agencies for the projects, the study was prepared in response to the requirement of major lending agencies environmental policy requirements.

After describing the existing environment, the policy and legal framework, the study identified significant environmental impacts of the project and potential mitigation measures for the construction and operation phases. Provision has also been made in the investment costs for the mitigative measures identified. The provision also includes a comprehensive health program. Finally the report presented, a pre-construction, construction and operation monitoring plan with the required cost to be included in the overall investment cost.

Weito Irrigation Project: Following a pre-feasibility study of Weito Irrigation Project the consultant was assigned to undertake a full feasibility study mainly of the agricultural aspect of the project. Health being an integral part, the feasibility study on the public and environmental health implications was undertaken by the Public and Environmental Health Planning Department of WRDA as an integral part of the Feasibility study to assist in the assessment and evaluation of the project as a whole. Therefore, the study includes two environmental annexes namely Environmental Effects and Public and Environmental Health Implication.

The Environmental Effect study was not made available for this review, however the Environmental Health Implications report was reviewed and found to be a detailed one describing the major health problems of the area, existing health facilities and results and findings of the health survey conducted. The study recommended measures to prevent water and vector borne diseases including provision of health services and the capital and annual operation and maintenance costs.

Amibara Irrigation Project: The feasibility study of Amibara irrigation project was conducted in 1969. The study as such did not include an environmental component. However, some of the investigations conducted were very much of an environmental investigation. After investigation of the soil and the drainage condition, the study concluded that the underlying aquifer possessed extremely low permeability and that the water table in the area could rise within 5-6 years after the onset of irrigation, with serious effects on yields. Systems of deep open drains were incorporated into the feasibility designs. Based on this feasibility submitted report appraisal was done by the World Bank mission and approved the financing of the project.

4.2.4 *Final Design*

Amibara Irrigation Project: In 1974, AVDA employed a firm of consultants to complete final designs of the project and to review cost estimates of the Amibara Irrigation Project. Based on the reviewed cost estimates the consultants reviewed the project components which deviated from the original plan thus components which deviated from the original plan thus requiring development strategy. There was no information on the availability of environmental component at this stage of the study.

Weito Irrigation Project: a private consultancy firm has conducted the final design of this project. Environmental concerns were also addressed. As the paper sets its boundary with the MWR undertakings, there will be no discussion on this stage of the project.

4.2.5 *Appraisal*

Appraisal of the Revised Amibara Irrigation Project: The Amibara project was first appraised after the feasibility study and this reappraisal is done after the final design. This reappraisal report significantly changed the original design report.

In this report, the projects environmental effect both positive and negative in the area of health has been recognized. The report agreed in a careful monitoring during the implementation period and allocated fund for the provision of control measures.

Another important aspect more relevant to the environmental consideration, the report identified is early ground water tables rise which will significantly affect the project, after implementation of irrigation. The document recommended additional water table control facilities as soon as the problem faced.

4.2.6 *Implementation*

It was reported that during the implementation of the Amibara irrigation project, activities relating to environmental health were undertaken. Among these, research on biliharziasis, construction of clinics, water supply and sanitation infrastructures are very much related to an environmental measure worth mentioning.

4.2.7 Operation

Although the need for sub surface drainage was identified earlier during the design of the irrigation project, as the ground water table was low at the time, it was decided to delay the installation of subsurface drains. However the water table rise and salinity problem occurred early as predicted by previous studies. The continuos monitoring conducted during the operation stage revealed the problem as they occur.

One of the measures considered to mitigate this environmental problem was to undertake a sub-surface drainage project. To implement this, the Master Drainage Plan for Melka Sadi and Amibara areas was conducted and this study put the rational development of an integrated surface and sub-surface drainage system, including flood protection works, and recommended a three-phased program of installation works. Based on this study recommendation, pilot drainage scheme was undertaken followed by implementation of phase I drainage project. Design of the second phase is completed and is waiting for implementation. Apart from this, the activity around environmental health was reported to be an active one in the provision of potable water supply, sanitation facilities, housing etc. A detail work was conducted on Biliharzia prevention, vector control and research by the Water Resources Development Authority in collaboration with other institutions at the project site.

4.2.8 Findings of EA Application in Irrigation Projects

Birr and Koga

The Birr and Koga studies pass through the conventional project cycle though the implementation of the project is still waiting.

The reconnaissance study was conducted in the early 1960's and no environmental consideration at that time. Environmental concern was at its infant stage at that time.

The pre-feasibility study conducted in 1987 considered environmental concern. As it was mentioned in the review, environment in those days was mainly health, and water supply and sanitation, and the study also reflects this approach.

The feasibility study, which was done in 1995, however, has the approach considered in the area of environment now days.

Weito

Full information on the project study and the associated environmental study was not available for the study. However, from the available information the following comments can be forwarded.

Environmental awareness in the water sector of the country goes up to the early 1980's. Even though it was mentioned that it was done to satisfy the requirements of financing agencies requirements, the study was done in great depth and quality which shows the capacity of the sector in the area of environment at that time.

Amibara

As the Amibara irrigation project study started early in the 1960's, no environmental study was incorporated at the beginning of the project cycle. However, at the design and appraisal stage of the project, major environmental issues were addressed though not tagged as environmental issues.

This project is one good example showing the importance of monitoring. The irrigation study delayed the sub-surface drainage system but recommended ground water and salinity monitoring. Monitoring these parameters picked the problem as they arise.

5.Constraints in the Introduction of EIA Procedures

EIA is generally perceived as an essentially negative statement, which retards development. This wrong perception tends to have influence on experts for not to undertake the study at all the stages of the project cycle ones the requirement of the funding agencies is met.

EIA is not usually undertaken until a late stage in project planning when changes to the project to mitigate adverse effects are difficult and costly. EIA is considered as a stand-alone report and is done separately rather than being an integral part of a wider process.

The available EIA procedures are too general in scope and they are not developed considering the situation in the developing countries. To meet the requirements of the funding agencies, different guidelines, which lack coherence, have to be used. In the absence of sufficient experienced personnel, this didn't make the problem easier.

Most undertaken EIA suggest the focus was only on negative aspects of environmental changes. The positive aspect of environmental change and how to enhance this is usually not considered or not been given enough emphasis. This can lead to discarding the project without really outweighing the project result in its entirety which adds to the view of EIA as being faultfinder.

EIA seldom continues to implementation and monitoring phase. EIA is conducted to clear the obligation of financing agencies. Conducting EIA by itself doesn't protect the environment unless it is implemented and considered in the monitoring phase of the project.

6.Recommendations

Environmental assessment can help us to design better projects. By early consideration of the environmental aspect, when proposed approaches are still open to second thought, problems can be averted easily and time and money saved. A timely investment in environmental consideration can mean better project, that can have a better chance of meeting the needs of the people we are trying to help.

Demystify EIA and it's associated techniques. The present perception of EIA is a wrong attitude, which evolved due to a number of reasons. One should recognize EIA as on of the tools, which bring sustainable development. Our country, of all others, is suffering from environmental degradation and this tool is nothing but a means to control further environmental degradation as opposed to development retardation. Awareness raising for the water engineers and other experts is an important step to have smooth working relation ship and better results.

The EIA should be an integral part of the overall planning and design of the project. It should be able to influence the project design and be conducted together with the other parts of the study and experts involved in the process.

Countries like ours need to review different available EIA procedures and need to adopt it to the local situation. EPA is developing guidelines and procedures. Care should be taken in the preparation of this to assimilate the local condition. In the absence of institutional and expertise capacity, the long procedure to get clearance for projects might result the wrongly perceived interpretation.

EIA is still under development even in the developed world. We have the opportunity to gear this tool to our local situation, ones we are convinced that it is a means to reach to a sustainable development. The most important aspect of the tool in our case should be that, on how do we enhance the positive impacts of the project to get the maximum benefit and look for alternative sites at the inception of the project to minimize the costs of the project. Stressing on the negative impacts cannot be applicable to our local situation, as we need every development oportunity in this country.

Academic institutions like AWTI have responsibility to change the present attitude towards EIA. Water engineers should be made aware and be equipped with design measures to mitigate negative impacts and enhance the positive aspect of water resource development projects here at the institution. Such institutions are also the place to conduct research an adaptation of standards, guidelines and procedures relevant to our situation.

The awareness should not be limited to water engineers. There are other most critical people in project planning particularly higher officials. They should also be equally convinced of the tool as an important means to reach to our goal.

Environmental economics should be developed to enhance the quality EIA. Positive impacts to some extent can be valued and can be used in the Cost-Benefit analysis of the project as has already been done for Tis Abay hydropower project.

Environmental monitoring is one aspect, which needs to be given more emphasis. Impacts, which were not predicted or anticipated at the preparation phase, can be detected at this stage. The Amibara irrigation project can be a good example for this concern.

7.References

African Development Bank, 1992, *Environmental Assessment Guidelines.*

African Development Bank, 1997, *Environmental Assessment Guidelines- Irrigation.*

Asian Development Bank,1991, *Environmental Guidelines for Selected Agricultural and Natural Resources Development Projects.*

Eric Helland-Hansen, Truls Holtedahl and Kire Amstein Lye,1995, Hydropower Development: *Environmental Effects*,Vol.3, Norwegian Institute of Technology.

EVDSA,1993,*Feasibility Study of the Birr and Koga Irrigation* Project,Acres International Limited in Association with Shawel Consult International.

FAO, 1995, *Guidelines for the Design of Agricultural Investment Projects,* FAO Investment Center.

FAO, 1965, *Report on Survey of the Awash RiverBasin,* vol.1, General Report.

FAO, 1996, Guidelines for Planning Irrigation and Drainage Investment Projects, FAO Investment Center.

International Commission on Irrigation and Drainage(ICID),1993, *The ICID Environmental Check-List,* To Identify Environmental Effects of Irrigation, Drainage,and Flood Control Projects.

Jarle Ravn, 1992, Hydropower Development: *Planning and Implimentation of Hydropower Projects,* Vol.5, Norwegian Institute of Technology.

Martha Aida Eid, 1986, *The Project Cycle,* FAO Investment Center.

MCE,1996, *Birale(Weito) Agricultural Development* PLC, Design of Diversion, Conveyance and Storage Systems, Vol.5, *Environmental Assessment.*

Ministry of Water Resources ,1997, *Tekeze Medium Hydropower Project*: Feasibility Study, Vol.5,Annex E - *Environmental Impact Assessment,* Howard Humphreys , Coyne Et Bellier and Rust Kennedy & Donkin.

Ministry of Water Resources, 1996, *Amibara Drainage Project* Phase II,*Environmental Impact Assessment Report,* WAPCOS.

Ministry of Water Resources, 1996, *Tis Abay II Hydropower Project, Feasibility Report,* Coyne Et Bellier, Howard Humphreys and Rust Kennedy & Donkin Limited.

Ministry of Water Resources, 1997, *Gojeb Medium Hydropower Project,Feasibility Study*,Vol.5, Annex E- *Environmental Impact Assessment,* Howard Humphreys, Coyne Et Bellier and Rust Kennedy & Donkin.

Ministry of Water Resources, 1997, *Tis Abay II Hydroelectric roject: Environmental Impact Assessment Final Report,* Coyne Et Bellier, Howard Humphreys and Rust Kennedy & Donkin.

United Nations Department of Technical Cooperation,*Integrated Water Resources Planning,* 1991, New York

Water Resources Development Authority,1995, *Feasibility Study of the Birr and Koga Irrigation Project:* Birr Irrigation Project, Annex 5, *Environmental Impact Assessment,* Accres International Limited in Association with Shawel ConsultInternational.

World Bank, 1977, Ethiopia- Appraisal of the Revised Amibara Irrigation Project.

WRDA, 1982, Weito Irrigation Project, Feasibility Study Final Report, Vol.8, *Public and Environmental Implications.*

WRDA,1986, *Master Drainage Plan for Melka Sadi and Amibara Area, Vol.2, Main Report,* Sir William Holcrow & Partners.

Commercialisation as Basis for Sustainable Water Services

Gerd Förch, Prof. Dr. -Ing., Siegen University, Germany, or c/o RODECO Consulting, P.O.Box 3066, Addis Ababa

Introduction

The demands for introducing new water resources management concepts are mainly flourishing since the Earth Summit held in 1992 and its Agenda 21 (EU1998).

These new concepts also dealt with water supply and sanitation which was already highlighted earlier (UN water supply and sanitation decade, Rio de la Plata) with the aim to provide access to safe drinking water and sanitation facilities for every body until the year 2000.

However, the latter was not successful; even by concentrating all efforts and resources towards this one goal it can't be achieved anymore in the given time. The available funds could not cope with the ever-increasing population growth mainly in countries burdened with rural and urban poverty. The Agenda 21 may prove a better concept than previous ones because of being more comprehensive and resourceful.

Dublin Principles	Agenda 21
♦ Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment ♦ Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels ♦ Women play a central part in the provision, management and safe-guarding of water ♦ Water has an economic value in all its competing uses and should be recognised as an economic good	♦ Ensure the integrated management and development of water resources ♦ Assess water quality, supply and demand ♦ Protect water resource quality and aquatic eco-systems ♦ Improve drinking water supply and sanitation ♦ Ensure sustainable water supply and use for cities ♦ Manage water resources for sustainable food production and development ♦ Assess the impact of climate change on water resources

The Problem

World Wide Scarcity

It is common sense that the worldwide available fresh water sources are limited and getting scarce. Already 1/5 of all countries is burdened with heavy water shortages. Furthermore, the demands are still increasing and spreading pollution especially in developing countries and so called emerging economies hampers the availability of freshwater for hygiene and health, for irrigation, domestic and cottage industries, that means for any kind of sustainable development.

Like in any market economy, which is the economic concept ruling most parts of the world at present, a scarce commodity will attract investors or capital because of profit prospects. And this is happening world wide as the German newsmagazine SPIEGEL (DOHMEN 1999) reported some weeks ago.

Big companies were fighting for buying shares of the Berlin Water Utilities, the water provider for the German capital, which was owned by the Municipality of Berlin. It was partially on sale because of the financial problems of the owner. Big international companies like banks were interested in buying shares because of profit expectations, not because of their long-standing involvement and experience in the water sector.

Eventually, a French-German consortium, comprising of a big German bank, a well known French trust active also in the water sector and a German trust providing energy, won the competition and bought 49.9 % of the shares of Berlin Water Utilities for about 3,300,000,000 DM.

African Poverty

On the other hand, the African continent is burdened with high population growth, wars and civil unrest, recurrent droughts, low service levels, low water coverage, large ratios of water borne diseases, etc. Water is already the limiting factor for socio-economic development.

In particular, since 20 years only 20 % of the population have access to safe drinking water. Tremendous investments in Ethiopia were financed over the same period by the Ethiopian Government and international donors like World Bank, German, Swedish and Finnish Governments, EU, UNDP, UNICEF, etc. However, this percentage didn't change substantially!

Why did we fail?

Mainly because of the wrong concepts:

Dominance of the public sector

The bureaucracy never formulated and introduced efficiency criteria

Dominance of investments instead of operation

Constructing new systems was more important for any politician or bureaucrat than taking care of operation – often more than 50% of RWSS were not functioning shortly after the official inauguration.

Lack of qualified manpower

A huge brain drain caused the loss of experts to the emerging private sector or the experts left the country at all.

Lack of financial resources allocation

Available budgets of the central and regional Governments could not fulfil all the demands locally

Lack of community involvement

Communities were only asked to contribute labour or funds, they were not asked to actively take over responsibilities

Lack of appropriate designs

Engineers had ready made design concepts (the famous standard design), however, they never adjusted their design to the affordability of the users

Bursting population growth
The increasing number of people to be served outweighed increasing numbers of new systems: the population growth is still more than 3% per year!
Poverty
The average family income is declining; employment opportunities outside the rural sector are marginal.
Low level of education
The literacy rate is below 40%, in some areas even declining; water related issues are not part of the curriculum at primary schools; the academic level of primary school teachers is extremely poor.
Lack of water resources management
Except for the large river basin master plans there is no water resources management concept in force, which would include monitoring of sources and consumption.
Lack of water quality control
There is no systematic concept to regularly monitor the quality of water sources for domestic use.

These experiences from Oromiya are similar to those from other regions, other countries and continents. There is a big demand for new concepts, which may lead to sustainable water resources management, and consequently water supply and sanitation, around the world.

The new Concept

Following terms found entrance into the new concepts as some of the key elements:
Comprehensive water resources management
Already at the first symposium on Integrated Water Resources Development two years ago I've formulated the demand for and the key elements of this approach as an urgent need for the improvement of water resources development in the country.
Commercialisation of services provision
It is common sense even in Ethiopia and her Regional States that traditional government institutions are not capable of providing water efficiently for all the population
Public private partnership
It is also accepted that government sources are too limited for providing water to all people. Consequently, private financial sources need to be incorporated if the water coverage should be improved eventually. However, more important is the utilisation of management efficiency of private commercial enterprises.
Community empowerment and management
The communities need to get involved as owners and managers of their water schemes and systems. They have to take over the responsibility for their systems.
Cost covering water tariffs
Water must be sold to the consumers at cost price. The local people or users may only accept responsibility if they are charged in accordance with the cost of a scarce commodity.

Towards Sustainable Water Resources Management Guidelines (EU 1998)

The European Commission published Guidelines under this heading for technical co-operation in the water sector, which are based on international policy considerations as well as practical experiences from projects. Following are the headlines for this strategy, which is already implemented in many cases.

Institutional and Management Principles

1.1 Roles of government and official bodies at all levels should be clearly defined and areas of responsibility officially established.

1.2 The structures and systems of management should be designed in such a way as to facilitate involvement by the responsible authorities at different levels.

1.3 Involvement of user organisations and the private sector should be encouraged.

1.4 Ongoing capacity building is needed within institutions and for participant groups at all levels.

1.5 Management systems should be transparent and accountable and appropriate management information systems should be established.

Social principles

2.1 A sufficient supply of water and adequate means of sanitation are basic human needs to which everyone should have access.

2.2 Users have an important role to play and their involvement should be fostered via a participatory approach.

2.3 Gender implications should be examined and taken into account at all stages of the planning and implementation process.

Economic and financial principles

3.1 Water has an economic value and should be recognised as an economic good.

3.2 Charging tariffs for water services is an important component of any strategy for sustainability.

3.3 Demand Management should be used in conjunction with supply provision.

Environmental Principles

4.1 Water-related activity should aim to enhance or cause at least detrimental effect on the natural environment and its health and life-giving properties.

4.2 The allocation and consumption of water for environmental purposes should be recognised and given appropriate emphasis.

4.3 Environmental change should be monitored so that improvements can be encouraged and detrimental impacts minimised.

Information, education and communication principles

5.1 A sound information and knowledge base is needed for effective actions within all water-related activities.

5.2 Education is a vital component of water-related schemes if health and life enhancement benefits are to be achieved and sustained.

5.3 Communication and awareness building are essential ingredients in all forms of water resources management.

Technological Principles

6.1 A balanced approach towards hardware and software components of projects should be adopted.

6.2 Choice of technology should be governed by considerations of its efficiency, appropriateness, cost, and suitability for local conditions.

Implementation Strategies

There are various approaches to implement these new principles. A few examples should illustrate the already started process:

Co-operation between the users of a source: The Nile Conference 2002 is a very promising step forward to get the

Nile water resources utilised for the benefit of all people in the Basin (Nile Council 1999)

Co-operation between stakeholders: For the design of appropriate and affordable technical solutions for rural water supply all stakeholders – users, planners, builders, financiers – need to get involved, as it is practised in Oromiya at zonal levels.

Establishment of water tariff policies: Without appropriate water tariffs for the provision of water these new principles will never work as it has been shown with the evaluation of the Water Tariff in Addis Ababa.

Two examples from the Project work should further demonstrate the new policy: The new management guidelines for rural water supplies and the efforts to re-organise the water sector in Oromiya Region.

RWSS Management Guidelines in Oromiya (OWMERDB 1998)

These guidelines were worked out by the Project and endorsed by the State Council in June 1998.

Objectives

Define the legal and economic status of the user groups or water committees

Water committees are defined as legal entities with all rights to use and manage the source and the system

Define their relationships with the Water Bureau, NGO etc

They are recognised by the Water Bureau as their agents; however, they are still supervised by the Bureau

Introduce the cost coverage concept

Full cost coverage is the aim for all RWSS. The implementation started in December 1998. It was shown, that water prices between 3 and 5 Birr per m^3 are affordable and covering the full cost

Re-organisation Study Water Bureau Oromiya(GTZ/RODECO/OWMERDB 1999)

A new structure has been proposed to improve the services of the Water Bureau

The Bureau has been divided into three new organisations, the new Water Bureau, the Irrigation Authority and the Water Works Construction Enterprise

The new structure considers the separation of regulatory from service functions

The new Water Bureau is responsible for formulating policies, monitoring of sources and activities, and guidance of users, whereas the services should be provided by autonomous institutions eventually

The new structure is heading towards the commercialisation of the water provision

The UWSS will be eventually commercialised like the RWSS; Construction activities will be under the WWCE; technical services will be taken out from government institutions

New management principles will be adopted

The new structure is only the basis for a new policy where the sources will be managed sustainable, the provision of water and services will be done efficiently and at cost prices, where flat hierarchies and modern principles of personnel management will be the basis for improved water resources management.

However, the re-organisation will take some time before the target of efficient service provision will be reached. At the start, only the separation of the former OWMERD Bureau into the three new organisations was endorsed. Further reforms, like the introduction of modern management principles, are still under consideration.

Conclusions

"Efficient provision of water on sustainable basis is a management problem rather than a technical one.

"Public funds are limited as well as the water resources.

"Better management and source allocation is essential for any development.

"Commercialisation is essential for providing water at affordable prices and to limit consumption in accordance with available sources.

"Oromiya is already on the right way; however, it will take some years to realise the benefits of the changes.

Acknowledgements

It should be mentioned that above elaboration is the result of a learning process, which was mainly achieved through assisting the Water Supply Project Oromiya as technical and management adviser since 1996. Without the fruitful discussions between the Project, international and national consultants and the Management staff of the Oromiya Water Bureau the results would have been less encouraging.The German Government since 1990 finances the Project.

References

DFID (1997) Private Sector Participation in the Water and Sanitation Sector, Water Resources Occasional Paper No 3, Water and Assistance to Developing Countries, London, July 1997

F.Dohmen (1999), (Der neue Geldstrom: Großunternehmen aus aller Welt haben einen künftigen Milliardenmarkt entdeckt: das Geschäft mit dem Trinkwasser) The new flow of capital: International large companies from all over the world identified a new market worth billions: the business with drinking water. Der Spiegel No. 14, 1999, Hamburg 1999

European Commission (1998) Towards sustainable water resources management, A Strategic Approach, Guidelines for Water Resources Development Co-operation, Luxembourg, September 1998

GTZ/OWMERDB/RODECO (1999) Re-organisation Study of the OWMERD Bureau, Final Report, Addis Ababa, June 1999

MWR (1998), Water Sector Paper (Draft, unpublished), Addis Ababa, 1998

Nile Council of Ministers Meeting (1999), Water Strategies, Working paper (unpublished), Addis Ababa, May 1999

OWMERDB (1998) Guidelines on Management of Rural Water Supply Systems, Finfinne, June 1998

Steuerzahler (1999), (Kuhhandel oder Königsweg- Public-Private-Partnership Models auf dem Prüfstand) Horse-trade on ideal way - Public-Private-Partnership models put on test, Der Steuerzahler, Bonn, June 1999.

Ethiopia and the Issue of the Nile Waters

Abebe Belachew, *Lecturer, Arbaminch Water Technology Institute, P.O.Box.21,Arbaminch, Ethiopia*

Abstract

The issue of the Nile waters is a pressing issue to Ethiopia. It is clear that Ethiopia's socio-economic development is hampered by the age-long wars it has been involved and the frequent droughts that have occurred. Most of the country's water resources potential is located in the Nile River basin. Although, the Nile river basin is the longest river in the world encompassing ten sovereign states and traversing through 6,825 kilometers, there is no comprehensive agreement binding all the riparian states so far. The few agreements that exist to date are entered between some of the riparian states mainly with the aim of securing the interests of one riparian state (Egypt) or to some extent (Sudan) to the total exclusion of other riparian states. Therefore, those who contribute almost all the waters use almost none but those who contribute nothing use most of its waters. This paper presents the socio-political realities of the Nile waters from International water law point of view.

Introduction

Ethiopia, with a total geographical area of 1.13 million square kilometer, has a highly rugged topography and its rainfall resource is highly variable. Moreover, the country is naturally endowed with quite a substantial amount of water resources potential in its 12 drainage basins (Fig. 1). Among these river basins Blue Nile (201000 km2), Tekeze (82000 km2), Barro-Akobo (74104 km2) and Mereb-Gash (23900 km2) make up Ethiopia's contribution to the Nile waters (in which they cover more than 381000 km2 geographical area and more than 86% of the total Nile waters).

According to recent studies by Ministry of Water Resources (MOWR, 1998), the total annual surface water potential of the country is estimated to be 110 billion cubic meter and the total annual groundwater potential amounts in the order of 2.6 billion cubic meter. Moreover, the potential land for irrigation is more than 3.5 million hectares with less than 3% of potential being presently utilized. The potential annual hydropower production of the country on the other hand is estimated to be 161,000 Gega Watt Hour; with less than 1.5% of the potential being presently utilized. This makes Ethiopia the second country with huge hydropower potential in Africa next to Democratic Congo (former Zaire). Therefore it is a paradox that the world knows about Ethiopia by its recurring droughts linked with famine rather than by its vast natural resources. This impression is however largely due to media images. Almost the majority of the country's irrigation and hydropower production potential is from the Nile waters.

Although, the Nile river basin is the longest river in the world encompassing ten sovereign states and traversing through 6,825 kilometers, there is no comprehensive agreement binding all the riparian states so far. The few agreements that exist to date are entered between some of the riparian states mainly with the aim of securing the interests of one riparian state (Egypt) or to some extent (Sudan) to the total exclusion of other riparian states. Therefore, those who contribute almost all the waters use almost none but those who contribute nothing use most of its waters.

This paper presents the socio-political realities of the Nile waters from International water law point of view.

Water law

There is no as such well-defined field of specialization called water law. Water law covers a combination of laws that have developed in one or more of the various fields of law that had somehow a connection with water. Laws of state such as constitutional law, administrative law, criminal law, civil law, agrarian law, mining law, environmental law, etc. are fields of law that may have connection with water law. However, judicial systems are moving in the direction of establishing a comprehensive water law.

Water law has been defined as the creation, allocation and distribution of water rights. Water law is made up of all the provisions which in one way or other govern the various aspects of water management, i.e. water conservation, use and administration, the control of the harmful effects of water, water pollution and so on (Caponera, 1992).

Over the last two thousand years, five different systems of water law and administration have developed. These are: customary law, Roman law (common law countries & civil law countries), Islamic law, Soviet law and Hindu & Buddhist law. Based on which different countries have developed their national water law.

What is more interesting from the objective of this paper is international water law not national water law. So far there is no comprehensive legislation regarding international river basins that is binding every UN member states. However, there are principles, rules, and codification that apply to the use of international river basins.

International Water Resources Law

In order to manage international water resources in a sustainable way, the international community is not yet able to have convention or treaty or legislation. The reason to this is partly due to the significant regulating nature of water resources to activities of man

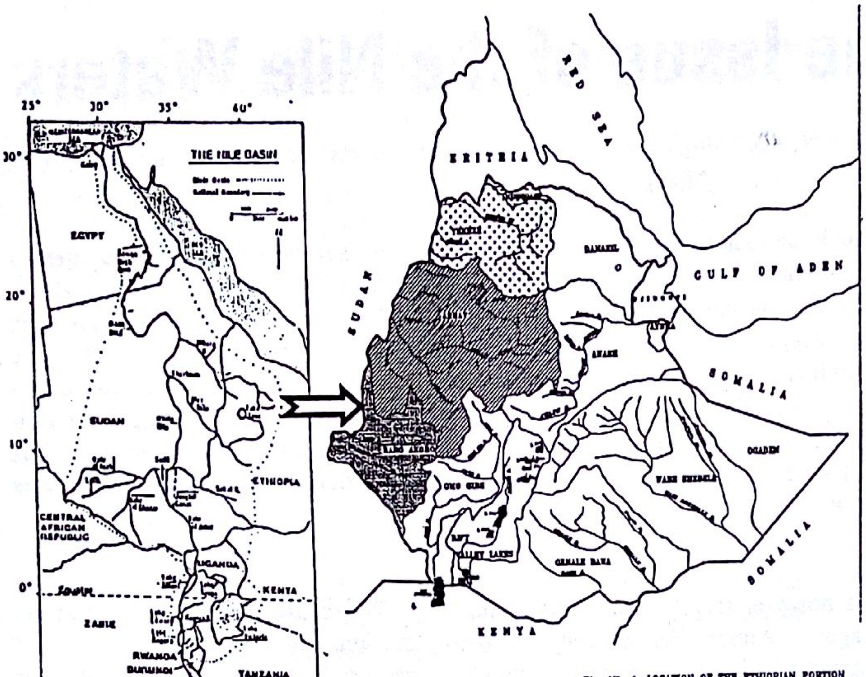


Fig. No. 1. LOCATION OF THE ETHIOPIAN PORTION OF THE NILE BASIN

and partly due to unequal economic and power balances among riparian states sharing international water resources. In this regard a brief discussion of basic principles and rules of international water resources law is presented in this section.

Principles

The two main principles of traditional international water law conflict with each other. They are:

(1)Absolute Territorial Sovereignty (the Harmon doctrine) ; by virtue of which a state can dispose freely of the waters actually flowing through its territory, but has no right to demand the continued free flow from other countries.

(2)Absolute Integrity of State Territory ; by virtue of which a state has the right to demand the continuation of natural flow of waters coming from other countries, but may not for its part restrict the natural flow of waters flowing through its territory into other countries. Gradually these two extreme principles became eroded to arrive at the following additional principles:

(3)Community of Property in Water by virtue of which rights are either vested in the collective body of riparians or are divided proportionally, or any other kind of absolute restriction on the free usage of the waters by the riparians is created in such a way that no one state can dispose of the waters without the positive cooperation of the others. This approach streams from the practical consideration that the geography of a river often has little if any relationship to the political frontiers that divide its waters; it is often necessary to develop an integrated program for the entire river basin.

(4)Restricted Territorial Sovereignty; In practice this is the most prevalent principle and attempts at combining the principle of absolute sovereignty and the principle of absolute integrity of state territory but does not go as far as the principle of community of property in water.

(5)Sovereignty Subject to Duty;The Resolution on Permanent Sovereignty over Natural Resources, 1962 (G.A. Resolution 1803 (XVII) G. A. O. R. 17th session) declares that,

a. The right of peoples and nations to permanent sovereignty over their natural wealth and resources must be exercised in the interest of their national development and of the well-being of the people of the state concerned;

b. The free and beneficial exercise of the sovereignty of peoples and nations over their natural respect of states based on their sovereign equality;

c. Violation of the rights of people and nations to sovereignty over their natural wealth and resources is contrary to the spirit and principles of the charter of the United Nations and hinders the development of international cooperation and the maintenance of peace.

It is quite clear, thus that sovereignty over natural resources is exercised only in the "interest of national development and is based on mutual respect for the sovereignty of other states."

At Stockholm in 1972, the Declaration on the Human Environment stated that: "States have in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other states of areas beyond the limits of national jurisdiction" (Stockholm declaration, 1972 Principle 21).

(6)The Principles of Reciprocity ; In the case of non-navigable rivers, the upper riparian always felt it had the greatest power to do what it liked with the waters of the flowing rivers. It was towards the second half of the last century that upper riparians began to feel somewhat vulnerable and began to impose duties in the lower riparians. I think this is what gave rise to the principle of reciprocity and that reinforced the principle of good neighborliness

(7)The Principle of Good Neighborliness; Duty Not to Cause Injury; This is based on Principle 74 of the UN Charter that recognizes the principle of good neighborliness. Other declarations, cases, arbitral tribunal such as the Declaration of American states at the Montevideo conference of 1933, the lake Lannoux case of France, the Madrid Resolution of the Institute of International Law 1911, The Inter-American Bar Association at its conference in 1957, the decision of the Arbitral Tribunal in the Trail Smelter dispute between Canada and the US States are also the basis of this principles. In the Lake Lannoux case for example, France upheld that: " the sovereignty in its own territory of a state desirous of carrying out hydropower developments," and at the same time recognized " the correlative duty not to injure the interests of a neighboring state."

(8)Equity ; " If state A is dependent upon the waters of a territory, it would seem that it has a prescriptive or historic right to the enjoyment of the river. The right to use water is based on immemorial usage." The International Law Association (ILA) at its Dubrovnik conference in 1956 stated: " states upon an international river should in reaching agreements, and states or tribunals in settling disputes, ... weigh the benefit to one states against the injury done to another through a particular use of the water. For this purpose, the following factors, among others, should be taken into consideration. (ILA, 1957):

a) The right of each to a reasonable use of the water;

b) The extent of the dependence of each state upon the waters of that river;

c) The comparative social and economic gains accruing to each and to the entire river community;

d) Pre-existent agreements among the states concerned;

e) Pre-existent appropriation of water by one state."

The principle of prior appropriation is sometimes regarded as the guiding principle. A UN report states that: "historic uses and priority of appropriation have come to have an almost sacred significance, irrespective of the actual benefits derived, or whether the water is being put to the best use." The starting point seemed to be the protection of existing uses in both the upper riparian country and the lower riparian country. First in time is also first in right. This principle unfortunately although out of date in theory is very much prevalent in practice and can cause major problem when an underdeveloped country like Ethiopia is dealing with a developing country like Egypt as in the Nile water case.

Rules and Codifications:

The Helsinki Rules on the Use of Water of International Rivers; ILA prepared the rules on the use of waters of international rivers in 1966. According to these rules , "each basin state is entitled, within its territory, to a reasonable and equitable share in the beneficial uses of the waters of an international river basin". It states that "a basin state may not be denied the present reasonable use of the waters of an international drainage basin to reserve for a co-basin state a future use of such waters." Importantly, it provides that "A use will not be deemed an existing use if at the time of becoming operational, it is incompatible with an already existing reasonable use (Article VIII)."

The ILC Law on Non-navigational uses of International Watercourses; ILC, a UN body, does not facilitate the preparation of Treaties or Convention. But it codifies the development of law if requested to do so. The ILC presented this law to the General Assembly of UN in 1991. At its 49th session in 1994, the General Assembly invited states to present their written comments on the ILC law by 1 July 1996. In October 1996, a framework law was expected to be adopted by the states on the non-navigational uses of international watercourses. But as we all know, this could not become possible.

In fact in the codified law, Article 3 empowers watercourse countries to enter into watercourse agreements with each other which apply and adjust the provisions of the code to the characteristics and uses of a particular international water course. Furthermore, every watercourse state has a right to participate in the agreement. This law requires that the general principles will be equitable and reasonable utilization of the water should be consistent with adequate protection of the watercourse.

Equitable utilization, for the purpose of this code implies taking, into consideration the following (Article 6):

- Geographic, hydrographic, hydrological, climatic, ecological and other factors of a natural character.
- The social and economic needs.
- The effects of the use of watercourses by one state on another state.
- Existing and potential uses.
- Conservation, protection, development and economy of the use of water and the costs of measures taken to that effect.
- The availability of alternatives

The code requires watercourse nations to use the water in such a way "as not to cause appreciable harm to other watercourse states." (Article 7). Dr. R. D. Hayton of the ILA explains that " Appreciable " is less than "substantial " and more than " perceptible."

For measures that are planned, each watercourse state is obliged to inform his co-watercourse states of the planned measure and its possible adverse effects (Article 12). The notified state has six months to respond. If it has objections to the plan, there should be consultations and negotiations and each state must in good faith pay reasonable regard to the rights and legitimate interests of the other state. (Article 13).

Article 8 states general obligation to co-operate "watercourse states shall cooperate on the basis of sovereign equality, territorial integrity and mutual benefit in order to attain optimal utilization and adequate protection of an international watercourse". Regular exchange of data and Information is also stated in Article 9 as " pursuant to article 8, watercourse states shall on a regular basis exchange reasonably available data and information on the condition of the watercourse, in particular that of a hydrological, meteorological, hydrogeological and ecological nature, as well as related forecasts."

Furthermore Article 26 states, "watercourse states, shall, at the request of any of them, enter into consultations concerning the management of an international watercourse, which may include the establishment of a joint management mechanism. Finally, Article 29 states that at times of armed conflict water resources should be protected.

Summarizing, all the above international water law principles or rules or codifications support Ethiopia's rights to the Nile water. On the contrary some of the principles are being skillfully used by Egypt not to fully acknowledge Ethiopia's sovereign rights to the Nile waters. For this purpose, it is important to briefly discuss the existing treaties on the Nile river basin.

Existing Agreements and Treaties

The presence of British colonialism in Egypt and Sudan in the 19th and early 20th century basically dictated the issue of agreement and treaties about the Nile river basin. British interest in this regard was to secure water rights that favoured a single state (Egypt) at the expense of the interests of the whole basin. As the British never had any control of Ethiopia, they tried different schemes to achieve the same objectives indirectly through colonial horse-trading. Italy, which had long lasting colonial designs on Ethiopia came handy in this ploy.

With the end of British colonial rule in the area, Egypt continued to follow the old British objective of putting the whole of the Nile waters to its exclusive benefit through various schemes. An Eritrean view in Ethioscope magazine (January 1995) states this Egypt's objective by a proverb "A curse for someone may be a blessing for another", and vice versa. Based on which, Egypt has used skillfully its geopolitical and strategic position in the region to give it a near monopoly over the Nile waters.

The following are some of the existing agreements and treaties (Girma, 1997):

The protocol signed in Rome on 15 April 1891, between Great Britain and Italy; stipulated in its third article that "the Italian Government undertakes not to construct on the Atbara any works that might sensibly modify its flow into the Nile." This treaty has no binding effect on Ethiopia since Italy was not able to colonize Ethiopia.

The 1902 Agreement between the Great Britain and Ethiopia; this agreement, signed at Addis Ababa on 15 May 1902, is one of the earliest agreements regarding the Nile waters. In fact the treaty between Great Britain and Emperor Menelik of Ethiopia was basically to demarcate the frontiers between Ethiopia and Sudan. However, Article III was about the use of the Nile waters which reads "His Majesty the Emperor Menelik II engages himself toward the Government of His Britannic Majesty not to construct or allow to be constructed, any work across the Blue Nile, Lake Tana or the Sobat which would arrest the flow of their waters into the Nile, except in agreement with His Britannic Majesty's Government and the Government of the Sudan."

By this agreement, assurance was made against a probable unilateral and complete "stoppage" of the Nile waters before an agreement was reached on mutually satisfactory basis. According to the Amharic version, as long as Menelik did not "stop" the flow of the Nile waters, Article III of the 1902 treaty did not restrict him from using the Nile waters through diversion. One can also argue that the agreement by specifying "except in agreement with... the Government of Sudan" is made in favor of Sudan and, according to the principle of treaties, Egypt can not claim any rights from the agreement.

Even if one assumes that the signatories originally intended to subordinate Ethiopia's interest on the Nile waters to Sudan's consent, it could be contested that, in the circumstances of close to a century since the signing of the 1902 agreement, situations on the use of waters have changed dramatically rendering the article on water inapplicable based on the doctrine of **rebus sic stantibus.**

According to Caponera, Ethiopia never ratified the 1902 agreement. Furthermore it also maintained that the British could not obtain any right from the treaty as they had subsequently denied the sovereignty of Ethiopia by their act of accepting Italian sovereignty over Ethiopia. "In 1935 when Great Britain recognized Italy's annexation of Ethiopia, a situation was created whereby Ethiopia could argue that all agreements to which Great Britain was a party and which requires Ethiopia's approval was void."

The 1906 Tripartite Treaty between Britain, Italy and France; Subsequent to the 1902 agreement, a second formal reference to Ethiopia in connection with the Nile waters is contained in the so-called Tripartite Agreement between Great Britain, France and Italy signed in London on December 13, 1906. Without consulting Ethiopia, the three colonial powers collaborated to act together to safeguard the interest of Ethiopia. Emperor Menelik rejected the agreement as a sinister ploy against the sovereignty of Ethiopia.

The 1925 Anglo-Italian Exchange of Notes; in this exchange of notes 14 and 20 December 1925, Italy recognized the prior hydraulic rights of Egypt and the Sudan in the headwaters of the Blue and White Nile and their tributaries and agreed not to construct on the headwaters any works which might sensibly modify their flow into the main river. When the news of this exchange of notes reached Addis Ababa, it aroused an angry reaction and Ethiopia, by then a member of the League of Nations, dispatched a protest note to members of the League against the designs of the two Governments on its sovereignty. The Ethiopian protest note was circulated to members of the League and the British and Italians who were embarrassed, backed away from their position and declared publicly that they did not have any ambition on the sovereignty of Ethiopia. The colonialist ploy was thus, effectively challenged and the agreement never materialized.

The 1929 Nile Waters Agreement between Egypt and Great Britain; Paragraph 4 of the Exchange of Notes between the Great Britain and Egypt, signed in Cairo on 7 May 1929 provided: "save with the previous agreement of the Egyptian Government, no irrigation or power works or measures are to be constructed or taken on the

in recognized Italy's annex-
hiopia, a situation was cre-
by Ethiopia could argue that
ents to which Great Britain
rty and which requires
approval was void."

**06 Tripartite Treaty be-
ain, Italy and France;** Sub-
the 1902 agreement, a sec-
reference to Ethiopia in
with the Nile waters is con-
so-called Tripartite Agree-
een Great Britain, France
gned in London on Decem-
906. Without consulting
e three colonial powers col-
o act together to safeguard
t of Ethiopia. Emperor
jected the agreement as a
y against the sovereignty of

25 Anglo-Italian Exchange
n this exchange of notes 14
cember 1925, Italy recog-
prior hydraulic rights of
the Sudan in the headwaters
e and White Nile and their
and agreed not to construct
adwaters any works which
ibly modify their flow into
ver. When the news of this
of notes reached Addis
oused an angry reaction and
y then a member of the
Nations, dispatched a protest
bers of the League against
of the two Governments on
ty. The Ethiopian protest
culated to members of the
he British and Italians who
assed, backed away from
n and declared publicly
not have any ambition on
nty of Ethiopia. The
oy was thus, effectively
nd the agreement never

**Nile Waters Agreement
pt and Great Britain;**
f the Exchange of Notes
reat Britain and Egypt,
o on 7 May 1929 pro-
ith the previous agree-
yptian Government, no
wer works or measures
ructed or taken on the

Nile River and its branches or on the lakes from which it flows, so far as all these are in the Sudan or in countries under British administration, which would, in such a manner as to entail any prejudice to the interests of Egypt, either reduce the quantity of water arriving in Egypt or modify the date of its arrival, or lower its level." By virtue of this agreement, Egypt recognized the Sudan's right to water adequate enough for its own development, so long as Egypt's "natural and historic rights" were protected. The agreement, through an accompanying document, allocated to Egypt 48 billion cubic meters of the Nile waters as against 4 billion cubic meters of water to the Sudan annually. What is most interesting about this agreement is Egypt's insistence in inserting a phrase showing its claim to prior appropriation use of the Nile waters.

Ethiopia did not recognize the validity of this agreement nor did it ever accept Egypt's claim to acquired or historic rights. Moreover, as the agreement was signed between Egypt and Britain, it can not have a binding effect on Ethiopia. According to the principle of treaty making, a treaty made between two parties can not have a binding effect on a third party without its consent **res inter alios acta**. Other riparian countries such as Uganda, Tanzania, and Kenya did not consider themselves bound by this agreement after independence. Even the Sudan, after its independence formally repudiated the agreement in 1958 on the grounds, inter alia, that "economic and technical development since 1929 had rendered these provisions obsolescent."

The 1959 New Agreement between Egypt and Sudan; Paragraph 1 of the preamble of this agreement reads "As the River Nile needs projects, for its full control and for increasing its yield for the full utilization of its waters by the Republic of the Sudan and the United Arab Republic on technical working arrangements other than those now applied."

Both during the negotiation and at the conclusion of the 1959 agreement Ethiopia has rejected the validity of the 1959 agreement. In a communiqué issued on 6 February 1956, Ethiopia announced its plans for the utilization of the vast irrigation and hydrological potential of Ethiopia and in a 1957 aide Memoir, the Government: "reasserted and reserved now and for the future the right to take all such measures in respect of its water resources and in particular, as regards that portion of the same which is of the greatest importance to its welfare, namely, those waters providing so nearly the entirety of the volume of the Nile, whatever may be the measure of utilization of such waters sought by recipient states situated along the course of the river." The Aide-Memories concluded: "The Government must naturally draw the necessary consequences and conclusions and assert the full measure of its freedom of action as regards discussion being pursued concerning the water flowing from its territory and as to which, unlike the discussion pursued in the period between 1924 and 1951, it has not been consulted. Under these circumstances, Ethiopia, alone the sources of nearly the entirety of the waters involved must, once again make it clear that the quantities of the water available to others must always depend on the ever increasing extent to which Ethiopia the original owner will be required to utilize the same for the needs of her expanding population and economy."

At the UN water conference at Marda de Plaata, Argentina, in 1977. Ethiopia also made its position clear that, it reserved its right to exploit its natural resources to the benefit of its people. Likewise in a statement of 27 August 1959, Great Britain, this time acting on behalf of its East African colonies, reserved their rights to negotiate for additional water should the need arise. The statement reads "The territories of British East Africa will need for their development more water than they at present use and will wish their claims for more water to be recognized by the other states concerned."

An interesting factor as far as the legal principle in the 1959 agreement is concerned is the changes in Egypt's position of "acquired rights." While the 1929 agreement clearly stipulated the long standing position of Egypt on the principle of "acquired rights" or "priority of appropriation" of the Nile waters, the 1959 agreement made a clear departure by abandoning the use of the term "acquired rights." "Only the 1959 agreement did Egypt distance itself from this doctrine **[of absolute integrity of state territory]** and accept the principle of more equitable allocations of waters..." The 1959 agreement had implicitly accepted the evolving principle of equitable utilization by recognizing, the rights of annual share of Sudan to 18.5 billion cubic meters and 55.5 billion cubic meters to itself as measured at Aswan.

Egypt and Sudan have made a provision in the agreement "To study together" and "Adopt a unified view" on other riparian claims to a share in the Nile waters. "If such studies result in the possibility of allotting an amount of the Nile waters to one or the other of these territories, then the value of this amount as at Aswan shall be deducted in equal shares from the share of each of the two Republics."

Problems for Negotiation and Cooperation

In spite of the above basic principles of international water resources law and existing agreements, Egyptian attitude regarding the Nile waters still reflects its adherence more to absolute integrity of state territory than to equitable utilization. The construction of major projects on the Nile such as the Aswan High Dam, recently the Peace Canal across the Suez Canal to Sinai desert and of late the Tochka Canal without consultation with upper riparian states, amply demonstrates this rigid Egyptian position.

As far as the Nile is concerned, there is no single statement or agreement which acknowledges that all the riparian countries have rights to their water resources or that these rights are limited in any way and guided by the principle of just and equitable water sharing. However, from the overwhelming development of international law in the use of international

Table 1. International Water Disputes (After Gupta, 1995)

RIVER	COUNTRIES IN DISPUTE	ISSUES
Nile	Egypt, Ethiopia, Sudan	Water flows, siltation, flooding, diversion
Euphrates, Tigris	Iraq, Syria, Lebanon	Reduced water flow, salinisation
Jordan, Yamruk, Litani, WestBank aquifer	Israel, Jordan, Syria, Lebanon	Water flow, diversion
Indus, Sutleji	India, Pakistan	irrigation
Ganges, Brahmaputra	Bangladesh, India	Siltation, flooding, water flow
Salween	Myanmar, China	Siltation, flooding
Mekong	Cambodia, Laos, Vietnam, Thailand	Water flow, flooding
Parana	Argentina, Brazil	Dam, land inundation
Lauca	Bolivia, Chile	Dam, salinization
Rio Grande, Colorado	Mexico, United States of America	Salinization, water flow, agrochemical pollution
Rhine	France, Netherlands, Switzerland, Germany	Industrial pollution
Mass, Schelde	Belgium, Netherlands	Salinization, industrial pollution
Elbe	The Czech and Slovak Republics and Germany	Industrial pollution
Szamos	Hungary, Romania	Industrial pollution

watercourses that has been applied by almost all other international river systems in the apportionment of water right should have been welcome by the Nile riparian countries, too. But, political leaders and regimes in Egypt are reluctant to negotiate and cooperate based on the principle of equitable distribution of the Nile waters, sticking to maintaining the **status quo** at the total expense of others.

An Eritrean view in the January 1995 issue of Ethioscope magazine clearly explained the attitude of policy makers of Egypt. Egyptian policy towards the Horn of Africa turned the region to turmoil, war, misery and famine that have taken the lives of millions and hampered the socio-economic development of the region. Egypt's primary concern among the countries of the Horn has been with Ethiopia. In the last 30 to 40 years, Egypt followed the Cold War mentality of "destabilizing a country or force that constituted a potential threat to one's interests." To thwart the threat that Ethiopia posed to the Nile waters, Egypt greatly entertained in the establishment of opposition parties from Eritrea (mainly the Islamic League) to the extent of actively co-operating in allowing radio broadcasts and student activities on its soil. Regarding Sudan, Egypt has been pursuing a hegemonistic and unfair policy to undermine Sudan's full independence especially during Nimeir's government. Egypt played also a major role in prodding both Djibouti and Somalia to join the Arab League in order to secure its control in the Red Sea (so-called Arab Lake) and the Horn of Africa region. And in the eyes of the Egyptians, Ethiopia would have been encircled by the Sudan, Eritrea, Somalia and Djibouti. Moreover, the turmoil in Uganda due to barbaric dictatorship has been also welcome by Egypt.

It must be acknowledged that all the myriad conflicts that prevailed in the Horn were not instigated by Egypt. As a matter of fact, most of these conflicts were spawned by the concerned countries/regimes themselves. The net result of the prevailing turmoil and conflict- whether seen in isolation or in their totality- however, proved the promotion of Egypt's interests and, thus, constituted a blessing. However, the issue of the utilization of the Nile waters is not the only disputable one. There are several international watercourses that are still disputable (Table 1).

5.Conclusion

As it has been briefly discussed above, there is neither binding international convention or legislation nor specific convention or agreement binding all Nile riparian countries on the utilization of international watercourses. In fact all the existing principles of international water resources law or existing agreements do not deprive Ethiopia's legitimate right to the Nile waters. However, there is a purposeful and determined effort by Egypt to use and constantly maximize the use of every bit of Nile waters even beyond its natural drainage basin based on its policy of turning the Horn- as a case of misplaced hostility for the last 30 to 40 years. Even today Cairo's policy-makers still follow the cold tradition of becoming reluctant to entertain new ideas being backed by certain diplomatic advantages that they still enjoy. The fact that as a major broker in promoting the Arab-Israeli relationship in general and the Israeli-Palestine issue in particular, thereby earning the gratitude of the United States of America. This, coupled with the access they enjoy to the international media for certain reasons, is pushing them to gloss over and Suppress certain major issues regarding the Nile waters. But will this disposition be sustainable in the long-term? Is it the only alternative they have? The author would like to remind Cairo's policy-makers to stop their pace for a second, think and draft their policies in a sustainable way for the benefit of all peoples sharing their god given gift of the Nile waters.

What is surprising is the recent Eritrean aggression against Ethiopia that aggravates the Horn's age of turmoil, war and misery. The Asmara's policy-makers who have expressed their view's clearly in the January 1995 issue of Ethioscope magazine that Egypt's attitude towards the Horn is still based on the local proverb: "A curse for someone may be a blessing for another." within 2 to 3 years, changed their view and are in fact promoting Egypt's interest once again.

However, what is sustainable and justice regarding the issue of the Nile waters is to negotiate and cooperate in good faith on the basis of the principle of equitable utilization. The riparian states of the Nile can thus avoid the danger of engaging in competitive and conflicting use of the Nile waters and embark on a beneficial and optimal utilization of the Nile waters.

One such strategy for upstream - downstream cooperation in the utilization of the Nile waters, as has been confirmed by various river basin studies, is the construction of the Lake Tana Reservoir for irrigation (which could prevent the loss of nearly 15 billion cubic meter annually) and the Upper Blue Nile Reservoirs for hydropower (which could reduce losses at Lake Naser and Rosiers Reservoirs by more than 50%) (Whittington, et al. 1994). Moreover, recent studies by MOWR indicate that if the Upper Blue Nile reservoirs are constructed and the produced hydropower is exported, Ethiopia will earn foreign currency more than twice that of coffee annually. Ethiopia, with its growing population of approximately 122 million by the year 2025 (20% higher than that of Egypt), sooner or later will seek to tap its abundant water resources of the Nile (present utilization is less than 1 billion cubic meters) for its development needs, to ensure food security and avert the dangers of frequently recurring droughts which it had painfully experienced.

Finally, the author would like to stress his view that Ethiopia's policymakers being backed with the above facts and the various principles of international water resources law, have great responsibility to direct the country's policy towards building of a self-sufficient, coherent, developed, powerful and dignified nation through utilization of the country's water resources.

References

Caponera, D. 1992. Principles of Water Law and Administration, A.A. Balkema, Rotterdam.

Ethioscope, 1995. Egypt and the Horn - a Case of Misplaced Hostility- an Eritrean View. January issue of official magazine of Foreign Affairs Ministry of Federal Democratic Republic of Ethiopia.

Girma, A. 1997. The Imperative Need for Negotiation on the Utilization of the Nile Waters. Vth Nile 2002 conference, Addis Ababa, Ethiopia.

Gupta, J. 1995. An Introduction to Water Law, Policies and Institutions: National and International Aspects. IHE lecture note series, HH258/95/1.

ILA, 1966. Helsinki Rules on the uses of waters of international rivers, International Law

Design of Monitoring Networks for River Water Quality Mangement in Ethiopia

Berhanu Adugna, *Lecturer, Arbaminch Water Technology Institute, P.O.Box.21,Arbaminch, Ethiopia*

Abstract

Water quality management is an important issue in various environmental programs and is one of the key issues towards achieving sustainable development. It is considered as an important environmental planning and management tool to detect, control, or to evaluate the human-health or ecological effects of single chemical or mixture of chemicals. Coming from the International Conference on Water and Environment in Dublin there is an acknowledgment in the Conference Statement that data and information on water resources and water use provide the knowledge base necessary to sustainable development. In most countries, most water quality management laws always require water quality monitoring which is the first step in water quality management. However, in Ethiopia water quality management progression may be restricted by lack of funds and therefore remains at levels involving fewer activities. The lack of appropriate water quality monitoring activities can limit many governmental and private efforts in accomplishing specific water quality management. When a society moves towards industrialization and development in the living standards, the waste materials are bound to increase in concentration and type. Evidently pollution is creeping to different rivers in Ethiopia. Thus, Ethiopia could face water quality problems that may be more demanding and difficult to handle than those of quantity. Hence, water quality monitoring network, which can greatly contribute to establishing sustainable water resources development in Ethiopia, must be established. The objective of this paper is to design a monitoring network for river water quality management purposes in Ethiopia based on World Meteorological Organization (WMO) recommendations to obtain as much as data and information as needed.

1. Introduction

Water is a precious and finite resource serving present and future generations. Water is the most essential of all life supporting resources and likewise for development of social life. The people of Ethiopia are making increasing demand on its water for all faces of development. Rapid population growth generates more wastes, which are disposed of without proper treatment in watercourses, and hence causes severe microbial and chemical contamination to the rivers of Ethiopia. The availability of sustainable sources of water of acceptable quality has had a profound influence on human development. The management of river basins deals with variety of user functions and environmental aspects. Recently, water quality management in many countries has evolved into an expensive and complex series of activities designed to protect and control the quality of water for different uses. However, in other countries water quality management progression is restricted by the lack of funds and specific scientific information and therefore remains at levels involving fewer activities.

Water quality monitoring is an important issue in various environmental programs. It is considered as an important environmental planning and management tool to detect, control, or to evaluate the human-health or ecological effects of single chemical or mixture of chemicals. Monitoring is the first step in water quality management.

The quality of water has probably been a major concern since the beginning of humanity: saline and bitter waters had to be avoided for human and cattle. *Water quality* still has not got a universally accepted definition. One definition refers to the chemical composition of waters as: (i) a set of concentrations, speciations and physical partitions of inorganic and organic substances. In addition to this objective description resulting from the analysis at a given time for a given station, two major subjective attributes may be associated to water quality: (ii) the modification of natural composition and its impact on the aquatic biota, and (iii) the relevance of measured chemical composition to the multiple human uses. The first approach is mostly found in the earth sciences, the second one in ecology, while the last one is more a water management point of view. The definition of water quality has now been extended to the overall quality of the aquatic ecosystem based on water chemistry, particulate matter chemistry, and health of the biological communities and organisms. The aquatic environment is no longer regarded for its potential use by humans, such as for drinking water, irrigation, cleaning, transportation, and power but also for its capacity to sustain aquatic biota in equilibrium with the local natural conditions. This last concept, a recent one in the history of humankind, has been particularly developed in the last 40 years as the result of fast and irreversible changes.

2. The Necessity of Design of Water Quality Network in Ethiopia

At present, quite reliable information on water levels and discharges are available in Ethiopia. However, the component of water quality monitoring within the water monitoring system of Ethiopia has not yet been addressed very well. In Ethiopia, like many other countries, water conservation should

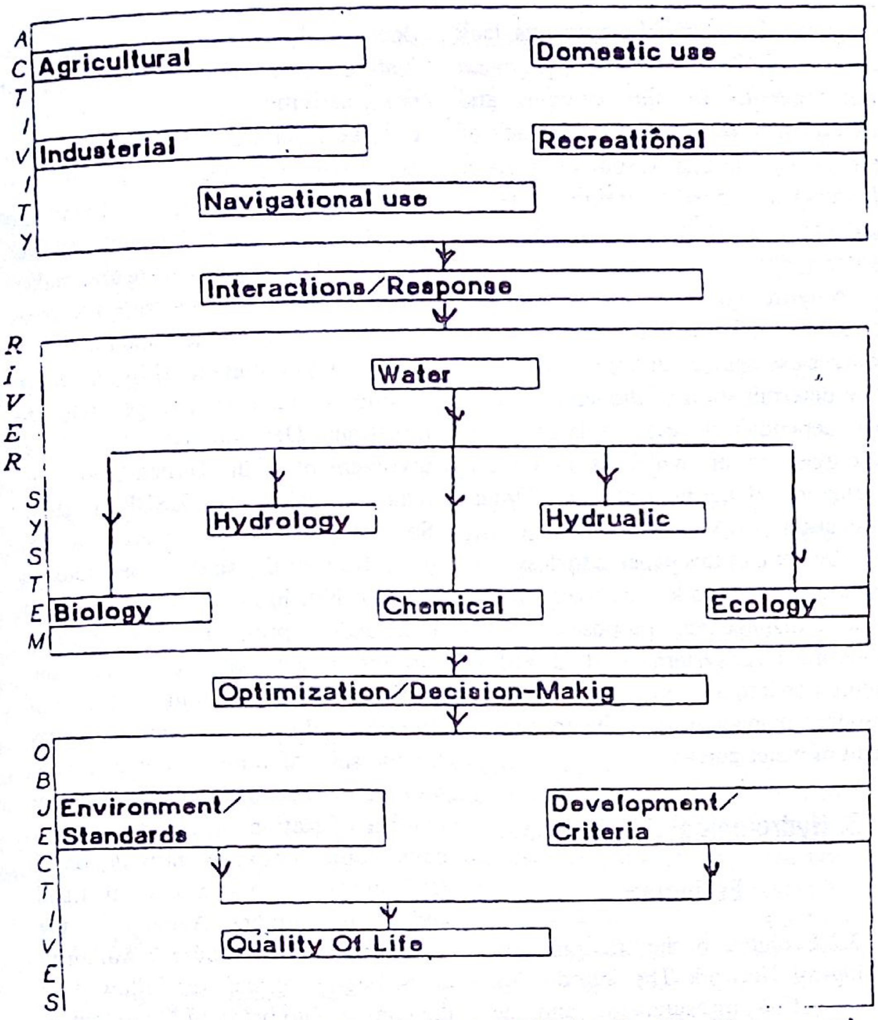


Figure 1: Analytical Framework of Water Quality Managment

receive high attention before its deterioration reaches a state that is difficult to recover. In general, protection and conservation are easier to implement than remedial of polluted water resources. The water utilization of the Ethiopian River System for irrigation, domestic and industrial uses and power generation is bound to alter the quality of its water and the natural environment. Thus several points need to be taken into consideration for the necessity of design of water quality network in Ethiopia which could be made as follows:

1. Quality and quantity are two equally important features of water resources. This is because the chemicals and biological features may make fresh water hazardous to life.

2. Considering the high population growth rate in Ethiopia and the possible touching of 120 million populations in less than 20 years from now leading to increase in demand for safe water, there is going to be a tremendous pressure on irrigated agriculture, industrial expansion, urban and rural development and the like. With this perspective in mind, Ethiopia should even draw plans for the design of water quality monitoring networks. The life standard of the population and the development of the society of its water cannot be separated from considerations of these points.

3. The reliability of rainfall as water resource in Ethiopia for agricultural products is rather limited. Dams have been and will be built across the rivers and their tributaries for different purposes. This transforms a watercourse which is seasonal and annually viable to conserve water for irrigation or power generation or other purposes. These dams control the river and substantially affect the river flows. Building of a dam creates a reservoir which induces problems related to environmental aspects.

4. The impact of human activities within the river system due to agricultural, urban and industrial development affects both the quality and quantity of its water. For example, the introduction of industries and employment of auxiliary means in agriculture, fertilizers and the use of agro-chemicals like pesticide could disturb the natural quality of the river water. Deforestation increases soil erosion and sediment loads. Table 1 can be referred for the sources and causes of water quality deterioration in rivers.

Thus, to maintain acceptable quality of water resources in Ethiopia, the Ministry of Water Resources may be responsible for implementation of a national water quality monitoring program. Water quality monitoring should be carried out as a regular routine activity and should not be used or regarded as a means of response to crisis situation. Rivers in Ethiopia suffer from inputs of effluents from both point and non-point sources. Some rivers affected by Municipal and Industrial effluents are Akaki river, Mojo river, Borkena river, Awash river, etc., a situation that indicates a continuos threat to their sustainability. Thus protection against pollution is extremely urgent and necessary as a precautionary measure for conservation of the river waters. A framework is used to analyze the cause and effect relationship of water quality. It comprises an objective, natural system and a number of activities with interactive process between them to achieve the objective as shown in figure 1. The interactive process between the different activities along the river resulted in a number of pollutants as classified in Table 1. The river system has a capacity to assimilate some level of waste without apparent damage. This capacity is the result of physical and biological processes occurring within the aquatic environment to break down the waste into harmless subsistence. Recognizing the limited assimilative capacity of the river system decisions should be taken to meet these criteria (for e.g., the criteria for the quality of irrigation water) and standards (for e.g., WHO drinking water quality standards). Pollution regulations may be specified in terms of stream quality. For setting the efficient regulation the limited assimilative capacity of the river system must be recognized.

Hence, in translating criteria for

Table 1: Source and causesof water quality deterioration (Barrram & Balance.1996)

Effluent Source	Factors Affecting Quality Deterioration
Domestic sewage	BOD. suspended solids, ammonia nitrate, phosphate
Vegetable processing	BOD. suspended solids, color
Chemical industry	BOD. ammonia, phenols, non-degradable organic
Iron and steel manufacture	Cyanide, phenols, thiocyanate, pH, ammonia, sulfides
Coal mining	Suspended solids, iron, pH, dissolved metals
Metal finishing	Cyanide, copper, cadmium, nickel, pH
Brewing	suspended solids, BOD, pH
Dairy products	BOD, pH
Oil refineries	Ammonia, phenols, oil, sulfide
Quarrying	Suspended solids, oil
Agriculture	Nitrate, phosphate, BOD

sustainable development of river basins there is a clear need of establishing water quality monitoring network in Ethiopia to enable proper evaluation of its status and define the proper protection and management means. It is required to monitor the extent of pollution in controlled waters, to establish water quality objectives for controlled waters, and to ensure that the specified water quality objectives are met at all times. The Government should decide to establish water monitoring systems and the network should be put into operation as soon as possible. Effluent quality standards and guidelines on water quality control methods in Ethiopia should be formulated and enforced by Environmental Protection Authority. The main constraints in Ethiopia which affect the water quality monitoring program may be financial constraints, lack of transport, lack of suitable equipment and provision for the servicing and maintenance of equipment and lack of experienced human resources. Hence, there is a high need for training courses and capacity building in the field of water quality monitoring.

A hydrological service provides the necessary information for water resources assessment, and it is defined as "the determination of the sources, extent, dependability and quality of water resources up on which is based on evaluation of the possibilities of their utilization" (WMO, 1995). However, the objective of this paper is to design a monitoring network for river water quality management purposes in the Ethiopian river system based on WMO recommendations. One aspect of water resource management is the management of water quality.

3. Hydrological Services in Ethiopia

3.1 Evolution of the Ethiopian Hydrological Network The introduction of river flow measurements and the commencement of hydrological studies in Ethiopia are not well fixed in the course of development. But it has been learnt that river flow stage measurements were first embarked at the outlet of Lake Tana in 1920 (Hurst, 1952). Even though there is no record evidence in the archives of a government institution engaged in such kinds of study activities, the station at the outlet of Lake Tana was interrupted in February 1926 and reopened in February 1928 and was reported to be functional till December 1932. Later, the studies of river basin schemes were undertaken by technical assistance from Overseas Development Agencies, and the first of its type was commenced by the cooperation of United States Agency for International Development US-AID and involvement of the United States Bureau of Reclamation USBR in 1958. So, the recorded information so far dates back to the start of this study in the Blue Nile basin. The existence of an independent program for monitoring through a sectional hydrological network started in the mid 1960's after hydrological stations came into reality for the sake of water resources inventory of various sites. The increasing number of stations in the river basins gave momentum in the formulation of Hydrometeorological Section in Land and Water Studies Agency of the Ethiopian Water Resources Authority at the beginning and was followed by the coming into being of Hydrological Studies Department (HSD) which currently undertakes the hydrological activities of the country as a whole. Countrywide networks have evolved over time to meet the changing national needs. The Department runs the national hydrometeric networks and is responsible for the installation, operation and maintenance of the hydrometeric stations as well as for collecting, processing, publication and analyzing of the obtained data. The Department has eight regional offices and these offices are responsible only for operation, carrying out flow measurements and supervision of observers. They also execute installation and maintenance of stations.

Basin wide classification of these stations is given in Table 2. The hydrological network consists of 507 gauging stations in 12 river basins of which 338 stations are operational in 1997. While a number of these stations were abandoned for operational and hydrological reasons under normal circumstances, the majority of stations which have been either damaged or fallen into

Table 2 Status of stream gauging by basin in 1997(Kidane,1997)

BASIN	ESTABLISHED	ABANDONED	NON-OPERATIONAL	OPERATIONAL
Danikil	12	-	3	9
Awash	95	24	14	57
Wabi-Shebelle	47	43	21	22
Geneale-Dawa	23	20	1	19
Rift Valley	69	11	8	41
Gihbe Omo	53	2	2	40
Baro Akobo	31	26	5	24
Abbay-Blue	143	-	17	100
Nile	32	-	5	26
Tekeze	2	-	2	-
Mereb Gash	-	-	-	-
Ogaden	-	-	-	-
Aysha				
Sum	**507**	**91**	**78**	**338**

Table 3 Recomended minimu network density criteria

Physiography	Precipitation Non-recording	Precipitation Recording	Evaporation	Discharge	Sediment	Water Quality
	900	9000	50000	2500	25000	50000
Coastal	250	2500	50000	1000	10000	20000
Mountainous	575	5750	50000	1750	17500	35000
Interior plains	575	5750	50000	1750	17500	35000
Hilly (undulating)	25	250	50000	3000	30000	6000
Small mountainous islands (<20000 km^2)	10000	100000	100000	20000	200000	2000000
Polar	10000	100000	30000	20000	65000	80000
Arid						

disuse for some other reasons (Kidane, 1997). The numbers of operational stations in 1989 and 1996 are 386 and 338. respectively (Michael, 1997). Thus, it can be concluded that a hydrological network in Ethiopia is generally in state of decline. Funds were simply not being made available to the hydrological services to allow them to perform their duties in an effective manner. Only quantitative aspects of water have been observed and water quality has not yet been addressed very well. The component of groundwater monitoring within the water monitoring system in Ethiopia is not yet recognized.

3.2 Adequacy of the Hydrometeric Network

WMO developed the concept of the basic network, that hydrological network which has minimum necessary number of stations to give a meaningful countrywide coverage of the hydrological variables. Consequently the WMO guidance is valuable for establishing the adequacy of existing national networks. Applying Table 3, Ethiopia needs at least 740 hydrometeric stations. The result of evaluation of the network shows that some 256 additional new stations should be installed in order to satisfy the minimum WMO network density requirements (see Table 4). However, the network distributions in the central part of Ethiopia generally satisfy the standard recommended by WMO. The network density is below the adequate standard at border areas, which characterized by lack of sufficient road network. Stations for water discharge measurements are mainly installed on the largest rivers and relatively quite sufficient. The number of stations on the small streams is quite insufficient and consequently current information for small watersheds is insufficient for verification and evaluation of extreme discharge events. From recent experience, for the design of the Borekna dams there were only seven suspended sediment load measurements. The design was based on limited data and empirical equations which resulted in loss of a lot of money (Michael, 1997). Hence, as to determine sediment discharge measurements, the number of measuring should be increased, the objectives of the network up-dated. It is also apparent that networks in mountainous areas do not often come up to the desired minimum density levels. This is something of a paradox. Most of the country water resources originate in mountainous areas, yet knowledge of the hydrology of these areas is usually lacking.

The Sub-Saharan Africa (SSA) Hydrological Assessment Project identified the following problems in Sub- Saharan African Countries (WMO, 1995): (a) a decline in the size and quality of hydrology services, (b) lack of skilled manpower, (c) inadequate maintenance of equipment, (c) maintenance of stream gauging was curtailed due to financial and social reasons, and (e) getting moral, financial and technical support for data collection and processing.

Table 4 Design of the networks

BASIN	REGION (Km^2)					EXISTING HYDROMETERIC STATIONS	PRPOSED NUMBER OF STATIONS							
	MOUNTAINOUS (A)		FLAT (B)	ARID (C)	TOTAL		HYDROMETERIC STATIONS				BASIC WATER QUALITY STATIONS			
	>2500m	1500-2500m					A	B	C	TOTAL	A	B	C	TOTAL
Abbay (Blue Nile)	38000	104400	60800	0	203200	100	143	25	0	168	7	1	0	8
Rift Valley	8759	30250	137300	0	52739	41	39	6	1	45	2	1	0	3
Awash	7478	29123	73718	3377	112692	57	37	30	0	68	2	2	1	5
Ghibe Omo	10002	33915	34296	0	78213	39	44	14	2	58	2	1	0	3
Tekeze	11769	27461	105412	26400	171042	19	40	43	0	85	2	2	1	5
Genale Dawa	1208	23358	49586	0	74172	24	25	20	1	45	1	1	0	2
Baro Akobo	6126	27479	152682	16400	202697	22	34	61	0	96	2	3	1	6
Wabi Shebelle	11628	43183	35180	0	90001	26	55	14	0	69	3	1	0	4
Dankil	41	7700	27801	38460	74002	9	8	11	2	21	1	1	1	3
Mereb Gash	32	12611	11289	0	23932	2	13	5	0	18	1	1	0	2
Ogaden**	0	0	-	-	77121*	0	0	0	0	0	0	0	0	0
Aysha**	0	0	-	-	2223*	0	0	0	0	0	0	0	0	0
Sum						**507**				**673**				**41**

Note: * - Both basins fall in the flat and arid regions.

** - The basin does not have any streams and consequently no stream gauging stations exist in this basin.

4. Purposes of River Water Quality Monitring in Ethiopia

In order to meet its water quality planning and management objectives, Ethiopia should implement comprehensive water quality programs. These programs provide the information needed to make management decisions in a timely fashion. Decision making in a water quality management context requires the following:

- Determining whether water quality is improving or not,
- Determining compliance of discharges with standards,
- Locating discharges that are not licensed or violating licenses condition, and
- Identifying the nature and extent of specific pollution problems.

There are as many valid reasons for the measurement of water quality in Ethiopia as there are purposes for which water may be used. Indeed, these uses will determine the requirements and may for example be used in both

Table 5 Estimated Distance for comlete mixing in streams and rivers(Bartram &Balance,1996)

Average Width (m)	Mean depth (m)	Estimated Distance for Complete Mixing (Km)
5	1	0.08 – 0.7
	2	0.05 – 0.3
	3	0.03 – 0.2
10	1	0.3 - 2.7
	2	0.2 - 1.4
	3	0.1 - 0.9
	4	0.08 – 0.7
	5	0.07 – 0.5
20	1	1.3 – 11.0
	3	0.4 - 4.0
	5	0.3 - 2.0
	7	0.2 - 1.5
50	1	8 – 70
	3	3 – 20
	5	2 – 14
	10	0.8 – 7
	20	0.4 – 3

the management of national water resources and for international environmental quality programs. The scope of water quality measurement program will tend to overlap these requirements. In general the main reasons for measurement of water quality may be grouped into the following broad categories (WMO, 1981):

(a) Classification of water resources for the planned development and utilization according quantity and quality criteria;

(b) Collection of baseline data to establish the natural quality of water in order to indicate long term changes which may interfere with present or future uses of the resource;

(c) Continuous monitoring of water quality in relation to its uses as the raw water source supply for drinking and other purposes;

(d) Surveillance to establish the suitability of a water course or lake for recreational purposes, or to determine the effectiveness of wastewater management programs;

(e) Investigation of the causes of pollution and effectiveness of the remedial measures. In this case, specific parameters known to be causing the pollution will be measured and the survey should continue until the effect of pollution has disappeared due to collective measures, natural dispersal or self-purification of the water body;

(f) Forecasting water quality and estimating capacity of a body of water to accept effluents from sewage treatment works, industrial premises or power generation plant, etc. Studies with these criteria in mind will enable a rational choice to be made of water pollution control measures and alternatives in water resources management.

The prediction of long term water quality changes will require examination of all the factors which may influence water quality, whereas short term forecasting will serve more as a warning system. The use of mathematical water quality models has been found to be considerable benefit for both long and short terms forecasting of water quality (which could help in the process of policy formulation and master planning) in rivers, lakes and reservoirs. However, the validity of the model depends upon the quantity and quality of the data used to formulate the model; hence the need to establish the correct sampling frequency and data gathering system.

5.Criteria of the Selected River Water Quality Parameters

Since water, which occurs naturally, contains a wide variety of constituents, it is necessary to select a group of parameters to statistically characterize the water quality population on which the design of any water quality monitoring program will be based. For the purpose of design criteria, water quality parameters are grouped based on their behavior in nature. From each group, a number of representative parameters are selected taking into consideration the data availability of these parameters. The selected parameters from each group are as follows:

Physical parameters: Temperature, pH, electrical conductivity, total dissolved solids, total suspended solids

Chemical parameters: Dissolved oxygen, total alkalinity, total hardness, chloride, calcium, sodium, magnesium, potassium, BOD, COD, oil and grease and orthophosphate

Biological parameters: Fecal coliform

6. Design of Networks for Montoring River Water Quality

Some of the elements that should be considered during the planning of water quality monitoring network system are:

6.1Management Goals

In designing a water quality monitoring system the first and most important step is to clearly define the objectives of the system. Only when the objectives have been clearly stated, it is possible to design the networks on a rational basis.

Monitoring must be undertaken for a purpose, and programs can be designed to meet a variety of information goals, for example, the assessment of ambient conditions, trends, or the detection of excursions beyond regulatory limits. The ultimate management goals are to control, maintain and improve the water quality of the rivers of Ethiopia.

6.2 Network Design and Administration

6.2.1 Network Design Criteria

The design considerations of net-

Table.6 Selected Water Quality Parameters for the Designed Water Quality Monitoring Network

Type of Survey	Physical Water Quality Parameters		Chemical Water Quality Parameters						Biological Water Quality Parameters	
			Inorganic		Organic		Nutrient			
	Name of Parameters	River/Point Sources	Name of Parameters	River/Point Sources	Name of Parameters	River/Point Sources	Name of Parameters	River/Point Sources	Name of Parameters	River/Point Sources
[1] Proposed for inclusion in all Surveys (core parameters)	Flow	$R_{B\ and\ I}$, Ag., In.	Dissolved Oxygen	$R_{B\ and\ I}$, Ag., In.	Chemical Oxygen Demand	$R_{B\ and\ I}$, Ag., In.	Total Phosphorous	$R_{B\ and\ I}$, Ag., In	Total Coliform	$R_{B\ and\ I}$, Ag., In
	Color									
	Oder									
	pH				Total Organic Carbon					
	Temperature									
	Conductivity						Total Kjeldahl Nitrogen		Faecal Coliform	
	Turbidity									
[2] Recommended additional parameters to [1] for collection of base line data or trends	Total Suspended Solids	$R_{B\ and\ I}$, Ag., In. (base line) R_B, Ag., In. (trends)	Total Alkalinity	$R_{B\ and\ I}$, Ag., In. (baseline) or R_B, Ag., In. (trends)	Biological Oxygen Demand	$R_{B\ and\ I}$, Ag., In. (baseline) or R_B, Ag., In.. (trends)	Nitrite - N	$R_{B\ and\ I}$, Ag., In. (baseline) or R_B, Ag., In.. (trends)	Faecal Streptococci	$R_{B\ and\ I}$, Ag. (baseline) or R_B, Ag. (trends)
	Total Dissolved Solids		Total Acidity						Salmonella typhosa	$R_{B\ and\ I}$ (baseline) or R_B (trends)
			Total Hardness						Salmonella (~ 1700 spp)	
			Carbonate						Vibrio Cholera	
			Bicarbonate						Algae Count	
			Chloride				Nitrate - N		Total Count	
									Cholorphylls a, b, c	
			Iron						Plankton Counts	
			Calcium						Benthos	
			Magnesium						Fish	
			Potassium						# Salmonella typhosa	R_I
			Sodium				Ammonia - N			
			Manganese							
			Selenium							
			Silver							
			Boron							
			Aluminum							
[3] Recommended additional parameters to [1] related to the enforcement of regulations.	Total Suspended Solids	R_I, Ag., In.	Total Alkainity	R_I, Ag	Biological Oxygen Demand	R_I Ag., In.	Organic Nitrogen	R_I		
	Total Dissolved Solids		Iron	R_I, Ag., In.						
	Ash of Total Suspended Solids	In.	Manganese		Oil and Grease					
	Ash of Total Dissolved Solids		Selenium	R_I					Salmonella (~ 1700 spp)	
			Silver	In.	Phenol		Nitrate - N	R_I, Ag., In.		
			Fluoride	R_I, Ag., In.						
			Sulfates	R_I, In.	Surfactant					
			Lead							
			Arsenic	R_I,Ag., In..	Tannin and Lignin				Vibro Cholera	
			Mercury			R_B, Ag.	Ammonia - N	R_I,Ag		
			Zinc		Cyanide					
			Cadmium							
			Chromium							
			Copper		#Pesticides		Inorganic Phosphate (Ortho & Poly)	Ag., In.		
			Residual Chlorine	In.						
			Nickel							

Note:
* Field measurements except pH can also be measured in the laboratory

R_B: Basic Station, R_I: Impact Station, Ag : Agricultural drain, In.: Industrial effluent.

Table 7 Estimated distance for complete mixing in streams and rivers (Bartram & Balance,1996)

Average Discharge (m^3/s)	Type of Stream or River	Number of Sampling Points	Number of Sampling Depths
<5	Small stream	2	1
5-140	Stream	4	2
150-1000	River	6	3
≥ 1000	Large river	≥6	4

work involve the study of the characteristics and physical features of the area, topography, geological structures and vegetation. On the other hand, cost benefit analysis should be made on the effectiveness of data gathering, quality of data required, and the worth of the data produced. Operation of a network requires trained personnel, adequate spares and replacement, workshops, laboratories, a fleet of land and water transport vehicles, all of which entail sizable financial resources (WMO, 1971). Thus, the network requirements must be defined in response to consideration of what the data are to be used for and the budget which is available. The considerations must take into account not only the scientific or management requirements for information but also the technical difficulties of collecting data. The network design with the most complete coverage of a watershed may not seem feasible to operate due to logistical difficulties with power supplies, or difficulties with security, for example. On the other hand, the network coverage must ensure adequate information for planning and operating water resource development and protection activities.

However, there remains the problem of the scientific design of hydrological networks; while a number of research networks exist which have been designed according to scientific methodology, there are few example of these methods being used for operational networks. This lack of success considers to be due to the difficulty of the subject in an intellectual sense and of course in the practical sense. Because of these difficulties, WMO has promoted the concept of minimum density of networks as a guide to the numbers of instruments required in particular physiographic conditions (Table 3). This concept is seen as an interim step towards the development of a methodology which can be implemented readily, a methodology currently being pursued by WMO. In addition, certain countries have developed their own criteria for minimum network densities for certain variables, in order to make measures of their own performance.

In order to obtain representative samples of water quality of the area, the WMO introduced a general guide to the density of water quality stations given in Table 3 to give a meaningful countrywide coverage. Therefore, the design of river water quality monitoring network of Ethiopia can be done against these recommendations given by WMO. Hence, as per the WMO norms, Ethiopia needs at least 38 basic water quality stations (see Table 4). Standard instruments and observational procedures are recommended to ensure that all measurements are comparable and consistent. It can be planned to establish eight basic water quality stations annually in order to meet the minimum density requirements in the coming five years. The water quality sampling network should be fully integrated with the stream gauging stations. In the case of Ethiopian river system, three network types are needed. The first network may be referred to as the primary network, collects information of standard violations and trend. The second network, collects information on trends only, while the third network, designed to study compliance with the law, if any.

6.2.2 Administration

Many agencies, water and environmental institutions and scientific research centers can monitor the water quality. Various institutions have the responsibility to plan for the development and conservation of water resources in Ethiopia and prevent pollution. Institutions that may involve include: Ministry of Water Resources, Ministry of Health, Environmental Protection Authority, Ministry of Agriculture, Research Institutes, Universities, etc. However, the Ministry of Water Resources (HSD) of Ethiopia should be responsible for the construction, operation and maintenance of the national stations as well as for processing, publication and analysis of the obtained data. All data should be stored in the Ministry of Water Resources. This data will be available in the future to other interested users. In Ethiopia, hydrological and related data have always been difficult to access. They are often treated as a state secrete and are not available to potential users, except in particular circumstances. A similar attitude also exists amongst certain groups within scientific communities, where ideas are guarded and data closeted until a paper has been published in a prestigious journal.

A well-planned monitoring system can provide proper and timely corresponding measures and resolutions on water quality monitoring as well as controlling the pollution sources. However, lack of planning and careful consideration in selecting the monitoring station location and sampling frequency will result in deficiency of water quality data and misjudgment of the actual river data status as well as difficulty in controlling the pollution sources, and, particularly, the waste of money.

6.3 Spatial Distribution of Sampling Sites

A sampling site is the general area of water body from which samples are to be taken and is sometimes called a "macrolocation". The exact place at which the sample is taken is commonly refereed to as a sampling station, or sometimes, a "microlocation". The location of a permanent sampling station is considered the most critical design factor in any water quality monitoring network. A network of water quality monitoring stations sited strategically along a river catchment can be a useful tool in water quality management. Selection of sampling sites requires consideration of the monitoring objectives and some knowledge of the geometry of the watercourse system, as well as the uses of water and of any discharges of wastes into it. In the past, the design of a monitoring station system was generally based on subjective personal experience and ease of access. A realization that this approach did not necessarily lead to the best design or justifiable monitoring program. The Kriging theory can be applied for selecting the optimal locations when record of water quality data exists from the catchment to improve the design.

Due to the lack of water quality monitoring system and time series for various important water quality issues in Ethiopia, a first trial of sampling site selection can be done based on Sharp's approach. Sharp's (1971) is the only published algorithmic method for station placement when establishing new sampling program. His algorithm used data generated to describe a river drainage network in terms of Shreve's (1967) stream order numbers, and successively divide a catchment into halves, then quarters, then eighths, etc. The division points, called centroids, were postulated as the optimum sampling sites. This is the only published method for the optimum placement of sampling sites that do not require an existing record of water quality data from the catchment.

The selection of the sampling station locations within the river system is done by taking into consideration the calculation of mixing length (see Table 5) and certain criteria. The selection of the station location and the site of the measurements require ease of accessibility and the selection of the cross section that has a stable bed profile and that covers, if possible, all ranges of discharge. The following measures are used for the selection of the sampling sites: (a) at the mouth of the main rivers and principal tributaries of the river system, (b) downstream of river development projects such as dams, (c) at state boundaries, (d) downstream of waste outfall, (e) at industrial and urban centers, and (f) at points of water use.

Based on the above, two types of stations can be identified, i.e., **impact stations** – usually selected downstream of the present urbanization areas, intensive agricultural and industrial activities and **basic stations**- stations required to achieve the specified management goal and monitoring objectives and are mainly operated for collection of baseline or reference data.

The flows from outfalls or tributaries do not mix instantly with main streams, but require some time and distance to become homogeneous. That is the lateral mixing is not complete within the river, and as a result, multiple sampling points in the lateral transect at any station is required. It is suggested to divide the river cross sections at any sampling station location into subsections with relatively equal area or equal distances and sampled at their respective midpoints in order to achieve the evenly spaced sampling points (i.e. systematic sampling). Suggestions are provided in Table 7 for the number of points from which samples should be obtained in streams or rivers of different sizes and with different flow rates, taken on a lateral transect, to characterize an unmixed stream or river. However, for practical purposes, the cross section of each site can be divided into three points then from each vertical integrated samples might be collected and then mixed together to form composite samples. Since vertical mixing is assumed at any sampling stations along the river, the sample collected at the midpoints is column sampling by the vertical integrated sampler. A representative sample should be collected at both low and high flows. Flow measurements at each station and flow velocity at 0.6 of the water depth at each sampling point in the transect should be recorded.

6.4 Sampling Frequency

The frequency of sampling is of great importance when designing a monitoring program to meet specified information goals, because the confidence intervals of estimates are function of the number of samples taken. The sampling frequency can be determined by the proportional sampling method with respect to variance of water quality, the significance level and confidence interval.

In any water quality monitoring network design, the question of how often water quality samples should be collected is perhaps the only aspect which has received remarkable attention in the past. Sampling frequency depends largely on the purpose of the network, the relative importance of the station and the variability of the data. It is also influenced by accessibility of the station. Finally, the workload involved and the financial commitment for a decided frequency of sampling must match the available resources (human, budget, laboratories, etc.). An interval of one month between the collection of individual samples at a station is generally acceptable for characterizing water quality over a long time period (e.g. over a year in a river), whereas for control purposes weekly sampling may be necessary. If significant differences are suspected or detected, samples may have to be collected daily or on a continuous basis. Hence, for basin-wide water quality management in the Ethiopian river system only monthly data would be needed. In the case of operational management real-time data is needed. In this paper, the following sampling frequency is recommended: (a) monthly sampling frequency for the primary network which includes basic, impact stations and all point sources of pollution (located along the rivers on both sides) for baseline information; (b) bimonthly sampling frequency for the secondary network which includes basic stations and the heavily polluted point sources for detecting trends; (c) as required by inspection for law enforcement for third network which includes impact stations and inspected point sources of pollution; and (d) daily sampling frequency for early warning.

6.5 Selecting Water Quality Parameters to be Measured

Deciding what to monitor is as important as deciding why, where and when. Water quality data are collected to meet a variety of management needs. The quality of the water body is usually described by sets of physical, chemical and biological parameters which are mutually interrelated. The water quality parameters that are chosen to be measured in the monitoring networks must reflect the monitoring objectives and the associated management goals.

In some countries, water quality parameters are identified in law through Environmental Clear Water Act. The selection of water quality issues is based on the quality parameters can be identified by the Ethiopian panel of experts. These parameters can be classified as: physical, chemical, microbiological and hydrobilogical, which may be categorized as follows (see Table 6): (1) parameters proposed to be measured in all surveys; (2) parameters to be added to category 1 for collection of baseline data or trends; and (3) parameters to be added to category 1 related to the enforcement of regulations, for instance.

6.6 Sampling Analysis

All composite samples can be analyzed at water quality laboratory according to standard methods for the examination of water and wastewater (APHA, 1989), for instance.

6.7 Data Analysis

Data analysis methods are an integral part of a complete monitoring program design, and should be considered at the planning stage. The choice of data analysis methods (which follows from the information goals - which could be to detect a trend, assess the effect of an intervention, or determined ambient condition) should be made before sampling program design. The detection of a trend in water quality data gathered over time is a common aim in data analysis. The use of nonparametric statistics can be recommended. For trend, the seasonal Kendall test, with or without correction for correlation where appropriate, appears to be the best choice.

7. Conclusions

In any process of decision-making for planning or management of a natural system, the environmental dimensions are very important to be considered. Water quality is an essential part of the environmental quality and can play role in sustainable development. The quality of water resources availability has a direct impact on the economic success of agriculture, energy, industry, flood control, public health and recreation. Water quality monitoring is the foundation on which water quality management is based. Meeting the sustainability challenge for water resources development in Ethiopia requires an integrated water resources management in which water quality management, which is one of the key issues towards achieving sustainable development, is of great importance. The existence of the monitoring network can serve as the backbone to plan and management of water resources. The monitoring program aims to identify the natural variation of water quality. In order to meet its water quality planning and management objectives, Ethiopia should implement comprehensive water quality programs. Hence, there is a need to design adequate monitoring network for water quality in Ethiopia, which can contribute to establishing sustainable development, in order to provide the necessary data and information on which decisions are to be made and laws to be enforced.

The result of the design of the network presented in this paper shows that some 38 basic water quality stations should be installed in order to satisfy the minimum WMO network density requirement. It can be planned to establish eight basic water quality stations annually in order to meet the minimum density requirements in the coming five years. The water quality sampling network should be fully integrated with the stream gauging stations. The HSD of Ethiopia should also undertake these activities. A public awareness program plays a central role in the provision of management and safeguarding of water resources of the country. Legislation for protecting water quality should be introduced in Ethiopia. The component of groundwater monitoring within the water monitoring system of Ethiopia is not yet realized and should be put into operation. Integrate hydrological networks and services with government departments and agencies with the environment and whose responsibilities include environmental monitoring. The paper is concluded with stressing the high need for training courses and capacity building in the field of water quality monitoring.

8. References

1. Adam, I.S. and Hamad, O.T., 1997. Water Quality Management for the Nile River System. Proceedings of the 5th Nile 2002 conference, Addis Ababa, Ethiopia.

2. American Public Health Association (APHA), 1989. Standard Methods for the Examination of Water and Wastewater, 17th edition, Washington DC.

3.Bartram and Balance (editors), 1996. Water Quality Monitoring: A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programs, E and FN Spon, London, UK.

4.Hurst, H.E., 1952. " The Nile" Constable. London.

5.Kidane Assefa, 1997. Aspects of Water Resources Monitoring and Assessment in Ethiopia. Paper presented at 5th Nile 2002 conference, Addis Ababa, Ethiopia.

6.Michael Abebe, 1997. Status of Hydrological Data Availability and Assessment in Ethiopia, a paper presented at the 1st Symposium of Sustainable Water Resources Development in Ethiopia held at Arbaminch Water Technology Institute, Arbaminch.

7.Sharp, W.E. (1971). A Topographically Optimum Water Sampling Plan for Rivers and Streams. Water Resources Research, 7(6), 1641 - 1646.

8.Shreve, R.L. (1967). Infinite Topologically Random Channel Network. Journal of Geology, 75, 178 - 186.

9. WMO, 1981. Guide to Hydrological Practices, Vol. I: Data Acquisition and Processing, WMO-No.168, Geneva, Switzerland.

10.WMO, 1971. The Role of Hydrology and Hydrometerology in the Economic Development of Africa, Vol. I, WMO No. 301. In: Conference ECA/WMO, Addis Ababa, 13-23, September 1971.

11. WMO, 1994. Guide to Hydrological Practices, 5th edition. World Meteorological Organization, Geneva, Switzerland.

Impact of Increment in Water Tariff on Consumption: The Case of Addis Ababa City

Mieraf Shewaye, Addis Ababa Water & Sewerage Authority Addis Ababa, Ethiopia

Abstract

Addis Ababa Water & Sewerage Authority (AAWSA) charged its customers water tariffs of Birr 0.5/cubic meter for more than half a century. A new water tariff of different rate has been applied since July 1995. In order to find the impact of the new water tariff on its customers in addition to the justification given by the Authority for increasing water tariff, secondary data has been used and consumption pattern of customers before and after tariff increase has been analysed. The result of the research, therefore, shows that the past water tariff was below water production and distribution costs and hence increase of water tariff is found reasonable & justifiable. As a result, increase in water tariff has not resulted in decrease in consumption.

1. Introduction

1.1Background

Water is one of the most basic necessities for the existence of living things in general and human beings in particular, specially potable water in modern big cities like Addis Ababa, there is a need to properly manage the said vital scarce resource. However, for any metropolitan city, one of the basic and essential services by all standards is efficient service in water supply. Unless and until this demand of the city is efficiently met, the health of the community and developmental activities are highly affected. Since Ethiopia is categorised from among low-income economies in general and Addis Ababa, the capital, in particular faces the problem of resource management.

According to World Bank estimate for the year 1990, not more than 62% of the population in low-income economies obtain clean water while the corresponding figure for middle-income and high-income economies are 74% and more than 95% respectively. A further categorization indicates that most of the countries with 50% or more of their population lacking access to potable water are located in Africa. Further down on the low coverage end are five African countries (including Ethiopia with just 18% in 1990) that have only 25% or less of their population with access to clean water (World Bank, 1994).

Despite the low coverage in Ethiopia in general efforts to improve the supply of potable water has been in place for a long time. Government policies in the last few decades strongly supported the urgency of providing safe water to as much population as possible. For instance, within the two decades between 1970 and 1990, the World Bank estimated that expansion in the service enable the coverage to increase from 6% to 18% of the total population (World Bank , 1994). This is an indication that a modest growth in the level of annual investment for the provision of improved water services had been undergoing.

It is also evident that the Legedadi dam and treatment plant construction as well as expansion works were carried out within the above said decades and hence contributed to the improvements & efforts made to the supply of potable water at a national level.

1.2 Objective of the Study

The basic objective of the study is to assess the effect of water tariff increment on consumption.

Finally, Conclusion & Recommendations will be made on the basis of the findings.

1.3 Data Base

The paper uses secondary data for the study.

2.Historical Background of Drinking Water Supply and Existing Water Supply System

2.1Historical Background of Drinking Water Supply

Pipe water supply for the city of Addis Ababa started some years after the foundation of the city during the time of Menelik II in the year 1901 to serve only a very limited number of the population even though Addis, the capital of Ethiopia, was established in November 1886. Piped water supply service, for the first time in history, was given to the then palace, patriarch and Menelik II Hospital. The City of Addis Ababa was originally served by a number of springs located at the base of Entoto mountain range together with a series of hand dug wells. A proportion of the spring was treated at the Entoto Treatment plant which was commissioned in 1938 to treat water from a number of springs and the nearby Kechene and Kebena rivers which lasted until 1942.

Before 1936 and 1938, the people of Addis Ababa began making a limited use of pipe water facilities. The number of customers at this time was about 163 having a total length of 11,300 meters of pipe supplying 11,000 cubic meter of water per day. It is also recorded in history that dwellers of Addis Ababa consumed water from streams until some private water purveyors constructed a network of pipes in the years 1927 and 1928. Particularly in the way to Gojam, currently known by the name Dilber area, the said private water purveyors were used to lay pipes to Arada & nearby areas so as to sell water and generate income.

But as the city was expanding in size and population the Municipality established the Water Service Department in 1942 to meet the water demand of the constantly increasing population and then, after three decades the said Department was turned into the Addis Ababa Water and Sewerage Authority in 1971.

Gefersa was proved to be the most convenient and feasible in those days and was recommended that the municipality should enlarge the dam, the construction of which was already started by Italians during the Facist invasion. Consequently, the construction of the dam was undertaken and it was the first source of treated water supply for the city until 1960, when its facilities were modified to increase its capacity from 15,000m³ to 25,000 m³ of water per day. In addition, a small dam capable of holding 2 million cubic meters of water was built as a supplementary to the Gefersa dam with the view of satisfying more fully the water demand of the city.

The Gefersa Dam construction was carried in two stages: first, the gravity type dam was built in 1944 with its total height of 9 meters and second, in 1960 its height was increased to 15meters. In the same way, the Gefersa treatment plant was constructed in two stage: the-first with one accelator (Clarifier) and six filters in 1960 for the production of 15,000m³/day and the second stage doubled the treatment facilities in 1966 to bring its output to 30,000 m³ /day. It was at this time that the majority of springs were taken out of service.

The supply from Gefersa was inadequate as the population increased and therefore, in order to increase the supply of water, the construction of the Legedadi dam was started in November 1967 and completed in August 1970. It had a capacity of holding 40 million cubic meter and a water treatment plant capable of purifying 50,000 cubic meters of water per day which was delivered 18.2 km to the reservoir and pumping station at shola terminal.

The construction of Legedadi Dam and Treatment plant like that of Gefersa was carried out in two stages: the first stage was constructed, as has been mentioned earlier, in 1970. The second stage was constructed in 1986 under the Water Supply Project Stage IIA.

As a result of the completion of the second water project, the Legedadi Treatment Plant is able to produce 100,000 cubic meters of water per day in addition to the previous production of 50,000 cubic meters per day which makes the total design capacity of 180,000 cubic meters of water per day from the two treatment plants.

2.2 Existing Water Supply System

2.2.1 Water Treatment Plant

There are two conventional water treatment plants located along the two reservoirs of Gefersa and Legedadi.

2.2.1.1 Gefersa Water Treatment Plant

After the rehabilitation work had been done under the Water Supply Project Stage IIA in 1986, the treated water production capacity of the treatment plant has been raised to the design capacity of 30,000 cubic meter per day. But the treatment plant is operated under capacity and produces only 23,000 cubic meter per day as the transmission lines which convey the treated water to the city do not have the corresponding capacity due to their age and poor condition.

2.2.1.2 Legedadi Water Treatment Plant

The Legedadi Water Treatment plant had been built in two stages. The first one was built together with the dam in 1970 and had a design capacity of 50,000 m³ of treated water per day. This first part of the treatment plant was aging and its production had reduced. But through the Water Supply Project Stage IIA, a rehabilitation work had been done and the capacity was upgraded to produce 50,000m³ of treated water per day.

The second part of the treatment plant was constructed in 1986 under the Water Supply Project Stage IIA. The capacity of the newly built treatment plant is 100,000 m³ of treated water per day. Thus, the total capacity of Legedadi Water Treatment Plant is 150,000 m³/day.

But at the moment the plant produces less than its capacity due to the safe yield of the dam which cannot provide all the daily raw water requirement of the treatment plant (in 1995 the average daily production was 127,000m³). Therefore, the total water production of both treatment plants is far below their design capacities being only 150,000m³ versus the design capacity of 180,000 m³.

2.2.2 Transmission Lines

The transmission lines convey the treated water from both Legedadi and Gefersa Treatment Plants to the city. The transmission lines include:-

2.2.2.1Gefersa Transmission Lines

There are two parallel 400mm steel pipes conveying water from Gefersa which were laid in 1955 and 1960. These pipes and their appurtenances (below off and air vents) are in poor condition and due to collapse a significant portion of the line has been replaced.

2.2.2.2 Legedadi Transmission Lines

A transmission line from Legedadi to terminal reservoir, originally a 900mm transmission line was laid in 1970, together with the old treatment plant. Later, during the water supply stage IIA in 1986, because of the rehabilitation of the existing treatment plant and the construction of a new one, the capacity of the transmission line had to be increased. Therefore, the first 685.7 m of the 900 mm transmission line was abandoned because its location was expected to be flashed by a future reservoir and substituted with a 1400mm steel pipe. The later portion of 11570m. up to terminal reservoir has been augmented with a 1200mm steel pipe, operating in parallel to the existing and rehabilitated 900mm line.

2.2.3 Distribution

2.2.3.1Reservoirs and Pumping Stations

Due to the terrain of the area to be served with water only, part of Addis Ababa can be supplied by gravity. Most other parts of the city can only be served from reservoirs fed by pumping stations. Thus, the system has a total of 36 reservoirs at 19 different sites and two separate pumping stations.

3. Why Increase Water Tariff and Its Effect on Consumption ?

3.1Why Increase Water Tariff ?

3.1.1General

The Addis Ababa Water and Sewerage Authority is an autonomous gov-

Table 3.1 Income of AAWSA by Service in '000 Birr(1987/88-1994/95)

income from Operation: G.C (E.C)	*1987/88 (1980)*	*1988/89 (1981)*	*1989/90 (1982)*	*1990/91 (1983)*	*1991/92 (1984)*	*1992/93 (1985)*	*1993/94 (1986)*	*1994/95 (1987)*
Water Sales	13.031.8	13,531.1	13,079.6	14,038.7	16,134.4	17,389.2	16,336.9	19,213.0
Meter Rent	583.9	592.7	656.0	682.6	733.2	749.9	2,860.3	2,944.5
Connection Fee	898.0	1,525.1	1,703.6	1,449.7	1,888.2	1,038.2	1,023.4	1,497.3
Sewerage Service	478.8	614.9	463.0	419.4	577.7	1,286.9	2,055.6	2,150.3
Other Incomes	1,037.5	1,046.3	712.3	749.4	1,236.4	519.9	1,501.0	1,163.4
Total	16,030.0	17,310.1	16,614.5	17,339.5	20,569.9	20,984.1	23,777.2	26,968.5

Source:- Finance Department External Audit Report), AAWSA

ernment authority which is charged with providing supply water and sewerage disposal services for 2.23 million inhabitants of Addis Ababa spread over an area of more than 300 km^2. The Authority was created as an autonomous body through the order No. 68 of 1971 and proclamation No. 298 of 1972 by assigning the Authority with the responsibility of providing water and sewerage services.

The recent proclamation and regulations issued there under promulgated on May 20th, 1995 has re-established the Authority to provide services for regarding the water supply, sewerage system and waste water facilities as well as the various rates applicable to the customers for such services.

By virtue of proclamation No. 10/1995, the Addis Ababa Water and Sewerage Authority has been re-established by the council of Region 14 as an autonomous public Authority. The areas of the Authority shall be the boundaries of Region 14 Administration. The Authority shall be supervised by the council of Region 14 through its Executive Committee.

3.1.2 Financial Position of AAWSA

AAWSA used to give the greatest priority in giving service and hence the share of income and expenses for water service have therefore briefly been tried to be seen. Let us try to see each one of them one by one.

3.1.2.1 Income

Income from water sales accounts the greatest share from among the income generated from water service. Other water service related incomes such as income from meter rent and connection fee should not be underestimated.

As can be seen in Table 3.1 above, connection fee served as the second major source of income for the Authority next to water sales income between the year 1988/89 - 1991/92. But between the year 1992/93 - 1994/95, income from sewerage service served as the second source of income. In general, the total income generated (or collected) from connection fee between the years 1987/88 - 1994/95 registered to be a total income of Birr 11,023,531 and annual average income of Birr 1,377,941.37 (Appendix 3). In the same way income generated from sewerage service shows a significant annual increase specially between the years 1992/93 - 1994/95 when compared with previous years.

Within the past eight years, the total income collected from sales of water is only Birr 122,754, 801.00 with annual average income of Birr 15,344,350.12. It is evident that the water tariff of Birr 0.50/cubic meter remained unchanged for half a century. The above being the income generated from sales of water, the water produced and distributed with un-accounted for water is shown in the following table 3.2.

As it can be seen in Table 3.2 the amount of water produced in the past eight years is between 37.5 million to 57.9 million cubic meters out of which the volume of water billed varies between 25.5 million to 40.3 million cubic meters. According to water Leakage Detection project Report, the amount of unaccounted for water for five years varies from 26.87 percent in 1990/91 to 36.73 percent in 1995/96 which brings the volume of water billed or consumed to be decreased.

3.1.2.2 Expenses

The main cost items are Depreciation, Chemicals, Salaries and related benefits and Amortization the sum of which accounts for 69.7 percent in 1992/93; 74.3 percent in 1993/94 and 74.3 percent in 1994/95 of the total yearly budget. On the other hand, if one tries to see amortization expense in particular, it increased from 26.6 percent 1993/94 to 61 percent in 1994/95 taking 1992/93 as a base year. Of course, amortization does mean to put money aside, as in a sinking fund, or a future payment, as a debt. In other words, its major concerns are the determination of the initial costs and the recognition of periodic cost expiration which is attributable to the passage of time or a decline in usefulness.

Expenses required for the above mentioned titles including other titles expended for water production (treatment) and distribution within the past eight years in addition to increment practised is presented in Table 3.3 below.

As presented in Table 3.3 above, the water treatment and distribution expense has increased from Birr 24 million in 1987/88 to Birr 52 millions in 1994/95. In other words, the increase is about 109 per cent out of which the greatest percentage of the expenses were incurred for chemicals followed by salaries and related benefits which accounts for 404.5 and 65.2 percent, respectively. The profit and loss statement of the Authority is presented in (Appendix 3) includes salaries and related expenses of employees engaged in sewerage services and hence an effort has been made to screen out expenses which relate to water service only. Hence, the total expense for the latter accounts for 98 per cent for the

Table 3.2 Produced & Distributed Treated in Comparison to Unaccounted for water cubic meter 1987/88-19994/95

Year (G.C)	*Water Produced*	*Volume of Water Billed or Distributed*	*Unaccounted for Water in*	*Year (E.C)*
1987/88	37,457,760	25,471,276	32.0**	1980
1988/89	38,012,386	25,848,422	32.0**	1981
1989/90	44,434,385	28,882,350	35.36*	1982
1990/91	53,841,157	39,304,044	26.87*	1983
1991/92	57,550,119	39,134,080	32.0**	1984
1992/93	55,053,019	37,436,052	32.0**	1985
1993/94	55,218,825	40,309,742	26.97*	1986
1994/95	57,940,229	38,240,551	34.20*	1987
1995/96			36.73*	1988

Table 3.3 Water Production and Distribution Expenses in (Birr)

No	Description	1987/88 (1980)	1988/89 (1981)	1989/90 (1982)	1990/91 (1983)	1991/92 (1984)	1992/93 (1985)	1993/94 (1986)	1994/95 (1987)
1	Interest and Bank Charges	3,497,084	3,203,729	3,365,969	3,689,125	3,178,838	6,109,333	4,109,917	2,908,048
2	Salaries and Related Benefits	5,639,485	6,042,886	6,486,637	6,632,949	6,885,715	7,903,638	8,860,316	9,318,674
3	Depreciation	8,346,137	8,464,557	7,980,442	7,634,118	10,367,207	12,850,014	12,640,942	12,375,655
4	Chemicals	2,131,007	2,649,233	3,339,202	2,879,776	3,988,965	3,998,620	7,703,697	10,750,539
5	Fuel and Lubricants	421,668	552,589	618,894	472,549	734,464	883,873	812,367	917,971
6	Store Issues & Other Expenses	1,205,491	955,343	1,162,968	1,312,907	2,112,140	1,661,614	2,990,791	2,702,845
7	Electricity	2,258,506	2,026,868	2,223,486	2,603,690	2,987,554	2,731,874	2,821,841	2,728,129
8	Utilities and Other Services	169,778	292,036	284,518	350,222	305,969	402,526	516,715	876,009
9	Amortization	202,030	-	-	-	-	3,806,018	4,934,290	6,129,212
10	Audit Fee	18,000	18,000	20,000	30,000	30,000	45,000	82,300	24,434
11	Loss on Currency Fluctuation (Gain)	-	-	-	3,318,476	5,518,761	(322,505)	(589,190)	-
12	Miscellaneous	909,584	1,424,113	1,972,103	2,458,683	889,733	893,357	1,084,348	3,157,516
	TOTAL	24,798,790	25,628,354	27,454,219	31,382,495	36,999,366	40,963,362	45,968,334	51,889,032

years 1992/93 1993/94 and 1994/95. The same rate has been applied for the remaining five years included in the study.

As has been presented earlier, the water production (or treatment) and distribution expenses has shown a drastic change and hence the increased expenses can be seen in terms of produced (or treated) water in the following Table 3.4

As one can see it in Table 3.4 above, water production and distribution expense has increased from Birr 0.662 /cubic meter to Birr 0.895/ cubic meter in the said budget years. The increase was registered due to increases in depreciation, salaries and related benefits, chemicals, fuel and lubricants, store issues and other expenses, utilities and other expenses, etc.

In order to fulfill the increasing water demand of the city, a need arises to expand the existing in addition to seeking for new sources of water and hence this would be reflected in water production and distribution expense in the form of depreciation and interest and Bank charges. As a result, expenses incurred for the said two titles accounts the highest amount. Moreover , the capacity of Legedadi treatment plant and availability of raw water capacity does contribute to the increase in the unit price per cubic meter. Moreover, the difference in the amount of water produced and distributed (or billed) in its turn does contribute to the increase in the unit price. Therefore, the increase in the raw water so as to fulfill the treatment capacity in one side and the amount of water produced (or treated) and distributed (or billed) on the other side, that is to say, to decrease the unaccounted for water need attention on the part of the authority. However, effort has been made so as to increase raw water through the construction of Emergency Dire Dam Project which is planned to be treated by Legedadi treatment plant and hence this might minimize or reduce the unit price.

Like any other governmental organizations, AAWSA's employees have also increased in the above said eight years. In other words, its employees increased by 28 percent. As a result of salary increament made by the government as well as a need for additional employees, the salaries and related benefits which was Birr 0.151 /cubic meter in 1987/88 has increased to Birr 0.161/cubic meter in 1994/95 which implies an increase of 6.6 percent. Of course compared to the percentage increase in water production & water sales, the increase in staff seems justifiable.

Increase in chemical expense arises for two reasons: first, due to increase of price in the market; second, due to increase in the amount of chemicals in the treatment process. This is because both sources of water are associated with inadequate water catchment area protection which is the main problem associated with water quality. The last one being devaluation of the Ethiopian Birr by the government. During the years 1987/88 to 1994/95, water production (treatment) & distribution expense has increased from Birr 0.662/ cubic meter to Birr 0.895/cubic meter which shows and increase of 35.1 percent.

Water production and distribution expenses are based on the total amount of water treated in the Authority's two treatment plants (Legedadi & Gefersa Treatment Plants). However, if the unaccounted for water could be reduced it would reduce the unit cost of water sold. This can better be explained in Table 3.5 below.

As can be seen in Table 3.5 above, out of the total amount of water produced which is 399,507,900 cubic meters in the above said eight years, it is only 271,906,517 (271 million) cubic meter which is billed (or reached customers) which is 68.06 percent of what has been treated. The total annual

Table 3.4 Water Treatment & Distribution Expense in (Birr) From the Year 1987/88-1994/95

No	Description	1987/88 (1980)	1988/89 (1981)	1989/90 (1982)	1990/91 (1983)	1991/92 (1984)	1992/93 (1985)	1993/94 (1986)	1994/95 (1987)
1	Interest and Bank Charges	0.093	0.084	0.075	0.068	0.055	0.111	0.074	0.050
2	Salaries and Related Benefits	0.151	0.160	0.146	0.124	0.120	0.144	0.160	0.161
3	Depreciation	0.223	0.222	0.180	0.142	0.180	0.233	0.229	0.214
4	Chemicals	0.057	0.069	0.075	0.053	0.069	0.073	0.140	0.185
5	Fuel and Lubricants	0.011	0.015	0.014	0.009	0.012	0.016	0.015	0.016
6	Store Issues & Other Expenses	0.032	0.025	0.026	0.024	0.037	0.030	0.054	0.046
7	Electricity	0.060	0.053	0.050	0.048	0.052	0.050	0.051	0.047
8	Utilities and Other Services	0.005	0.008	0.006	0.007	0.005	0.007	0.009	0.015
9	Amortization	0.005	-	-			0.069	0.089	0.106
10	Audit Fee	.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
11	Loss on Currency Fluctuation (Gain)	-	-	-	0.061	0.096	(0.006)	(0.010)	-
12	Miscellaneous	0.024	0.037	0.044	0.046	0.015	0.016	0.020	0.054
	Birr/m^3	0.622	0.674	0.617	0.583	0.642	0.744	0.832	0.895

Table 3.5 Water Treatment (or production) & Distribution Expense (in Birr)

Description(G.C) (E.C)	1987/88 (1980)	1988/89 (1981)	1989/90 (1982)	1990/91 (1983)	1991/92 (1984)	1992/93 (1985)	1993/94 (1986)	1994/95 (1987)	Total and/or Average
Running Cost (or Operational Cost)	12,935,549	13,691,068	16,107,808	20,059,252	23,453,321	22,004,051	29,217,475	36,605,329	174,363,817
Depreciation	8,346,137	8,464,557	7,980,442	7,634,118	10,367,207	12,850,014	12,640,942	12,373,655	80,659,092
Interest & Bank Charges	3,497,084	3,202,729	3,365,969	3,689,125	3,178,838	6,109,333	4,109,917	2,908,048	30,061,043
Total	24,798,790	25,628,354	27,454,219	31,382,495	36,999,366	40,963,362	45,968,334	51,889,032	285,083,952
Produced Water in m^3	37,457,760	38,012,386	44,434,385	53,841,157	57,550,119	55,053,019	55,218,825	57,940,229	399,507,583
Production & Distribution Expense (Birr/m^3)	0.662	0.674	0.617	0.583	0.642	0.744	0.832	0.895	0.714
Volume of Billed Water in m^3	25,471,276	23,128,422	28,882,350	39,304,044	39,134,080	37,436,052	40,309,742	38,240,551	271,906,517
Production & Distribution Expense (Birr/m^3)	0.973	1.108	0.950	0.798	0.945	1.094	1.140	1.357	1.048
If Leakage decreases to 20%	29,966,208	30,409,908	35,347,508	43,072,925	46,040,095	44,042,415	44,175,060	46,352,183	319,606,300
	0.827	0.842	0.772	0.729	0.804	0.930	1.040	1.119	0.892

average production cost of the same period is Birr 0.714 /cubic meter. On the other hand, the average water production and distribution has increased from Birr 0.973 in 1987/88 per cubic meter to Birr 1.357/cubic meter in 1994/95. Here, one can observe the difference between cost of production & cost of water billed is significant for the very fact that the unaccounted for water is a large amount which need to be decreased. However, the water tariff of the authority remain unchanged Birr 0.50/cubic meter for more than half a century. But, the cost incurred for production & distribution in all the above said years used to be more and above the selling price and hence worsen the financial position of the Authority. This fact brought about the necessity for the increase in the new water tariff.

3.2 Water Demand, Production & Supply

Addis Ababa with its ever increasing population, has reached a state of critical water shortage. To satisfy the rapidly increasing water demands of the city, the Addis Ababa Water and Sewerage Authority has done major expansions of the water treatment plant, transmission & distribution facilities in the past, while successive works are continuing. Major water sources or combination of sources must have been urgently developed in order to overcome the current shortage as well as to meet the requirements of the growing population.

There are various projects undertaken by AAWSA out of which, in this paper only those projects which have significant contribution to the increase in water supply that are briefly discussed.

3.2.1. Addis Ababa Water Supply project Stage IIIA

The project is intended to have a final design and tender document prepared to satisfy the water supply demand upto 2020. It is financed partly by grant and partly by loan from the African Development Fund (ADF) and a counterpart fund allocated by the Ethiopian Government. It has four (4) major components. i.e., final design and tender document preparation, drilling of twenty five (25) deep wells, geotechnical investigation and maping. The project is planned to be completed in 1997 and ready for implementation.

3.2.2. Emergency Dire Dam Project

At the moment the city is facing water shortage upto 40%. To cope up with this problem, two emergency projects are under implementation one of which is the construction of Emergency Dire Dam Project. This is an earth impounding dam to augment the raw water shortage in one of the biggest treatment plant for the city. i.e., Legedadi treatment plant. The dam will have a capacity of 19 million cubic meter of raw water. It is planned to be operational by late 1998. Both the study & implementation is being financed locally by the Ethiopian Government (Region 14).

3.2.3. Emergency Ground Water Development (Akaki) Project

This is the second emergency project intended to alleviate the water shortage in the city. It is designed to provide 72,000 m^3/day ground water from the southern part of the city upto the center of the city. This project is also financed locally by the Ethiopian government. The total capacity of the aquifer is estimated to be 125,000 m^3/day. So, the remaining potential is planned to be extracted in the near future under water supply stage III A scheme.

3.2.4. Akaki Water Supply Project

This is a project for the provision of water to Akaki town (which is now part of Addis Ababa as industrial zone) from 4 boreholes. The project is financed by International Development Association (IDA) credit and budget allocated from Region 14.

3.2.5. Water Leakage Control Study

The un-accounted for water in the city is estimated to be 36%. It is believed to economically reduce this figure to about 20%. The study has tried on four (4) pilot areas and to be duplicated throughout the system as a routine job of the authority. This study is financed by " Region 14".

To conclude, despite the high cov-

Table 3.6City of Addis Ababa Population and Water Demand Projection

Year	Population	Demand (l/c/day)	Demand (m^3/day)	Supply (m^3/day)	Surplus (m^3/day)	Surface Water		Ground Water		WSP III A Surface Water	
						Existing	Dire	Akaki & Emergency	WSP III A	Gerbi	Sibilu
1994	2,113,000	96	203,000	135000	- 68000	Legedadi (110) & Gefersa (25)					
1995	2,190,000	98	215,000	135000	- 80000	Legedadi (110) & Gefersa (25)					
1996	2,270,000	101	229,000	135000	- 94000	Legedadi (110) & Gefersa (25)					
1997	2,360,000	103	243,000	220000	- 23000	Legedadi (110) & Gefersa (25)		Akaki (13) & Emergency (72)			
1998	2,450,000	106	259,000	260,000	- 1,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)			
1999	2,540,000	108	275,000	260,000	- 15,500	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)			
2000	2,640,000	111	293,000	333,000	40,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)	WSP III (73)		
2001	2,740,000	114	311,000	333,000	22,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)	WSP III (73)		
2002	2,840,000	116	330,000	410,000	80,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)	WSP III (73)	Gerbi (77)	
2003	2,950,000	119	352,000	410,000	58,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)	WSP III (73)	Gerbi (77)	
2004	3,060,000	122	373,000	410,000	37,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)	WSP III (73)	Gerbi (77)	
2005	3,180,000	125	398,000	565,000	167,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13)		Gerbi (77)	Sibilu (300)
2006	3,300,000	128	423,000	565,000	142,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13)		Gerbi (77)	Sibilu (300)
2007	3,420,000	132	451,000	565,000	114,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13)		Gerbi (77)	Sibilu (300)
2008	3,550,000	136	482,000	565,000	83,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13)		Gerbi (77)	Sibilu (300)
2009	3,680,000	140	515,000	565,000	50,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13)		Gerbi (77)	Sibilu (300)
2010	3,820,000	144	551,000	565,.000	14,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13)		Gerbi (77)	Sibilu (300)
2011	3,960,000	149	588,000	637,000	49,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)		Gerbi (77)	Sibilu (300)
2012	4,110,000	153	629,000	710,000	81,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)	WSP III (73)	Gerbi (77)	Sibilu (300)
2013	4,260,000	158	671,000	710,000	39,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)	WSP III (73)	Gerbi (77)	Sibilu (300)
2014	4,420,000	162	718,000	865000	147000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13)		Gerbi (77)	Sibilu (300)
2015	4,590,000	167	768,000	865000	97000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13)		Gerbi (77)	Sibilu (300)
2016	4,760,000	172	820,000	865000	45000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13)		Gerbi (77)	Sibilu (300)
2017	4,940,000	177	877,000	937,000	60,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)		Gerbi (77)	Sibilu (300)
2018	5,130,000	183	938,000	1,010,000	72,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)	WSP III (73)	Gerbi (77)	Sibilu (300)
2019	5,320,000	188	1,002,000	1,010,000	8,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)	WSP III (73)	Gerbi (77)	Sibilu (300)
2020	5,520,000	194	1,071,000	1,010,000	- 61,000	Legedadi (110) & Gefersa (25)	Dire (40)	Akaki (13) & Emergency (72)	WSP III (73)	Gerbi (77)	Sibilu (300)

erage in the supply of water service on one hand and critical water shortage on the other, the current demand of the city is said to be 243,000 cubic meter per day (103 liters per capita per day-water III project, 1997) while the supply is about 140,983 cubic meter per day (60 liters per capita per day) for a total population of 2.34 million in 1997 (population and housing census, 1994) this shows that it is only 60 percent of the demand of the city which is satisfied. To meet the wide imbalance of the water demand and supply, therefore, the Authority is now undertaking different water supply projects such as Emergency Dire Dam and Emergency Akaki projects with an estimated total supply capacity of 125,000 cubic meter of water per day are under construction while the Akaki Water Supply Stage III, the Gerbi and Sibilu Dam Project with an estimated total production of 726,075 cubic meter of water per day (Water Supply Project Stage IIIA, 1997) are at their final design and tender document preparation stages.

However, it is by the year 2,000 that the demand is expected to be fulfilled and until such time the surplus of the demand over the supply continues to be observed. The water demands for domestic, industrial and administrative have not been put in detail by the Consultants of Design for Water IIIA Project. However, it can be seen on table 3.6 below.

3.3. Impact of Tariff

AAWSA is in charge of supplying water and sewerage services to the population of the city of Addis Ababa, which according to population and Housing projection of 1994 to be about 2.34 million in 1997.

The Authority has around 136,622 (Computer Service, AAWSA July 1997) active customers and supplies to around 97.75 per cent of the population, the remaining 2.25 per cent being supplied from independent sources (protected wells & springs; unprotected wells, springs, rivers and ponds). Some commercial and industrial users also supplement supply from the Authority with private sources, mainly from wells.

The Authority has been in a precarious financial situation for a long time and has therefore been unable to pay the principal and interests on its loans during this period.

Water tariff has remained with out any changes at a rate of 0.50 Birr/m³ since it was first adopted almost longer period than half a century. A few years back, it became very clear that water tariff had to be increased. A tariff study was consequently conducted by a consultant, PAS (Public Administration Service, and submitted to the then ONCCO (Office of the National Committee for Central Planing) and AAWSA. The final document was presented to the council of ministers in 1988. The council of Ministers on its deliberation of December 14,1989 gave an instruction for further study (Study of Tariff, April 1994). Accordingly, a new water tariff was being studied by a consultant known as price water house in association with SEVERN TRENT WATER, the final report was submitted in April 1994 and then after presented to Region 14 Administration (or Regional Government) for approval.

The main objectives of the tariff study are to:

i. develop and analyse alternative tariff strategies as a basis for implementing a policy of financial self - sufficiency for AAWSA operations;

ii. analyze and recommend progressive tariff structure for water supply and sewerage and desludging services which, in particular, ensure regular supply of water and sewerage services at rate affordable to urban poor.

The consultant shall, therefore, reviewed technical economical, social and financial conditions and devise a new tariff schedule. With the following aims and under the following considerations.

-bring selling price of water and sewerage and desludging services at or near marginal cost;

-allow access to safe water and sewerage and desluging services to low-income population;

-ensure financial availability of AAWSA in the short term on long range; and

-eliminate government subsidies.

As a result of the tariff study, the selling price of water at present, the tariff used by AAWSA is not constant and hence increases progressively as the consumption increase as it is illustrated here under. Therefore, the selling price in the short-run is:

. 0.5 Birr/m³ for the first 15m³

0.83 Birr/m³ for the next 16 - 40m³

.1.67 Birr/m³ any consumption greater than 40m3 and for all public taps, it is 0.50 Birr/m³

The number of customers by consumption range on the basis of the data obtained from the computer service of AAWSA is shown in the following Table 3.7

The above table 3.7 is presented to analyze and evaluate the effect of increment. In prior three years before the increment of the tariff, the distribution of costumers by consumption of water up to 15 m³ (BLOCK I) fluctuate and hence in the budget years of 1992/93; 1993/94 and 1994/95 it went on decreasing in consumption 59.0; 57.3 and 52.7 percent respectively. Eventhough the tariff has been increased since July 1995, after the increase of water tariff during the budget years 1995/96 and 1996/97 the distribution of customers in the consumption range followed the same trend as before the increase in tariff and hence shows 58.1 and 53.4 percent respectively.

In conclusion, if shift of customers have been observed from block III to Block II or from block II to Block I or from block III to block I, then it would have necessarily raise particularly the number of customers in block I to a greater & block II to lesser extent. However, this has not been seen but remained as it was before. From the above presented fact therefore, it can be concluded that the increase in water tariff did not result in decrease in consumption.

4. Problems Encountered

4.1Un-accounted for Water

Un-accounted for water, according to Leakage Detection Project is generally defined as the volume of water, expressed in percentage of the total volume of treated water production at the treatment plants, which is not billed to customers. In other words, it is the volume of water calculated as the difference between the water produced at the treatment plants and the amount of water legally consumed from the system for which corresponding billing has been performed through water meters or otherwise.

4.2 The Necessity of Replacement of Gefersa Transmission Lines

The existing Gefersa transmission lines (13kms) comprises two parallel 400mm diameter steel pipes. The system was built in two phases. Phase I in 1943 and Phase II in 1955. The system is thus more than 40 years old and the pipe line is leaking badly requiring frequent repair.

4.3 The Necessity of Replacement of Old Pipes in the City

The Addis Ababa Water and Sewerage Authority has compiled a record of stretches of pipe line

throughout the city for various reasons are in urgent need of replacement. In water IIB project the problem was partially addressed when about 14.3 kms of old and leaking pipes with diameters greater than 100mm were replaced. Capacity limitation occurred then due to shortage of money.

4.4 The Necessity of Rehabilitation of Gefersa Water Treatment Plant

The present Gefersa treatment plant was commissioned in 1960 and underwent remedial works as part of the Water Supply Stage IIA project including the insertion of values and new meters on the delivery mains. It has a design capacity of 30,000m³/day but is at present producing about 25,000m³/day.

5. Conclusion & Recommendations

The water supply for the city is becoming shorter every time with ever growing population. The recent population census has set the population of the city to be 2,112,737 in 1994. At an average growth rate of 3.79% per annum, the current population is estimated at 2.34 million (1997) and it is expected to grow to 5.5 million by the year 2020. Accordingly, the demand grows from 203,000m³/day in 1994 to 1.07 million m³/day while the current

Table 3.7:Number of Customers by Consumption Range during the years

Year	BLOCK I		BLOCK II		BLOCK III		Yearly average Total	Year (E.C)
	Up to 15	%	16 - 40	%	> 40	%		
1992/93	70,714	59.0	32,433	27.0	16,790	14.0	119,937	1985
1993/94	69,983	57.3	32,827	26.9	19,349	15.8	122,153	1986
1994/95	63,010	52.7	35,331	28.6	23,129	18.7	123,470	1987
1995/96	72,709	58.1	34,101	27.3	18,256	14.6	125,066	1988
1996/97	70,401	53.4	40,415	30.6	21,173	16.0	131,989	1989
Mean	69,763	56.0	35,018	28.1	19,739	15.9	124,521	-

supply is only 135,000m³/day.

The completion of the Emergency, Akaki and Dire Dam schemes will alleviate the current shortage but will not sustain long since the demand grows much faster to be followed by the biggest water supply project IIIA which is planned to supply till 2020 adequately provided the required fund is secured particularly from external sources. However, the current level of shortage is 40% of the demand.

With regard to water consumption, in prior three years or before the increment of the tariff, the distribution of customers by consumption of water up to 15m³ (Block I) fluctuate and hence in the budget years of 1992/93; 1993/94 and 1994/95 went on decreasing in consumption to 59.0; 57.3 and 52.7 percent respectively. After tariff increment during the years 1995/96 and 1996/97 the distribution of customers by consumption range followed the same trend as before the increase in tariff and hence shows 58.1 and 53.4 percent respectively. The above fact therefore will lead to the conclusion that the increase in water tariff did not result in decrease in consumption.

On the ather hand, the Authority has been in a percarious financial situation for a long time and has therfore, been unable to pay the principal and interests on its loan that forced the Authority to apply a new water tariff. However, the increase in water tariff did not result in decrease in consumption.

This paper has briefly indicated the major problem areas the Authority facing. The existence of these operational problems need remedies to be sought by the policy makers. From several points to be taken into account the following points are recommended:

5.1 Large water consumers other than drinking need to be encouraged to dig wells of their own. The effect of which will help to reduce the shortage of water which exists currently.

5.2 Increased siltation, high turbidity, high treatment cost and reduction in storage capacity of Legedadi & Gefersa raw water reservoirs should be avoided through integrated watershed management in collaboration with regional governments and the people in the catchment areas.

5.3 AAWSA should replace old pipes and rehabilitate the water treatment plants to minimize the unaccounted for water.

5.4 Those projectswhich have significant contribution to the increase in water supply need to search for **foreign fund** for its inplementaton which would help overcome the current shortage as well as meet the requirement of the growing population.

Finally, it is hoped that this study will contribute to a better understanding of many problems associated with the supply of safe & adequate water in urban Ethiopia in general and to the city of Addis Ababa in particular in addition to scarce resources to be managed which will help for the improvement of the service & increase efficiency.

6. References

Convey, Frank J. 1995. "Applying Environmental Economics in Africa, " World Bank Technical Paper

Number 277, Washington, DC., World Bank, African Technical Paper Series.

Crane, Randall, 1994. "World Markets, Market Reform and the Urban Poor, Result from Jakarta, Indonesia."

Central Statistics Authority, 1996, The 1994 Population and Housing Census of Ethiopia: Results of Addis Ababa, Vol. 1,

Stastical Report, August 1995, Addis Ababa.

Fissiha Abera, Estimating Willingness to pay for Water: A Contingent Valuation Study on Meki Town. A thesis submitted in (part) fulfillment for the degree of Masters of Science in Economics (Economic Policy Analysis) in the Addis Ababa University, May 1997.

Tajebe Beyene, Addis Ababa Tenager, Artistic Printing Press, July 1968 E.C. (Amharic).

Addis Ababa Water & Sewerage Authority, Water Supply in Addis Ababa, 1970, Magazine (Amharic).

Wegenie Yirko, An Overall View of the Ethiopian Economy, Asmara University, 1986.

World Bank 1994, World Development Report, New York, Oxford University Press.

Provisional Government of Ethiopia, Addis Ababa Water & Sewerage Authority, Addis Ababa Water Resource, Reconnaissance study, Vol. 2, Appendex, (AESL), September 1984, International Ltd Consulting Engineers.

Transitional Government of Ethiopia, Addis Ababa Water & Sewerage Authority, Master Plan Study for the Development of Wastewater Facilities for the City of Addis Ababa, Vol. 2, Cost Summary & Implementation Schedule, BCEOM & GKW Consult, November 1993.

Existing Situation and Design Criteria Report Vol. 1, Background Data Report, August 1993.

Review of Feasibility Study & Preliminary Design Report, Water Supply Project Stage III, Executive Summary, Associated Engineering (AE), April 1993.

Water Leakage Detection Project, Final Report, (BCEOM), April 1997.

Study of Tariff, Final Report, Price Water House in association with Severn Trent Water, 1995.

Master Plan, Preliminary Engineering Design, Vol. 5, Health Education Programme, April 1993.

Organization & Management and Computerized Management Information System Study, Human Resource Development, Final Report, Shawel Consult International, October 1993.

Organization & Staffing Manual, Final Report, May 1994.

Formulation & Appraisal Study for Addis Ababa Water Supply & Sanitation Improvement Project, Final Project Dossier, Vol. 1, November 1997.

Government Publications

Imperial Ethiopian Government, Negarit Gazeta, No. 10, Order No. 68, February 26, 1971.

Negarit Gazeta No. 12, Proclamation No. 298, 16 March,1972.

Negarit Gazeta No. 15, Legal Notice No. 432, AAWSA.

Regulations, 24 April, 1973.

Transitional Government of Ethiopia, Region 14 Administration, Addis Negari Gazeta, 3rd Year No. 4, AAWSA Regulations No. 5/1995, 20 May, 1995.

Proclamation No. 10/1995, AAWSA Re-establishment Proclamation, 3rd Year No. 3, 18 May, 1995.

Study on the Effect of Rainfall Intensity on Splash and Wash Erosion of Some Soils at Alemaya (Eastern Hararghe) Under Simulated Rainfall.

Fekadu Yohannes, Alemaya University, P.O.Box 138, Dire Dawa, Ethiopia

Abstract

At present accelerated erosion by water is a serious problem in various ecologically sensitive parts of Ethiopia. The major causes soil erosion and overall land degradation are the inappropriate crop and land management practices. The increasing population pressure has led to the cultivation of slopes as steep as 50%. In general, soil erosion arises from the effects of rainfall on the soil and is determined, among others, by rainfall erosivity and erodibility. Field plots were used by many researchers to measure a wide range of effects such as rainfall, soil type and erosion. Field experiments depend on natural rainfall which is always unpredicable. A rainfall simulator experiment was thus conducted using a spinning disc simulator which enables representative kinetic energy to be achieved at a wide range of intensities. Assessment of the effect of rainfall. Intensities on splash and wash erosion were made on five soil tyoes that were sampled at different places on a toposequence in Lake Alemaya watershed. The splash loss of Soil1 wa. the highest for all intensities with a range of 337.8 - 666.7 g/m2 followed by Soil5 (88.9 - 488.9 g/m2). The least splash loss was that of Soil4 for all intensities (24.7 - 102.2 g/m2). The results of the wash erosion showed that soil4 gave the highest wash loss with a range of 1408.9 - 2804.4 g/m2 followed by soil5 for the two highest rainfall intensities. The least was observed in Soil1, and Soil5 for the two lowest intensties. Linear simple and multiple regression analysis was also carried out relating splash and wash loss to rainfall intensity and kinetic energy.

Introduction

Most regions of sub-Saharan Africa suffer from several forms of environmental degradation with its determinetal impact on food and agricultural productivity and production. Hurni (1985) states that of all countries in this subregion Ethiopia has the greatest land degradation problems. The major causes of land degradation are the inappropriate crop and land management practices. The problems of land degradation are also closely linked with the development of propulations and land shortage.

At present accelerated erosion by water is a serious problem in various ecologically sensitive and densely populated parts of Ethiopia. As a consequence of accelerating soil degrdation, the productive capacity of the Ethiopian highlands is being greately undermined. It is estimated that the productivity is declining at a rate of 2-3% annually (Hurni, 1985).

Soil erosion is considered the major cause of soil degradation in the Ethiopian highland. The annual sediment loss from the high lands is estimated at one billion metric tons or about 20t/ha and measured soil erosion rates from slopes are even much higher than this (Hurni, 1985).

Estimates by the Ethiopian Highland Reclamation study (EHRS) (Weight 1984) show that around 52% of the area in the highland's is affected by various degrees of soil degradation, half of which is described as every severe. In the Hararghe Highlands of Ethiopia a removal of 2 to 3 cm layer of soil were observed on a cleanly plowed 5 to 6% slope lands from a 10 hours continuous forrential rainsform (Tamirie,1982).

Soil erosion from sloping lands also leads to sediment problems downslope in streams and lakes. Sedimentation of lakes reduces their storage capacity and life expectancy. In extreme cases, sedimentation changes an aquatic habitat into a terrestrial one. Chemical fertilizer (nitrogen and phosphorus) carried in sediment and runoff also causes eutrophication in lakes. Lake Alemaya located in Eastern Haraghe Zone at an altitude of 2000 m asl had once a maximum depth of 7- 8m(Brook, 1995); the sotage capacity of the lake has now decreased to 3 - 4 m due to siltation.

Despite the severe implications, there is a lack of quantitative data an current rates of erosion for most of the watersheds in Ethiopia. The solution to the problem of soil erosion and land degradation lies, among others, in quantifying erosion rates.

Soil erosion may be divided into splash erosion and wash erosion (sheet erosion). Under conditions of heavy rainfall raindrop splash is by far the most important part of the process (Hudson, 1981). Several experimental studies have established correlations between soil erosion, average drop size and thus kinetic energy and rainfall intensity (Bubenzer and Jones, 1975; Free, 1960; Osborne, 1954). Laws and Parson (1943: in Lal, 1994) found that average drop size increased as the rainfall intensity increased upto 150mm/hr.

Field scale plots (also called USLE plots) were used by Wishmeier and

Smith (1978) to measure runoff and sediment for predicting rainfall erosion losses. Small plots were used in the field to study the basic erosion processes such as splash and wash erosion that are difficult to study in detail on longer plots (Mayer and Harmon, 1985). Field plot experiments depend on natural rainfall which is always unpredictable. Rainfall simulators are widely used as experimental tools in that they apply water to small plots in a form similar to the natural rainfall.

(Claassens and Watt, 1993; Morin et.al 1967; Bubenzer and Meyer, 1965; Moldenhauer, 1965) Rainfall simulators are more rapid, more efficient, more controlled and more adaptable.

Materials and Methods

A rainfall simulator experiment was conducted in the laboratory using a spinning disc simulator (FEL Rainfall Simulator supplied by Armfield Ltd.) to generate an artificial rainfall. In this simulator a controlled flow of water is supplied to a vertically oriented nozzle directed downwards. The water from the nozzle is intercepted by a horizontal rotating disc having three segemented opperatores. Each time the disc passes under the nozzel a short burst of rain is sprayed through the appertures to the plot below.

Five different soil samples were taken from the upper 10-20 cm of soil surface at different elevations along a profile between lake Alemaya and the top of the subwatershed. Laboratory tests were conducted to determine the physical characteristics of the soils following the standard procedure (Bouyoucos, 1962) for particle size analysis and the procedures of Walkley and Black (Black 1965) for percentage organic matter (Table 1).

To determine the rainfall intensity received in the plot at different spots mini rain gages of 77mm diameter and 125mm high were placed and the rainfall simulator operated for 10 minutes. The water collected in each raingage was then used to calculate the rainfall intensity generated at different locations of the plot from which the respective kinetic energy (K.E.) and erosion index (EI) were calculated (Table 2). This information of the rainfall pattern were used to determine the placement of soil samples in manner to represent varying rainfall intensities.

In undertaking the experiment on splash erosion, six splash cups similar to those used by Ellison(1947) were placed in several positions where rainfall intensities were measured. The splash cups are 75 mm diameter and 55mm brass cylinders with gauze soldered into the bottom to allow dwater to drain through the soil sample which was placed upon a layer of cotton wool in the cylinders. The dried soil sample passed through a 60 gage mesh was filled in the cup. Moldenhauer(1965) states that more uniformity could be achieved by using disturbed samples than trying to take undisturbed samples since erosion is mainly from fields in the plow layer that is changing throughout the season. The splash cups were placed in shallow water until the soil was saturated and exposed to the rainfall for 10 minutes. After exposure and ovendrying, the cups with the soil were reweighed using a field balance and then the soil loss calculated.

Quantitative measurements of wash erosion were also assessed with the simulated rainfall under different rainfall intensities following the method used by Moldenhauer (1965). To measure the soil loss due to wash erosion wash-off trays 15x15 cm and 6cm deep were used for the xperiement. The trays have wire gauze placed in the bottom to allow saturation and drainage of the soil samples that were placed on a layer of cotton wool. The soil samples were passed through an 8 п m sieve and placed in 200gm layers into the tray with no compaction. Only light levelling was applied with a wooden board. After preparation of the soil trays they were placed on a plafform which was set at a constant slope of 15o and positioned each time at each of the spots representing the meausred rainfall intensities. The samples were then exposed to rainfall for 20 minutes and the runoff and sediments collected in containers through a plastic tube connected to the outlet of the trays. The sediment in the collected runoff was then allowed to settle and then separated by decanting the runoff water. The sediments obtained from each tray were then further oven dried and weighed to determine the wash erosion.

Raingauge Position	Test 1 Rainfall Intensity (mm/hr)	Test 2 Rainfall Intensity (mm/hr)	Test 3 Rainfall Intensity (mm/hr)	Mean [1] (mm/hr)	K.E. [2] (10^3J/ha)	Erosion Index (EI) 10^7J/ha x mm/hr
1	118.6	127.0	130.5	125.4	283	3.55
2	160	157.6	152.1	156.6	283	4.43
3	93.5	104.6	108.8	102.8	283	2.89
4	78.0	90.7	87.9	85.5	283	2.42
5	90.7	97.7	96.3	94.9	283	2.68
6	42.0	41.9	43.3	42.4	261	1.10

[1] All intensities(I) greater than 75 mm/hr have kinetic energy(KE) value of $283x10^3$ J/ha (Wischmeier and Smith, 1978).

[2] $KE = 118.9 + 87.3 \log_{10} I$

Table 2: Rainfall intensity measurements at different positions under the rainfall simulator

Soil	Size distribution (%)			Org. mat. %	Dry Bulk density g per cc	Slope (%)
	Sand	Silt	Clay			
Soil 1	48.3	22.1	29.7	0.97	1.38	15
Soil 2	50.6	33.4	16.0	1.61	1.42	12
Soil 3	51.5	19.5	30.0	2.07	1.34	8
Soil 4	37.3	20	42.7	1.68	1.30	6
Soil 5	19.6	30	50.4	2.91	1.23	0.5

Table 1. Summary of surface soil characteristics

Rainfall Intensity, I (mm/hr)	Soil Sample				
	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
125.4	666.7	226.7	128.4	102.2	488.9
156.6	764.4	173.3	128.9	62.2	328.9
102.3	426.7	115.6	115.6	66.7	217.8
85.5	484.4	53.3	97.8	17.8	262.2
94.9	506.4	177.8	93.3	84.4	311.1
42.4	337.8	26.7	66.7	26.7	88.9

Table 3: Effect of rainfall intensities on splash erosion of in gm/m2

Soil	Regression Equation	Correlation Coefficient
Soil 1	sl =3.83+143.45 (I)	0.94*
Soil 2	sl = 1.58 - 31.08 (I)	0.78
Soil 3	sl = 45.76 + 0.59 (I)	0.94*
Soil 4	sl = 10.54 + 0.49 (I)	0.58
Soil 5	sl = 22.93 + 2.57 (I)	0.75

* Significant at 1% level

Table 4: Regression equations relating splash loss to rainfall intensity.

Soil	Regression Equation	Correlation Coefficient for KE
Soil 1	sl = 1179.67+4.52(I) - 3.96 (KE)	0.60
Soil 2	sl = -331.49 + 1.38(I) + 1.15 (KE)	0.64
Soil 3	sl = -81.91 +0.50 (I)+ 0.49(KE)	0.78
Soil 4	sl = -137.61 + 0.39 (I) + 0.57(KE)	0.50
Soil 5	sl = -1372 + 1.64 (I) + 5.33 (KE)	0.72

Table 5 Multiple regression equations relating soil splash to the rainfall intensity and kinetic energy of the simulated rainfall.

Soil	Regression Equation	correlation coefficient for (I)
Soil 1	sl = 1228.73 + 1.46 (I)	0.12
Soil 2	sl = 2341.4 - 4.96 (I)	-0.28
Soil 3	sl = 1023.84 + 4.88 (I)	0.24
Soil 4	sl = -21.48 + 17.46 (I)	0.77
Soil 5	sl = 454.57 + 8.91 (I)	0.39

Table 6:Regression equation relating wash erosion to rainfall intensity

Soil	Regression Equation	Corelation Coefficient for KE
Soil 1	sl = 148323.04 - 4.34(I) - 516.90 (KE)	- 0.43
Soil 2	sl = -57816.04 - 2.58 (I) + 211.397 (KE)	0.29
Soil 3	sl = 189070.98 - 2.54 (I) - 660.82 (KE)	-0.43
Soil 4	sl = 45217.83 + 15.67(I) - 158.98 (KE)	-0.60
Soil 5	sl = 13846.82 + 3.47 (I) - 484.97 (KE)	-0.45

Table7: Multiple regression equations relating to rainfall intensity and kinetic energy under simulated rainfall

Results and Discussion

Splash Erosion

A rainfall simulator experiment was conducted to study the effects of rainfall intensity on splash erosion from the five soil samples taken at different locations in the field.

The different rainfall intensities used in the study and as measured at six different positions under the simulator and the associated kinetic energy (KE) and rainfall index (EI) are shown in Table 2. the highest rainfall intensity or kinetic energy recorded was 156.6 mm/hr and the lowest 42.4 mm/hr.

The effect of rainfall intensity on the splash loss for the five different soil samples was found to be consistent except for Soil2 and Soil3 under rainfall intensities of 85.5 and 42.4 mm/hr (Fig.1 and Table 3). The splash loss of Soil1 was the highest for all intensities with a maximum value of 666.7 g/m2 followed by Soil5. This can be attributed to the low organic matter content of Soil 1 and the high clay content of Soil 5.

The least splash loss was observed in Soil 4 for all intensities. The minimum value in this soil was 17.8g/m2. The relatively higher organic matter content and higher sand fraction of the soil might explain this observations. Soil2 and Soil3 showed intermediate splash loss values.

Based on the results of the comparisons presented and the results of the study of the dif

Fig .1 Effect of rainfall intensity on splash erosion (g/m2)

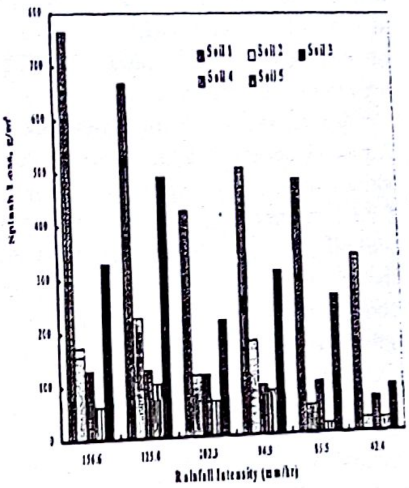
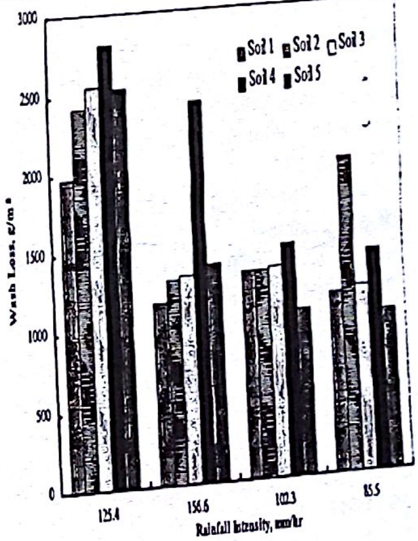


Fig 2. Effect of rainfall intensity on wash erosion (g/m2)



ferences in splash loss by soil type, linear simple and multiple regression analysis were performed on the data to establish empirical relationship between the splash rates and rainfall parameters.

The linear regression equation used to relate soil splash to intensity of the simulated rainfall was of the for sl = a + b (I) where sl was the splash loss in g/m2, I the rainfall intensity in mm/hr, and a and b are empirically determined constants.

The results of the regression analysis are shown in Table 4. The correlation coefficients for Soil1 and Soil3 are significantly higher than for all other soils. The multiple regression equation relating both kinetic energy and rainfall intensity to splash loss was of the form sl = c + d (I)+g(KE) where KE is kinetic energy in 103J/ha, and c, d and g are empirical constants.

The results of the multiple regression analysis are given in Table 5. The values of the correlation coefficients for KE are not better than the values of rainfall intensity. This is due to the fact that the soils were exposed to a nearly constant kinetic energy level and splash loss was influenced by rainfall intensity.

References

1.Black, C.A. 1965: Methods of soil analysis. Madison, Wis. Am. Soc. of Agronomy Inc.

2.Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soils. Agronomy J. 54 464-465.

3. Brook Lemma. 1995. Seasonal limnological studies on Lake Alemaya: a tropical African lake, Ethiopia. Arch. Hydrobiol./Suppl. 107:2. 263-285.

4. Babenzer, G.D. and B.A. Jones 1971. Drop size and impact velocity effects on the detachment of soils under simulated rainfall. Trans. ASAE 14:4, 625-628.

5. Classens, A.S. and H.H. Watt, 1993. An inexpensive, portable rain simulator: Construction and test data. S. Afr. J. Plant Soil 10:1, 6-11.

6. Ellison, W.D. 1944. Studies of raindrop erosion. Agricultural Engineering, 25:131-136, 181-182.

7. Free, G.R. 1960. Erosion characteristics of rainfall. Agricultural Engineering 41:447=455

8. Hudson, N.W. 1992. Soil Conservation. Batsford, London.

9. Humi, H. 1985. Erosion-Productivity-Conservation system in Ethiopia. Paper presented to the 4th ISCO conference, Maracay, Venezuela.

10. Lal, R. 1994. Soil erosion research methods. Soil and Water Conservation Society, St. Lucie Press, Florida.

11. Meyer, L.D. and W.C. Harmon 1985. Sediment losses from cropland furrows of different gradients. Trans. ASAE, 22:100-103.

12. Moldenhauer, W.C. 1965. Procdure for studying soil characteristics using disturbed samples and simulated rainfall. Trans. ASAE, 8:1, 74-75.

13. Morin, J., D. Goldberg, and J. Seginer, 1967. A rainfall simulator with rotating disc. Trans. ASAE, 10:1,74-77, 79.

14. Obsbome, B. Soil splash by raindrop impact on bare soils. J. Soil and Water Cons. 9:33-38 43,.

15. Tamire Hawando 1982. Problems of Soils and their implication on crop management program in Ethiopian context. Paper presented at the 1982 National Crop Improvement Conference of Ethiopia, Addis Ababa, Addis Ababa. University.

16. Wischmeier, W.H. and D.D. Smith 1978. Predicting rainfall erosion losses: a guide to conservation planning. USDA, Agriculture Handbook 537.

Author: Dr. Fekadu Yohannes Alemaya University,Dire Dawa,Ethiopia

Variations and Relations of Rainfall and Runoff in Western Shewa

Taffa Tulu, Associate Professor, Ambo College of Agriculture, P.O. Box 19, Ambo, Ethiopia

Abstract

The main rainy months which produced appreciable runoff in the selected representative watersheds of western Shewa, Ethiopia, were determined from the simulation result of a hydrologic model called HYBSCH. The variations of rainfall and runoff from year to year and the relations between rainfall and runoff were analysed for individual rainy months of the years 1966 to 1990. The watersheds differ in the process of runoff production. The year to year variations of rainfall and runoff are different for different months. July and August showed minimum variations in rainfall and runoff. June and September exprienced higher variations. Low coefficient of correlations were observed between rainfall and runoff for individual months in each study watersheds. They vary from month to month and from watershed to watershed. The relations between rainfall and runoff were found to be nonlinear. Several equations were produced from the regression analyses of rainfall-runoff relations. The probability of rainfall occurrence and frequency of exceedence were determined from the duration curve. A graphical representation of rainfall depth versus return period was found to be more suitable for the rainfall variation analysis.

Key words/phrases: Coefficient of correlation, linear and nonlinear relations, rainfall variation, rainfall-runoff relations, regression analysis, runoff variation

1. Introduction

While portion of a rainfall record may suggest an increasing or decreasing trend, there is usually a tendency to return to the mean; abnormally wet periods tend to be balanced by dry periods. The regularity of these fluctuations has been repeatedly investigated. More than 100 apparent cycles, ranging in period from 1 to 744 years, have been propounded (Shaw, 1942). No persistent regular cycles of any appreciable magnitude have been conclusively demonstrated (Mitchel, 1964). The extreme spatial coherence of rainfall anomalies and their persistence over long time periods are some of the features of drought. Among the main explanations of these anomalies are the Southern Oscillation and associated changes in sea-surface temperature (i.e., El Niño), changes in vegetation cover and albedo, changes in soil moisture, atmospheric dust and interaction with the middle-latitude atmosphere.

Much of the rain falling during the first part of a storm is stored on the vegetal cover as interception and, as rain continues, in surface puddles as depression storage. Except in very intense storms, the greater portion of the local soil moisture deficiency is satisfied before appreciable surface runoff takes place. Water infiltrating the soil surface and not retained as soil moisture either moves to the stream as interflow or penetrates to the water table and eventually reaches the stream as groundwater.

Relationships between precipitation and runoff and techniques of distributing the runoff through the time are bases for efficient forecasting for the operation of hydraulic projects, for the extension of flow records on gaged streams and for estimating the flow of ungaged streams. The quantity of runoff from a storm depends on the moisture conditions of the catchment at the onset of the storm and on the storm characteristics such as rainfall amount, intensity and duration. The soil moisture decreases logarithmically with time during periods of no precipitation (Kohler and Linsley, 1951). The rate of surface runoff starts at zero, increases slowly at first and then more rapidly, eventually approaching a relatively constant percentage of the rainfall rate. Both the percentage and the rate of runoff depends upon rainfall intensity. There is often a substantial lag between precipitation and the subsequent discharge of that portion which recharge the groundwater. Runoff rates are sensitive to the spatial variation in rainfall, soils and topography (Freeze, 1980; Yair and Lavee, 1985).

The investigations were carried out in the watersheds of Guder, Indris and Belo in Western Shewa, Ethiopia, for the main rainy months of the years from 1966 to 1990. The watershed areas are 524 km², 111 km² and 290 km² respectively. The Indris and Belo are sub-watersheds of Guder Watershed. These watersheds are part of the Ethiopian highlands. The Ethiopian highlands are the main sources of water, not only for Ethiopia but also for the surrounding neighbouring countries. The highland of Ethiopia comprises 45% of the total area of the country (Drabner, 1988). The considered watersheds are located in the highlands of western Shewa.

The Guder watershed is bounded by 8°45'N and 8°57'N latitude and also by 37°27'E and 37°48'E longitude. There are two rainfall periods in the region. In between the two periods, the rain falls quite seldom. The main rainfall period known as „big rains" occurs in this region from June to October. High concentration of rainfall occur in July and August. Much of his rainfall, often nearly 64%, occurs from June to September (Taffa, 1989). This also means that 80% to 90% of the total annual flows in the rivers occur during this period. The second rainfall period known as „small rains" occur from the last week of March to the first week of May. In the dry period between the end

Table 1 Average monthly values of rainfall & runoff for the year 1966 to 1990 in Guder, Indris, Belo & Fatto watersheds

Month	Rainfall (mm)	Runoff in mm			
		Guder	Indris	Belo	Fatto
January	23	0	0	0	0
February	41	0	0	0	0
March	82	0	0	0	0
April	79	0	0	0	0
May	155	9	13	8	2
June	203	40	28	36	2
July	253	141	135	128	98
August	243	213	212	190	201
September	183	153	142	160	155
October	67	47	38	58	54
November	26	1	1	0	1
December	18	0	0	0	0

of October and the end of February, the amount of rainfall is generally small. December is usually the driest month with only small cloud in the atmosphere and hence great radiation loss from the earth during the night giving rise to night frosts. Eventhough the relative humidity from November to March is small, there are greater differences between its values. The dry period terminates at the end of February or at the beginning of March. This dry period is characterized by strong day winds which blow east to west causing higher evaporation. The mean monthly temperature over many years fluctuates between 10°C and 20°C (Taffa, 1989). Hydrological information are present for some rivers of western Shewa such as Holetta, Berga, Guder, Indris, Belo and Fatto. The homogeneity tests of their streamflow were performed by Taffa (1989 and 1991).

The main objective of this paper is to analyse the variation of rainfall and runoff and also the relations between rainfall and runoff of individual rainy month over a long period of time in the selected watersheds of western Shewa, Ethiopia. A profound understanding of rainfall-runoff relations is necessary for deriving valid methods under varying rainfall. The possible existence of rainfall periodicity or systematic sequence of occurrence wll be assessed.

2. Materials and Methods

The simulated values of runoff using a deterministic conceptual hydrologic model called HYBSCH (Taffa, 1989, 1990 and 1991), as shown in (Table 1), and the corresponding observed values of rainfall made clear that the rainy months causing appreciable surface runoff are June, July, August and September. The method of the hypsometric curve was used in the calculation of the areal rainfall from point rainfalls observed at stations of Guder, Shenen, Gedo and Ginchi for the years 1966 to 1990 (Table 2). The volume of runoff was converted to runoff depth in millimeter using area of the watersheds, namely 524 km², 111 km² and 290 km² for Guder, Indris and Belo watersheds respectively(Table 3).

Table 2 Rainfall of Guder Watershed in the rainy months of June to September (1966-1990)

Year	June (mm)	July (mm)	Aug. (mm)	Sept. (mm)	Sum (mm)
1966	168	252	228	291	939
67	131	328	262	183	904
68	244	237	193	223	897
69	227	227	220	184	858
70	232	334	303	135	1004
71	186	202	265	180	833
72	114	247	188	177	726
73	161	224	189	127	701
74	241	238	254	261	994
75	245	309	314	187	1055
76	176	239	233	165	813
77	240	285	287	274	1086
78	163	263	259	237	922
79	124	199	309	248	880
80	286	275	281	210	1052
81	260	304	280	205	1049
82	197	161	208	210	776
83	87	232	290	229	838
84	210	301	175	142	828
85	191	231	218	116	756
86	285	156	149	100	690
87	156	170	210	91	627
88	172	283	300	144	899
89	243	219	181	73	716
90	325	417	270	190	1202
Mean	203	253	243	183	882

A frequently used measure of rainfall variability is coefficient of variation defined as:

$$V = \frac{Sd}{Pm} * 100\% \quad (1)$$

where Sd is the standard deviation of precipitation in percent and Pm is mean annual precipitation in mm. In most part of the arid world, rainfall is not normally distributed and Wallén (1968) had made use of the iterannual variability

$$V_I = 100 \frac{\sum (P_{n-1} - P_n)}{P_m (N - 1)} \quad (2)$$

(where n is an idividual year in a series of N years), which is the percentage ratio of the mean interannual precipitation difference (taken regardless of sign) to the mean annual precipitation.

To understand the availability of water, it is necessary to examine the statistical properties of frequency distributions of rainfall. Gibbs (1981) states that, unfortunately, the frequency distribution of most daily rainfalls, many monthly rainfalls and some annual rainfalls are far from normal (Gaussian), and the use of arithmetic means and standard deviations is quite inappropriate for many purposes including the study of drought. Frequency distributions, probability distributions, probability of exceedence and recurrence intervals (return periods) of rainfalls were determined for the month of June (Table 4). Similar computations were done for the months of July, August and September. A useful device is to use a diagram of percentage cumulative frequency versus rainfall depth (Fig. 1). A curve plotted on such a diagram shows the percentage of occassions a particular value is exceeded (Dyck, et al, 1980a and b; Dyck and Peschke, 1983).

Coefficient of correlation between rainfall and runoff for the individual rainy month in the study watersheds were determined (Table 5) for the time series of 1966 to 1990. The rainfall and runoff data from tables 2 and 3 respectively were used for the investigation of rainfall-runoff relations. Regression equations were derived for each month in each watershed (tables 6 and 7). The analytical technique for the relation between precipitation and runoff uses the equation (Linsley, et al., 1985):

Table 3 Runoff data for Guder, Indris & Belo watersheds for the rainy months of June to September (1966-1990)

Year	Runoff in mm for Guder				Runoff in mm for Indris				Runoff in mm for Belo			
	June	July	Aug	Sep.	June	July	Aug	Sep.	June	July	Aug	Sep.
1966	48	93	233	244	15	96	204	141	59	178	297	184
67	17	144	229	126	12	156	154	136	17	125	154	244
68	61	150	245	263	54	104	130	106	45	68	108	115
69	104	207	199	117	49	121	230	211	75	179	206	188
70	28	177	323	122	15	155	296	93	34	140	269	157
71	66	226	260	122	38	160	240	160	63	175	168	183
72	12	63	154	44	14	123	153	105	18	166	165	129
73	22	109	216	168	29	68	208	180	10	97	179	119
74	38	137	186	183	29	139	205	173	12	105	180	188
75	43	156	207	177	32	202	209	193	49	151	190	132
76	26	94	167	93	30	221	203	79	20	138	120	104
77	28	48	182	162	47	223	231	196	5	83	169	181
78	20	125	209	158	17	118	358	203	25	108	163	184
79	18	122	159	118	24	101	144	50	16	96	196	223
80	44	169	167	149	33	182	209	123	24	147	193	179
81	13	114	214	163	29	186	177	229	22	145	232	193
82	10	83	157	122	13	81	291	110	25	108	188	167
83	28	116	238	197	26	87	304	209	42	118	233	208
84	61	152	200	93	49	162	150	131	38	166	213	96
85	36	208	267	183	27	162	360	180	48	171	220	189
86	52	177	184	178	18	81	153	108	43	121	166	129
87	79	168	224	143	39	157	186	77	87	146	209	158
88	10	102	265	185	20	100	281	137	12	107	228	163
89	93	209	223	179	32	133	190	153	112	101	147	122
90	85	240	274	221	52	144	210	142	83	151	235	196
Mean	42	144	215	156	30	138	219	145	39	132	193	165

$$Q = (P^n + I_{ps}^n)^{\frac{1}{n}} - I_{ps} \quad (3)$$

where Q is direct runoff, P is storm rainfall, Ips is a runoff index approximating the first quadrant of a coaxial plot and n is a constant. Runoff index is defined as the ratio of direct runoff to precipitation. The linear regression model has been applied to annual rainfall-runoff data from small watersheds and large basins by Diskin (1970), Diskin et al. (1973) and to separate storms by Fink et al. (1979). For separate storms the model can be written as

$$R = 0 \quad \text{for } 0 < P \leq \delta$$

$$R = \omega (P - \delta) \quad \text{for } P > \delta \quad (4)$$

where R is runoff, P is precipitation, is threshold value and is runoff index. The runoff index of the individual rainy months of the watershed were calculated.

3. Results and Discussion

3.1 Rainfall Variations Within Individual Rainy Months

The coefficient of variation of rainfall from 1966 to 1990 were computed using Eq.(1) to be 29%, 23%, 20% and 31% for the months of June, July, August and September respectively. The coefficient of variation is over 25% in most parts of the dry world, and exceeds 40% along most desert margins. The months of June and September exhibit the charachter of dry region. Only July and August are, therefore, months of minimum rainfall variations. The interannual variation of rainfall was computed using Eq. (2) to be 15%.

If the sample of observations is sufficiently large, the percentage cumulative frequency curve may be used to deduce the probability of occurrence (figs. 1 and 2). Gibbs (1981) suggested that the square roots of hourly, daily, and monthly rainfall tend to be normally distributed, and has used a square root scale for the abscissa. The scale of the ordinate is such that, if the magnitude of the elements represented on the abscissa is normally distributed, the curve will be a straight line.

The graphical representations of rainfall depth versus percentage cumulative frequency (Fig. 1), rainfall depth versus duration curve of frequency (Fig. 2) and normalized rainfall (rainfall ratio to mean annual rainfall) versus return period (Fig. 3) have different slopes of curves and this has important implications for hydrologic and geomorphic processes. The slope of the rainfall frequency curve graphically represents the standard deviation, Sd, of the rainfall frequency distribution, and the higher the slope, the greater the standard deviation, or year to year variability in rainfall. Of these four months, rainfalls in the month of September are the most variable and rainfalls of June has intermediate variability and rainfalls of July and August are the least variable. The slopes are more defined and easily understandable in Fig. 2 than figs. 1 and 3. In Fig. 1, the slopes are least defined. It is, therefore recommended to use a graph of rainfall depth versus frequency of exceedence for rainfall variation analysis. The next alternative can be the use of Fig. 3.

The rainfall amount of the four rainy months were added together for each year of 1966 to 1990 (Table 2) and were compared with their annual mean of 882 mm. The aim was to test if there exists any periodicity or logical sequence of rainfall. The rainfall occurred below the long-term annual mean every 2, 3 or 6 years. For example, it was below the annual mean in 1969, after 2 years in 1971 and was extended up to 1973, after 3 years in 1976, after 6 years in 1982 and was ex-

Table 4 Rainfall frequency distribution for the month of June in the years 1966 to 1990 for the Guder Watershed

C	Cr	Fa	Fd	Fc	Pden	Pdis	Pe	Pn	Re	Rn
1	87 - 106	1	0.05	1	0.04	0.04	0.92	0.08	1.09	12.5
2	107 - 126	2	0.10	3	0.08	0.12	0.83	0.17	1.20	5.88
3	127 - 146	1	0.05	4	0.04	0.16	0.75	0.25	1.33	4.00
4	147 - 166	3	0.15	7	0.12	0.28	0.67	0.33	1.49	3.03
5	167 - 186	4	0.20	11	0.16	0.44	0.58	0.42	1.72	2.38
6	187 - 206	2	0.10	13	0.08	0.52	0.50	0.50	2.00	2.00
7	207 - 226	1	0.05	14	0.04	0.56	0.42	0.58	2.38	1.72
8	227 - 246	7	0.35	21	0.28	0.84	0.33	0.67	3.03	1.49
9	247 - 266	1	0.05	22	0.04	0.88	0.25	0.75	4.00	1.33
10	267 - 286	2	0.10	24	0.08	0.96	0.17	0.83	5.88	1.20
11	287 - 326	1	0.03	25	0.04	1.00	0.08	0.92	12.5	1.09

Note:
C = class
Cr = class range
Fa = absolute frequency
Fd = frequency density (Fa/ x)
sx = class interval (here 20 and once 40)
Fc = cumulative frequency
Pdis = probability distribution (Fc/n)
Pden= probability density(Fa/n)
Pe= probability of exceedence(1 - (r/(C+1)))
r= an individual class in C classes
Pn= probability of non-exceedence (r/(C+1))
Re= recurrence interval (return period) of frequncy of exceedence (1/Pe)
Rn= recurrence interval (return period) of frequency of non-exceedence (1/Pn)

tended up to 1987, and after 2 years in 1989. The cycle seems to follow a pattern of 2, 3, 6 and 2 years of return periods. However, it is very hard to generalize the logical sequence of repeatition using only data of 25 years.

Table 5 Coefficients of correlation b/n rainfall & runoff for the individual rainy month of the study watersheds

	Guder	Indris	Belo
June	0.442475	0.433864	0.261150
July	0.124431	0.418729	0.168452
August	0.238207	0.309646	0.333510
September	0.219980	0.214918	0.474487

Table 6 Regression equations derived for the individual rainy month of the study watersheds based on linear relations (Note: R=runoff; P=rainfall)

	Guder	Indris	Belo
June	R=0.2P	R=0.09P+10	R=0.1P+15
July	R=0.1P+117	R=0.3P+60	R=0.09P+109
August	R=0.2P+164	R=0.4P+118	R=0.3P+120
September	R=0.19P+122	R=0.18P+112	R=0.3P+103

3.2 Runoff Variations Within Individual Rainy Months

The variability in runoff reflects mainly the variability in rainfall. Although soil moisture and mechanisms of runoff production may vary during a storm, the physiographic characteristics of a watershed are essentially permanent (non-variable), and thus there is little basis for suggesting that over short time-scales the variability of rainfall reflects any thing more than the variability in rainfall amount or intensity. Patterns of runoff are strongly influenced by soil thickness and permeability (Kirkby, 1978). Typically, soils become thinner as gradient increases. It is more difficult to parameterize soil permeability or hydraulic conductivity over large areas and, therefore, I did not incorporate soil data into this analysis.

The coefficients of variation of runoff in 1966 to 1990 for the months of June, July, August and September were computed using Eq.(1) to be 65%, 35%, 20% and 31% respectively for Guder Watershed, 45%, 32%, 29 and 33% respectively for Indris Watershed and 70%, 24%, 22% and 23% respectively for Belo watershed. The coefficients of variations follow similar trend in the three watersheds, namely highest for June, high for July, intermediate for September and least for August. Comparing the watersheds, highest variability is seen in the Belo watershed and the least in the Indris watershed.

The runoff indices for the months of June, July, August and September for a period of 1966 to 1990 were determined to be 0.20, 0.50, 0.88 and 0.85 respectively for the Guder watershed, 0.15, 0.55, 0.90 and 0.79 respectively for Indris watershed, and 0.19, 0.52, 0.79, and 0.90 respectively for the Belo Watershed. The runoff index for June is the least in all the three cases and that of August is the highest for both Guder and Indris watersheds. The Belo watershed has very deep soils and can store more soil moisture till the end of August in which the ground water keeps soil moisture almost constant in September also. This might have contributed to the higher runoff index in September than in August.

The normalized frequency curves which were plotted for the four rainy months of the three watersheds have different slopes of curves (Fig. 4). The slope of the curves show the degree of variability. The higher the slope, the greater is the year to year variability of runoff in the considered month. In all the three watersheds, the month of June shows the highest year to year variation (Fig. 4) and August the least variation. The month of September shows higher variability than June. Therefore, the order of months with respect to year to year variation from least to highest variability is August, July, September and June. The runoff is almost stabler for Guder Watershed than those of Indris and Belo watersheds. The variability is higher for the month of June in the Guder and Belo watersheds than that of the Indris Watershed. These dif-

Table 7 Regression equations derived for the individual rainy month of the study watersheds based on nonlinear relations

	Guder	Indris	Belo
June	R=0.2(P+6)	R=0.15(P-6)	R=0.19(P+5)
July	R=0.5(P-2)	R=0.55(P-2)	R=0.52P
August	R=0.88(P+2)	R=0.9(P+1)	R=0.79(P+2)
September	R=0.85(P+1)	R=0.79P	R=0.9P

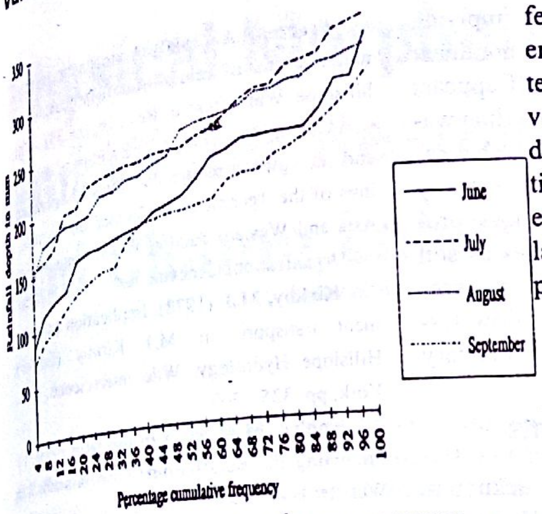


Fig.1 Percentage cumulative frequency curves of the four rainy months of the study watersheds in the years 1996

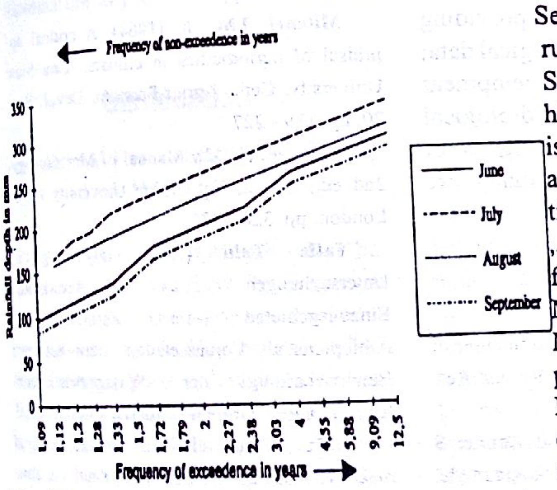


Fig. 2 Duration curves for the four rainy months of the study watersheds in 1966 to 1990

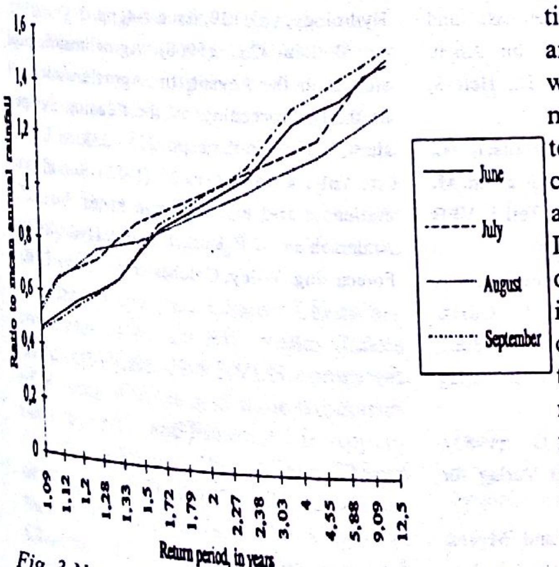


Fig. 3 Normalized rainfall frequency curves for the four rainy months of the study watersheds in the years from 1996 to 1990

ferences arise from difference in the portion of a watershed that is directly involved in the runoff production. The runoff production is influenced by vegetation cover, soil type, land use, geology and topography of a watershed.

3.3 Rainfall-Runoff Relations for the Individual Rainy Months

The order of months with respect to year to year variations in rainfall from least to highest variability was August, July, June and September while that of runoff was August, July, September and June. The highest variability in June is because of the moisture and groundwater conditions influenced by the „small rains" which occurs from the last week of March to the first week of May. The rainfall of this period is highly erratic. Heavy or small rainfalls can occcur during this period. Therefore, the soil moisture and groundwater level are also highly variable from year to year in this period. Correlations between the rainfall and runoff variables vary widely from month to month and from watershed to watershed (Table 5). The coefficients of correlations are relatively higher for the Indris Watershed than the others. However, they are insignificant for all the cases. Therefore, the relation between rainfall and runoff is nonlinear. I derived regression equations for the individual months of the study watersheds to estimate the runoff as a function of rainfall for the cases of linear and nonlinear relations (Tables 6 and 7). The nonlinear regression equa-

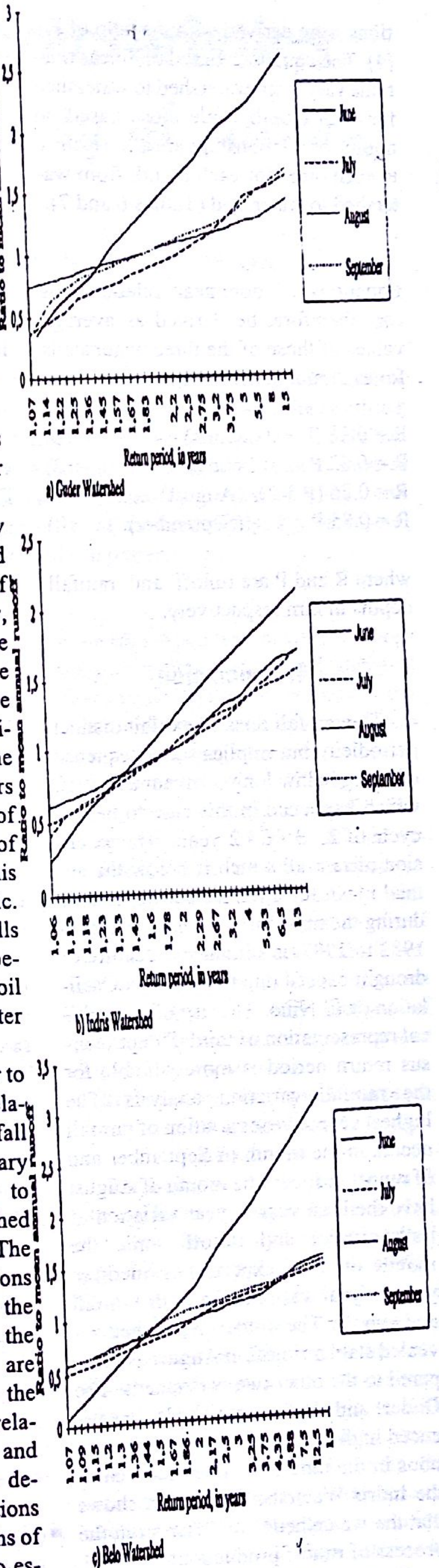


Fig 4.Normalized runoff frequency curves for a) Guder, b) Indris and c) Belo watersheds for the four months of the years 1966 to 1990

tions were derived with the help of Eq. (4). The equations based on linear relations vary from watershed to watershed for each month while those based on nonlinear relationships are almost close to each other for each month from watershed to watershed (Tables 6 and 7). \

Equations of nonlinear relationships can, therefore, be derived as average values of those of the three watersheds for each month as follows:

$R = 0.18\ (P + 2)$	(June)	(5)
$R = 0.52\ P$	(July)	(6)
$R = 0.86\ (P + 2)$	(August)	(7)
$R = 0.85\ P$	(September)	(8)

where R and P are runoff and rainfall depths in mm respectively.

4. Conclusion

The rainfall doesn't exhibit distinct periodicity but implies some sequence of being below long-term annual mean which happened in this case to have a cycle of 2 - 3 - 6 - 2 years. The extension of rainfall which is below the annual mean for a longer period of time during the main rainy months, e.g from 1982 to 1987, is similar to a feature of drought caused due to Southern Oscillation or El Niño. The use of a graphical representation of rainfall depth versus return period is more suitable for the rainfall variation analysis. The highest year to year variation of rainfall occurs in the month of September and of runoff in June. The month of August have the least year to year variation of both rainfall and runoff while the month of July experiences medium year to year variation in both rainfall and runoff. The Guder Watershed revealed stabler runoff in August as compared to the other two watersheds. The Guder and Belo watersheds experienced higher year to year runoff variations in the month of June than that of the Indris Watershed. This fact shows that the watersheds are different in the process of runoff production.

The coefficients of correlations between rainfall and runoff variables vary widely from month to month and from watershed to watershed. They are insignificant in all the cases implying nonlinear relationships. The nonlinear response of watershed runoff appears to be set by the process controlling watershed hydrological memory. The watershed hydrological memory is set by water retention and water loss processes related to such features as soil properties, vegetation, hillslope processes, regional groundwater flow systems, and the atmospheric boundary layer regime.

Acknowledgements

The author gratefully acknowledges the Alexander von Humboldt Foundation and the Ethiopian Science and Technology Commission for the research grant, the National Meteorological Service Agency for providing with the necessary meteorological data; and the Water Resource Development Authority for providing hydrological data. The friends and colleagues of Rostock University in Germany are also acknowledged.

References

Diskin, M.H. (1970). Definition and uses of the linear regression model. Water Resour. Res. 6, pp. 1668 - 1673.

Diskin, M.H., Buras, N. and Zamir, S (1973). Application of simple hydrologic model for rainfall-runoff relations of the Dalton Watershed. Water Resour. Res. 9, pp. 927 - 936.

Drabner, H.J. (1988). Die Bedeutung nomadischer Viehwirtschaft im ostafrikanischen Raum - Erfordernisse und Möglichkeiten ihre Entwicklung. In: Asien, Afrika und Lateinamerika, Band 16, Heft 3, Akademie Verlag, Berlin, p. 493.

Dyck, S., Grünewald, U., Hansel, N., Kluge, Ch., Lauterbach, D., and Schramm, M. (1980a). Angewandte Hydrologie. Teil 1, VEB Verlag für Bauwesen, Berlin, 528 pp.

Dyck, S., Beckeer, A., Flemming, G., Glugla, G., Golf, W., Grünewald, U., Gurtz, J., Kluge, Ch., and Peschke, G. (1980b). Angewandte Hydrologie. Teil 2, VEB Verlag für Bauwesen, Berlin, 544 pp.

Dyck, S. and Peschke, G. (1983). Grundlagen der Hydrologie. VEB Verlag für Bauwesen, Berlin, 388 pp.

Fink, D.H., Frasier, G.W. and Myers, L.E. (1979). Water harvesting treatment evaluation at Granite Reef. Water Resor. Bull., 15, pp. 861 - 873.

Freeze, R.A. (1980). A stochastic conceptual analysis of rainfall-runoff process on a hillslope. Water Resour. Res., 16, pp. 391 -408.

Gibbs, W.J. (1981). The nature of drought and strategies to reduce its effects. In: proceedings of the Technical Conference on Climate - Asia and Western Pacific, World Meteorological Organization, Geneva.

Kirkby, M.J. (1978). Implication for sediment transport. In: M.J. Kirkby (Editor), Hillslope Hydrology. Wile Interscience, New York, pp. 325 - 363.

Kohler, M.A. and Linsley, R.K. (1951). Predicting the runoff from storm rainfall. US Weather Bur. Res. Pap. 34.

Linsley, R.K., Jr., Kohler, M.A. and Paulhus, J.L.H. (1985). Hydrology for Engineers. 3rd ed., McGraw-Hill Book Company, Singapore, 508 pp.

Mitchel, J.M., Jr. (1964). A critical appraisal of periodicities in climate. Iowa State University, Cent. Agric. Econom. Devel. Rep. 20, pp. 189 - 227.

Shaw, N. (1942). Manual of Meteorology. 2nd ed., vol. 2, Cambridge University Press, London, pp. 320 - 325.

Taffa Tulu (1989). Hydrologische Untersuchungen an ausgewählten Einzugsgebieten im Zentralhochland Äthiopiens als Voraussetzung zur besseren Bewirtschaftung der Wasser-ressourcen. Rostock University, Ph.D. thesis, 135 pp.

Taffa Tulu (1990). Integration of macropore infiltration with a deterministic conceptual hydrologic model. SINET: Ethiopian Journal of Science, vol. 13, no. 2, pp. 71-82.

Taffa Tulu (1991). Simulation of streamflows for ungaged catchments. Journal of Hydrology, vol. 129, issue 1-4, pp. 3-17.

Wallén, C.C. (1968). Agroclimatological studies in the Levant. In: Agroclimatological Methods, Proceedings of the Reading Symposium, UNESCO, Paris, pp. 225 - 233.

Yair, A. and Lavee, H. (1985). Runoff generation in arid and semi-arid zones. In: M.G. Anderson and T.P. Burt (Editors), Hydrological Forecasting. Wiley, Chichester, pp. 183 - 220.

Physical Morphometric Characteristics and Water Resources Capacity of Abaya and Chamo Lakes

Seleshi B. Awulachew, and H.-B. Horlacher (Prof. Dr.-Ing.habil), TU Dresden, Germany

Abstract

The purpose of the study undertaken in this paper is aimed at studying the Abaya and Chamo lakes, which are not previously studied in any meaningful detail. The paper discusses the bathymetry survey undertaken and the resulting morphomoteric characteristics derived as a result. The background lake map has been digitised and surveyed data has been also developed as digital values. The digital values have been interpolated and grids of the elevation surface have been generated. From the digital values elevation area and elevation volume curves (capacity curves) of Abaya and Chamo Lakes have been developed, which can describe the water resources capacity of the lakes body. Furthermore, immediate application of the result as a continuation of the study is highlighted in the paper.

Introduction

1. General Description of the Lake and the Drainage System

The **Abaya and Chamo lakes** belong to the Ethiopian rift lakes system, which in turn is the component of African Eastern Rift Valley. In east Africa the drainage pattern began to change following upward movements and volcanic activity in Miocene times, starting 25 Million years ago, Crul (1995). A wide stretch of land from Eriteria to the Zambezi has been lifted more than 1,000 meters since the Miocene. The two edges have been raised further, forming two great rift valleys. Tectonic activities in and near these valleys formed series of splits in the earth's crust of which some are more than 1000 meters deep and have filled with water. In this way the Abaya and Chamo lakes as well as the other rift valley lakes (excluding Lake Victoria) has been formed.

The Abaya and Chamo Lakes are components of the Rift Valley Lakes Basin (RVLB). The RVLB comprises of 8 natural lakes and their tributaries see Figure 1.1 and Figure A1 in Appendix for details. The Abaya-Chamo drainage sub-Basin (ACB) comprises mainly the two lakes, Lake Abaya & Chamo, and rivers and streams which are Gelana, Bilate, Gidabo, Hare, Baso, Amesa & other small brooks and streams entering the Abaya lake. Outflow from Abaya with Kulfo and other streams Sile, Argoba/Wezeka and other brooks and streams are entering to Chamo and an overflow from Chamo through Metenafesha joins Sermale river to join Sagan river, which intern ends up in Lake Chew-Bahir at border of Ethiopia with Kenya. The Abaya & Chamo lakes are treated in conjunction as a single basin because the two lakes are hydrologicaly interconnected. The level difference between the two lakes is about 61m.

Morphometry is the measurement of the form characteristics of lakes and lakes basins. The three dimensional form of a lake basin and several aspects of the lake dependent on kind of topography in which it is formed, physical means by which the lake come in to existence and the conditions and events in the lake & drainage basin since its formation, Chow (1964). The most important standard general and morphometric parameters of lakes labelled according to Chow, for the two lakes are investigated in this paper. Field data collection work under the umbrella of the ACB research has been undertaken. The methodologies of data collection in the field survey work, analysis of data and derived results are presented in the following sections

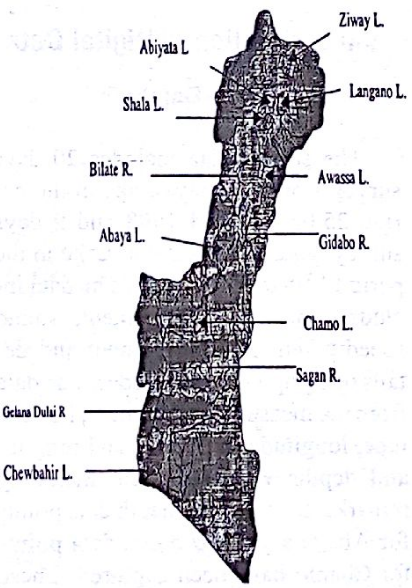


Fig. 1.1 Southern Rift valley Lakes Basin of Ethiopia

2. Bathymetry Survey of the Abaya and Chamo Lakes

2.1 General

The bathymetry data for Abaya & Chamo Lake is not readily available, and only lake Ziway has got bathymetry data in RVLB, Halcrow (1992). The absence of such data has hindered various useful studies and planning which would have facilitated the water resources development of the drainage area and the lake body itself. In their reconnaissance master plan study, Halcrow (1992) couldn't model the water balance of the two lakes because of absence of data. Similarly Alexander Gibb and Partners in their attempt to model the water balance of Abaya Lake in Gelana Irrigation Development Study, Gibb et. al.(1987), Sahilu, G. (1994) in his hydropower study for Kulfo river, assumed non-existing ideal lake volume and data. Earlier approximate depth contours of Lake Margarita (Lake Abaya) has been sketched by Morandini, G. in 1941 as reported in Riedel (1962) with few measured points. Thus for various future applications stated below and as an objective of the wider study of ACB, bathymetry data of Abaya and Chamo Lakes have been collected and the results are presented.

The data and result document have various applications, and among others the following are some of these applications:

- water resource quantity assessment of the lakes
- computation of water balance model for the lakes and entire drainage area
- assessment of project development impact on the lakes
- limnological and water quality study of the lakes
- hydrological/hydraulic study of the two lakes and their drainage system
- fisheries, tourism and agricultural development using the lakes.

The bathymetry survey of the Abaya as well as the Chamo Lake has been carried out in the first half of 1998. Only a short description of the equipment and methods used, data of the survey work, results and conclusions on the data collection have been contained in this document. Full document of the undertaken study is provided in other document in Seleshi (1999).

2.2 Equipment and Methods Used

The equipment used in the study includes Boat, Echo sounder, GPS and accessories. For details on accuracy of the equipment, capacity, needed modifications and etc., see Seleshi (1999)

An appropriate and optimal methodology has been set out in the field based on the first two days of reconnaissance work. The required parameters are depth and corresponding location. The method of measurement described as follows:

i. *GPS setting*: The GPS was set, and important parameters, which includes, latitude and longitude, travelled distance, orientation, have been set to be displayed.

ii. *Echosounder setting*: The setting is carried out according to the operating manual and adjusted to display shallow water depth both graphically and digitally.

iii. *Echosounder calibration*: the Echosounder is set and the boat was taken in to the position where sufficient depth is available for calibration. Actual depth is measured and the Echo sounder is adjusted to read the measured depth at the point, which ensures the calibration. Calibration value for sound speed in Abaya Lake of 1500m/s and 1550m/s for Chamo Lake provided good result. For possible errors of measurements refer limitations section 7 below.

iv. *Measurement*: During the measurement first an approximate orientation got chosen based on pre selected marks. While travelling in the selected orientation a quickly changing co-ordinate is pre-registered at intervals of 0.1minutes latitude or longitude distance (about 180m), the corresponding longitude or latitude respectively registered. At the same time the corresponding depth from the display of the echo sounder have been registered.

However, near banks, and where there were sudden depth variations, records were taken at shorter intervals.

3. Bathymetry Survey Database and Generation of Digital Data

3.1 The Database

The survey data includes 20 days survey work of Abaya Lake in the period 25.02 to 29.04 1998 and 9 days survey work of the Chamo Lake in the period 1.05 to 31.05.1998. The data includes date of measurement, sound speed taken for measurement and details of equipment as a header. The data from the measuring equipment, i.e. latitude, longitude in degrees and minutes and depths were recorded, including remarks. In total 4050 depth data points for Abaya and 2400 depth data points for Chamo have been captured. These data have been compiled and included in Seleshi (1999). The data routes and captured points are indicated in Figures A2, in Appendix.

The collected data should be adjusted using a reference value of lake water level to provide accurate computations with respect to reference datum. The adjustment is needed to cater for small variations during the investigation period. During the reporting period of this paper these values are not obtained from the MOWR, and data haven't been adjusted. According to observations during the data collection and previous monthly lake water level records this factor is expected to affect at maximum the lake level of Abaya by about 0.15m and that of Chamo lake by about 0.1m. Thus, to use information in this document one has to make necessary adjustments accordingly.

3.2 Interpolation and Generation of Digital Data

The spatial coverage of the survey can be considered as sampling values. To obtain regular grid data for the entire surface of the lakes the data have to be interpolated. The temporally adjusted and corrected lake water levels and depth data are mapped on top of digitised background Ethiopian Mapping Agency (EMA) map. Having superimposed the digitised background map and digital data the scattered data have been interpolated to create grid data, using various interpolation techniques, provided in surfer graphic software. The interpolated grid data are used to create contour maps and to derive various morphometric parameters of interest and maps of the lakes.

Gridding is the process of using original data points (observations) in an XYZ data file to generate calculated data points on a regularly spaced grid. A number of gridding methods and various softwares are available for the purpose. Interpolation schemes estimate the value of the surface at locations where no original data exists, based on the known data values (observations). Thus the grid is used to generate the contour map or surface plot.

The various grid methods include: Inverse Distance, Kriging , Minimum Curvature, Nearest Neighbour, Polynomial Regression, Radial Basis Functions, Shepard's method, Triangulation with Linear Interpolation. Having tested these methods with the collected data, the last method, i.e., triangulation with Linear Interpolation has been chosen to derive end results in this study. This method is fast with all data sets. When small data sets are used Triangulation generates distinct triangular facets between data points. One advantage of triangulation is that, with enough data, triangulation can preserve break lines defined in a data file. For example, if a fault is delimited by enough data points on both sides of the fault line, the grid generated by triangulation will show the discontinuity.

4. Computation of Lake Parameters

From the prepared digital data various morphometric characteristic parameters and maps of the two lakes have been prepared. Various morphometric parameters have been defined in Chow (64), and the included parameters in this study have been redefined and summarised in the following section. Contour maps, elevation-area, and elevation-volume curves. In addition correlation equations between depth and area as well as volume have been developed using polynomial curve fitting techniques. Procedures, methods of computations and results are described in the following sections.

4.1 Morphometric Characteristics

The most important parameters of morphometry of lakes according to, Chow (1964), are; area (A), maximum effective length (Lme), maximum width (Wme), mean width (W), shoreline (L) and depth (d). The following table and definitions provide these most important morphometric parameters and other computed general characteristics of the two lakes:

Lme , the maximum shore to shore length without being interrupted by islands, can be considered as fetch length similar to term in reservoirs.

Wme , the maximum shore to shore width without being interrupted by islands

W , Average width = Area/Lme

L , Average length

d , the mean depth of the lake = *V/A*

dmax ,.the maximum depth of the lake

A, the total surface area of the lake

V, the volume of the lake

Accordingly, the table below summarises these values for the two lakes

4.2 Contour Maps and Three Dimensional Maps of the Lakes

Based on generated grid data, contour maps have been developed and shown in Figures A3 to A4 in Appendix.

4.3 Elevation-Area Curve of Abaya and Chamo Lakes

The processed data is related to a reference lake level and used for computation of various elevation-area of the two lakes. Neither to get a bench mark for elevation around the lakes nor to set new reference datum with available equipment was difficult. Report provided in this document considers reference level according to Ethiopian Mapping Agency (EMA) 1972, which also used as abase map for the study [The time variation of lake levels are to be taken in to account according to discussion given above]

For various elevation points based on generated grid planar and surface areas can be computed. The surface area considers slope and elevation in to effect to compute the area, while the planar are computes the projected 2 dimensional plane area parallel to the water surface. However, the water area and the land area protruded as islands are computed as positive and negative areas respectively. Thus to obtain the water area the positive areas should be considered. Both values can be computed in surfer. The planar areas are summarised in Table 4.2 and 4.3 and are plotted in Figures 4.5 a) and 4.5 b) for Abaya and Chamo Lakes respectively. The fitted elevation area polynomial curves, which are shown on the Figures, are given by:

Abaya Lake

$A=0.015d^5-0.4596d^4+4.5807d^3-20.497d^2-1.0835d+1062$ with R^2 value of 0.9995

where d is depth of water in m, measured from lake level 1169m

Chamo Lake

$A=0.0029d^5+0.077d^4-0.7629d^3+2.9853d^2-15.282d+334.17$ with $R^2 = 0.999$ (4.1)

where d is depth below zero water lake level, measured from lake level 1110m above sea level

For complete list of fitted equation see Appendix, Table A1

4.4 Elevation Volume Curves

Based on the derived elevation-area curve and depth, elevation-volume can be computed using various methods, which are briefly described below:

i Average area or trapezoidal method

$$V = h\frac{A1 + A2}{2} \quad (4.3)$$

ii. Simpson's rule method

$$V \equiv h\frac{A1 + A2 + A3}{3} \quad (4.4)$$

iii. Simpson's 3/8 rule method

$$V = h\left[\frac{3}{8}A1 + \frac{9}{8}A2 + \frac{9}{8}A3 + \frac{3}{8}A4\right] \quad (4.5)$$

Table 4. 1: Summary Morphometric Characteristics of Abaya and Chamo Lakes

Table 4. 1: Summary Morphometric Characteristics of Abaya and Chamo Lakes		
Parameter	Lake	
	Abaya	Chamo
Altitude (m)	1169	1110 (NMSA 1:50,000 maps) 1108 (NMSA 1:250,000 maps)
Basin area, including lakes (km^2)	16,328.52	18599.8 (with Abaya Contribution)
A, including Islands (km^2)	1119.03	339.15
L_{me} (km)	79.2 b/n 5°58.5N & 37°39'E - 6°35'N & 38°02'E	33.5, b/n 5°42'N & 37°39'E to 5°58'N & 37°36'E
W_{me} (km)	27.1, ⊥ to L	15.5, ⊥ to L
W (km)	14.13	10.1
d_{max}, m	24.5, around the islands	14.2, near the middle
d, m	8.77	9.79
Shore line (km)	268.78	108.1
Volume, m^3	9.356925×10^9	3.9246×10^9

Where

h depth values

$A1, A2, A3, A4$ are planar areas at interpolation points.

The above three methods are also used to determine volumes in this study as well as in surfer software. The difference in the volume calculations by the three different methods also gives a qualitative measure of the accuracy of the volume calculations. If the three volume calculations are reasonably close together the true volume is close to these values. If the three values differ somewhat, one should probably produce a new denser grid file and perform the volume calculations again. The net volume can be reported as the average of the three values.

The relative error for the volume results can be estimated by comparing the results of the three methods. Then the relative error can be given as a percentage of the average volume. The relative error can be estimated using the following formula:

$$RE = \frac{(LR - SR)}{Aver}100 \qquad (4.6)$$

Where RE is the relative error

LR is the largest result from the three methods

SR is the smallest result from the three methods

AVER is the average of the three methods

Computation of volume by the above mentioned procedure provides the cut-minus fill volume above or below a specified level. In order to obtain the net water volume in the lake in surfer the cut volume should be considered when the water surface is taken as upper surface. Volume can be computed for various water depths.

In this way the volume of the lake for various elevation have been computed. The computed tabular results as well as plotted results are presented in Tables 4.2 and 4.3 and Figures 4.6 a) and 4.6 b) for Abaya Lake & Chamo Lakes respectively. The fitted volume curves for the two lakes are given by equations 4.7 and 4.8 as:

Table 4.2 Abaya Lake Capacity Curve Table

Depth (m)	Positive A (km^2)	Negative A (km^2)	Total A (km^2)	Water Volume (km^3)
0	1066.691	52.33788 (shows sum of Islands area)	1119.028	9.356925
1	1036.817	82.21347	1119.031	8.302469
2	1003.518	115.5128	1119.031	7.281539
3	968.3283	150.7031	1119.031	6.295095
4	928.46	190.5714	1119.031	5.345712
5	880.3798	238.6516	1119.031	4.440698
6	826.0861	292.9453	1119.031	3.586557
7	762.5418	356.4897	1119.031	2.79115
8	688.9053	430.1249	1119.03	2.06479
9	595.1979	523.8335	1119.031	1.421388
10	487.7305	631.3009	1119.031	0.880812
11	369.3047	749.7267	1119.031	0.631301
12	208.2988	910.7314	1119.03	0.158818
13	62.97251	1056.059	1119.031	0.035787
14	5.825874	1113.205	1119.031	0.002519
15	0.542863	1118.488	1119.031	0.000311

Table 4.3 Chamo Lake Capacity Curve Table

Depth (m)	Positive A (km^2)	Negative A (km^2)	Total A (km^2)	Water Volume (km^3)
0	336.5447	2.6089(shows island Area)	336.1187	3.2946
1	325.4763	13.6773	336.1187	2.9517
2	313.6010	25.5526	336.1187	2.6415
3	301.7742	37.3793	336.1186	2.3335
4	290.3477	48.8060	336.1189	2.0371
5	278.7112	60.4420	336.1182	1.7524
6	265.7132	73.4399	336.1182	1.4800
7	251.9657	87.1875	336.1182	1.2209
8	235.8908	103.2623	336.1181	0.9768
9	218.6410	120.5119	336.1180	0.7493
10	199.7751	139.3780	336.1181	0.5399
11	175.6627	163.4903	336.1181	0.3518
12	145.7259	193.4272	336.1181	0.1904
13	99.3924	239.7609	336.1184	0.0658
14	12.0387	327.1149	336.1187	0.0011
14.2998	0.0000	339.1530	336.1181	0.0000

Abaya Lake

$$V = -1E{-}05d^5 + 0.0004d^4 - 0.003d^3 + 0.0257d^2 - 1.0794d + 9.357 \qquad (4.7)$$

$R^2 = 1$

where d is depth of water in m, measured from lake level 1169m

Chamo Lake

$$V = 4E{-}06d^5 - 0.0001d^4 - 0.0011d^3 + 0.0013d^2 - 0.3286d + 3.2638 \qquad (4.8)$$

with $R^2 = 1$

where d is depth below zero water lake level, measured from lake level 1110m above sea level

(NB. Use of equation needs corrections)

For completed list of fitted equations, see Appendix Table A1

5. Applications and Limitations

5.1 Application in Related Study

One of the most important applications of the derived result is in water balance model of the lakes. The water balance model is important among others to assess the impact of water resources development on the lakes.

The water balance equation can be written, from continuity equation at any time, which is governed by the conditions that the water volume is not

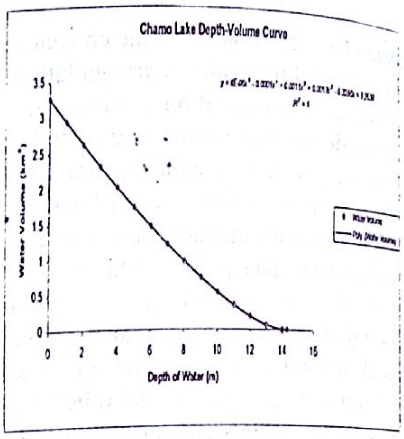


Fig. 4.5 a)

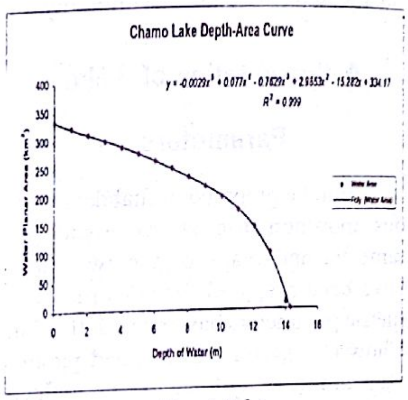


Fig. 4.5 b)

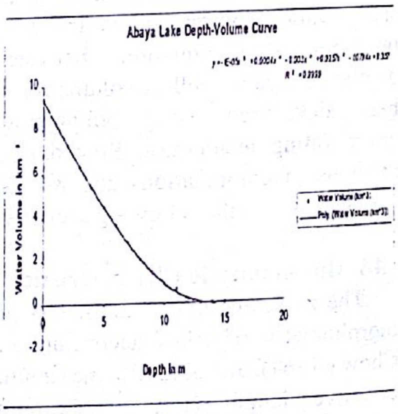


Fig. 4.6 a)

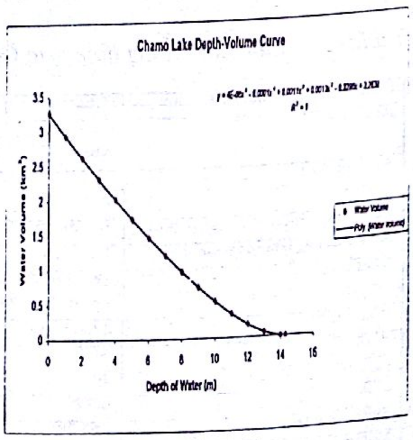


Fig. 4.6 b)

constant. The continuity equation intern governed by conservation of matter, which described by equilibrium between added water volume or depth, lost water volume or depth and change in volume or depth as

$$Q_{in}-Q_{ou}+P-E-S=0 \qquad (5.1)$$

Where
Q_{in} = surface and subsurface inflow
Q_{ou} = surface and subsurface outflow
P = Precipitation
E = Evaporation
S = Change in storage

Parameters can also be similarly defined in terms of depth of water.

The water balance is usually computed for seasonal or annual means. In ideal situation variables of the water balance equation are computed separately, and providing closed result. In practice however, the computation leads to a discrepancy or residual error, and the equation can be rewritten as:

$$Q_{in}-Q_{ou}+P-E-S=0 \qquad (5.2)$$

Where represents the error terms

Account for the water balance

-Water inflow from rivers and drainage areas along the whole perimeter

- Precipitation on the water surface
- Water out flow into a river or control structure
- Water losses through evaporation from water surfaces
- Peculiarities of in hydrology of watersheds.

Study is undergoing to develop the water balance models of the two lakes. Other possible applications are mentioned in 2.1 above.

5.2 Limitations

The surveyed data and result are not without limitations. The following are the most important limitations and further user should be aware of these limitations.

The accuracy of echo sounder is limited to 0.1m. The best equipment available on market is not used for the survey work, because of limitation of cost.

It is known that sound speed in water varies depending factors like salinity of the water, temperature of the lake and etc. These factors and variations are not taken in to account. The near shore calibration values for the Abaya lake gives sound speed of 1500m/s and for Chamo lake 1550m/s. However, it is possible that these values differ as one goes to the middle of the lakes where there are deeper depths and having temperature variations & stratification.

In cases of waves in the lakes, and during high speed of the boat there are possibilities of turbulence and separations around the tip of the echo-sounder sensor, which can cause error in measurement. These factors have prohibited the use of automatic data transfer in to computer.

The GPS's positional reading accuracy, is in the order of possible error of 10 to 15 meters. Indeed the accuracy is more than sufficient for the intended aim in this study. However, one has to keep in mind this level of accuracy for use in other applications, which may demand higher accuracy.

xLatest available map, which has be used as a background map, is according to NMSA 1972, 1:50,000 and 1:250,000 scale maps. Other large-scale background base maps are not available for the study.

6. Conclusion

Although the survey work has been quite demanding and dangerous to be tackled in wild lakes with no safety measures, data have been collected successfully. The surveyed data and digitised base maps have been developed to digital data to create grids. The digital data have been used to produce various useful results of morphometric parameters such as depth contours and capacity curves, which enable the understanding of the two lakes water resources. Results can be used for various applications including the water balance modelling of the two lakes and water resources development impacts on the lakes , which are currently undergoing.

Acknowledgments

Research leading to this paper and sponsorship of the study of the first author was made possible by kind financial support of the German Agency for Technical Co-operation (GTZ), through its support rendered to AWTI.

Appendix

Table A1

A1.1 Regression Equations Fitting the Computed Depth of Water Versus Area and Volume for Abaya Lake.

Polynomial Degree	Area km^2		Volume km^3	
	Equation	R^2	Equation	R^2
Two	$y = -3.8543x^2 - 20.457x + 1070.4$	0.9882	$y = 0.0404x^2 - 1.2543x + 9.5662$	0.9985
Three	$y = 0.2541x^3 - 9.5725x^2 + 12.759x + 1035.7$	0.9909	$y = 0.0015x^3 + 0.0063x^2 - 1.0564x + 9.3596$	0.9998
Four	$y = 0.1021x^4 - 2.8098x^3 + 19.389x^2 - 76.971x + 1083.5$	0.9974	$y = -4E-05x^4 + 0.0027x^3 - 0.0053x^2 - 1.0204x + 9.3404$	0.9998
Five	$y = 0.015x^5 - 0.4596x^4 + 4.5807x^3 - 20.497x^2 - 1.0835x + 1062$	0.9995	$y= -1E-05x^5 + 0.0004x^4 - 0.003x^3 + 0.0257x^2 - 1.0794x + 9.357$	0.9999

A1.2 Regression Equations Fitting the Computed Depth of Water Versus Area and Volume for Chamo Lake.

Polynomial Degree	Area km^2		Volume km^3	
	Equation	R^2	Equation	R^2
Two	$y = -1.6562x^2 + 3.4468x + 314.31$	0.9882	$y = 0.009x^2 - 0.3639x + 3.3024$	0.9992
Three	$y = -0.2189x^3 + 3.1122x^2 - 23.293x + 341.05$	0.9945	$y = 0.0004x^3 - 9E-06x^2 - 0.3133x + 3.2518$	0.9999
Four	$y = -0.0029x^5 + 0.077x4 - 0.7629x^3 + 2.9853x2 - 15.282x + 334.17$	0.999	$y = 4E-05x^4 - 0.0008x^3 + 0.0112x^2 - 0.3465x + 3.2684$	1
Five	$y = -0.0029x^5 + 0.077x^4 - 0.7629x^3 + 2.9853x^2 - 15.282x + 334.17$	0.999	$y = 4E-06x^5 - 0.0001x^4 + 0.0011x^3 + 0.0013x^2 - 0.3286x + 3.2638$	1

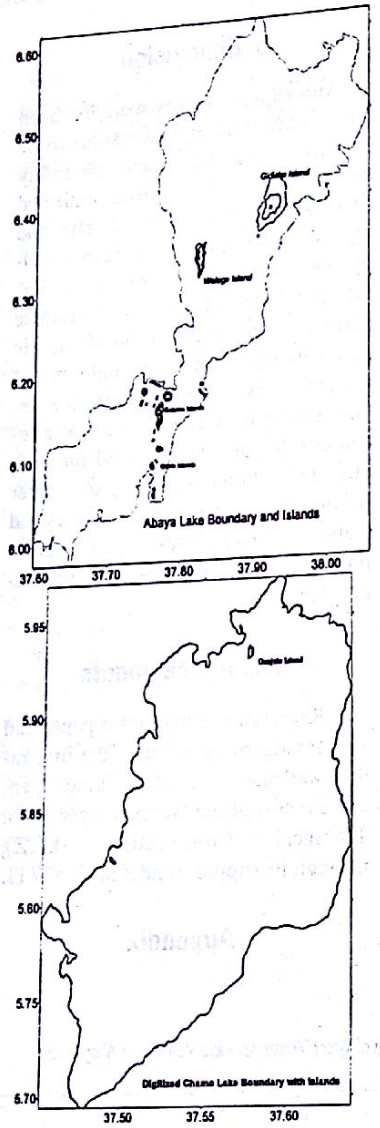


Fig. A1 Digitized Boundary Maps of Abaya & Chamo Lakes with their Islands

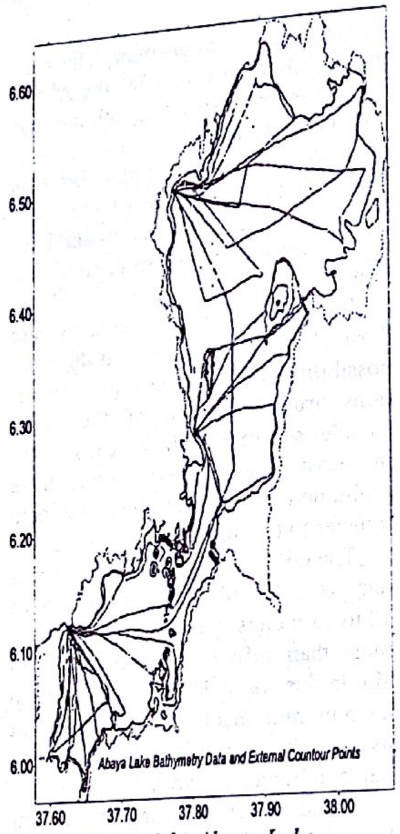


Fig. A2 b) Abaya Lake

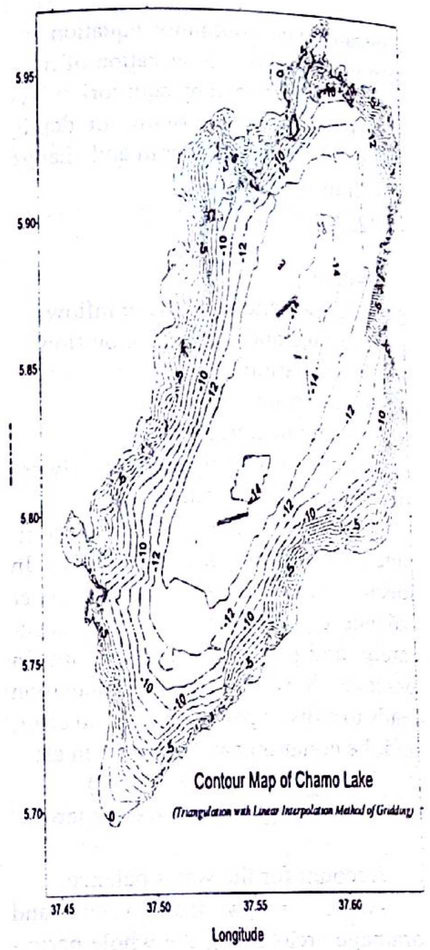


Fig. A3 Contour Map of Chamo Lake

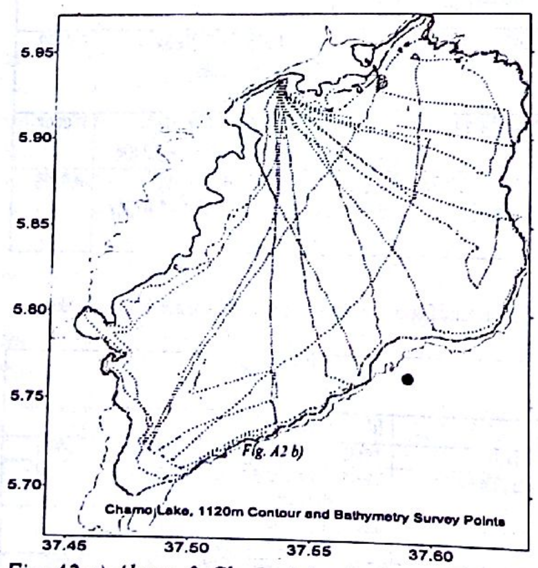


Fig. A2 a) Abaya & Chamo lakes Bathymetry Survey points, Boundary & Captured External Contour Line

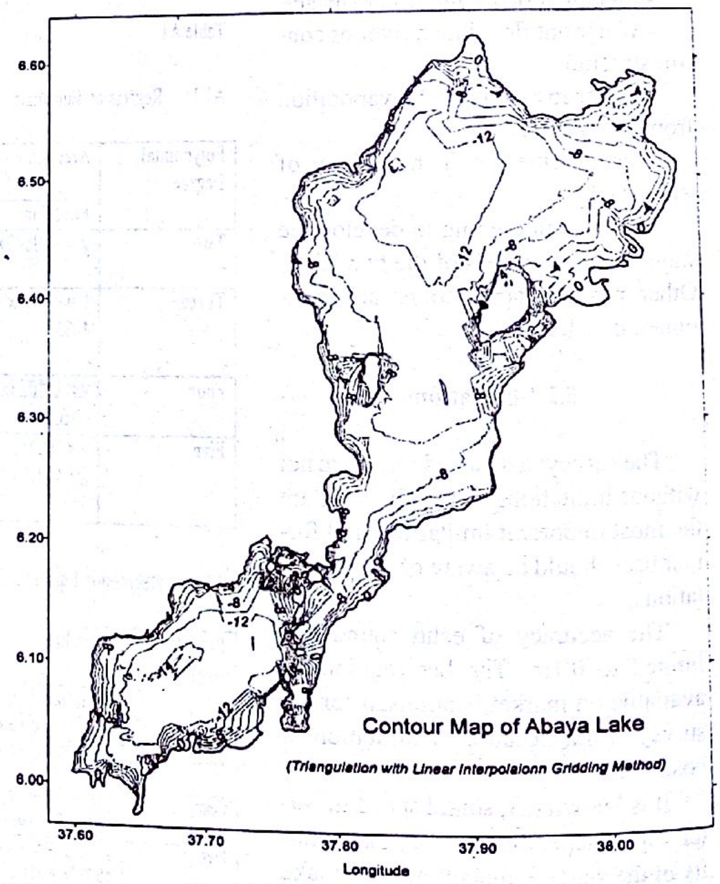


Fig A4 Contour Map of Abaya Lake

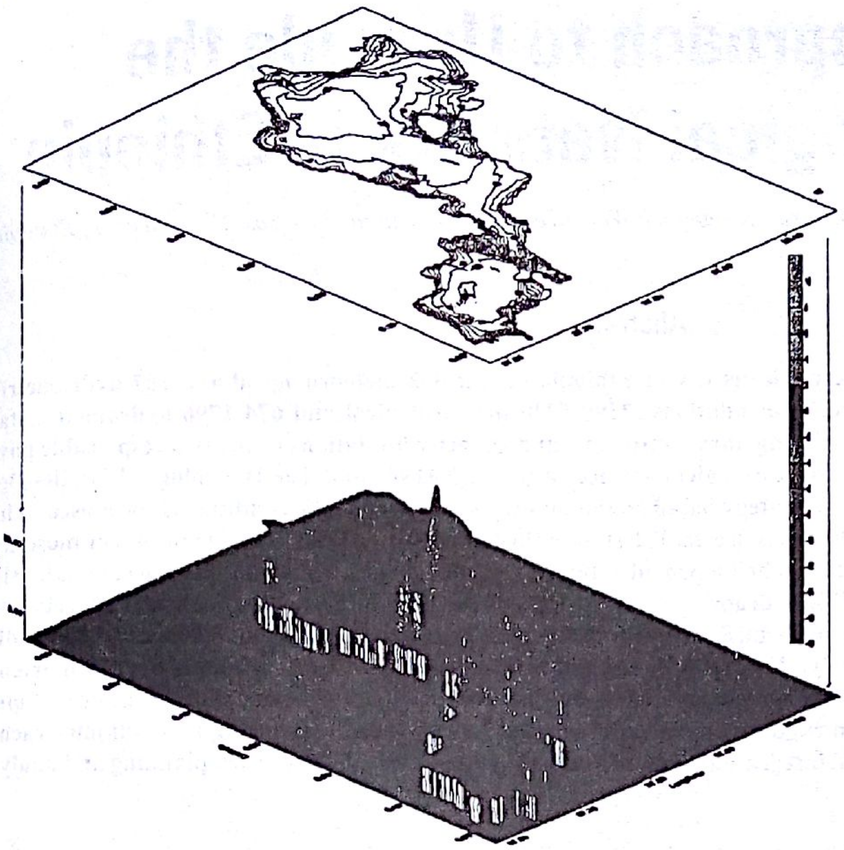


Figure A5: Abaya Lake Stacked Plots of Contour and Surface Maps

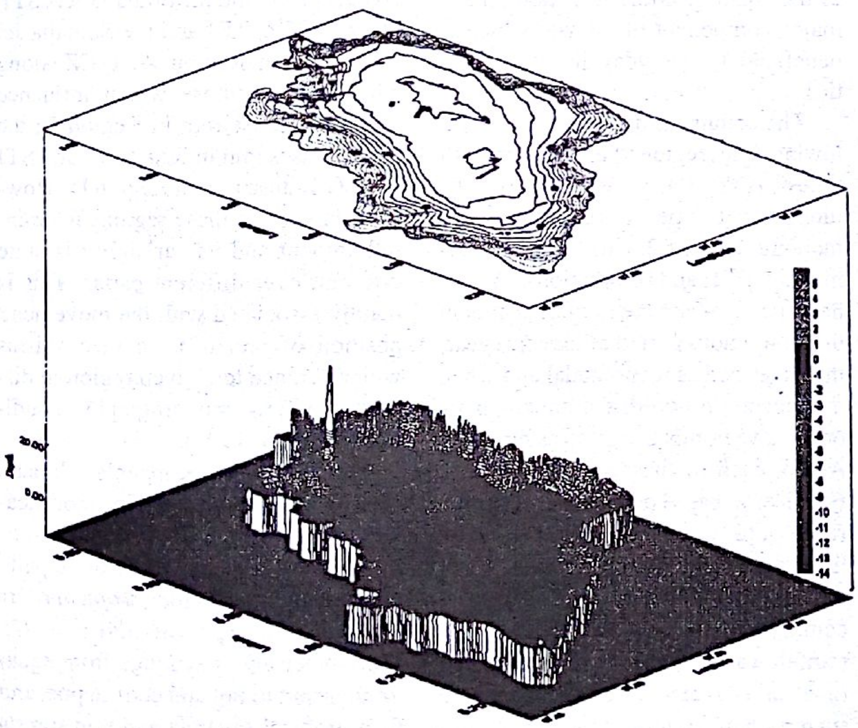


Figure A6: Chamo Lake Stacked Plots of Contour and Surface Maps

References

Chow, V.T., (1964), Hand Book of Applied Hydrology, Mc Graw Hill, New York.

Crul, Rudd C.M. (1995). *Limnology and Hydrology of Lake Victoria.UNESCO/IHP-IV Project M-5.1, in Studies and Reports in Hydrology 53*, UNESCO 1995.

Gibb, A. & Partners, (1987). *Gelana Irrigation Project Feasibility Study*, Volumes 1-10, December 1987

Halcrow, Sir W. & partners Ltd. (1992), Reconnaissance Masterplan for the Development of the Natural Resources of the Rift Valley Lakes Basin, Volume 3, Appendix C., ETH/88/001, Food and Agricutural Organization of the United Nations.

Keckler, D. (1995). *Surfer for Windows*, Golden Software Inc., Golden Collorado, USA

Press, W. H., Teukolsky, S.A., Vetterling, W. T., Flannery B. P., (19929). *Numerical Recieps in Fortran, 2nd ed.* Cmbridge University Press, Cmbridge

Riedel, D. (1962). *Der Margheritensee Zugleich ein Beitrag zur Kentnnis der Abessinischen Grabenseen.* Arch. Hydrobiologica 58: 435-466.

Seleshi B. Awulachew, (1999)."*Part 2: Processed Database of Abaya-Chamo Lakes Drainage, Volume 3: Lake Bathymetry Survey Data and Morphometric Characteristics.* ", unpublished report.

A Practical Approach to Upgrade the Hydrometerological Network in Ethiopia

Abebe Belachew, *Lecturer, Arbaminch Water Technology Institute, P.O.Box.21,Arbaminch, Ethiopia*

Abstract

The existing hydrometeorological network density of Ethiopia (about 832 meteorological and 507 hydrometric stations) does not satisfy the WMO's recommendations (2399-5428 meteorological and 674-1796 hydrometric stations). This problem is aggravated due to budgetary constraints and capacity limitations of the two responsible governmental organizations - The National Meteorological Services Agency (NMSA) and The Hydrological Studies Department (HSD). In this regard a rigorous strategy based on the country's socio-economic conditions is proposed. The proposed strategy for meteorological network is to establish stations in compounds of schools and churches or mosques with observers from these centers. Incentives being provided by the regional governments and the collected data will be processed and verified by regional NMSA branch offices. If 50% of the total number of schools and churches or mosques are fit and considered for station establishment, Ethiopia could have more than about 5,000 and 8,000 additional meteorological stations, respectively. For hydrological network, personnel for the various agricultural extension programs of the MOA could be utilized for supervision and/or observation. Establishment of observation stations could be conducted by senior students in engineering and related sciences with incentives during their summer vacation. Principal recommendation concern integration of meteorological and hydrological network planning and analysis.

1. Introduction

The principal purpose of a hydrometeorological network is to provide a suitable data base for Areal (or spatial) and temporal analysis. The problem of obtaining estimates of Areal data over a specified time period to a specified degree of accuracy from a set of point observations is a familiar one to all of us. The design of a specific network depends on specific network objectives, scientific considerations, and monetary constraints. Questions like for what purposes are the data to be used? What time scale is of principal interest? How accurate are the point measurements? How representative are they of the surrounding terrain? What economic factors are involved? are the major concern of hydrometeorological network design. In this paper a rigorous strategy is proposed which fully addresses some of these questions by considering Ethiopia's actual socio-economic conditions.

Background

Ethiopia, with a total geographical area of 1.13 million (km)2, has a highly rugged topography. According to NMSA (1996), Ethiopia's climate is characterized by high rainfall variability. It is therefore essential to assess rainfall with the associated weather systems in sufficiently rigorous fashion so as to evaluate its influence on the socioeconomic development activities of the country. Moreover, rainfall is a major component of climate which is beneficial to everyday human activities.

The country is divided into the following four regions based on rainfall types (Fig. 1): (i) Region B: monomodal type 1; (ii) Region D: monomodal type 2; (iii) Region A: bimodal type 1; and (iv) Region C: bimodal type 2. When the rainfall occurs in one continuous period of time in a year, this is termed as monomodal and when this occurs in two discontinuous periods in a year, this is termed as bimodal. Again, each of these are divided into type 1 or 2, based on the time of occurrence of the continuous period(s) or by the prominence of rainy periods. Even though the climatic features of the country are highly associated with the rainfall variability both in space and time, other meteorological parameters such as temperature, wind speed, humidity, potential evapotranspiration, etc. are also important.

The important weather systems that cause rainfall over Ethiopia are Sub Tropical Jet (STJ), Inter Tropical Convergence Zone (ITCZ), Red Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ) and the Somalia Jet. STJ, ITCZ, RSCZ, TEJ and the Somalia Jet cause rain in Region A; ITCZ along with some of those which influence Region A cause rain in Region B; the ITCZ causes rain in Region C; and STJ & RSCZ cause rain in Region D. However, in each of these regions the rainfall amount and its variability is quite different over different parts. This is mainly associated with the movement/position of rain causing mechanisms with reference to a given region in different seasons and orographic conditions (NMSA, 1996).

According to Koppen's climatic classification with certain modification, the country is divided into 11 climatic zones (Fig. 2). They principally come under *dry climates, tropical rainy climates and temperate rainy climates.* More precisely, they range from equatorial desert to hot and cool steppe, and from tropical savanna and rain forests to warm temperate and cool highlands. However, the temperate climates in many cases and not truly temperate but they are high altitude zones only

(NMSA, 1996).

There is a more commonly used local classification of climate in Ethiopia based solely on altitude and mean temperature. The five climatic zones are: (i) Wurch (alpine); (ii) Dega (temperate); (iii) Weina Dega (temperate and sub-tropical frost free zone); (iv) Kolla (tropical and desert low lands), and (v) Berha (desert) (Daniel, 1972).

The Wurch zone covers areas with altitude greater than about 3300 meters, where mean daily air temperature rarely exceeds 100C, where there is no cultivation practices, etc. The Dega zone covers areas with altitude from about 2300 to 3300 meters, where heavy frost occur in the highest regions of this zone even though many parts have much lower temperatures with a mean daily air temperature being in the range of 100C to 150C. The Weina Dega zone covers areas with altitude from about 1500 to 2300 meters, where mean daily air temperature being in the range of 150C to 200C. Most of Ethiopia's population inhabited in this and the Dega zones due to their pleasant weather. The Kolla zone covers areas with altitude from about 500 to 1500 meters, where mean daily air temperature being in the range of 200C to 250C. The Berha zone covers areas with altitude less than about 500 meters, where mean daily air temperature being greater than 250C.

Ethiopia, with the discussed above diversified climatic resources, is also naturally endowed with quite a substantial amount of water resources potential in its 12 river basins. According to recent studies by Ministry Of Water Resources (MOWR, 1998), the total annual surface water potential is estimated to be more than 110 billion cubic meter (Bm3) and the total annual groundwater potential amounts in the order of 2.6 Bm3. Moreover, the potential land for irrigation is more than 3.5 million hectares with less than 3% of potential being presently under irrigation. The potential annual hydropower production of the country on the other hand is estimated to be 161,000 Gega Watt Hour (GWH) with less than 1.5% of the potential being presently produced. This makes Ethiopia the second country with huge hydropower potential in Africa next to Democratic Congo (former Zaire). Therefore it is a paradox that the world knows about Ethiopia by its recurring droughts linked with famine rather than by its vast natural resources. This impression is however largely due to media images.

In fact the efforts made to utilize its natural resources for its socioeconomic development is one of the least mentioned in the world. This is partly due to poor information system; especially regarding hydrometeorological data. In this regard capacity limitations to build a good operational hydrology system is worth mentioning.

Scope

According to the definition adopted by WMO (1983), operational hydrology includes:

a)Measurement of basic hydrological elements from networks of hydrological and meteorological stations; collection, transmission, processing, storage, retrieval and publication of basic hydrological data;

b)hydrological forecasting;

c)methods, procedures and techniques used in; (i) network design; (ii) instrumentation and methods of observation; (iii) data transmission and processing.

The scope of this paper is therefore concentrated on how to upgrade the existing hydrometeorological network of Ethiopia from operational hydrology point of view. Therefore the paper addresses practical ways of upgrading the hydrometeorological network density for the observation of the most important basic hydrometeorological elements - precipitation (rainfall) and stage and/or discharge of stream flow within short time frame economically. However, other basic hydrometeorological elements such as temperature, wind speed, humidity, sediment load sampling, etc. can also be included whenever their importance is detrimental.

This paper has been prepared based on available literature survey and the author's experience of his country (Ethiopia) and other African countries. This paper will also create a discussion forum among the decision maker and professionals in the subject to criticize, suggest, and outline further areas of research.

2.Status of the Existing Hydrometeorological Network

A hydrometeorological network should have a good spatial and temporal coverage in order to provide a reliable information for inventory, planning, design, construction and operation of Water Resources Development (WRD) projects in the country. In principle the network should be developed on the basis of a nationwide plan which considers long term objectives in addition to current and short term ones. However, in Ethiopia the hydrometeorological network has developed in an empirical manner related to ongoing data needs.

Network design in an operational sense must take into account the existing network and try to adjust it so that long-term objectives can be satisfied at a minimum cost. In this paper attention will be given on the acquisition of data for local- and broad- scale planning purposes.

The existing hydrometeorological network is operated by the two governmental agencies under MOWR: NMSA for meteorological data and the HSD for hydrological data. However, according to the tradition of data acquisition strategy by these two agencies will not enable the country to achieve the desired hydrometeorological network density within a short time frame economically due to capacity limitations.

Hydrometeorological networks require an infrastructure (stations, measurement and data transmission equipment, repair and maintenance shops, rating laboratories, transportation means- plus the corresponding staff) and a superstructure (for planning and running the network, and for collecting, checking and processing the data and disseminating the resulting information to the users). Therefore upgrading the hydrometeorological network by these responsible governmental agencies only is far reaching unless a rigorous approach is followed.

Moreover, data collected on the time and space variation of hydrometeorological characteristics of an area may be categorized into three major groups: *historical data, real time data and special survey data.*

Historical data

Historical data are collected to obtain a space/time series of data on meteorological and hydrological elements of the relevant area from which the hydrological characteristics can be estimated. The density of the stations is primarily dictated for this group by the variability of the elements to be measured and the acceptable errors of estimation at the ungauged locations. Budgetary constraints often override these considerations. It is largely from historical data point of view that hydrometeorological network of Ethiopia has been developed.

In Ethiopia, the most significant difficulty in the realm of operational hydrology is the sheer lack of measurement stations. Four major reasons are responsible for this: (i) budgetary constraints, (ii) low level of know how of the society and the decision maker on the importance of hydrometeorological data, (iii) few skilled manpower in the profession, and (iv) problem of accessibility due to the mountainous topography of the country.

The WMO (1970) in Ferguson (1973) makes recommendations with respect to the density of rainfall and flow measurement stations in *mountainous, flat, arid regions of temperate, Mediterranean and tropical zones.* Table 1 shows the required hydrometeorological stations for Ethiopia by basin according to the WMO recommendations. Fig. 3 presents the status of the existing stream gauging stations in Ethiopia by basin. The total number of meteorological stations in Ethiopia are about 832 (WRC, 1987).

One of the peculiarities of meteorological stations in Ethiopia is their location being limited in the towns and related sites. Accessibility is the major reason in this consideration. Several towns in Ethiopia were established by former local governors on fortified places from military strategy point of view. Therefore, the existing meteorological network of the country lacks sound consideration of the variability of the meteorological elements (mainly rainfall) to be measured.

Moreover, the existing hydrometric stations for stream gauging are mostly located at bridge sites due to problem of accessibility even though bridge sites are not hydraulically very suitable sites. On top of this the nature of the streams in this country are mostly hilly catchments in which the variations of stream flow is significant within smaller reach of the streams. Moreover, The practice of groundwater observations based on network design principles is at an infant stage in Ethiopia.

Real time data

Real time data are transmitted as they are recorded to data-collection, processing and dissemination centers in order to monitor or forecast water-related phenomena for various practical operational purposes. The bulk of real time data is required in tropical countries in connection with forecasting flood elements. However, use is also made of real time hydrological data for the operation of Water Resources Development (WRD) projects. However, real time data practice in Ethiopia is not adequate due to capacity limitations.

Real time data, when stored and processed appropriately, also become part of the historical data. In addition they can provide early indications of rare events taking place in the region and allow more efficient use to be made of the staff and equipment available to operate the historical data network. The infrastructure for real time data consists of gauging network subsystems and remote sensing subsystem.

Special surveys

Special surveys are defined as surveys for obtaining hydrometeorological data which are conducted occasionally or periodically in addition to the regular network observations (e.g. survey of the minimum flow of ungauged streams during a drought). As many special surveys are not carried out by official meteorological and hydrological organizations but frequently by engineering consultants (river basin master plan studies, planning WRD projects, etc.). There is a need, particularly in Ethiopia to collect and coordinate the information contained in reports on such special surveys.

3. Proposed Strategy to Upgrade Meteorological Network

In addition to efforts made by NMSA to upgrade the existing network, a rigorous strategy that takes into account Ethiopia's cultural, social, economical, religious and environmental condition is proposed.

Primary and junior schools can be used as one of the promising sites for meteorological stations. According to 1995/96 educational statistics by Central Statistics Authority (CSA), there are about 9704 primary schools and 1304 junior schools in Ethiopia. If the average (50%) of the total number of these schools are fit and considered for station establishment from hydrometeorological characteristics and operational point of view, there could be more than 5,000 additional meteorological stations.

Instruments such as raingauges, wind vanes, thermometer can be supplied by NMSA preferably locally manufactured in metal workshops, Regional governments and/or the respective development associations better be responsible for data acquisition through the respective regional education bureau. The school director can assign staffs or students for observation and supervise the data acquisition in the station located in his/her school compound. It is better if incentive is provided to the data observers by the respective regional governments. However, simple and standardized data sheets should be prepared by NMSA and distributed through the newly opened regional NMSA branch offices.

Data observed by the individual schools will be transmitted to regional NMSA branch offices. The collected data can be processed and verified based on the data from the stations which are already operated by NMSA. Detailed year books will then be published region-wise and summary year books published at federal level.

Data acquisition in the schools will have three major purposes: (i) for upgrading meteorological network density, (ii) serving as a practical demonstration center in the schools for students learning science and geography subjects, and (iii) for awareness creation on the importance of hydrometeorological data for socio-economic development by combating droughts and desertification in Ethiopia. In fact there were meteorological data acquisition practices in the schools in previous times.

Other promising sites are religious centers (churches and mosques). It is known that in most parts of Ethiopia every village has church and/or mosque. Therefore advantage can be gained from this condition in upgrading the existing meteorological network. According to the 1994 housing & population census report by CSA, more than 17,000 peasant association are available in Ethiopia. If the average (50%) of the total number are fit and considered for station establishment from hydrometeorological characteristics and operational point of view, there could be more than 8,000 additional meteorological stations. Observations could be made by server of the churches or mosques who are able to read and write with incentives provided by the regional governments. The data transmission, processing and verification will be conducted in a similar manner like that discussed for schools. However, there will obviously be duplication of stations when schools and religious centers are used jointly. Therefore, further research is necessary based on meteorological and operational characteristics of specific areas to come up with the appropriate meteorological network density.

If the above discussed strategy is positively considered and justified by further research, Ethiopia could not only meet the WMO recommendations for meteorological network density but also will have a denser network with minimum cost and within a shorter period of time. Some African countries like Zimbabwe follow similar strategies of data acquisition. For example, Zimbabwe with a total geographical area of 400,000 (km)2 has more than 1,100 meteorological stations which are operated by the official meteorological agency, schools, religious centers, commercial farms, etc. (DOMS, 1981).

The installation of instruments and demonstration of observation readings can be conducted by senior college students in engineering and related sciences during their three months summer vacation with incentives provided by the respective regional governments. All round assistance can be obtained from international and local NGOs, CBOs, and UN organizations.

4.Proposed Strategy to Upgrade Hydrological Network

Effort made by the HSD of MOWR is satisfactory towards achieving the WMO's recommendations for hydrometric network density. However, small-scale WRD projects also require information about the hydrological characteristics of smaller ungauged streams. Therefore the target should not only be in achieving the WMO recommendations in the case of stream gauging.

Based on the country's socio-economic policy, the agricultural sector has been given high priority. For this purpose, skilled personnel are assigned to several peasant associations in more than 600 districts of the country for the implementation of the various agricultural extension programs by the Ministry Of Agriculture (MOA). Stream gauging stations can be established in sites identified by river basin master plan studies or new sites which can be selected by a hydrometeorological team in the respective regional governments. A regular observer with incentives can be supervised by the extension workers of the MOA. The data acquisition and transmission can be done through either MOA or MOWR branch offices to the eight regional branch offices of the HSD of MOWR. Groundwater observation wells can be established and the observation readings can be handled by the personnel of the various agricultural extension programs. In this regard use of existing private hand dug shallow wells and existing deep wells is advantageous.

The same strategy like that discussed in the case of meteorological network can be followed for the establishment of stream gauging stations. However, since stream gauging stations require relatively more expensive infrastructure, as much as possible equipment and appurtenant structures better be locally manufactured and preferably be pre-fabricated materials.

5.Conclusion

Ethiopia's climate is characterized by high rainfall variability. It is known that rainfall is also affected by various topographical factors such as orography, continentality, topographic trend distance, aspect, slope, etc. (Abebe and Savenije, 1995). The effect of these topographical factors on hydrometeorological elements is significant for mountainous countries like Ethiopia. This makes the hydrometeorological network costly and operationally difficult.

The existing total number of meteorological stations in Ethiopia which are operated by NMSA of MOWR are about 832. The corresponding WMO recommendation is in the range of 2399-5428. To achieve the lower, average, and upper limits of this range, NMSA should show considerable effort by increasing the existing number of stations by nearly 3, 5, and 7 times the existing number of stations, respectively. In fact these targets are far reaching if NMSA follows its tradition of establishment of new stations. However, if the rigorous strategy proposed in this paper is implemented, Ethiopia can have more than about 5,000 and 8,000 additional stations in schools and churches or mosques, respectively. This will enable NMSA not only to achieve the WMO norms with least cost and shorter period of time but also will create a good opportunity for its staff to concentrate on data processing and analysis and prepare handbooks, year books, nomograms, empirical relations between the various hydrometeorological elements, etc. using the collected data.

The total number of stations according to the strategy proposed might seem very much in excess of the WMO recommendations. However, this dense network will be operated for about 5 to 10 years and several stations can be abandoned after the hydrometeorological characteristics of the country are well understood by research activities.

The other alternative to upgrade the meteorological network is by using remote sensing techniques such as ground radar and geostationary meteorological satellite measurements. Since 1997/98 a joint USA-Japan satellite mission on Tropical Rainfall Measuring Mission (TRMM) at Goddard Distributed Active Archive Center (DAAC) is a break-through in the field of remote sensing for rainfall measurement. However, for poor countries like Ethiopia, the monetary constraint and capacity limitations will hamper the larger scale use of this alternative. Therefore, the proposed strategy is still the most attractive alternative for Ethiopia.

The existing total number of hydrometric stations in Ethiopia which are operated by HSD of MOWR are about 507. The corresponding WMO recommendation is in the range of 674-1796. To achieve the lower, average, and upper limits of this range, HSD should show considerable effort by increasing the existing number of stations by nearly 1.5, 2.5, and 3.5 times the existing number of stations, respectively. However, if the rigorous strategy proposed in this paper is implemented, Ethiopia not only will achieve WMO's recommendations but also will have a denser network which will create an adequate hydrometeorological data base system for planning, design, construction and operation of small-, medium-, and large-scale WRD projects. Moreover, staffs in HSD of MOWR will concentrate not only on data acquisition and processing but also on the preparation of handbooks, year books, nomograms, empirical relations between the various hydrometeorological elements, etc. using the collected data.

Principal recommendation concern integration of meteorological and hydrological network planning and analysis, increased emphasis on the use of physiographic models, consistent application of benefit-cost analysis and the development of a classification system for representative results. Therefore, the hydrometeorological network design should follow a multi-critera analysis.

References

Abebe, B.B. and Savenije, H.H.G., 1995. Filtering the effect of orography from moisture recycling patterns. Physics and chemistry of the earth, Pergamon. Vol 20, No 5-6, 521-526.

Central Statistical Authority (CSA), 1995. The 1994 population and housing census of Ethiopia. Office of population and housing census commission, Addis Ababa, Ethiopia.

Daniel Gamechu, 1972. Aspects of climate and water budget in Ethiopia. Addis Ababa University publication, Addis Ababa, Ethiopia.

Department of Meteorological Services (DOMS) of Zimbabwe, 1981. Climate handbook of Zimbabwe. Meteorological report series. 551. 582 (689.1).

Ferguson, H.L., 1973. Precipitation network design for large mountainous areas. Proceedings of Geilo symposium on distribution of precipitation in mountainous areas. Vol 1, WMO publ No 326.

Kidane Assefa, 1997. Aspects of water resources monitoring and assessment in Ethiopia. Proceedings of 5th Nile 2002 conference, Addis Ababa, Ethiopia.

Ministry Of Water Resources (MOWR), 1997. Federal water resources policy draft document. Federal water policy and strategy development project office, Addis Ababa, Ethiopia.

National Meteorological Services Agency (NMSA), 1996. Climatic and agroclimatic resources of Ethiopia. Meteorological research report series. Vol 1, No 1.

Water Resources Commission (WRC), 1987. The opportunities and challenges of WRD in Ethiopia. WRC bulletin, Addis Ababa, Ethiopia.

WMO, 1983. Operational hydrology in the humid tropical regions. Proceedings of the Hamburg symposium. IAHS publ No 140.

The Abaya Chamo Basin (ACB) Drainage Parameters and Information System by Linking GIS and Hydrologic Modelling System

Seleshi B. Awulachew, and H.-B. Horlacher (Prof. Dr.-Ing.habil), TU Dresden, Germany

Abstract

The Abaya-Chamo Basin, which is the sub basin of Ethiopian Rift Valley Lakes Basin, has been modelled to derive its basic drainage parameters, and as a result the basin watersheds physical information system has been developed. The purpose of the derivation of basin characteristics is to serve as an input to further study and research which enables the water resources investigation and its exploitation as well as environmental rehabilitation of the basin. The study has been carried out by coupling ArcView GIS and Hydrologic Modelling Software System known as WMS. Available digital data has been prepared to obtain Digital Elevation Model (DEM) and in turn the DEM enabled the Digital Terrain Modelling of the basin. After identifying the stream flow gauging stations, they have been overlapped on the model to further subdivide the basin in to sub basins. The subdivisions in to sub-basins enabled identification of gauged and ungauged sites and thereby detailed physical parameters have been derived which can be used as an input to various hydrologic and hydraulic modelling.

1.Introduction

With the advent of digital information and advancement in computer and software technology, today coupling Geographic Information System (GIS) and hydrologic models is possible, and is an ongoing effort of research and development. The approach enables professionals in water resources field to deal with complex modelling problems of especially distributed nature in quite efficient way in generating and handling data.

The GIS is a highly sophisticated data management system which can efficiently store, retrieve, manipulate, and analyse data, Beven et. al. (1993). The essential features of GIS approach to hydrological modelling are that the model uses remotely sensed data and a Digital Elevation Model (DEM) as the principal input parameters, and that the model interfaces with a GIS, which provides the data management function.

As the approach has got widespread application in developed countries, where suitable data in most forms are available, the application in developing countries, where there are limited data, enables obtain or derive useful information. Use of GIS coupled with remote sensing technology for water resources can supplement significant and useful data. In this paper the Abaya-Chamo Basin (ACB), which is a complex basin from the point of view of hydrologic modelling and from the perspective of absence of dependable data and existing study, has been modelled coupling GIS, hydrologic model systems and graphic software. Through this effort the basin physical characteristics, which can be a spring board for further research in the accompanying study of this paper and others useful projects in future, are determined and results have been produced as digital information system and hard copies. Full modelling of the entire basin as distributed model is beyond the scope of this study. However, from the analysis of DEM and through Digital Terrain Modelling (DTM) in WMS and ArcView software useful parameters for basin and watersheds characterisation have been derived. The methodologies and results generated are discussed further in this paper.

2.The Abaya-Chamo Basin

2.1General

The Abaya-Chamo sub-basin, here in after regarded as a "basin", is a sub-basin of the Ethiopian rift valley basin, whose location on Ethiopian map is shown in Figure 2.1.

2.2 Conceptual Set-up of the Study Basin

The Abaya and Chamo Lakes and the Chew Bahir Lake, further South at the Kenyan border, are hydrologicaly interconnected with surface flow. Accordingly the conceptual set-up of the lakes drainage system, as depicted from analysis of digital data to be dis-

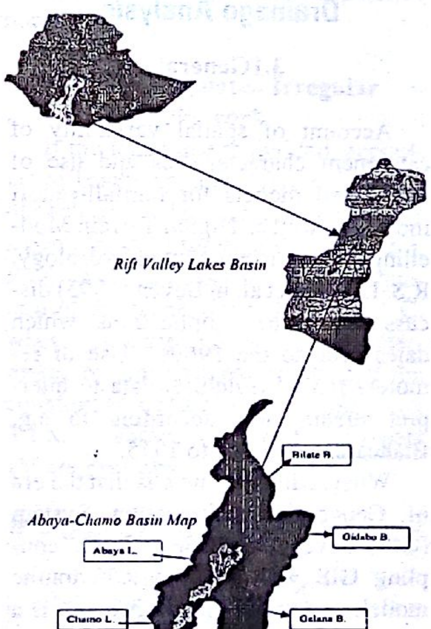


Fig.2.1 Location of Abaya-Chamo Basin

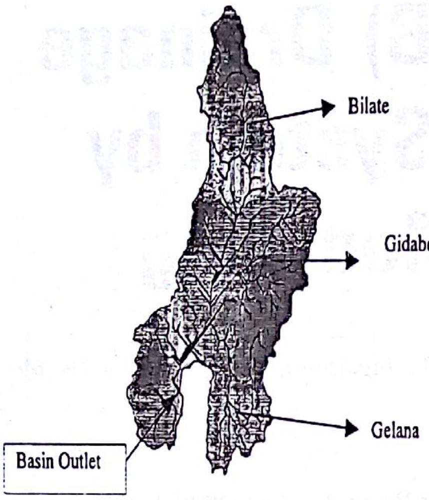


Fig.2.2 Schematic Representation of ACB on surface flow interconnection, red mark is basin outlet

cussed in the following sections, produces the following schematic form of the ACB.

The drainage outlet is captured at outlet point of Chamo Lake, and the Figure shows clearly the drainage system and inter-linkage of various rivers. While the above shows conceptual set-up of the basin system detail investigation based on DEM and DTM coupled with GIS and WMS hydrologic model will be given below.

3.The Use of GIS and Hydrologic Modelling for Drainage Analysis

3.1General

Account of spatial variability of catchment characteristics and use of distributed models for rainfall-runoff models as well as Digital Terrain Modelling (DTM) is not new in hydrology. R.S. Drayton et al. in Beven (1993) discuss the earlier applications which dates back to the 1960s. Use of remotely sensed (satellite) data to interpret stream flow according to e.g. Blancard dates back to 1975.

What is different now is that the era of Geographic Information System (GIS) Beven(1993). Specifically coupling GIS with hydrologic/hydraulic models is gaining importance and is a paramount tool. The use of DTM in hydrology has been reported by Moore et al. (1987), whereas Vieux et al. (1988) linked a terrain model with a hydrological model and applied the FEM to an actual watershed in Nebraska using 2-D elements, see Beven . Neumann and Schultz (1989) outlined the general approach to the use of GISs in Hydrology, see Drayton in Beven et.al (1993). Although GIS has been an excellent tool for data storage and management, and with the creation of GRID in Arc/Info and the Spatial Analyst in ArcView, as a useful tool for hydrologic data development, yet much of these data, both stored and developed in the GIS remains "locked" to hydrologic modellers Maidment (1997).

In this study modified interactive methodology will be shown how to "unlock" GIS data and use it for drainage analysis and through which important basin hydrological parameters are investigated and derived. This possibility and investigation will be carried out by coupling ArcView GIS and hydrologic modelling software known as Watershed Modelling System (WMS). WMS is a comprehensive environment for hydrologic Analysis. It was developed by the Engineering Computer Graphics Laboratory (ECGL) of Brigham Young University in Co-operation with the U.S. Army Corps of Engineers Waterways Experiment Station (WES), Boss International and et. Al (1998). The focus of WMS is to provide a single application, which integrates DTM with industry standard run-off models such as HEC-1 and TR-20.

ArcView gives the power to visualise, explore, query and analyse data geographically, ESRI (1996). ArcView is made by Environmental Systems Research Institute (ESRI).

In this study ArcView with its extension of Spatial Analyst, 3D-Analyst, Hydrologic Modelling v1.1 and WMS has been employed to analyse the digital data and drainage analysis.

3.2 Coupling WMS and ArcView Software

While in ArcView Hydrologic Modelling v1.1 enables analysis and modelling of the watershed for drainage parameters, the extension of WMS with Hydrologic Modelling v1.0 which has been developed by joint effort of ESRI and ECGL of Brigham Young University enables the linking the ArcView drainage data to WMS software and vice-versa. The linkage is made through three shapefiles consists of: arc layer defining streams, a point layer defining basin outlet and a polygon layer defining watershed and sub-basin boundaries. Furthermore, WMS if suitable DEM data available can carry-out drainage analysis by itself through its integrated TOPAZ sub-module. In this study the extension of WMS Hydrologic Modelling v1.0 has been obtained from the ECGL, and DEM preparation as well as DTM and drainage analysis has been carried out interactively.

4.Manual Basin Delineation & Generation of Digital Line Graph

4.1 Manual Basin Delineation

As there was no relevant maps, the ACB basin has been manually delineated from 1:250,000 scale maps and sub basins have been identified. For selected watersheds, Kulfo and Hare a 1:50,000 scale maps have been delineated (not presented in the paper). The delineation is based on EMA, 1972 maps. The delineated basin has been traced to produce manual hard copy of the basin.

4.2 Digital Line Graph (DLG) of the ACB River Network and Basin System.

After preparing the manual identification of the basin, the digital line graph of the basin has been developed in WMS software from scanned maps feature points of the 1:250,000 scale map of EMA. The steps include delineation of features, scanning, geo-coding, creating features, building attributes and computation of parameters

Using the above mentioned method Figure 2.1 Ethiopian drainage map, location of RVLB and ACB have been produced. These Figures have been also used as input to ArcView to enable map editions. However, the result obtained in this way has no digital information regarding topography and is not suited to various drainage data generation, hydrological parameters computations and analysis. It produces only basin areas. Furthermore, as the initial delineation is made manually, results are subject to subjective errors especially in identifying drainage divides.

Thus after having understood the general set-up of the whole basin system and its basic information using the above method, the study further concentrated in generating more detailed information system by coupling AutoCAD, Arc/View GIS and WMS software.

5.Digital Terrain Modelling to Delineate Abaya-Chamo Basin Physical Characteristics

Digital terrain Models (DTMs) can be defined as ordered arrays of numbers that represent the spatial distribution of terrain attributes, I.D. Moore et al, (1991). The procedure followed to generate DTM for the ACB starts from creating the DEM. In addition to the DLG form of the basin discussed above, the DTM enabled the derivation of comprehensive geometric attributes and required watersheds. However, the presence of the Abaya and Chamo Lakes made the terrain-modelling task quite complex and difficult. Methods and procedures have been developed in this study to overcome these problems, and are discussed below

5.1Digital Elevation Model

A Digital Elevation Model (DEM) is an ordered array of numbers that represents the spatial distribution of elevations above some arbitrary datum in a landscape, and is a subset of DTM. DEM may consists of elevations sampled at discrete points or the average elevations over a specified segments of landscape, Moore (1991).

Generally DEMs can be structured in three principal ways. These are: **Triangular Irregular Networks** (TINs), which are represented by planes joining three adjacent points in the network whose x,y and z co-ordinates are known. **Grid based networks** which are represented by regularly spaced triangular, square, or rectangular grid or a regular angular grid. Data can be stored in variety of ways, the most efficient is as z co-ordinates corresponding to sequential points along the profile with a starting point and grid spacing also specified. **Contour-based networks** consists of digitised contour line stored as Digital Line Graphs (DLGs) in the form of x,y co-ordinate pairs along each contour of specified elevation. Detail discussions on DEMs can be found in various GIS literature.

5.2 Grid Interpolation

As discussed by Moore et. al in Beven (1993), the topographic attributes of a landscape can be calculated directly from the DEM using only the point values without the assistance of surface fitting smoothing operation or the assumption of continuity. However, this approach has limited usefulness, is restricted to grid based DEM, and doesn't produce physically realistic result particularly in the calculation of flow direction in flat areas.

Thus, estimating topographic attributes involves fitting a surface to the point elevation data using either linear or non linear interpolation. A wide variety of methods are available to fit surface to the point elevation data such as linear, inverse distance weighted, spline, krigging, finite difference methods and etc., and commercial software are available for the purpose.

According to the discussions given in Beven (1993), if a surface defined by the function F(x,y,z) is fitted to the DEM, then a number of hydrologically important topographic attributes can be derived from these functions at the point (x0, y0, z0). Consider determination of aspect and slope from the function F(x,y,z) using geometry. (For sited names in 5.2 refer Beven (1993))

The fitted surface: The equation of the tangent palne to the point (x0, y0, z0) is

$$\left.\frac{\partial F}{\partial x}\right|_{x=x_0}(x-x_0)+\left.\frac{\partial F}{\partial y}\right|_{y=y_0}(y-y_0)+\left.\frac{\partial F}{\partial z}\right|_{z=z_0}(z-z_0)=0 \qquad 3.1$$

$$\text{Let } a=\left.\frac{\partial F}{\partial x}\right|_{x=x_0};\ b=\left.\frac{\partial F}{\partial y}\right|_{y=y_0};\ d=\left.\frac{\partial F}{\partial z}\right|_{z=z_0} \qquad 3.2$$

The equation of the plane tangent at the point (x_0, y_0, z_0) is

$$a(x-x_0)+b(y-y_0)+d(z-z_0)=0 \qquad 3.3$$

$$\frac{a}{d}x+\frac{b}{d}y+z+\frac{c}{d}=0 \qquad 3.4$$

Where
$C = -ax_0 -bx_0 -dz_0$ = Constant

The partial derivatives defined by equation 3.2 may be estimated directly from the analytical form of F(x,y,z) or, if the DEM uses a square grid, as finite differences.

The maximum slope angle, ß, is defined as the intersecting angle of the plane with horizontal plane(i.e. z = 0) and is given by

$$\cos\beta=\left|\frac{d}{\sqrt{a^2+b^2+d^2}}\right| \text{ or } \tan\beta=\left|\frac{\sqrt{a^2+b^2}}{d}\right| \qquad 3.5$$

Aspect is orthogonal to (x_0, y_0, z_0) in the horizontal plane (i.e. with z=z0= constant). Simplifying 3.1 to 3.4 with $z = z_0$, the equation tangent to (x_0, y_0, z_0) in the horizontal plane is

$$y=-\frac{a}{b}x-\frac{c}{b} \qquad 3.6$$

where $c = -ax_0 - by_0 = constant$

This is equation of a line with slope -a/b; so the slope of its orthogonal is b/a. Therefore, the aspect, y , measured in degrees clockwise from north is

$$\psi=180-\tan^{-1}\left(\frac{b}{a}\right)+90\left(\frac{a}{|a|}\right) \qquad 3.7$$

when x is positive east and y is positive north.

5.2.1 Triangulated Irregular Network

If the landscape is divided, according to Tajchman, in to TINs and surface of each triangular segment or patch by a plane passing through $P_1 (x_1, y_1, z_1)$, $P_2(X_1, Y_1, Z_1)$, $P_3 (x_1, y_1, z_1)$, the equation of the plane is z = Ax + By + C, where the constants A,B,C are determined by simultaneous solution of the equation at the three points. Following 3.1 to 3.7 above, the slope P and aspect xV are given by

$$\beta=\tan^{-1}(A^2+B^2)^{1/2}. \qquad 3.8$$

$$\psi=180-\tan^{-1}\left(\frac{B}{A}\right)+90\left(\frac{A}{|A|}\right) \qquad 3.9$$

where y is positive north and x is ositive east. And the area of the trian-

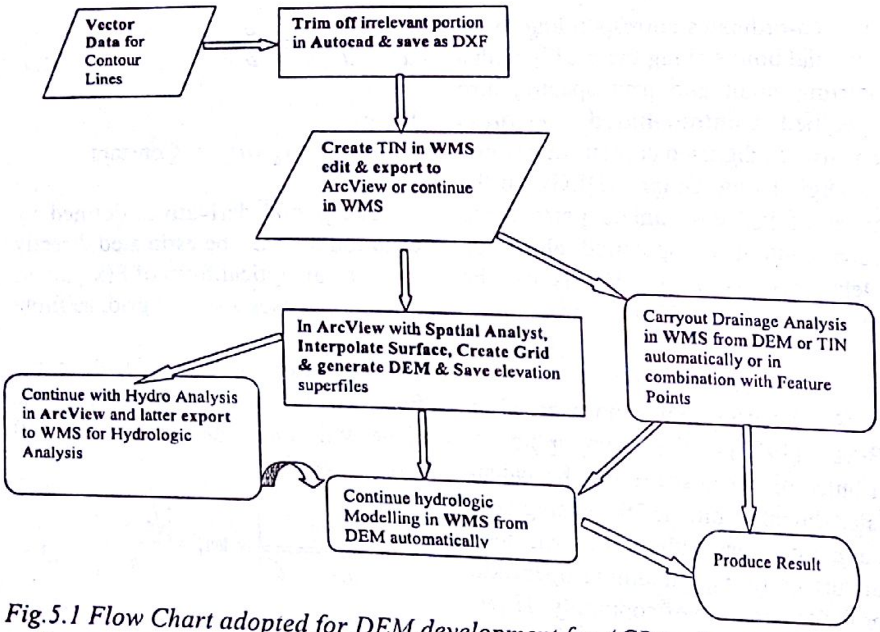


Fig.5.1 Flow Chart adopted for DEM development for ACB in absence of sufficent and relevant data

gular segment in the horizontal plane is given by

$$A_h=+0.5(x_1y_2+x_2y_3+x_3y_1-x_1y_3-x_2y_1-x_3y_2) \qquad 3.10$$

Because the surface is assumed to be planar the method doesn't provide point estimates of slope or aspect but average values over each triangular elements. It can't also calculate topographic attributes such as profile and plan curvature because the second derivatives of the surface functions do not exist. More complex techniques that use piece-wise continues curved patches, such as those described by Bmahill and Boehm , do have these capabilities.

5.2.2 Regular Grid Networks

Evans fitted five-term quadratic polynomial to the interior grid point of a moving 3x3 square grid network. Herdegen and Beran used the same scheme to calculate a variety of distributed catchment topographic attributes including slope, aspect and plan, and profile curvature. Zevenbergen and Thome modified this method by fitting the following quadratic polynomial to this moving grid.

$$Z=Ax^2y^2+Bx^2y+cxy^2+Dx^2+Ey^2+Fxy+Gx+Hy+I \qquad 3.11$$

The 9-term polynomial exactly fits all 9 points in the 3x3 moving grid, whereas Evans 5-term polynomial does not. Determining the values of the coefficients in this equation is simplified by having a uniform grid, which allows the coefficients to be expressed solely as functions of the grid point elevations and the grid spacing X. The slope, P, aspect, y, profile curvature, @, plan curvature, (o, and curvature, X, which is the Laplacian V2 of the function defining the surface, of the mid point in the moving grid can then be calculated using the following relationships.

$$\beta=\tan^{-1}(G^2+H^2)^{1/2} \qquad 3.12$$

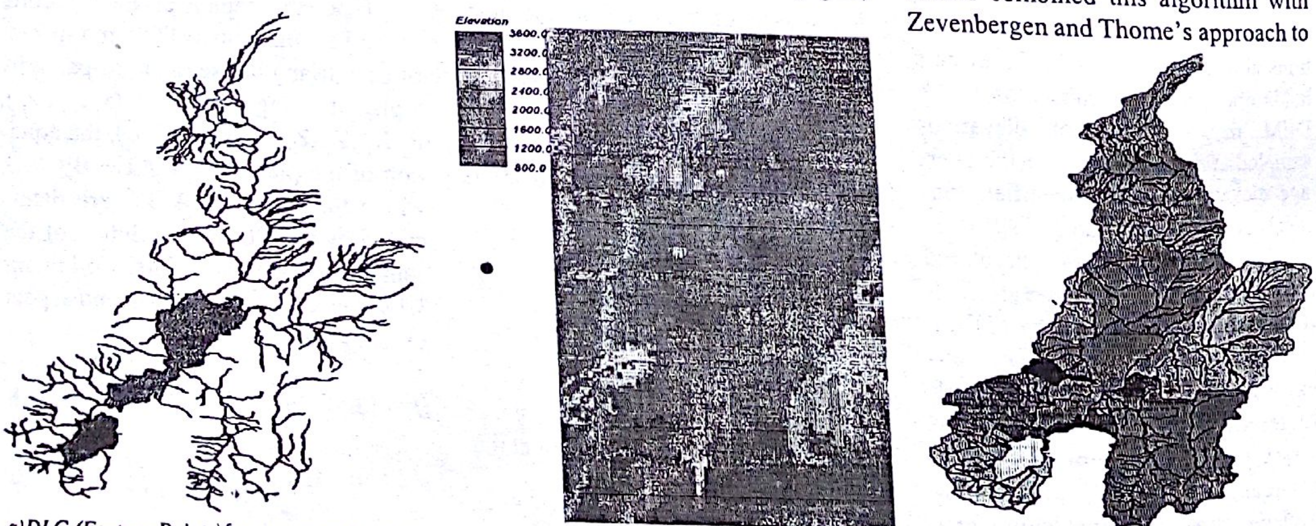
$$\psi=180-\tan^{-1}\left(\frac{H}{G}\right)+90\left(\frac{G}{|G|}\right) \qquad 3.13$$

$$\varphi=-2\frac{DG^2+EH^2+FGH}{G^2+H^2} \qquad 3.14$$

$$\omega=2\frac{DH^2+EG^2+FGH}{G^2+H^2} \qquad 3.15$$

$$\chi=\omega-\varphi=2E+2D \qquad 3.16$$

The plan area in the horizontal plane is characterised by each node or grid-point is Ah =,k2. Jensen and Dominigue describe a computationally efficient algorithm for estimat'ng flow directions and hence catchment ai s and drainage path lengths for each node in a regular grid DEM based on the concept of a depressionless DEM. They assume that water flows from a given node to one of eight possible neighbouring nodes, based on the direction of steepest descent. Morre and Nieber combined this algorithm with Zevenbergen and Thome's approach to



a)DLG (Feature Points)for stream and outlets

b)DEM with contours

Fig.5.3 Drainage Analysis and network of ACB

No.	Sub-Basin	Total Area in Km^2
1	Abaya Drinage Area Excluding Lake Area	15219.62
2	Lake Area including Islands	1108.9
3	Chamo Drinage Area Excluding Lake Area and Abaya Contribution	1942.65
4	Chamo Lake	328.63
5	Total	18599.8

Table 6.1 Summary ACB Drainage Area

Summary of Abaya and Chamo Lakes Drinage Basin

S. No.	ID	Basin/Subbasin	Drinage Area km^2	Remark
		Abaya Basin	16328.52	
1				
1.1	35,41,29	Bilate	5756.88	Because of Boyo Swamp Subdivided in to 3
1.2	40	AV1	156.95	
1.3	42	Gidabo	3446.62	
1.4	38	AV2	208.6	
1.5	39	AV3	47.76	
1.6	37	AV4	97.06	
1.7	36	Gelana	3463.26	
1.8	33	AV5	33.22	
1.9	34	AV6	24.55	
1.10	31	AV7	67.06	
1.11	30	AV8	58.13	
1.12	21	AV9	71	
1.12	15	AV10	39.78	
1.13	8	Hare	183.29	
1.14	17	AV11	54.14	
1.15	14	Basso	180.57	
1.16	25	AV12	120.64	
1.17	18	Lo'c	161.93	
1.18	28	AV13	59.5	
1.19	27	Boredo	71.93	
1.2	26	AV14	60.1	
1.21	24	Irae	105.38	
1.22	23,32	Amesa	751.27	Amessa with Southern AV and AV from Bilate Side
1.23		Gudicho island	19.22	ID is not shown
1.24		Algae Island	3.94	ID is not shown
1.25	22	Abaya Lake	1085.74	(1108.9-Algae & Gudicho)
2		Chamo Basin	(16328.52)+2271.28	
2.1	3,20,106	Kulfo	492.25	
2.2	16	AV15	57.79	
2.3	19	AV16	56.10	
2.4	13	Doyasso	140.89	
2.5	108	AV17	56.58	
2.6	109	AV18	5.33	
2.7	107	AV19	6.82	
2.8	95	Okkotte Wezeka	225.34	
2.9	9	AV20	4.5	
2.10	2	Arguba Wezeka	151.41	
2.11	5	AV21	47.62	
2.12	96	Wezeka	66.01	
2.13	100	AV22	9.04	
2.14	1	Sego	277.16	
2.15	7	AV23	61.12	
2.16	4	Sile	237.05	
2.17	11,12	AV24	16.89	
2.18	10	AV25	30.75	
2.19	103	Chamo Lake	328.63	
3		Total	18599.8	

Table 6.2 Detailed drainage area size of ACB. Refer the map for naming and detail.

6.3 Bilate Sub-Basin

Drainage data created by WMS
From the file [Bsubs.map]
For the drainage coverage [default coverage]

Basin Name/ID	Area (km^2)	Basin Slope (m/m)	Centrodi to MFD (km)	Max Stream Length (km)	Max Stream Slope (m/m)	Baisn Length (km)	Basin perimeter (km)	Basin Average Elevation (m)
1B/1	1260.20	0.0401	4.29	64.75	0.0324	56.795	277.47	1554.9
9B/4	2356.70	0.0350	0.05	87.00	0.0103	65.8070	322.8400	1832.8000
7B/5	88.47	0.0670	0.44	20.58	0.0249	17.2980	58.6830	2507.9000
10B/8	114.23	0.0367	3.47	23.27	0.0215	20.8690	76.1320	2503.1000
11B/9	579.28	0.0644	1.38	55.36	0.0217	54.6050	205.1600	2642.8000
12B/11	1311.00	0.0417	7.64	80.55	0.0099	57.5940	249.0700	2063.7000
Total	5709.88							

estimate a wide variety of hydrologically significant topographic attributes.

5.2.3 Contour Based Networks

Moore et al. (1988a), Moore (1988), and Moore and Grayson (1989, 1990), see Beven (1993) have developed a method of computing contour-based networks for topographic analysis. Their scheme is called TAPE-C and computes the average slope of each element as

$$\beta = \frac{\kappa}{2}\frac{(L_u + L_d)}{A_h} \qquad 3.17$$

Where, K is the contour interval, L,, and Ld are widths of the element along the up slope and down slope contours respectively, and Ah is the area of the element in the horizontal plane. Aspect, y, is calculated at the midpoint of the lower contour segment of each element as the down slope direction orthogonal to the contour at that point. Ah is calculated using trapezoidal numerical integration.

The above discussion provides demonstration how various drainage parameters can be computed. Such methodologies build up the basis of various computations procedures integrated in various softwares. It is not the intent of this study to focus any further on various interpolation schemes rather to utilise the available software to derive useful parameters for the basin under investigation.

5.3 Digital Elevation Data Sources for ACB and Generation of DEM

5.3.1Source of Digital Data for ACB

Digital elevation data can be produced from various information. From processing aerial photos, satellite imagery or by digitising topographic maps. The idea of using combination the AutoCAD, WMS and ArcView software mentioned above, is employed to make the most use of the available digital data obtained during data collection from Woody Biomass , Ethiopia, which was in vector (DXF) format of topographic contours. This data is the only obtainable high resolution digital data suited for the basin under investigation.

6.4 Gidabo Sub-Basin

Drainage data created by WMS								
Basin Name/ID	Area (km^2)	Basin Slope (m/m)	Centrodi to MFD (km)	Max Stream Length (km)	Max Stream Slope (m/m)	Baisn Length (km)	Basin perimeter (km)	Basin Average Elevation (m)
1B/1	2504.70	.0617	4.37	96.320	.0179	64.0930	432.3900	1792.7000
2B/2	593.94	0.0682	0.03	38.79	0.0208	31.1790	141.5600	2120.8000
3b/3	108.12	0.0679	6.45	13.94	0.0143	24.4070	91.6260	2159.7000
4B/4	264.33	0.1368	3.12	22.17	0.0451	21.9210	91.7440	2180.4000
Total	**3471.09**							

6.5 Gelana Sub-Basin

Drainage data created by WMS								
Basin Name/ID	Area (km^2)	Basin Slope (m/m)	Centrodi to MFD (km)	Max Stream Length (km)	Max Stream Slope (m/m)	Baisn Length (km)	Basin Peri-meter (km)	Basin Average Elevation (m)
2B/2	1800.50	0.0932	1.89	99.02	0.0182	877.680	357.3800	1597.2000
3B/3	1033.40	0.0802	1.00	70.86	0.0156	347.220	233.7500	1772.8000
4B/4	320.27	0.1052	12.92	34.96	0.0060	339.320	129.7800	1982.2000
5B/5	253.18	0.1369	5.10	19.65	0.0429	200.280	105.6700	2289.8000
Total	3407.35							

6.6 West and South western Area of ACB including Lakes & their Peripheries

Drainage data created by WMS								
Basin Name/ID	Area (km^2)	Basin Slope (m/m)	Centrodi to MFD (km)	Max Stream Length (km)	Max Stream Slope (m/m)	Baisn Length (km)	Basin perimeter (km)	Basin Average Elevation (m)
13B	235.98	0.1759	0.01	33.11	0.0391	28.4070	98.4550	1976.5000
11B	3.13	0.1816	0.83	1.65	-0.0183	2.0839	10.0790	1310.3000
12B	394.78	0.2253	0.61	38.82	0.0456	34.0720	124.4800	2252.8000
18B	72.45	0.0848	0.84	14.55	0.0368	14.0280	219.5100	1545.2000
4B	443.13	0.0511	1.43	50.21	0.0231	43.7240	302.7700	1647.1000
5B	105.32	0.1402	0.55	18.75	0.0552	17.6450	119.4000	1830.4000
6B	17.80	0.1216	1.49	10.26	0.0465	11.1040	98.5510	1509.5000
7B	165.28	0.1805	4.38	29.72	0.0548	27.0850	96.2940	2106.9000
8B	183.19	0.1552	1.89	24.90	0.0655	23.2980	130.9200	2233.1000
9B	199.14	0.1861	4.60	32.15	0.0578	28.0220	93.4390	2323.5000
15B	148.95	0.1048	4.05	19.03	0.0435	18.9800	86.8080	1622.3000
3B	276.25	0.1193	0.22	31.70	0.0180	24.7390	155.0300	1639.5000
24B	0.68	-0.0000	0.07	3.45	-0.0000	1.8554	162.7800	1108.2000
14B	62.19	0.0836	0.00	12.37	0.0333	10.0280	38.6700	1348.5000
2B	85.81	0.0990	8.39	0.69	-0.0005	14.0150	76.7810	1362.9000
34B	0.70	0.0000	0.09	3.81	0.0000	2.7372	32.6870	1108.0000
16B	227.00	0.0893	0.85	30.41	0.0173	20.6830	131.6200	1458.4000
17B	142.33	0.0860	2.02	25.07	0.0236	23.6240	181.4300	1496.4000
38B	0.72	0.0005	0.09	3.61	0.0001	3.3204	80.0060	1178.5000
21B	56.25	0.1195	1.99	16.45	0.0533	14.8530	97.5990	1508.9000
10B	71.91	0.0985	2.80	12.34	0.0482	13.1200	51.6560	1403.1000
19B	9.79	0.0883	4.55	3.95	0.0000	7.4518	8.4468	1338.8000
37B	0.68	0.0000	0.04	3.35	0.0000	3.2206	33.0210	1108.0000
20B	4.82	0.1626	0.65	7.10	0.0830	7.3193	21.8600	1537.6000
22B	25.20	0.0865	3.29	9.91	0.0602	9.4607	64.9830	1439.9000
36B	0.00	0.0000	0.00	0.00	0.0000	0.0000	0.0000	0.0000
40B	0.45	-0.0003	0.02	2.37	-0.0008	2.1840	298.8200	1169.2000
+ Avs								

5.3.2 Analysis of Elevation Data

As the DXF is imported to the PC version of WMS, limitation of memory and running time didn't allow the use of DXF data conversion directly to create digital elevation data in GRID or TIN formats and further drainage analysis. The DXF format data is then imported in AutoCAD software and extra points of the DXF data has been cut (trimmed off). Having the most relevant portion of the data, the DXF (vector) format has been red into WMS and corresponding scalar TIN data has been generated. The produced TIN data has been investigated on accuracy and significant edition and improvement of the quality of data have been made. Having obtained TIN feature points, x, y in UTM co-ordinate and elevation values as z co-ordinate, the data has been exported to Arc/View GIS for grid formation advantageously in efficient way than in WMS and parallel Hydro analysis for comparison purposes. The initial development of TIN points in WMS has an advantage in that it uses all elevation points from all features, points, lines and polygons to be exported as point values, which otherwise is not possible to combine in ArcView. In ArcView with Spatial Analyst, the imported TIN data has been interpolated to produce Surface and Surface to GRID, with the above mentioned interpolation schemes. The GRID form is thus DEM, from which one can carryout further analysis for various applications. The produced GRID data is exported to WMS for use

Appendx

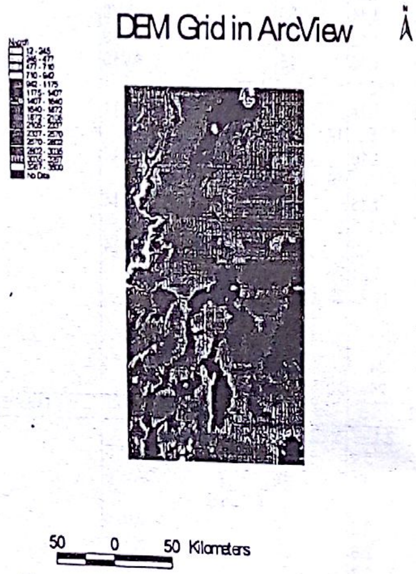


Fig 3.1 a) DEM Grid.(Legend shows elevation class in meters)

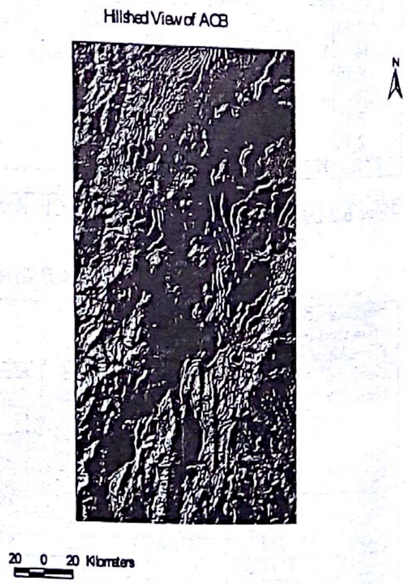


Fig.5.2 b) Hillshed View

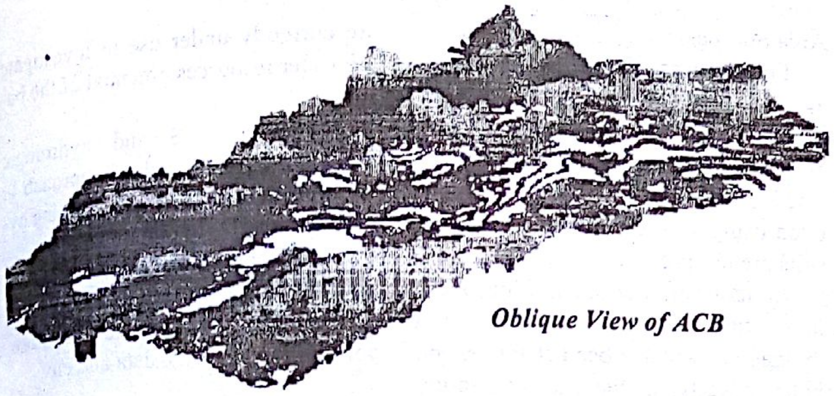
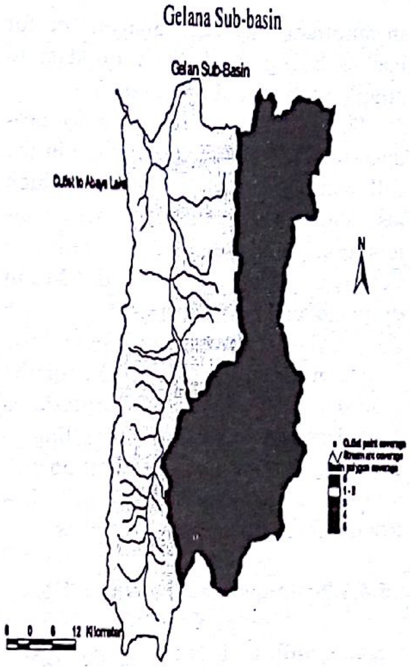


Fig. 5.2 c) Oblique View at View angle of 315° and 45 azimuth with contours



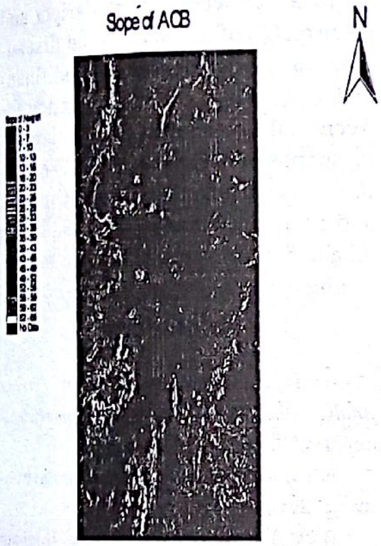
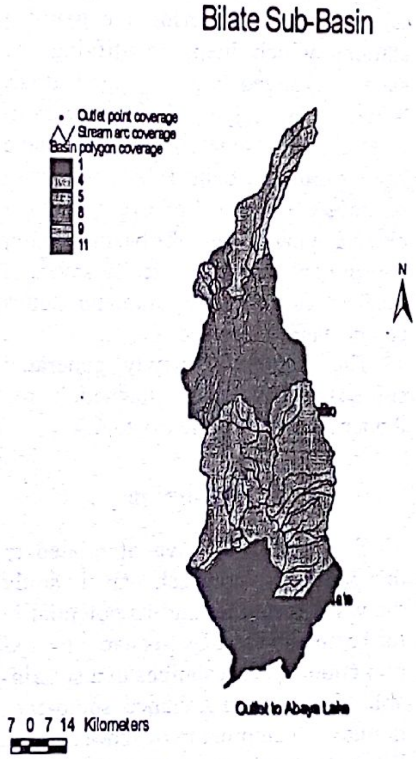
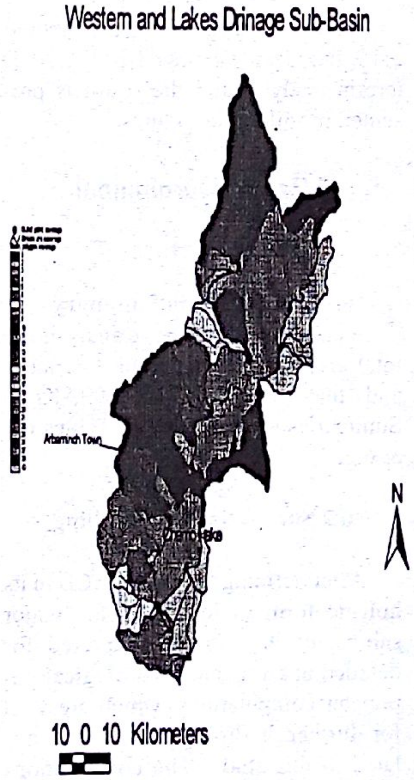
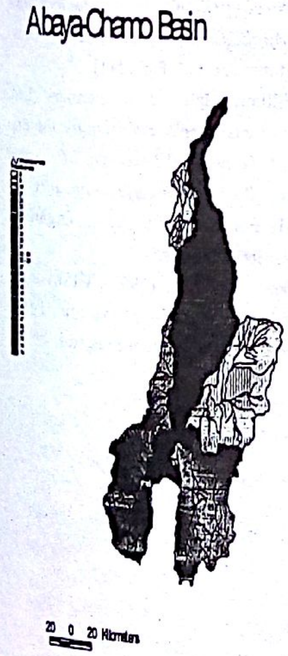


Fig.5.2 d) Slopes







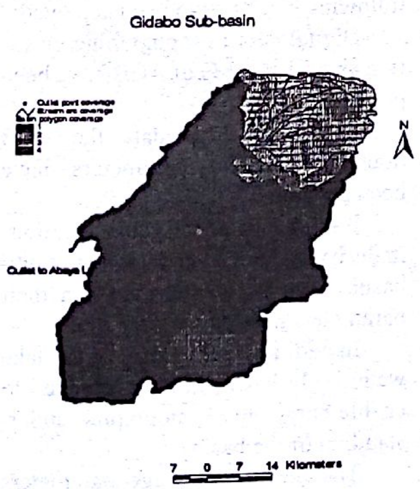


Fig.5.3 c)

in automatic drainage analysis or for use as background elevation data to couple with digital line graphs.

The procedures followed to produce the DEM can be presented in the following schematic diagram, which also shows various possibilities of interaction and independent computations possible in ArcView and WMS in drainage analysis.

5.4 Drainage Analysis

Having obtained the DEM for the required study area, the procedures considered in the terrain modelling to generate physical data information system can be summarised as in the following three different approaches.

5.4.1Drainage Analysis from DEM or TIN Data

5.4.2Combined Drainage Analysis from Feature Point and DEM

5.4.3Combined Drainage Analysis from Feature Points and TIN

From the above methods, method 5.4.2 has been employed in the ACB terrain analysis and the result is presented in following Figures

6.Basin Hydrological Parameters

6.1General Basin Summary

As a result of the above analysis the total area of ACB including the lakes and their islands is 18,599.8Km2. Summaries are provided in Tables 6.1 & 6.2.

6.2 Sub-basins Remodelling

After defining the whole ACB in its holistic form as in above, the major sub-basins have been recaptured for detailed analysis and hydrological parameter computations, which are vital for further hydrological analysis related to this study. The computations have been carried out on major river and collective small rivers basis.

The subdivision of the sub-basin for hydrological parameter computation includes

1. Bilate Sub-basin
2. Gidabo Sub-basin
3. Gelana Sub-basin
4. ACB West and South West Area Sub-basin

Furthermore, the remaining drainage area i.e. the two Lakes body is thoroughly investigated based on bathymetry survey carried out in related study. The Kulfo catchment has been re-modelled using 1:50,000 based DEM. Results are not presented in this paper.

In addition after subdividing ACB in to a total of 6 sub-basins, the 4 land drainage areas have been characterised independently. In the characterisation of the land areas the undertaking involves creating new grids for the DEM, generating new TOPAZ flow data, creating watersheds and constituting parameters by considering the gauging stations which helps identifying the sizes of gauged and ungauged areas. After generating the drainage parameters certain characteristic values have been summarised in Tables below in sections 6.3 to 6.6. However, in WMS extensive parameters for basin, stream, and outlets are automatically saved in database files and this parameter values can be easily retrieved.

The figures of newly generated sub-basins have been attached in the Appendices, in Figure 6.1 to 6.4.

7.Conclusion

The wider objective of related to this paper is to comprehensively study the water resources and its potential in the basin and there by to enable the exploitation of the resources in a sustainable manner and enhance socio-economic development of the region. What has been presented in this paper is the primary investigation regarding the drainage basin and in summary the following results have been achieved:

-Digital data of topographic elevation as well as DLG of ACB have been prepared.

-Based on these data the ACB drainage physical parameters have been generated.

-Having located the gauge locations in the basin, gauged and ungauged sub-basins have been identified and their parameters have been computed.

-In addition bathymetry of the lake water body has been also surveyed to enable complete physiographic understanding of the basin

-The derived drainage parameters are currently under use to investigate the water resources potential of the basin

-Coupling GIS and hydrologic models provided a robust approach in handling data needed in developing hydrologic and hydraulic models.

-The basic information system developed can be further extended to include other parameters like land use, soil, socio-economic data and etc.

Acknowledgments

Research leading to this paper and sponsorship of the study of the first author was made possible by kind financial support of the German Agency for Technical Cooperation (GTZ), through its support rendered to AWTI. The authors also thank the Woody Biomass and Strategic Planning Project, Addis Ababa for their kind assistance in providing data.

References

Beven, K.J. and Moore, I.D., 1993. *Terrain Analysis and Distributed Modelling in Hydrology*, J. Willey, Chichester, England

ESRI, 1996. *Using ArcView GIS*, Environmental Systems Research Institute, USA.

Boss International, Inc. And Brigham Young University, 1998. *WMS Watershed Modelling System User's Mannual.*

Moore, I.D., Grayson, R.B. and Ladson, A.R., 1991. *Digital Terrain Modelling: A Review of Hydrological, Geomorphological and Biological Applications*, Hydrological Process-An International Journal, Parts 5(1).

Sir William Halcrow & partners Ltd. (1992*), Reconnaissance Masterplan for the Development of the Natural Resources of the Rift Valley Lakes Basin, Volume 3, Appendix C.*, ETH/88/001, Food and Agricutural Organization of the United Nations.

Maidment, David R. (1997), GIShydro97 WMS-Watershed Modelling System. {\fs24 HYPERLINK http://www.ce.utexas.edu

GIS-based Hydrologic Modeling

Mekuria Beyene, Managing Director of ProAqua GmbH, Aachen, Germany and Lecturer at the University of Siegen, Germany

Abstract

One basic prerequisite for sustainable water resources development is the knowledge of hydrologic properties. These can be derived from geographic data and from results of computations with hydrologic models.More and more data availability and data quality is improving, hardware performance is increasing and software is becoming more powerful. Due to the advancements in information technology (IT), appropriate computer aided planning methods are being adapted continuously in the water sector. One of these technologies is GIS, geographic information systems.The main focus of this paper is to recommend geographic information systems (GIS) as a basis for hydrologic modeling and thus for water resources development in Ethiopia. Two examples are used to demonstrate and discuss the usage of GIS-applications in hydrology and water resources development.

1. Introduction

In the last two decades information technology has evolved rapidly and in parallel the costs for hardware and software are decreasing. The water sector and other related disciplines have benefited from these developments in the past and it is very likely, that this progress will continue at a comparable pace.

Until the beginning of the 1990ies the usage of geographic information systems (GIS) for water resources development was limited to a small group of researchers. At present GIS is a fast growing technology due to the technological advancements in the software and especially in the hardware industry. This is boosted by the increasing demand for and supply of geographic information. In other words GIS-technology has become more and more acceptable and affordable.

This also applies to the water sector. GIS-based applications and methods for hydrology and related topics are being developed world wide. Furthermore because of the fast growing internet everyone can have access to these tools and to geographic information easily.

Can the water sector in Ethiopia profit from this development? If yes what are the prerequisites and how can the benefits be achieved? In view of these questions this paper gives a brief overview on GIS:

1.An explanation on basic features and definitions of GIS is given.

2.The significance of GIS for water resources development with emphasis on hydrologic modeling is discussed.

3.Examples are used to demonstrate scope and limitation of GIS-based methods in hydrologic modeling.

Today know-how evolves rapidly, especially know-how related to information technology (IT). Therefore the aspect of human resources development has to be considered when GIS is introduced and implemented.

2. What is a GIS?

A GIS is designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information.

2.1 Components of GIS

Referring to the name itself GIS can be viewed as follows:

1.Geographic: The system deals with data relating to geography and geographic scales of measurement. This is referenced by some coordinate system to locations on the surface of the earth.

2.Information: The system allows for the storage and extraction of specific meaningful attribute information. This data is connected to some geography, and is organized around a model of a real world. Spatial and non-spatial queries are possible.

3.System: An automated system includes an integrated set of procedures for the input, storage, manipulation and output of geographic information.

The most useful definition of geographic information systems describes a GIS as a five-component-model: A GIS is an organized collection of the following components:

1.Hardware: A GIS must contain hardware to support data input, output, storage, retrieval, display and analysis. Hardware essentials focus on the platform and the peripheral devices.

2.Software: There are many GIS software packages on the market with either out of the box or customized installations. The levels of functionality differ. Therefore a thorough requirement analysis is necessary before purchasing a product.

3. Data: In almost all cases data has geographic reference. One aspect of data is purely descriptive and non spatial (attributes of objects). The other aspect is geographic or spatial. A GIS must be capable to handle both types of data. Spatial data deals with information on where objects are located and their spatial relationship to other spatial objects.

4.Personnel: A fully functional GIS comprises of professionals, which can be categorized as follows: system user, end user and data generator. The skills and abilities of the professionals are essential for the performance of a GIS.

5.Methods: GIS software packages provide programming interfaces, so that repetitive tasks can be standardized and automated. The more a GIS is used, the more processes have to be automated and standardized. This leads to more efficient usage and reproducible results.

A GIS is based on the integration of three areas of computer technology:

1.Cartographic and graphic capabilities to depict, graph and plot geographic information

2.Database management system to

store, update and manipulate data (relational for non-graphic information, file systems for graphic information)

3. Spatial analytical capabilities to facilitate manipulation and spatial analysis

2.2 Data Types in a GIS

Data managed in a GIS can be divided into two groups, spatial data and tabular data. Spatial data is modeled as vector data and grid data.

The vector model has three features:

1. Points: A point is a single x, y coordinate and represents the shape of a geographic feature, which is too small to be depicted as a line or as an area. Points are also referred to as nodes. Attributes to points are linked to the point ID. Examples are pumps or gauges.

2. Lines: A line is a set of ordered coordinates and represents the shape of a geographic feature, which is too narrow to be depicted as an area. Lines are also referred to as arcs or segments. Attributes to lines are linked to the line ID. Examples are streams or power lines.

3. Polygons: A polygon is a closed figure with series of lines comprising its boundary, which encloses a homogeneous area. Polygons are also referred to as areas. Attributes to polygons are linked to the polygon ID. Examples are land use or soil types.

Tabular data contains descriptive information on geographic objects, which are modeled as vector objects. Tabular information is organized in columns (also referred to as fields or attributes) representing properties of the objects. Every line in the table represents a geographic object. The object is identified with an ID, which corresponds to the ID in the geographic database. A cell in the table contains a value representing a property of the object.

The **grid data** model contains spatial information organized in a regular matrix comprising lines and columns. The features of a grid are the x, y coordinate of the lower left corner, number of lines and number columns and width and height of the cells x, y. Every cell in this matrix contains a numerical value representing a geographic information. Typical examples for grid data are digital elevation models.

2.3 Topology

Topology is the spatial relationship between geographic objects. For example the topology of a line of a polygon includes its from-point and to-point and its left and right polygon. The four major topological concepts are:

1.Directionality: Every line has a starting point (from-node) and an ending point (to-node).

2.Connectivity (arc-node topology): Connectivity is defined as the topological identification of a set of lines, that connect each point.

3. Area definition (polygon-arc definition): Area definition consists of a list of lines, that make up a polygon.

4.Contiguity (left-right topology): The topological identification of adjacent polygons is given by the left an right polygons of each line.

2.4 Functions in a GIS

Basically functions are used for analysis purposes. There are two types of analyses, attribute data analysis and spatial analysis. Spatial analysis can be divided into analysis on the basis of vector data and grid data.

1.Attribute data analysis: Normally attribute data analysis is based on SQL (structured query language) – the standard language for relational database management systems - consisting of the following four components: SELECT, UPDATE, INSERT and DELETE. In a GIS-application the components SELECT and UPDATE are used. Attribute data analysis enables the user to query data with a specified criteria within a theme. The criteria is a logical expression similar to those logical expressions in programming languages. Attribute data analysis is based on set algebra, it is not procedural.

2.Vector data analysis: Basically vector data analysis is based on spatial query making use of the topological features of geographic objects. The results of the operations can be used for mapping purposes. The most important operations are:

a.Data manipulation like coordinate change or projection

b.Spatial analysis like measurement, aggregation and classification

c.Overlay similar to set query operators (UNION, INTERSECT, MINUS and DIFFERENCE); Map algebra is based on this operation

d. Buffering

3.Grid data analysis: The basis for grid data analysis is grid algebra, which has all algebraic components. An algebraic expression of grids results in a grid. Another feature of grid data analysis is spatial interpolation like for example voronoi-diagrams, weighted-distance analysis or kriging. The scope implemented in the software depends on the software product.

Furthermore vector data can be transformed into grid data and vice versa. The above mentioned functions of geographic information systems can be combined, so that complex queries and operations can be carried out. The results can be visualized making use of the mapping facilities of GIS.

3. Benefits of GIS-Applications for Computerized Hydrologic Modeling and Water Resources Development

Water resources development and hydrologic modeling are disciplines mainly dealing with geographic data. Furthermore hydrologic properties have to be calculated when dealing with water resources potential in the course water resources development planing.

The planning process makes use of quasi static data like morphologic parameters and of highly time variant information like water demand depending on socio-demographic and economic parameters. On the other hand short-, medium-, and long-term analyses have to be carried out and results have to be updated regularly.

Today these complex requirements can only be met making use of modern information technology.

3.1 Hydrologic Modeling on the Basis of GIS

Hydrologic properties are the key for the assessment of water resources potential. Since this information is the basis for water resources development, which basically balances water demand and water supply, hydrology can be regarded as one of the main disciplines in the water sector.

Hydrologic models have evolved in the last four decades. Almost all hydrological properties have geographical reference and formerly properties of watersheds had to be highly parameterized. This was necessary because detailed acquisition of geographic properties was difficult and time consuming. For example morphological parameters like hydraulic gradients of watersheds had to be derived and were used as input parameters for hydrologic models.

Now that geographic information systems are widely used and that digital geographic information is easily accessible, the hydrologic models have evolved accordingly. It is not necessary to parameterize every property anymore. Some geographic properties like elevation can directly be used. That's why modern hydrologic models are directly linked to geographic information systems. The following methods can be implemented making use of the basic functions as described in chapter 2.4 .

On the basis of the above methods and the basic GIS-functions mentioned in chapter 2.4 further hydrologic methods like calculation of mean precipitation for watersheds, calculation of time of concentration (for every cell in a grid) or generation of unit hydrographs can be derived.

Every process in a hydrologic model from precipitation to flow is directly linked to geographic properties. The most obvious benefits of computerized hydrological modeling are:

· Large amount of data like time series have to be processed

· A hydrologic system is a network; this concept can easily be computerized

· The impact of scenarios (variation of input parameters) on the response of hydrologic systems has to be analyzed in the course of water resources development planing

Data pre-processing is very time consuming if geographic data is acquired on a non-digital manner. Geographic properties in maps have to be digitized and/or scanned using CAD-tools. Field data has to be processed with different types of tools. At present GIS-technology comprising the 5 components explained in chapter 2.1 is improving at a high pace. This leads to the following advantages of GIS-based hydrologic modeling:

·Data pre-processing like importing digital geographic data, digitizing and/ or scanning maps, importing field work data (e.g. surveying with GPS) is very efficient.

·Modeling is comprehensive and yet easy to understand.

·Updating results for different input parameters and scenarios is simple due to the degree of automation.

·Results can easily be visualized in maps; errors can easily be identified in the modeling process and decisions based on the results become more transparent.

3.2 Integrated Data Processing with GIS

Water resources development is an interdisciplinary process comprising social sciences, economics, geo-sciences and engineering, with the objective to balance water demand and water supply. This complex task involves different types of studies and modeling. The results have to be combined and be viewed in an integrated manner. Furthermore input parameters change with time, so that results have to updated regularly.

Due to the large amount and variety of data and the related costs the "production cycle" has to optimized on one hand. On the other hand the results have to be monitored and presented in an easy to understand manner. This is necessary because of the different types of disciplines involved.

This can only be reached with a high degree of automation and with mapping. Today both objectives can be reached with the use of GIS. Beside the GIS-features explained in chapter 2 a GIS is used for mapping purposes. Therefore GIS can be regarded as the common factor of all disciplines involved.

4.Examples for GIS-Applications in Water Resources Development

In order to demonstrate the above described advantages of GIS as a basis for hydrologic modeling and hence for water resources development two examples have been prepared.

The first example shows the capabilities of a GIS for catchment modeling. The second example shows how GIS can be used for the identification of dam sites and the calculation of reservoir properties.

4.1 Drainage and River Basins of Ethiopia and Eritrea

This example shows the capabilities of GIS-based basic hydrologic methods. The region of interest is Ethiopia and Eritrea. The objective is to identify the drainage and river basins within the region. In order to demonstrate scope an limitation of this method a comparison of the results with the maps of the National Atlas of Ethiopia (Ethiopian Mapping Agency, 1986) was carried out.

The digital elevation model used

Table 1:GIS-based basic hydrologic methods (components of hydrologic models)

Key Words	Short Description
Flow Direction	Calculate direction of flow in every cell in a digital elevation model; Gradient is calculated comparing elevation of neighboring 8 cells
Identify Sinks	Create grid showing location of sinks in a digital elevation model
Fill Sinks	Fill sinks in a digital elevation model
Flow Accumulation	Calculate the accumulated flow or the number of upslope cells in every cell in a digital elevation model on the basis of flow direction
Watershed	Calculate watersheds as polygons on the basis of flow accumulation; every watershed has one pour point
Flow Length	Calculate flow length of every cell in a digital elevation model to the pour point of the corresponding watershed
Stream Network	Create vector stream network and calculate stream order on the basis of flow accumulation

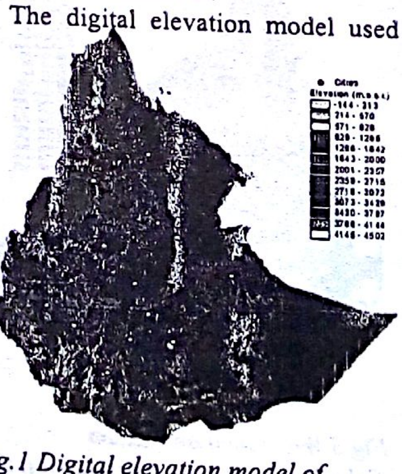


Fig.1 Digital elevation model of Ethiopia and Eritrea

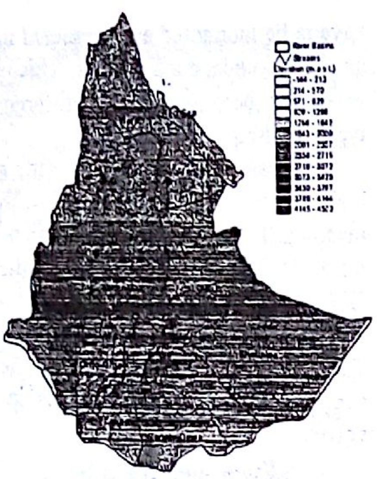


Fig. 2 Drainage and river basins according to the National Atlas of Ethiopia

was extracted from the global 1 km elevation data provided by USGS and NASA. The region contains 1,250,000 cells.

Based on the digital terrain model the following calculations were carried out:

1.Flow Direction: Direction of flow in every cell in the digital elevation model

2.Identify Sinks: Grid showing location of sinks in the digital elevation model

3.Fill Sinks: Fill sinks in the digital elevation model (it was possible to identify the lakes Tana and Turkana)

4.Flow Accumulation: Accumulated flow or the number of upslope cells in every cell in the digital elevation model on the basis of flow direction

5.Watershed: Watersheds as polygons on the basis of flow accumulation; every watershed has one pour point

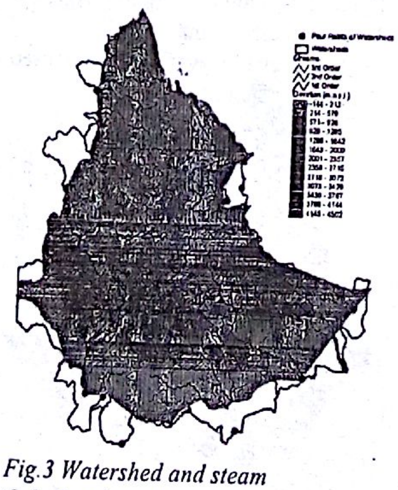


Fig.3 Watershed and steam Calculated (incl.stream order)on the basis of the digital elevation model

6.Flow Length: Flow lengths of every cell in the digital elevation model to the pour point of the corresponding watershed

7.Stream Network: Vector stream network with stream order on the basis of flow accumulation

A Comparison of the computed watersheds with those from the National Atlas of Ethiopia leads to the following results:

·The boundaries of the watersheds in the mountainous regions match very well, especially those boundaries at the edge of the Rift Valley (e.g. Abay-Awash or Tekeze-Afar)

·The boundaries of the watersheds in the lowlands, especially those boundaries in of the Rift Valley don't match (e.g. Awash-Afar or Awash-Lakes)

A Comparison of the computed streams with those from the National Atlas of Ethiopia leads to the following results:

·All streams especially those with deep gorges like Abay or Tekeze match very well. The slight mismatches of all streams are due to precision of digitization.

·In the Afar lowlands and in the lower Awash area two streams with 1st stream order are generated, although streams do not exist in that area. The extreme arid condition can be the reason, but morphological analyses could give a detailed explanation.

This simple example shows that reasonable hydrological input parameters can easily be generated for modeling purposes. The scale presented here can be used for master plans for river basins. For detailed hydrological analyses it is necessary to acquire more detailed geographic data.

When selecting geographic data for water resources development planning purposes scale and degree of aggregation play a major role. Grids are one basis for the hydrologic modeling. The following phenomena are to be considered:

· Appropriate grid size is highly dependable on the terrain geometry. The flatter the terrain the smaller the grid size has to be.

· If the grid size is too small, the digital model may be very accurate, but data processing becomes too slow. This

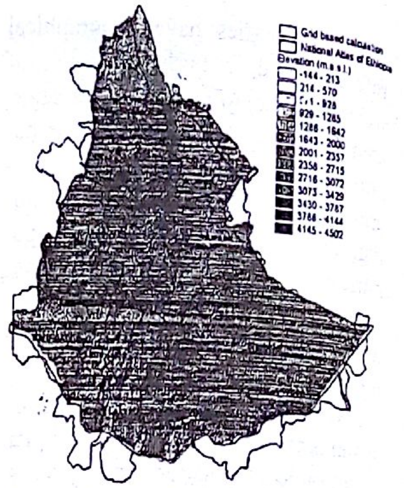


Fig.4 Calculated watersheds compared to watersheds of the National Atlas of Ethiopia

may lead to unnecessary costs for data acquisition without improving quality of results.

·In the course of a project a sensitivity analysis on the relationships between cell size, elevation accuracy, area of the region to be analyzed and accuracy of the results has to be carried out. If the amount of cells in the project area is not sufficient the quality of results can become low and hence useless.

4.2 Pre-Selection of Dam Sites and Calculation of Reservoir Properties

Another classical example is the identification of dam sites and the calculation of reservoir properties. The first steps of the dam site identification procedure are purely geographical. The most obvious parameters, that determine the pre-selection are:

· Shape of the valley

· Longitudinal profile of the stream

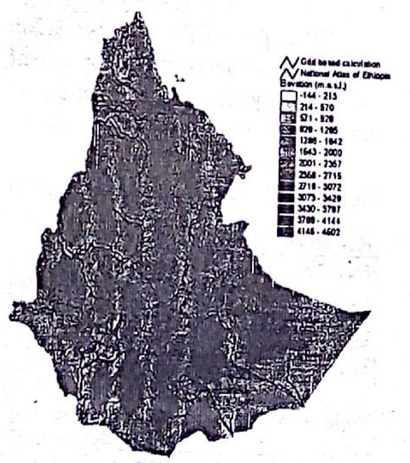


Fig.5 Calculated stream network compared to streams of the National Atlas of Ethiopia

· Potential storage
· Land use

Furthermore other important properties like hydro-geological parameters or infrastructure can be geo-referenced as well.

Provided data is given, queries for each property can be formulated. In addition the queries can be combined with logical operators like OR, AND or NOT. The advantage is that the criteria have to be formulated precisely and the result is prompted by the system. If the method – a combination of procedures and criteria - leads to promising results, it can be stored, so that results can be reproduced any time at minimum error rate and probability. Of course the quality of the result is highly dependant on the quality of the input data.

For example if dam sites for large reservoirs in the Abay or Tekeze region are to be pre-selected, satellite images on land use and the digital elevation model presented in chapter _Ref455452495 are sufficient. Once the potential sites are pre-selected, a detailed study is necessary. Detailed output requires detailed input data.

In the course identifying potential dam sites, reservoir properties have to be assessed. One classical parameter is the area-capacity-curve. This property can be generated automatically making use of the digital elevation model. The principal functions are:

1.Determine upstream and downstream for a given point in the stream (the potential dam site).

2.Generate a water surface grid with an elevation equal to the dam height; set downstream cells to NULL.

3.Subtract water elevation grid from water surface grid.

4.Calculate statistics on generated grid.

In practice contour lines are still digitized for detailed studies to minimize data acquisition costs. This infers high accuracy. But in most cases the results can be misleading. In most small and medium scale projects it should be recommended to carry out field work and surveying of coordinates with GPS (global positioning system) - cost / accuracy-ratio is acceptable. Data is automatically stored electronically, so that after completion of the surveying work, data can be transformed and processed to a digital elevation model easily.

Conclusion and Recommendation

GIS-based planning in the water sector requires medium and long term investments in hardware, software, data and human resources. Investments in hardware and software are relatively affordable. Difficulties arise in the investments for data provision and human resources development. Costs are high, the processes are time consuming and continuity has to be guaranteed.

Furthermore data collection and provision in the water sector in Ethiopia is not well developed. So why should GIS-based planning in the water sector be enforced in Ethiopia although appropriate data is not available?

· When setting up a system, there are tasks that should be carried out in parallel, so that objectives can be reached as early as possible.

· Data collection and capacity building can be carried out in parallel to some extent.

· If one assumes that the international data market develops in the same pace, by the end of the next decade satellite data to any geographic topic will be available and affordable.

· By that time project costs can be reduced effectively. Project upgrading life cycles will become much more efficient.

· At the same time the production of results becomes more reliable.

· Once the data collection and provision situation is improved, a fully functional and reliable ready to use system can be utilized out of the box.

Acknowledgement

I thank my colleagues Mr. Carlos Rubín and Mr. Martin Dörr for the support and cooperation in preparing this paper.

References

Dörr, M., 1999: Untersuchungen zur Kopplung von deterministischen Niederschlag-Abfluß Modellen mit einem Geographischen Informationssystem, Diploma thesis at the University of Siegen, Germany

ESRI, 1996: ArcView Spatial Analyst, Advanced Spatial Analyst using Raster and Vector Data, Software Manual by Environmental Systems Research Institute Inc.

Holdstock, D. A.,1998: Basics of Geographic Information Systems, Journal of Computing in Civil Engineering, January 1998

http://edcwww.cr.usgs.gov/landdaac/30asdcwdem/30asdcwdem.html

http://www.ce.utexas.edu/centers/crwr/

http://www.ccgl.byu.edu

Kopp S., 1998: Developing a Hydrology Extension for ArcView Spatial Analyst, ArcUser, the magazine for ESRI Software Users, ArcUser April-June 1998

Contamination of the Hydrogeologic System in Dire Dawa

Taye Alemayehu, Team Leader, Geological surveys Team, Oromia WMERD Bureau, P.O.Box 30664, Addis Ababa, Ethiopia

Abstract

Dire Dawa has remained the main fast growing city in Eastern Ethiopia. Its fast growth rate as an industrial and commercial center, lack of proper sewers and other waste disposal facilities, presence of about 20,000 open pit latrines, favorable geological, morphological, climatological and conditions have facilitated pollution of the hydrogeologic system. In this city there has been shortage of water and population increases at a higher rate. In 1965 population was only 23.33% of that of today's but after only three decades, in 2030, it is predicted to grow by 3.73 times.

Apart from the future danger of possible water shortage, the quality of ground water storage is questionable. The soft alluvium deposits, the main aquifers, has been polluted for the past ten decades by descending pollutants, which eventually reached the groundwater vertically and as far as Shinile town down stream. As a result there are excessive concentrations of nitrate, sulphate and chloride. The drop in water-table due to decrease in precipition and over pumping is considerable.

Methods

To pinpoint reasons of pollution and reach in to convincing conclusion, 20 out of 50 boreholes, 4 out of 12 dug wells and 2 out of 4 springs which are found in the town and its vicinity are randomly sampled and analyzed. Population density of different zones of the town is correlated with degree of pollution. The geological, structural and hydrogeological characteristics of the surrounding rock formations is analyzed. Rainfall data which is recorded starting from 1931 and temperature records starting from 1951 is analyzed. The potential evapotransipiration is calculated from available recorded data. Finally, record of the largest hospital of the city is taken to analyze impact of polluted water on residents. Different Organizations such as the Alemaya University of Agriculture, Ministry of Health and the City's municipality are consulted for possible impact of pollution on their activities.

Results and Discussion

The dominant lithology is the Mesozoic sedimentary deposit consisting limestone, sandstone, shale, and chalk. Most part of the plain is covered by loose & recent superficial deposits consisting sand, silt, clay, river gravels, fans and travertine with considerable thickness.

Joints of tectonic origin, faulting and fracturing are dominant structural features in the area. The Mesozoic sediments are major aquifers in the area with high discharge. The nature of structures has increased the quality of aquifers. Static water level measurement at different time intervals reveal a decrease in the ground-water table. Ground water table drop up to twelve meters is measured in twelve various wells between the year 1960-88 (Greitzer,1970,Tesfamichael,1974, ASE,1982).

Volume of ground water storage is $12.9x10^9M^3$ in the 400m thick alluvial plain and $7.09x10\ ^9M^3$ in the 150m thick escarpment zone (Tesfamichael, 1974). The rainfall pattern has decreasing trend. In the period 1931-37 and 1953-63 the average rainfall amount was 650 and the annual average figure for the period 1964-73 was 563mm, which is less by 103mm. The mean monthly temperature in the period 1951-70 was 24.2°C. This figure increased by 1°C in the coming years-1971-85. Accordingly, the potential evapotranspiration in the period 1951-70 was 1711.5mm. This figure increased by more than 40mm in the coming years 1971-85. Meanwhile, the amount of rainfall in the period between 1971-85 was minimum and is only about one-third of the total potential evapotranspiration. These factors have considerable impact in aggravating pollution by minimizing the dilution effect by decreasing precipitation and increasing evapotranspiration.

From records found from the Out Patient Department Of Dire Dawa Hospital, 10 out of 15 most common diseases are directly or indirectly related to water. Among the top 15 diseases, duodenitis and gastritis and kidney infection ranks 4th and 13th respectively. The presence of the methemoglobinemia or blue baby disease, a killer disease caused by drinking water with high nitrate concentration and that affects infants (Uark et al, 1970), case is unknown. The health workers are unaware of water pollution in the city. In fact the public water source is safe for domestic consumption, but still people might use sources outside the public water supply.

The source of contamination of the hydrogeologic system are two types. The first and dangerous one is the point

Table 1. Predicted Comparison of Water Use and Waste Water Production.

Year	Population	Total Water Demand[1]		Domestic Consumption[2]		Amount of Domestic Waste[3]	
		l/c/d	ml/yr	l/c/d	ml/yr	l/c/d	ml/yr
1982*	88,000	42.5	1334	21.3	667	14.9	468
1995	169,793	77	4772	38.5	2113	27	1502.8
1998*	192,070	78	5475	39	2738	27.3	1917
2000	208,543	86	6553	43	3277	30.1	2293
2010	313,682	126	14438	63	7219	44.1	5053
2020	474,842	166	28788	83	14394	58.1	10076

* Actual Figures 1. Computed considering an average 4 l/c/d increment per year 2 Estimated at 50% of the total water demand 3 Estimated at 70% of the total domestic consumption

Table 2. Groundwater Quality change in time (Selected water sources)

Name of water point	TDS/mg/l/			Hardness as $CaCO_3$			Nitrate		Sulphate			Chloride		
	1960	1974	1988	1960	1974	1988	1960	1982	1960	1974	1988	1960	1974	1988
Cotton Factory Bh1	-	-	500	-	568	661	-	-	-	169	411	-	-	-
Cotton Factory Bh2	854	987	3500	520	512	629	trace	62	100	136	205	106	175	177
Cotton Factory Bh39	-	-	400	-	606	704	-	86	-	-	288	-	-	132
High Way Bh	946	721	1000	360	456	716	45	110	60	56	82	53	78	709
Dire Dawa Hosp. Bh	460	1497	3500	240	1019	920	45	-	60	22	164	46	57	354
Tony Farm HDW	-	840	989	-	384	373	-	49	-	67	205	-	78	155
Chandris HDW	698	957	3500	461	456	526	trace	48	60	59	41	46	60	132
Ras Hotel HDW	344	911	1371	240	500	965	35	-	40	32	205	18	135	709
Lege Hare Sp.	486	772	1020	240	448	640	48	38	60	74	41	53	107	496

Source: Various Sources   Bh - Borehole   HDW- hand dug well

source contamination , which is caused by more than 20,000 unprotected pit latrines found in the city. These latrines carry the human excreta to the hydrogeologic system through the loose formation. The second source of contamination is the line source contamination caused by the discharge of enormous amount industrial and domestic waste water (Table 1) into the sandy stream channels. This effluent percolate within few hundreds of meters distance from their sources. Chemical analysis carried on two waste drainage, in Textile and Soft Drinks Factories, shows extremely high total dissolved solids. The textile mills discharge waste water has a TDS value of 7500mg/l. Sodium, chloride and sulphate are the most abundant components (Fig 1).

From the overall analysis of available data of almost 30 years period total dissolved solids reveals alarming increase. In wells located at the heart of the town ten fold increase in TDS from that of 30 years back is measured. Most wells show two to three fold increase. The degree of hardness in all waters of the city is very hard; all have values greater than 300mg/l.

Trend analysis of past years record shows a growing calcium ion concentration which is mainly caused by the drop in the amount of annual precipitation within and outside the basin. The content of bicarbonate ion is also not suitable for food processing.

The concentration of chloride in some water points is more than 700 mg/l and the trend is growing. Sulfate is increasing at an alarming rate. The value of sulfate in most water points in 1959 was less than 100mg/l. After 30 years most wells have values greater than 200mg/l value. Some localities show up to three fold increase. The source of sulfate is mostly the human excreta and sewage.

Similar to sulphate nitrate concentration is fast growing and thus potentially dangerous. In 1959, the maximum concentration record was only 45 mg/l at the heart of the city. Value measured in 1982 was as high as 320mg/l in a similar well. Many wells shows more than two fold increase in two decades.(Fig.2, Table 2.)

Conclusion

From the over all analysis made, it is concluded that, the rainfall pattern, over-pumping and depletion of recharge from the highlands, as indicated by the recent drop in water table, is making the groundwater storage non-dependable. Most of all the degradation of the main groundwater storage, mainly by human activities, will leave the city without any nearby possible source of water supply in the future.

Sewage related pollution already has manifested itself in drinking and food processing water and with increasing volumes of water use and pollutant disposal it is likely to occur at increasing amounts in the future,. Irrigation east and west of the city and some geologic formations like cliche formation are part of the problems for high nitrate values. The way human excreta has been disposed for almost a century is the main reason for the current high nitrate concentration. Degree of pollution is directly related with population density and groundwater flow direction. While the most precious natural resource, water, is polluted in such a way no state measure is taken to protect the hydrogeologic environment. Therefore, government's political, ecological and moral responsibility for the protection of ground water is inescapable. Modification in the master plan of the city, to protect safe zones of the basin and the construction of pit latrines using impermeable casings, and bottom lining by concrete and construction of sewage system and strong environmental monitoring have paramount importance to control further aggravation of the problem.

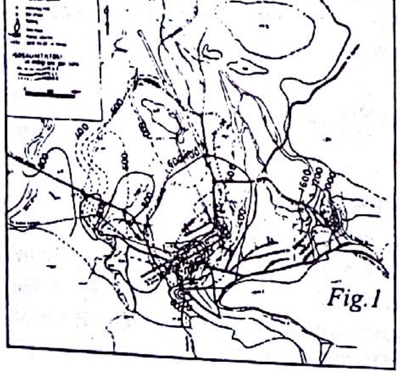


Fig.1

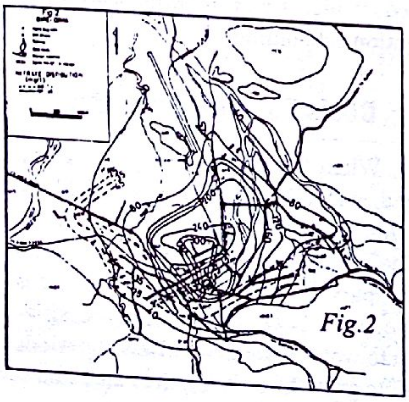


Fig.2

Reference

1.Associated Engineering Survey Ltd. Oct. 1982. *Dire Dawa Feasibility study for Water Supply.*

2. CSA, 1995. *The 1994 population and Housing Census of Ethiopia*, Oct. 1995 Addis Ababa.

3.Greitzer Yeshayehu, 1970. *Stratigraphy, Hydrogeology and Jurassic Communities of the Harar and Dire Dawa Area.* EIGS, Addis Ababa

4.Ketema Tadesse, 1982. *Hydrogeology of the Dire Dawa Area.* EIGS, Addis Ababa.

5.Mezmure HaileMeskel, 1980. *Report on well construction and pumping test.* EIGS, Addis Ababa.

6. Tesfamichael Keleta, 1974. Unpublished Report No. 11, *Hydrogeology of Dire Dawa Area, A statement of present knowledge.* EIGS, Addis Ababa.

7.Uark W.John and Warren Viessman. 1970. *Water Supply and Pollution control.*

Sensitivity Analysis of Optimal Irrigation Scheduling using a Dynamic Programming Model

Ketema Tilahun, Aemaya University,P.O.Box. 53, Alemaya, Ethiopia

Abstract

An optimisation dynamic programming model is used to analyse the effects of various irrigation levels, yield response factors and initial soil moisture on the water allocation pattern to the sensitivity stages. The inputs are crop evapotranspiration, rainfall data, soil moisture holding capacity, length of crops sensitivity stages with yield response factors. Irrigation scheduling at weekly irrigation interval is obtained for a given supply of irrigation water. Allocation pattern to the sensitivity stages under different levels of irrigation is observed. The effect of varying yield response factors around the values given in literature on the water allocation pattern to the sensitivity stages is analysed. The contribution of residual soil moisture and its effect on irrigation scheduling is dealt with. These information can be of great importance in optimal irrigation water management under limited water condition.

Introduction

Water is the single most important input to the crop production system. The fast rising demand for food and fibre makes the sagacious use of water a global concern. Howell et al., (1975) used Dynamic Programming (DP) to apply small quantities of irrigation at high frequency. Their conclusion was that irrigation amounts could be substantially reduced without a large decrease in expected yield provided the irrigation was distributed optimally over the season. Others authors like Hall and Butcher, 1968, Brass and Cordova, 1981 and Yaron and Dinar, 1982 have used DP in the analysis of optimal irrigation scheduling under limited water condition. In these models analysis concerning the effect of the parameters and variables of irrigation water scheduling has not been dealt with.

The yield response factors derived by Doorenbos and Kassam, 1979 though they are helpful for planning purposes, they are still site specific. The extent to which error in the choice of the value of this factor affects irrigation scheduling worth analysis. Analysis concerning the extent to which the level of initial soil moisture at the beginning of an irrigation season affects the irrigation water required for a crop and its effect on the irrigation scheduling is essential. Here, it is aimed to analyse the influence of these parameters and variables on the irrigation water scheduling.

The procedure proposed by Rao et al. (1990) as used in the generalised dynamic programming model Colorado State University Dynamic Programming, CSUDP (Labadie, 1990) is adopted. It is assumed that the crop yields are limited only by water. The model uses average weekly potential evapotranspiration and rainfall at specified probabilities of exceedence and crop and soil related inputs. The output from the model is optimal sequence of weekly irrigation decisions which maximise the crop yield.

The specific objectives of this study are to apply the DP model for the analysis of the irrigation water allocation pattern to the sensitivity stages under different levels of irrigation water, the effect of yield response factor on irrigation water allocation to the sensitivity stages, and the contribution of initial soil moisture to the crop water requirements and its influence on irrigation scheduling.

Basic Equations and Data

When the available supply is limited, water deficits are unavoidable in some periods of the growing season. The scheduling problem then becomes complex because irrigation decisions need to be based on the crop's sensitivity to water deficits in different periods of its growth. This requires an evaluation of alternative irrigation schedules and choosing the schedule which maximises yields for the given level of water supply.

To solve the growth stage level problem, the multiplicative dated water production function proposed by Rao et al., (1988b) is maximised by dynamic programming to obtain water allocations to sensitivity stage.

$$Y/Y_m = \prod_{i=1}^{N_k}\left[1 - K_i(1 - AET/PET)_i\right] \quad (1)$$

where Y=actual yield; Y_m= maximum yield i.e. when AET = PET; N_k= number of sensitivity stages of crop k ; K_i = stress sensitivity factor for the i^{th} sensitivity stage; AET_i actual ET for i^{th} sensitivity stage and PET_i = maximum ET for i^{th} sensitivity stage. To avoid having to define an additional state variable associated with the limited water supply availability this constraint is placed into the objective function via a Lagrange multiplier. Since logarithm function is unique, Equation (1) can be written equivalently as

$$\max \sum_{i=1}^{N_k} \ln\left[1 - K_i(1 - AET/PET)_i\right] - \lambda\left[\sum_{i=1}^{N_k} U_i\right] \quad (2)$$

Where U_i is water allocated to sensitivity stage i. The method of solution is to fix a value of and to solve the problem using DP algorithm and then repeat the same procedure for a different value of . The detailed discussion of the under-

Sensitivity Stage(I)	Cotton		Maize		Groundnut		Sorghum	
	Days	Ky	Days	Ky	Days	Ky	Days	Ky
Vegetative	63	0.2	56	0.4	35	0.2	49	0.2
Flowering	98	0.5	21	1.5	42	0.8	21	0.55
Yield formation			42	0.5	42	0.6	42	0.45
Ripening	21	0.25	21	0.2	21	0.2	14	0.2
Total growing season	182	0.85	140	1.25	140	0.7	126	0.9

Table 1. Length of sensitivity stages and corresponding yield response factor (Ky)

Week	1	2	3	4	5	6	7	8	9
Reference crop ET	37.6	37.8	37.8	38.0	37.2	37.8	38.2	39.2	40.0
80% exceedence rain	0	0	0	0	0	0	0	0	0
Standard week	10	11	12	13	14	15	16	17	18
Reference crop ET	45.6	46.7	46.6	46.3	42.3	41.4	40.5	39.0	37.9
80% exceedence rain	0	0	0	0	0	0	8.3	20.6	16.0
Standard week	19	20	21	22	23	24	25	26	
Reference crop ET	37.0	36.6	36.4	36.1	37.7	37.8	37.9	37.9	
80% exceedence rain	16.7	0	7.1	0	0	0	0	0	

Table 2. Weekly reference evapotranspiration and 80 % dependable rainfall

lying equations and subroutines is given in Tilahuh, 1997.

All the crop, soil, and climatic data refers to a project area in Ethiopia, Amibara Irrigation Project. Its altitude, latitude and longitudes are about 700m above sea level, 10°N and 40°E respectively. Total annual rainfall and temperature are about 500 mm and 26°C respectively. The soil of the area is fine sandy loam with total available moisture holding capacity of 1.25 mm/cm. The crops grown in the project area are cotton, maize, groundnut and sorghum. The length of sensitivity stages and corresponding yield response factor (Ky) taken from Doorenbos and Pruit, 1974 are as given in (Table.1)

Results and Discussion

(A) Effect of different levels of limited seasonal irrigation

If water supply is not limited, irrigation is applied to the crops to fulfil potential evapotranspiration. But when water is limited the available water should be applied in such away that the yield is maximised. Depending upon the seasonally available water for the project, individual crops can receive different amounts of water each season. If the amount of water allocated to a crop is smaller than that necessary for relative yield of unity, there is corresponding decrease in the relative yield. If the limitation is continuously increased, from which growth stage will the water be decreased?.

Different water supply levels (mm) are provided for each crop using 80% exceedence rainfall and initial soil moisture level of 0.4 mm/cm and the following result was obtained.

From **Table 3** it can be seen that priority is given to the most sensitive stage. If it is found that there is shortage of irrigation water, reduction is done from the less sensitive stages without much loss in yield due to optimisation. The most sensitive stage gets almost constant amount of water until there is such a small amount of water available and reduction from this stage is started. Interestingly, **Table 3c** shows that for groundnut evenif lower amount of water is applied to the most sensitive stage, as the water available is lowered, more water is applied to this stage until the shortage is high enough and this allocation starts to decrease again.

Amount allocated to a given sensitivity stage is determined more by the length of the stage than by its sensitivity. The yield response factor for a given sensitivity stage is an indicator for the *priority* of water allocation when there is shortage. Therefore it doesn't mean that the most sensitive stage gets the highest amount of water. The latter is true only under severe shortages. There is a limit to the

a. Cotton

SS	Ky	524.2	357.9	301.4	53.5	28.7	15.4	0
1	0.2	167.0	0.8	0.8	0.3	0.3	0.3	0
2	0.5	357.2	357.1	300.6	1.7	1.7	1.7	0
3	0.25	0	0	0	51.5	26.7	13.4	0
Relative	Yield	1.000	0.835	0.737	0.429	0.402	0.388	0.357

b. Maize

SS	Ky	480.6	472.1	465.0	395.1	333.2	121.0	46.0	23.9	6.0
1	0.4	140.8	140.9	133.8	63.9	2.0	2.0	1.4	0	0
2	1.5	114.7	114.7	114.7	114.7	114.7	115.2	44.6	23.9	6.0
3	0.5	224.9	216.5	216.5	216.5	216.5	3.8	0	0	0
4	0.2	0	0	0	0	0	0	0	0	0
Relative	Yield	1.000	0.998	0.981	0.818	0.673	0.376	0.142	0.075	0.023

c. Groundnut

SS	Ky	453.6	432.3	348.9	324.9	126.6	44.2	12.4	0
1	0.2	97.6	59.8	24.0	0	0	0.3	0.3	0
2	0.8	154.6	171.1	171.1	171.1	126.6	43.9	12.1	0
3	0.6	168.1	168.1	153.8	153.8	0	0	0	0
4	0.2	33.3	33.3	0	0	0	0	0	0
Relative	Yield	1.000	0.966	0.799	0.735	0.251	0.141	0.099	0.084

d. Sorghum

SS	Ky	446.8	411.8	307.0	136.8	112.6	55.5	13.7	0
1	0.2	121.0	121.0	16.5	16.5	0	2.6	2.6	0
2	0.55	120.3	120.3	120.3	120.3	112.6	52.9	11.1	0
3	0.45	205.5	165.5	164.2	0	0	0	0	0
4	0.2	0	5.0	6.0	0	0	0	0	0
Relative	Yield	1.000	0.997	0.853	0.487	0.445	0.326	0.259	0.194

Table 3. Scheduling pattern under different levels of water application (mm)

amount of water a sensitivity stage can take.

For groundnut, the flowering period is the most sensitive to water deficit, followed by the yield formation period. Therefore, in the case of limited water, savings should be made during the periods other than flowering and early yield formation. Maize is relatively tolerant to water deficits during the vegetative and ripening periods. Greatest decrease in grain yield is caused by water deficits during the flowering period. Therefore, when rainfall is low and irrigation water supply is restricted, irrigation scheduling should be based on avoiding water deficits during the flowering period. As regard to sorghum, the timing of supply should aim at reducing water deficits to a minimum during flowering and yield formation. Where water supply is limited during the flowering period, water savings can be made without causing additional heavy yield losses by reducing irrigation water supply during the vegetative, late yield formation and ripening period.

(B) Effect of yield response factor

The knowledge of crop yield response to water is important for decision making in irrigation activities such as optimal decisions for irrigation systems design and water resources planning. The need for using this knowledge becomes more compelling as water becomes increasingly scarce and/or expensive.

The yield response is different for different crops and for a given crop different stages can have different yield responses. After analysing the available information on crop yield response to water, Doorenbos and Kassam, 1979 derived yield response factors for the total growing season and the individual sensitivity stages for about 26 crops. These factors are the indices for sensitivity to water stress over the whole growing season and specialised physiological growth stages of a crop respectively. They are recommended for planning and operation of irrigation systems. As these values are just empirical averages, there can be variation in different regions of the world under different climatic conditions. Therefore, it is important to see how water allocation to the sensitivity stages behaves when the yield response factor of a given stage is varied.

a.

SS*	Ky	U*(mm)
1	*0.2*	0
2	0.8	171.2
3	0.6	153.8
4	0.2	0
	Total	325.0
	RY*	0.735

b.

SS	Ky	U(mm)
1	*0.25*	0
2	0.8	171.2
3	0.6	153.8
4	0.2	0
	Total	325.0
	RY	0.695

c.

SS	Ky	U(mm)
1	*0.15*	0
2	0.8	171.2
3	0.6	153.8
4	0.2	0
	Total	325.0
	RY	0.776

SS* stands for sensitivity stage RY* stands for relative yield U* stands for depth of irrigation

d.

SS	Ky	U(mm)
1	0.2	0
2	*0.8*	171.2
3	0.6	153.8
4	0.2	0
	Total	325.0
	RY	0.735

e.

SS	Ky	U (mm)
1	0.2	0
2	*0.85*	171.2
3	0.6	153.8
4	0.2	0
	Total	325.0
	RY	0.735

f.

SS	Ky	U (mm)
1	0.2	0
2	*0.75*	171.2
3	0.6	153.8
4	0.2	0
	Total	325.0
	RY	0.735

g.

SS	Ky	U (mm)
1	0.2	0
2	0.8	171.2
3	*0.6*	153.8
4	0.2	0
	Total	325.0
	RY	0.735

h.

SS	Ky	U (mm)
1	0.2	0
2	0.8	171.2
3	*0.65*	153.8
4	0.2	0
	Total	325.0
	RY	0.733

i.

SS	Ky	U (mm)
1	0.2	0
2	0.8	171.2
3	*0.55*	153.8
4	0.2	0
	Total	325.0
	RY	0.737

j.

SS	Ky	U (mm)
1	0.2	0
2	0.8	171.2
3	0.6	153.8
4	*0.2*	0
	Total	325.0
	RY	0.735

k.

SS	Ky	U (mm)
1	0.2	0
2	0.8	171.2
3	0.6	153.8
4	*0.25*	0
	Total	325.0
	RY	0.720

l.

SS	Ky	U (mm)
1	0.2	0
2	0.8	171.2
3	0.6	153.8
4	*0.15*	0
	Total	325.0
	RY	0.750

Table 4. Relative yield and water allocation (mm) when Ky value of sensitivity stages is varied

This analysis is done for groundnut using 80% exceedence rainfall and initial soil moisture content of the soil at the beginning of the season as 0.4 mm/cm and irrigation level of 325.0 mm. Yield response factor, Ky, values were varied around the value given in literature for each sensitivity stages.

Higher yield response factor of a given sensitivity stage or a given crop means that the stage or crop is more sensitive to water stress. Similarly, when the Ky value is decreased it means that less sensitive stage or crop is considered. When the Ky value for the first stage of groundnut is increased from 0.2 to 0.25, relative yield decreased by about 5.5 %. Similarly, when it is decreased to 0.15 relative yield increased by about 4.1 %. For this level of irrigation (325.0 mm) no water is allocated to this sensitivity stage. But this stage can actually take about 97.0 mm of irrigation water for maximum yield when there is no water limitation. This shows for more sensitive stages, more water should be applied otherwise there is a decrease in the yield.

In the second stage, evenif Ky value is increased from 0.8 to 0.85, there is no change in the relative yield. The same is true if it is decreased. But 171 mm is the maximum this stage can take for maximum yield when there is no water limitation; and this amount is already applied. It shows that once a stage has got what it can potentially take, increasing or decreasing Ky value will not affect the relative yield. When the yield response factor Ky for the third stage is decreased from 0.6 to 0.55, relative yield is increased by about 0.2%. This increase is high when compared to the one of the second *a)Cotton*

W_o	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.25
SS 1	217.8	215.0	182.1	167.1	153.6	152.5	151.4	150.2	147.3	143.0	138.9	134.3	131.7
SS 2	362.1	359.2	358.1	357.1	356.1	355.0	354.0	352.9	351.9	350.9	349.8	348.8	348.3
SS 3	31.5	0	0	0	0	0	0	0	0	0	0	0	0
Total	611.4	574.2	540.2	524.2	509.7	507.5	505.4	503.1	499.2	493.9	488.7	483.1	480.0

b)Maize

W_o	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.25
SS 1	155.3	150.5	145.7	141.0	126.8	125.4	124.0	121.6	116.9	112.1	107.3	102.5	95.0
SS 2	116.8	116.1	115.4	114.7	114.0	113.3	114.1	112.7	111.3	111.0	109.8	109.1	108.8
SS 3	231.2	229.1	227.0	224.9	222.8	220.7	160.8	195.0	193.0	191.0	189.0	157.3	157.0
SS 4	0	0	0	0	0	0	37.8	0	0	0	0	26.8	26.8
Total	503.3	495.7	488.1	480.6	463.6	459.4	436.7	429.3	421.2	414.1	406.1	395.7	387.6

c)Groundnut

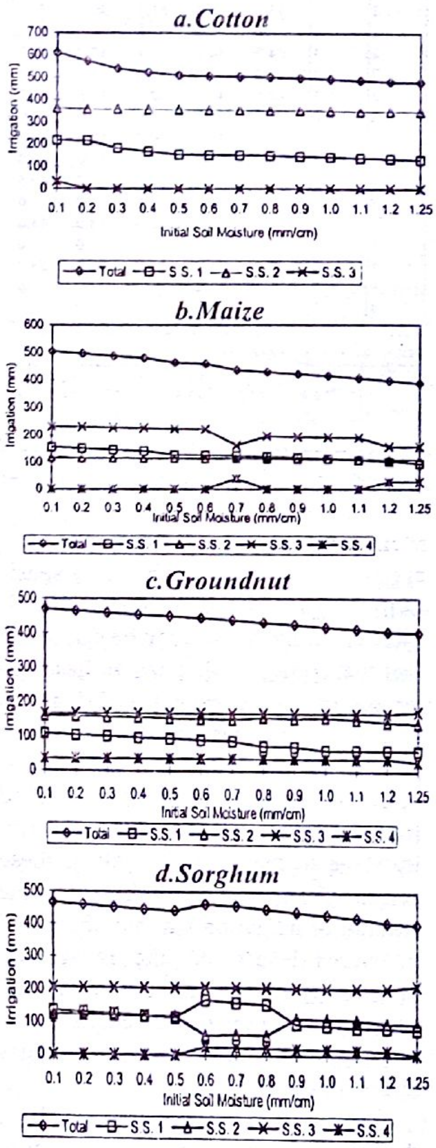
W_o	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.25
SS 1	108.4	104.7	101.1	97.4	93.7	90.0	86.5	72.6	71.0	60.7	60.6	60.6	60.3
SS 2	159.7	158.0	156.3	154.6	153.0	151.3	149.6	155.6	151.9	155.7	149.3	142.8	139.9
SS 3	166.0	166.0	166.0	166.0	166.0	166.0	166.0	166.0	166.0	166.0	166.0	166.0	173.0
SS 4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	28.4
Total	469.5	464.1	458.8	453.4	448.1	442.7	437.5	429.8	424.3	417.8	411.3	404.8	401.6

d)Sorgum

W_o	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.25
SS 1	135.0	130.8	125.9	121.0	116.1	169.0	162.0	157.0	96.5	91.6	87.5	84.7	81.5
SS 2	124.1	122.7	121.3	120.3	119.6	60.5	63.7	62.3	114.5	113.1	110.5	101.8	99.6
SS 3	206.2	206.0	205.7	205.5	205.2	207.1	206.8	206.6	206.3	206.1	205.8	205.5	215.9
SS 4	0	0	0	0	0	25.1	24.1	22.1	21.1	19.1	18.1	16.1	5.9
Total	465.3	459.5	452.9	446.8	440.9	461.7	456.6	448.0	438.4	429.9	421.9	408.1	402.9

Table 5. Minimum irrigation water (mm) under various residual soil moisture (mm/cm)

Fig1. Minimum irrigation requirement and its allocation to the sensitivity stages under different initial soil moisture



stage (no increase) and lower when compared to that of the first stage (4.1%). But groundnut can take 168 mm of irrigation water for maximum yield when there is no water limitation. Here about 154 mm of water is allocated. Therefore there is still small room to apply water and a decrease or increase of Ky value brings a slight change in relative yield. Indirectly, this shows that increasing water application for a stage above what it can potentially take will not increase the yield.

(C) Effect of initial soil moisture

Initial soil moisture content () is the soil moisture at the beginning of the irrigation season. High rainfall during the rainy season may bring the soil moisture content close to or at field capacity. In studies of the effects of water shortage on crop yield, hydrologic inputs and outputs during growing season of the crop are carefully taken care of and analysed. But the effect of stored soil moisture at the beginning of the growing season is dependent on the preceding season rainfall condition and is usually ignored. But where water is scarce and yield is limited, the stored water in the soil is an important factor and worth analysis. Therefore, it is necessary to see how important is this moisture when it is at permanent wilting point, critical soil moisture, field capacity or any state in between or outside. In this study, the effect of residual soil moisture on the following aspects is to be analysed: the minimum irrigation required for the relative yield of 1, the allocation pattern to the sensitivity stages and weekly irrigation scheduling.

To analyse this effect, discrete initial soil moisture levels were taken from 0.1 to 1.25 mm/cm at an interval of 0.1 mm/cm. The model was run for each initial soil moisture conditions until RY = 1 is obtained. Then the minimum total irrigation needed and the corresponding allocation pattern to the sensitivity stages of each crop is shown in (Table 5).

Table 5 and **Figure 1** show that there is a decrease in the required irrigation water when the stored soil moisture is increased. Evenif the relationship is not linear, when is increased from 0.1mm/cm to 1.25 mm/cm, the irrigation demand decreased by 21.5 % for cotton, 23 % for maize, 14.5 % for groundnut and 13.4 % for sorghum . These variation between crops may be due to length of the growing season of the crop and the root depth. This means the longer the growing season and the deeper the root depth the higher the crop makes use of the stored soil water.

From the water allocated to the sensitivity stages and the corresponding curves, it can be seen that the stored moisture variation affects almost only the earlier stages. The decrease in the required total supply as the stored

Stage	Week	1.25	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
1	1	0	0	0	0	0	0	27.9	29.9	31.9	33.9	35.9	37.9	39.9
1	2	33.9	34.9	36.9	38.6	40.9	42.0	0	0	0	0	0	0	0
1	3	0	0	0	0	0	0	37.1	37.64	38.2	38.8	39.3	39.9	40.4
1	4	26.4	25.7	23.7	22.1	30.1	30.6	0	0	0	0	0	0	0
1	5	0	0	0	0	0	0	21.3	22.5	23.6	24.7	25.9	26.9	28.1
2	1	45.1	46.8	51.1	55.0	49.3	50.9	42.3	42.8	43.4	44.0	44.5	45.1	45.6
2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	54.2	54.8	55.9	57.0	58.1	59.2	60.4	60.5	60.5	60.5	60.5	60.5	60.5
2	4	0	0	0	0	0	0	0	0	0	0	0	0	0
2	5	40.6	41.2	42.3	43.5	44.5	45.6	46.9	48.0	49.1	50.1	51.3	52.4	53.6
2	6	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5
3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	3	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5
3	4	0	0	0	0	0	0	0	0	0	0	0	0	0
3	5	52.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0
3	6	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	28.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4
4	2	0	0	0	0	0	0	0	0	0	0	0	0	0
4	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Total		401.6	404.8	411.3	417.8	424.3	429.8	437.5	442.7	448.1	453.4	458.8	464.1	469.5
RY		1	1	1	1	1	1	1	1	1	1	1	1	1
SS	1	60.3	60.6	60.6	60.7	71.0	72.6	86.5	90.0	93.7	97.4	101.1	104.7	108.4
	2	139.9	142.8	149.3	155.7	151.9	155.6	149.6	151.3	153.0	154.6	156.3	158.0	159.7
	3	173.0	166.0	166.0	166.0	166.0	166.0	166.0	166.0	166.0	166.0	166.0	166.0	166.0
	4	28.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4

Table 6. Irrigation scheduling for different initial soil moisture (mm/cm) for groundnut

moisture is increased is the result of decrease in the supply in the early sensitivity stages. The latter stages are almost unchanged. This can be due to the fact that root growth stops at these latter stages. Some exceptional features seen in the curves is due to optimisation pattern. As the initial soil moisture is increased, the first irrigation is shifted from the first week of the first sensitivity stage to the second week of these stages. There is sudden change in the amount of irrigation water at these soil moistures levels. As the initial soil moisture is lowered and the first irrigation is given in the first week, the overall supply is increased more than it does in the other cases.

From **Table 6** it appears that W_o, though it affects the minimum amount of irrigation water one should apply for the relative yield of 1, does not significantly influence weekly irrigation sequences. This is because the incremental soil water due to root extension is small compared to the total soil-water content of the effective root zone. A second factor is the fixed capacity of the irrigation water delivery system compared to the available soil-storage capacity. The result is that, under such conditions, when available supplies are highly deficient, irrigation decisions are governed more by crop and irrigation system-related factors than by the soil-water availability. However, when supplies approach adequate levels, irrigation frequencies rise and W_o influences the timing of irrigations significantly.

The carry-over moisture stored in the soil during the preceding rainy season or irrigation contributes substantially to the crops of the current season. The amount of stored soil moisture from the preceding rainfall is important to decide whether pre-irrigation is required at the time of sowing. This moisture should be taken into account especially when there is limited water.

Conclusion

A considerable potential for a dynamic programming model in the analysis of the effect of different irrigation levels, significance of yield response factor, and initial soil moisture in irrigation water management has been demonstrated. Irrigation amounts could be substantially reduced without a large decrease in expected yield if the irrigation is distributed optimally over the season. Optimisation keeps the relative yield high enough by allocating more water to the more sensitive stages at the expense of the less sensitive stages.

Increasing the yield response factor of a sensitivity stage decreases the relative yield for a given quantity of water available for the crop. But once a sensitivity stage has got its full water requirement, increasing or decreasing the yield response factor will not change the relative yield. The most sensitive physiological growth stage of a crop is not necessarily the stage which consumes the maximum amount of water. The yield response factor of a sensitivity stage is an indicator for the priority of water allocation when there is shortage. In fact, the amount of water a sensitivity stage requires is dependent on both its length and the yield response factor.

Stored soil moisture has great potential value for boosting overall production. This indicates the importance of water conservation practices to increase soil moisture storage with emphasis on off-season irrigation with waters which would otherwise be wasted. But although its contribution to the crop water requirement is significant, the effect of initial soil moisture on the irrigation scheduling is limited to the first one or two sensitivity stage(s) of a crop.

References

Bras, R. L., and Cordova, J. R., 1981. Inraseasonal water allocations in deficit irrigation. Water Resources Research, 17:866-874.

Doorebos, J., and Kassam, A. H., 1979. Yield response to water. FAO Irrig. Drain. Pap. 33, Food and Agric. Organ., Rome, Italy.

Doorenbos, J., and Pruitt, W. O., 1974. Crop water requirements. FAO Irrig. Drain. Pap. 24, Food and Agric. Organ., Rome, Italy.

Hall, W. A., and Butcher, W. S., 1968. Optimal timing of irrigation. J. Irri. Drain. Eng., ASCE, 94(IR2):267-275.

Howell, T. A., Hiler, E. A., and Reddell, D. L., 1975. Optimisation of water use efficiency under high frequency irrigation - II. System simulation and dynamic programming. Transactions of the ASAE, 18:879-887.

Tilahun, K., 1997. Optimal irrigation water allocation and scheduling under a multiple cropping system, MSc Thesis, Catholic University of Leuven, Belgium.

Labadie, J. W., 1990. Dynamic programming with the microcomputer. In : A. Kent (editor), Encyclopaedia of microcomputers. Marcel Dekker, New York.

Rao, N. H., Sarma, P. B. S., and Chander, S., 1988b. A simple dated water production function for use in irrigated agriculture. Agric. Water Manag., 13:25-32.

Rao, N. H., Sarma, P. B. S., and Chander, S., 1990. Optimal multicrop allocation of seasonal and intraseasonal irrigation water. Water Resources Research, 26:551.559.

Yaron, D., and Dinar, A., 1982. Optimal allocation of water on a farm during peak season. Am. J. Agric. Econ., 64:681-689.

A Practical Approach To Upgrade The Hydrometeorological Network In Ethiopia

Abebe Belachew, Lecturer, Arbaminch Water Technology Institute, P.O.Box.21,Arbaminch, Ethiopia

Abstract

The existing hydrometeorological network density of Ethiopia (about 832 meteorological and 507 hydrometric stations) does not satisfy the WMO's recommendations (2399-5428 meteorological and 674-1796 hydrometric stations). This problem is aggravated due to budgetary constraints and capacity limitations of the two responsible governmental organizations - The National Meteorological Services Agency (NMSA) and The Hydrological Studies Department (HSD). In this regard a rigorous strategy based on the country's socio-economic conditions is proposed. The proposed strategy for meteorological network is to establish stations in compounds of schools and churches or mosques with observers from these centers. Incentives being provided by the regional governments and the collected data will be processed and verified by regional NMSA branch offices. If 50% of the total number of schools and churches or mosques are fit and considered for station establishment, Ethiopia could have more than about 5,000 and 8,000 additional meteorological stations, respectively. For hydrological network, personnel for the various agricultural extension programs of the MOA could be utilized for supervision and/or observation. Establishment of observation stations could be conducted by senior students in engineering and related sciences with incentives during their summer vacation. Principal recommendation concern integration of meteorological and hydrological network planning and analysis.

1. Introduction

The principal purpose of a hydrometeorological network is to provide a suitable data base for Areal (or spatial) and temporal analysis. The problem of obtaining estimates of Areal data over a specified time period to a specified degree of accuracy from a set of point observations is a familiar one to all of us. The design of a specific network depends on specific network objectives, scientific considerations, and monetary constraints. Questions like for what purposes are the data to be used? What time scale is of principal interest? How accurate are the point measurements? How representative are they of the surrounding terrain? What economic factors are involved? are the major concern of hydrometeorological network design. In this paper a rigorous strategy is proposed which fully addresses some of these questions by considering Ethiopia's actual socio-economic conditions.

Background

Ethiopia, with a total geographical area of 1.13 million (km)2, has a highly rugged topography. According to NMSA (1996), Ethiopia's climate is characterized by high rainfall variability. It is therefore essential to assess rainfall with the associated weather systems in sufficiently rigorous fashion so as to evaluate its influence on the socioeconomic development activities of the country. Moreover, rainfall is a major component of climate which is beneficial to everyday human activities.

The country is divided into the following four regions based on rainfall types (Fig.1):(i) Region B: monomodal type 1; (ii) Region D: monomodal type 2; (iii) Region A: bimodal type 1; and (iv) Region C: bimodal type 2. When the rainfall occurs in one continuous period of time in a year, this is termed as monomodal and when this occurs in two discontinuous periods in a year, this is termed as bimodal. Again, each of these are divided into type 1 or 2, based on the time of occurrence of the continuous period(s) or by the prominence of rainy periods. Even though the climatic features of the country are highly associated with the rainfall variability both in space and time, other meteorological parameters such as temperature, wind speed, humidity, potential evapotranspiration, etc. are also important.

The important weather systems that cause rainfall over Ethiopia are Sub Tropical Jet (STJ), Inter Tropical Convergence Zone (ITCZ), Red Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ) and the Somalia Jet. STJ, ITCZ, RSCZ, TEJ and the Somalia Jet cause rain in Region A; ITCZ along with some of those which influence Region A cause rain in Region B; the ITCZ causes rain in Region C; and STJ & RSCZ cause rain in Region D. However, in each of these regions the rainfall amount and its variability is quite different over different parts. This is mainly associated with the movement/ position of rain causing mechanisms with reference to a given region in different seasons and orographic conditions (NMSA, 1996).

According to Koppen's climatic classification with certain modification, the country is divided into 11 climatic zones. They principally come under *dry climates, tropical rainy climates and temperate rainy climates.* More precisely, they range from equatorial desert to hot and cool steppe, and from tropical savanna and rain forests to warm temperate and cool highlands. However, the temperate climates in many cases and not truly temperate but they are high altitude zones only (NMSA, 1996).

There is a more commonly used local classification of climate in Ethiopia based solely on altitude and mean temperature. The five climatic zones are: (i) Wurch (alpine); (ii) Dega (temperate); (iii) Weina Dega (temperate and sub-tropical frost free zone); (iv) Kolla (tropical and desert low lands), and (v) Berha (desert) (Daniel, 1972).

The Wurch zone covers areas with altitude greater than about 3300 meters, where mean daily air temperature rarely exceeds 10OC, where there is no cultivation practices, etc. The Dega zone covers areas with altitude from about 2300 to 3300 meters, where heavy frost occur in the highest regions of this zone even though many parts have much lower temperatures with a mean daily air temperature being in the range of 10OC to 15OC. The Weina Dega zone covers areas with altitude from about 1500 to 2300 meters, where mean daily air temperature being in the range of 15OC to 20OC. Most of Ethiopia's population inhabited in this and the Dega zones due to their pleasant weather. The Kolla zone covers areas with altitude from about 500 to 1500 meters, where mean daily air temperature being in the range of 20OC to 25OC. The Berha zone covers areas with altitude less than about 500 meters, where mean daily air temperature being greater than 25OC.

Ethiopia, with the discussed above diversified climatic resources, is also naturally endowed with quite a substantial amount of water resources potential in its 12 river basins. According to recent studies by Ministry Of Water Resources (MOWR, 1998), the total annual surface water potential is estimated to be more than 110 billion cubic meter (Bm3) and the total annual groundwater potential amounts in the order of 2.6 Bm3. Moreover, the potential land for irrigation is more than 3.5 million hectares with less than 3% of potential being presently under irrigation. The potential annual hydropower production of the country on the other hand is estimated to be 161,000 Gega Watt Hour (GWH) with less than 1.5% of the potential being presently produced. This makes Ethiopia the second country with huge hydropower potential in Africa next to Democratic Congo (former Zaire). Therefore it is a paradox that the world knows about Ethiopia by its recurring droughts linked with famine rather than by its vast natural resources. This impression is however largely due to media images.

In fact the efforts made to utilize its natural resources for its socioeconomic development is one of the least mentioned in the world. This is partly due to poor information system; especially regarding hydrometeorological data. In this regard capacity limitations to build a good operational hydrology system is worth mentioning.

Scope

According to the definition adopted by WMO (1983), operational hydrology includes:

a)Measurement of basic hydrological elements from networks of hydrological and meteorological stations; collection, transmission, processing, storage, retrieval and publication of basic hydrological data;

b) hydrological forecasting;

c) methods, procedures and techniques used in; (i) network design; (ii) instrumentation and methods of observation; (iii) data transmission and processing.

The scope of this paper is therefore concentrated on how to upgrade the existing hydrometeorological network of Ethiopia from operational hydrology point of view. Therefore the paper addresses practical ways of upgrading the hydrometeorological network density for the observation of the most important basic hydrometeorological elements - precipitation (rainfall) and stage and/or discharge of stream flow within short time frame economically. However, other basic hydrometeorological elements such as temperature, wind speed, humidity, sediment load sampling, etc. can also be included whenever their importance is detrimental.

This paper has been prepared based on available literature survey and the author's experience of his country (Ethiopia) and other African countries. This paper will also create a discussion forum among the decision maker and professionals in the subject to criticize, suggest, and outline further areas of research.

2. Status of the Existing Hydrometeorological Network

A hydrometeorological network should have a good spatial and temporal coverage in order to provide a reliable information for inventory, planning, design, construction and operation of Water Resources Development (WRD) projects in the country. In principle the network should be developed on the basis of a nationwide plan which considers long term objectives in addition to current and short term ones. However, in Ethiopia the hydrometeorological network has developed in an empirical manner related to ongoing data needs.

Network design in an operational sense must take into account the existing network and try to adjust it so that long-term objectives can be satisfied at a minimum cost. In this paper attention will be given on the acquisition of data for local- and broad- scale planning purposes.

The existing hydrometeorological network is operated by the two governmental agencies under MOWR: NMSA for meteorological data and the HSD for hydrological data. However, according to the tradition of data acquisition strategy by these two agencies will not enable the country to achieve the desired hydrometeorological network density within a short time frame economically due to capacity limitations.

Hydrometeorological networks require an infrastructure (stations, measurement and data transmission equipment, repair and maintenance shops, rating laboratories, transportation means- plus the corresponding staff) and a superstructure (for planning and running the network, and for collecting, checking and processing the data and disseminating the resulting information to the users). Therefore upgrading the hydrometeorological network by these responsible governmental agencies only is far reaching unless a rigorous approach is followed.

Moreover, data collected on the

time and space variation of hydrometeorological characteristics of an area may be categorized into three major groups: *historical data, real time data and special survey data.*

Historical data

Historical data are collected to obtain a space/time series of data on meteorological and hydrological elements of the relevant area from which the hydrological characteristics can be estimated The density of the stations is primarily dictated for this group by the variability of the elements to be measured and the acceptable errors of estimation at the ungauged locations. Budgetary constraints often override these considerations. It is largely from historical data point of view that hydrometeorological network of Ethiopia has been developed.

In Ethiopia, the most significant difficulty in the realm of operational hydrology is the sheer lack of measurement stations. Four major reasons are responsible for this: (i) budgetary constraints, (ii) low level of know how of the society and the decision maker on the importance of hydrometeorological data, (iii) few skilled manpower in the profession, and (iv) problem of accessibility due to the mountainous topography of the country.

The WMO (1970) in Ferguson (1973) makes recommendations with respect to the density of rainfall and flow measurement stations in *mountainous, flat, arid regions of temperate, Mediterranean and tropical zones.* Table 1 shows the required hydrometeorological stations for Ethiopia by basin according to the WMO recommendations. Fig. 2 presents the status of the existing stream gauging stations in Ethiopia by basin. The total number of meteorological stations in Ethiopia are about 832 (WRC, 1987).

One of the peculiarities of meteorological stations in Ethiopia is their location being limited in the towns and related sites. Accessibility is the major reason in this consideration. Several towns in Ethiopia were established by former local governors on fortified places from military strategy point of view. Therefore, the existing meteorological network of the country lacks sound consideration of the variability of the meteorological elements (mainly rainfall) to be measured.

Moreover, the existing hydrometric stations for stream gauging are mostly located at bridge sites due to problem of accessibility even though bridge sites are not hydraulically very suitable sites. On top of this the nature of the streams in this country are mostly hilly catchments in which the variations of stream flow is significant within smaller reach of the streams. Moreover, The practice of groundwater observations based on network design principles is at an infant stage in Ethiopia.

Real time data

Real time data are transmitted as they are recorded to data-collection, processing and dissemination centers in order to monitor or forecast water-related phenomena for various practical operational purposes. The bulk of real time data is required in tropical countries in connection with forecasting flood elements. However, use is also made of real time hydrological data for the operation of Water Resources Development (WRD) projects. However, real time data practice in Ethiopia is not adequate due to capacity limitations.

Real time data, when stored and processed appropriately, also become part of the historical data. In addition they can provide early indications of rare events taking place in the region and allow more efficient use to be made of the staff and equipment available to operate the historical data network. The infrastructure for real time data consists of gauging network subsystems and remote sensing subsystem.

Special surveys

Special surveys are defined as surveys for obtaining hydrometeorological data which are conducted occasionally or periodically in addition to the regular network observations (e.g. survey of the minimum flow of ungauged streams during a drought). As many special surveys are not carried out by official meteorological and hydrological organizations but frequently by engineering consultants (river basin master plan studies, planning WRD projects, etc.). There is a need, particularly in Ethiopia to collect and coordinate the information contained in reports on such special surveys.

3.Proposed Strategy to Upgrade Meteorological Network

In addition to efforts made by NMSA to upgrade the existing network, a rigorous strategy that takes into account Ethiopia's cultural, social, economical, religious and environmental condition is proposed.

Primary and junior schools can be used as one of the promising sites for meteorological stations. According to 1995/96 educational statistics by Central Statistics Authority (CSA), there are about 9704 primary schools and 1304 junior schools in Ethiopia. If the average (50%) of the total number of

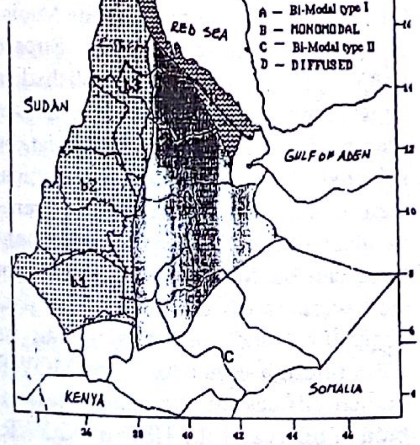


Fig.1 Rainfall Regimes of Ethiopia

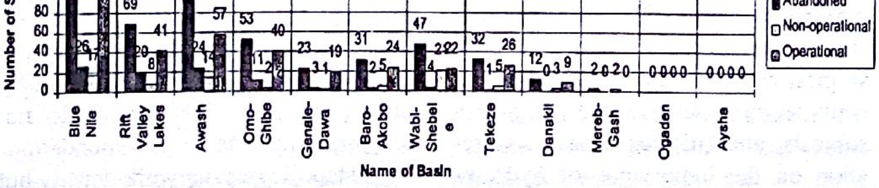


Fig.2 Status of stream gauging stations in Ethiopia by basin (after kidane,1997)

Table 1.Hydrometeorological Specification in Ethopia by basin based on WMO (1970) recommendation

S.N	Name of basin	Area (km)²			# meteorological stations			Total	# hydrometric stations			Total
		Mount.	Flat	Arid	Mount.	Flat	Arid		Mount.	Flat	Arid	
1	Blue Nile	142400	60800	-	570-1424	68-102	-	638-1526	143-475	25-61	-	168-536
2	Rift Valley Lakes	39009	13730	-	156-390	16-23	-	172-413	39-130	6-14	-	45-144
3	Awash	36601	73718	3377	147-366	82-123	1-3	230-492	37-122	30-74	1	68-197
4	Omo-Ghibe	43917	34296	-	176-440	39-58	-	215-498	44-147	14-35	-	58-182
5	Genale-Dawa	39230	105412	26400	157-393	118-176	3-18	278-587	40-131	43-106	2-6	85-243
6	Baro-Akobo	24566	49586	-	99-246	55-83	-	154-329	25-82	20-50	-	45-132
7	Wabi-Shebele	33605	152682	16400	135-336	170-255	2-11	307-602	34-112	61-153	1-4	96-26
8	Tekeze	54821	35180	-	220-549	39-59	-	259-608	55-183	14-36	-	69-219
9	Denakil	7741	27808	38460	31-78	31-47	4-26	66-151	8-26	12-28	2-8	22-62
10	Mereb-Gash	12643	11289	-	51-127	13-19	-	64-146	13-43	5-12	-	18-55
11	Ogaden	-	77121		-	15-74		15-74	-	no streams		
12	Aysha	-	2223		-	1-2		1-2	-	no streams		
Total number of stations required								2399-5428				674-1796

these schools are fit and considered for station establishment from hydrometeorological characteristics and operational point of view, there could be more than 5,000 additional meteorological stations.

Instruments such as raingauges, wind vanes, thermometer can be supplied by NMSA preferably locally manufactured in metal workshops. Regional governments and/or the respective development associations better be responsible for data acquisition through the respective regional education bureau. The school director can assign staffs or students for observation and supervise the data acquisition in the station located in his/her school compound. It is better if incentive is provided to the data observers by the respective regional governments. However, simple and standardized data sheets should be prepared by NMSA and distributed through the newly opened regional NMSA branch offices.

Data observed by the individual schools will be transmitted to regional NMSA branch offices. The collected data can be processed and verified based on the data from the stations which are already operated by NMSA. Detailed year books will then be published region-wise and summary year books published at federal level.

Data acquisition in the schools will have three major purposes: (i) for upgrading meteorological network density, (ii) serving as a practical demonstration center in the schools for students learning science and geography subjects, and (iii) for awareness creation on the importance of hydrometeorological data for socio-economic development by combating droughts and desertification in Ethiopia. In fact there were meteorological data acquisition practices in the schools in previous times.

Other promising sites are religious centers (churches and mosques). It is known that in most parts of Ethiopia every village has church and/or mosque. Therefore advantage can be gained from this condition in upgrading the existing meteorological network. According to the 1994 housing & population census report by CSA, more than 17,000 peasant association are available in Ethiopia. If the average (50%) of the total number are fit and considered for station establishment from hydrometeorological characteristics and operational point of view, there could be more than 8,000 additional meteorological stations. Observations could be made by server of the churches or mosques who are able to read and write with incentives provided by the regional governments. The data transmission, processing and verification will be conducted in a similar manner like that discussed for schools. However, there will obviously be duplication of stations when schools and religious centers are used jointly. Therefore, further research is necessary based on meteorological and operational characteristics of specific areas to come up with the appropriate meteorological network density.

If the above discussed strategy is positively considered and justified by further research, Ethiopia could not only meet the WMO recommendations for meteorological network density but also will have a denser network with minimum cost and within a shorter period of time. Some African countries like Zimbabwe follow similar strategies of data acquisition. For example, Zimbabwe with a total geographical area of 400,000 (km)2 has more than 1,100 meteorological stations which are operated by the official meteorological agency, schools, religious centers, commercial farms, etc. (DOMS, 1981).

The installation of instruments and demonstration of observation readings can be conducted by senior college students in engineering and related sciences during their three months summer vacation with incentives provided by the respective regional governments. All round assistance can be obtained from international and local NGOs, CBOs, and UN organizations.

4.Proposed Strategy to Upgrade Hydrological Network

Effort made by the HSD of MOWR is satisfactory towards achieving the WMO's recommendations for hydrometric network density. However, small-scale WRD projects also require information about the hydrological characteristics of smaller ungauged streams. Therefore the target should not only be in achieving the WMO recommendations in the case of stream gauging.

Based on the country's socio-economic policy, the agricultural sector has been given high priority. For this purpose, skilled personnel are assigned to several peasant associations in more than 600 districts of the country for the implementation of the various agricultural extension programs by the Ministry Of Agriculture (MOA). Stream gauging stations can be established in sites identified by river basin master plan studies or new sites which can be selected by a hydrometeorological team in the respective regional governments. A regular observer with incentives can be supervised by the extension workers of the MOA. The data acquisition and transmission can be done through either MOA or MOWR branch offices to the eight regional branch offices of the HSD of MOWR. Groundwater observation wells can be established and the observation readings can be handled by the personnel of the various agricultural extension programs. In this regard use of existing private hand dug shallow wells and existing deep wells is advantageous.

The same strategy like that discussed in the case of meteorological network can be followed for the establishment of stream gauging stations. However, since stream gauging stations require relatively more expensive infrastructure, as much as possible equipment and appurtenant structures better be locally manufactured and preferably be pre-fabricated materials.

5. Conclusion

Ethiopia's climate is characterized by high rainfall variability. It is known that rainfall is also affected by various topographical factors such as orography, continentality, topographic trend distance, aspect, slope, etc. (Abebe and Savenije, 1995). The effect of these topographical factors on hydrometeorological elements is significant for mountainous countries like Ethiopia. This makes the hydrometeorological network costly and operationally difficult.

The existing total number of meteorological stations in Ethiopia which are operated by NMSA of MOWR are about 832. The corresponding WMO recommendation is in the range of 2399-5428. To achieve the lower, average, and upper limits of this range, NMSA should show considerable effort by increasing the existing number of stations by nearly 3, 5, and 7 times the existing number of stations, respectively. In fact these targets are far reaching if NMSA follows its tradition of establishment of new stations. However, if the rigorous strategy proposed in this paper is implemented, Ethiopia can have more than about 5,000 and 8,000 additional stations in schools and churches or mosques, respectively. This will enable NMSA not only to achieve the WMO norms with least cost and shorter period of time but also will create a good opportunity for its staff to concentrate on data processing and analysis and prepare handbooks, year books, nomograms, empirical relations between the various hydrometeorological elements, etc. using the collected data.

The total number of stations according to the strategy proposed might seem very much in excess of the WMO recommendations. However, this dense network will be operated for about 5 to 10 years and several stations can be abandoned after the hydrometeorological characteristics of the country are well understood by research activities.

The other alternative to upgrade the meteorological network is by using remote sensing techniques such as ground radar and geostationary meteorological satellite measurements. Since 1997/98 a joint USA-Japan satellite mission on Tropical Rainfall Measuring Mission (TRMM) at Goddard Distributed Active Archive Center (DAAC) is a break-through in the field of remote sensing for rainfall measurement. However, for poor countries like Ethiopia, the monetary constraint and capacity limitations will hamper the larger scale use of this alternative. Therefore, the proposed strategy is still the most attractive alternative for Ethiopia.

The existing total number of hydrometric stations in Ethiopia which are operated by HSD of MOWR are about 507. The corresponding WMO recommendation is in the range of 674-1796. To achieve the lower, average, and upper limits of this range, HSD should show considerable effort by increasing the existing number of stations by nearly 1.5, 2.5, and 3.5 times the existing number of stations, respectively. However, if the rigorous strategy proposed in this paper is implemented, Ethiopia not only will achieve WMO's recommendations but also will have a denser network which will create an adequate hydrometeorological data base system for planning, design, construction and operation of small-, medium-, and large-scale WRD projects. Moreover, staffs in HSD of MOWR will concentrate not only on data acquisition and processing but also on the preparation of handbooks, year books, nomograms, empirical relations between the various hydrometeorological elements, etc. using the collected data.

Principal recommendation concern integration of meteorological and hydrological network planning and analysis, increased emphasis on the use of physiographic models, consistent application of benefit-cost analysis and the development of a classification system for representative results. Therefore, the hydrometeorological network design should follow a multi-critera analysis.

References

Abebe, B.B. and Savenije, H.H.G., 1995. Filtering the effect of orography from moisture recycling patterns. Physics and chemistry of the earth, Pergamon. Vol 20, No 5-6, 521-526.

Central Statistical Authority (CSA), 1995. The 1994 population and housing census of Ethiopia. Office of population and housing census commission, Addis Ababa, Ethiopia.

Daniel Gamechu, 1972. Aspects of climate and water budget in Ethiopia. Addis Ababa University publication, Addis Ababa, Ethiopia.

Department of Meteorological Services (DOMS) of Zimbabwe, 1981. Climate handbook of Zimbabwe. Meteorological report series. 551. 582 (689.1).

Ferguson, H.L., 1973. Precipitation network design for large mountainous areas. Proceedings of Geilo symposium on distribution of precipitation in mountainous areas. Vol 1, WMO publ No 326.

Kidane Assefa, 1997. Aspects of water resources monitoring and assessment in Ethiopia. Proceedings of 5th Nile 2002 conference, Addis Ababa, Ethiopia.

Ministry Of Water Resources (MOWR), 1997. Federal water resources policy draft document. Federal water policy and strategy development project office, Addis Ababa, Ethiopia.

National Meteorological Services Agency (NMSA), 1996. Climatic and agroclimatic resources of Ethiopia. Meteorological research report series. Vol 1, No 1.

Water Resources Commission (WRC), 1987. The opportunities and challenges of WRD in Ethiopia. WRC bulletin, Addis Ababa, Ethiopia.

WMO, 1983. Operational hydrology in the humid tropical regions. Proceedings of the Hamburg symposium. IAHS publ No 140.

Author: Abebe Belachew, Lecturer, Department of Hydraulic Engineering, Arbaminch Water Technology Institute, Arbaminch, Ethiopia

The Focal Area Approach TO Watershed Management

Miriti Joseph Minyori, Ministry of Agriculture, P.O.Box 68, Nairobi, Kenya

Abstract

Agriculture, being the economic staple of sub-saharan Africa, sound watershed management for sustainable agricultural production is of major importance.The " Catchment Approach" a participatory methodology towards sound watershed management is described. Experiences are drawn from the National Soil and Water Conservation Programme of the Ministry of Agriculture in Kenya, focusing on Tharaka- Nithi District in Eastern Province.

This paper is an outline of watershed management activities in two catchment areas taken as case studies in two different agro-ecological areas in the District.

The importance of involving the land users through use of PRA in technique/ project identification, planning and implementation to ensure ownership and hence proper operation and maintenance for sustainability is emphasised.

In summary, the following are the findings from the two case studies:

a) Use of PRA in participatory watershed management techniques development where farmers/land users' innovations are improved for sustainability, e.g. The water jars are an improvement of the traditional clay pots.

b) Involving the land users or farmers in any watershed management technique identification, planning and implementation , ensures ownership and hence proper operation and maintenance for sustainability, e.g. The operation and maintenance of the soil and water conservation structures is done by the farmers without problems and,

c) The willingness of the land users to participate in any watershed management practices for success, however depends on their economical status and the direct impact they have on their lives. With some assistance and sensetization, the farmers can do great things for themselves.

1.0 Introduction

Watershed management is a concept which is gaining popularity in the management of soil and water for increased and sustainable agricultural production. Agriculture is the economic staple of sub-saharan Africa, and agricultural production will be increasingly important to her citizens (Lii lundgren & Geoff Taylor - From Soil Conservation To Land Husbanry, Guidelines Based On SIDA Experience). Agricultural production in turn, depends on the sound management of soil and water resources.

The area drained by a river and its tributaries is known as a **river basin** or **catchment area;** and the boundary of the catchment area is usually formed by the crest line of the sorrounding highland called the **watershed.** A watershed separates one catchment area from the next.(R. B Bunnett-Physical Geography). In the National Soil and Water conservation Programme (NSWCP), a programme implemented by all the districts in Kenya, a watershed is synonymous to a catchment area.

This paper describes the catchment approach, a participatory methodology towards sound watershed management.

Further, the paper describes Tharaka Nithi District in terms of location, agroecological zones, soils and rainfall. Two case studies have also been taken from different agroecological zones of the district. The purpose of taking the two case studies is to outline the differences in watershed management activities in the two.

Through Dryland Agricultural Research Programme (DAREP) at one of the ASAL stations in the district, it has been established that water conservation, management and harvesting leads to increased crop yields but adoption by land users is low. This is due to research ignoring the land users' participation and recognition of the traditional techniques. Before initiating any water resource development project, views regarding water conservation, management and harvesting should be sought from the beneficiary community through a PRA.

2.0 Catchment Approach Strategy

The Catchment approach is a strategy used by the National Soil and Water Conservation Programme (NSWCP), since 1987/88 financial year in all the districts in Kenya in reaching out to the farmers/land users'.

A catchment area is a focal point of learning and extension. The catchment approach focuses on well defined catchment areas where all farmers undertake soil and water conservation at a given time.

The catchment areas to be worked on are identified early-about nine months prior to implementation. The divisional planning team (DPT-one agricultural technical officer and two agricultural assistants) involve local leaders in proposing priority catchment areas within the administrative division. As a starting point, the DPT conducts a Participatory Rural Appraisal (PRA) prior to launching of the work in the catchments. The PRAs give chance to all members of the community to offer views regarding soil and water conservation and management and afforestation / agroforestry among other local problems. Data collected during the PRA is analysed problems affecting farmers/land users ranked in order of seriousness and a catchment action plan (CAP) is prepared for further discussion with the farmers during the catchment launching baraza{CAP is the plan of action to address the catchment farmers/land users' problems}.At the conclusion of the PRA, i.e. during the launching baraza, The CAP is discussed with the farmers and a catchment committee(CC) is elected by the community. In this context a CC is taken as a committee of elders, men and women who are ready to co-ordinate conservation / management activities (implementation of CAP) among members of the community without payments. The work in the catchment among other things, involves the development of a land management plans (LMPs) to address the specific problems of each farmer/land user in the catchment.

In recent years, a number of agricultural extensionists, NGOs and rural development agents have adopted PRA that gives chance to all members of the beneficiary community to offer views regarding extension and other development issues in their area.

The overall goal of the programme (NSWCP) is " **increased production among land users (Farmers and pastrolists) through sound land husbandry**". Incorporating sound soil and moisture (water) management, land users attain increased agricultural production and hence improved living conditions.

3.0 Tharaka Nithi District.

The district lies in Eastern province of Kenya on the windward side of Mt. Kenya. It has varied agro-ecological zones ranging from upper highland (UHO-forest zone) to lower midland (LM6-lower midland ranching zone).

Annual rainfall in the district ranges from 600 mm to 1800 mm with an annual average of 1500 mm for the upper zones and 600 mm for the lower zones.

The upper zones (UHO, LH1, UM1-UM3) have very deep clay to clay loam soils of moderate to high fertility prompting forest kind of vegetation.(See Map 1)

The lower zones (LM3 - LM6) have predominantly shallow sand loam soils of moderate fertility and characterised by grass type of vegetation coupled with scattered trees and shrubs.

Due to this wide range of climatic and topographic variation, catchment areas use different methods of water shed management depending on their locality.

The district has a potential in water conservation, management and harvesting structures. This can be clearly seen from the examples below and two catchment areas taken as case studies; one in the upper high rainfall zone and the other from the lower low rainfall zone.

Some of the water conservation harvesting and management activities carried out in the district either by farmers themselves or by projects (collaborators) which emphasise the importance of local community involvement include;

a)Tied ridges for the growing of maize and millets- These are contour ridges dammed with small ties down the slope to prevent runoff flow from one end of the field to another. The ties increase surface storage of rain water. This is practised in all agroecological zones but more by the farmers in the ASAL areas of the district.*(see figure 1)*

b)Rock catchments- Kireru rock catchment in Tharaka South division (an ASAL area) is a good example where rain water is harvested from the rock to the side stone gutters, through the sieves then to the two storage masonry tanks from where it is taped to water kiosk for washing and other domestic uses. This is a very successful and a well managed structure due to the use of the traditional (local) knowledge, expertise and management practices of the land users. *(See figure 2)*

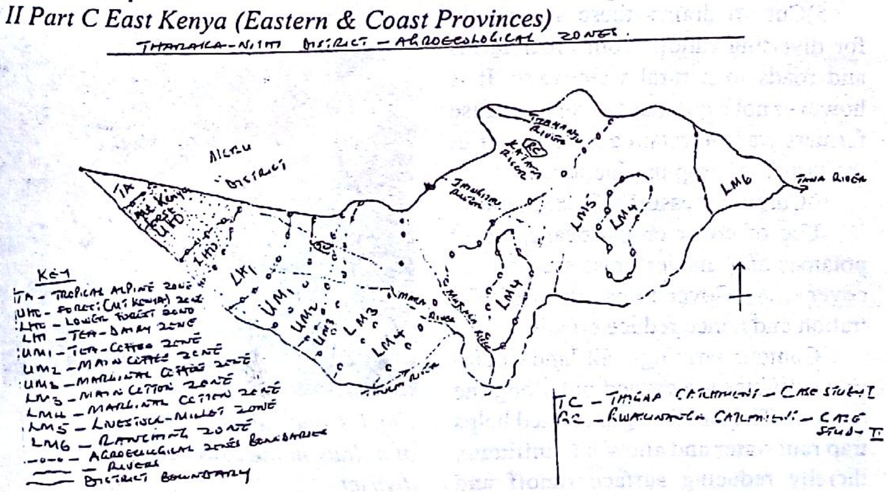
c)Gully control- This is wide spread activity in the district which involves use of check dams to control the speed of runoff and hence increase infiltration and encourage deposition for the gully healing. These have been very successful where the local community has been involved and vise versa where not. Gully control at the Kathwana soil conservation site was successful but maintenance of gabbions lacking because the local community was not fully involved.

d)Basacha sand dam(in ASAL)-- This was constructed by building a stone barrier across the basacha seasonal stream. The barrier was meant to harvest water storage sand whose water was channelled to water kiosk for domestic and livestock use. The structure was however destroyed after completion due to not involving the community at all levels.

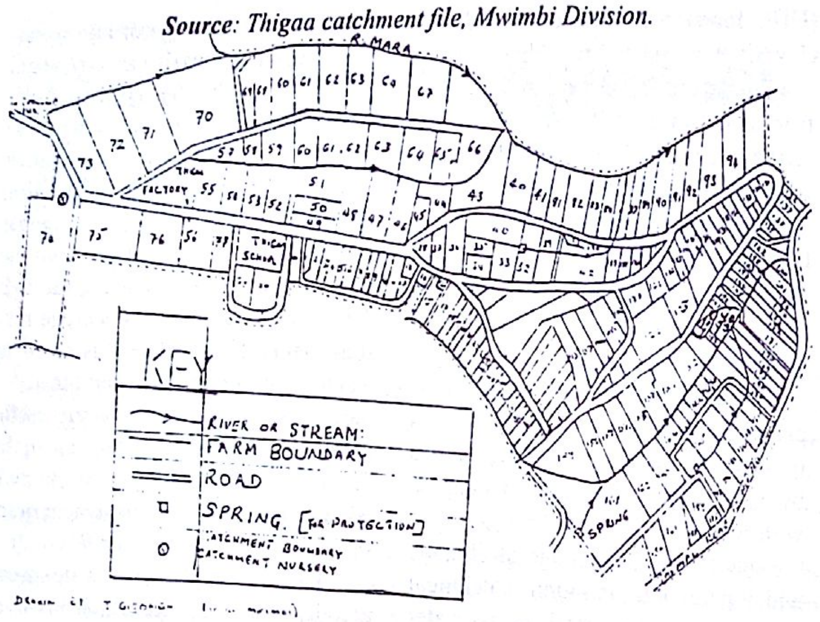
e)Bore holes/shallow wells These are sunk by the Tharaka water and sanitation project in the ASAL areas of the district and dug by individual farmers in other areas. They are good in supplying water for livestock, domestic and kitchen gardening. To some of boreholes sunk by the project operations and maintenance is at the balance once the project winds up due to low community participation.

f) Spring protection/development. This is a practice scattered all over the district. The farmers/land users were involved at all levels protection from identification, planning and implementation. They have spring protection committees who oversee smooth operation and maintenance for

Source: Ralph Jaetzold & Helmut Schmidt-Farm Management Hand Book, Vol II Part C East Kenya (Eastern & Coast Provinces)



Source: Thigaa catchment file, Mwimbi Division.



sustainability. Examples include; Kijege, kaauni and kanyuru springs. (*see figure 3*)

3.1 Case Study 1: Thigaa Catchment

Introduction

Thigaa catchment is in Mwimbi Division. It is in the agro-ecological zone UM2

(Main coffee zone) and covers an area of about 4km2 with about 200 farms. The average slope is 30% due to the presence of Thigaa hill which is about 55% slope but cultivated.

The average annual rainfall is 1200mm and is bimodal. The soils are red sandy loam,which are very erodible.

The population density is about 500 persons per km2 with an average family size of 7 persons.(Map 2)

After the PRA data analysis, the following were found to be the major problems in the catchment;

a)Low yields leading to low incomes,

b)Poor road conditions- the roads were impassable due to rill erosion caused by road runoff, surface runoff from Thigaa hill, shopping centre and farms. This led to difficulties in taking the farm produce (coffee, milk and other foodstuffs to the markets and,

c)Insufficient distribution of water resources.

To address the above problems, the CAP involved developing the following land management plans;

1) Fanya juu terraces--these are made by digging a trench and throwing the soil uphill to form an embankment. They are mainly level terraces with napier grass on the embankment for stability. The trench harvest rain water and the embankment reduce the runoff and hence water infiltrates into the soil profile.

2)Napier grass strips-- napier grass is planted on marked structures instead of digging fanya juus due to lack of capital or labour. the strips reduce runoff and hence increased infiltration

3)Trash lines -- on the marked structures in newly opened farms before putting permanent structures. The trash reduce runoff, increase infiltration and when it rots increases soil fertility.

4)Retention ditches/channels- mainly below the homesteads to harvest and retain the runoff from the same. The water then infiltrates into the soil.

5)Cut off drains--these are mainly for diverting runoff from other farms and roads to natural waterways. It is however not a popular practice because farmers want to retain all the runoff in the farms for crop production.

6)Cultural measures. Examples are;

-Use of cover crops--beans, sweet potatoes and napier grass are used as cover crops. Cover crops increase infiltration and hence reduce erosion.

-Contour farming-- all land operation activities are carried out along the contour. The small ridges created helps trap rain water and allow it to infiltrate, thereby reducing surface runoff and erosion.

-Early planting--early planted crops utilise well the first rains, shoots fast and protect the ground quickly against raindrop impact hence reducing runoff and increasing infiltration.

-Conservation tillage-- herbicides have been used for weeding by a few able farmers. This maintains the soil structure, increase infiltration and hence reduced runoff. When weeds rot they increase soil nutrients and hence fertility.

7) Coffee box terraces with mulching -- every one or two tree stumps are enclosed in a box of soil bunds. These harvest the rain water in situ, increase infiltration and hence reduce runoff.

8)Soil fertility maintenance/improvement practices,

Use of FYM (*Thuumu*). The animal droppings and beddings are swept into a pit where it rots, turned severally for some time after which it is removed and hipped somewhere and covered for further curing after which it is taken to the farm to increase the organic matter content in the soil and hence fertility. Organic matter improves soil structure and water holding capacity.

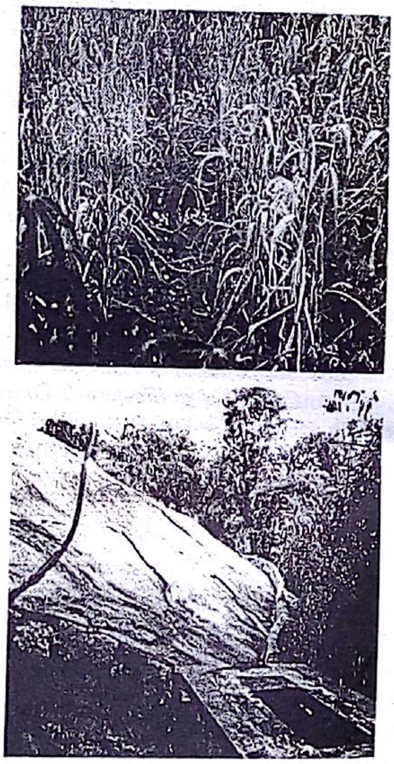


Fig.1 Tioed ridges for the production of millets in the lower zones of the district

...nyori

--early planted crops
st rains, shoots fast
und quickly against
nce reducing runoff
ltration.
tillage-- herbicides
weeding by a few
maintains the soil
infiltration and
ff. When weeds rot
nutrients and hence

erraces with mulch-
two tree stumps are
f soil bunds. These
ter in situ, increase
ce reduce runoff.
maintenance/im-
s,
Thuumu). The ani-
beddings are swept
ts, turned severally
which it is removed
ere and covered for
which it is taken to
the organic matter
and hence fertility.
roves soil structure
apacity.

*the production
zones of the*

-Mulching -- mainly in coffee farms. This is done by use of weeds, crop residues and agroforestry tree cuttings. These protect the ground from raindrop impact, increase infiltration and when they rot, increases the organic matter and hence fertility into the soil.

-Intercropping other crops with leguminous plants such as beans (legumes fix nitrogen into the soil)

-Crop rotation-- maize which cannot cover the ground well is rotated with beans or sweet potatoes which covers the ground well against raindrop impact and hence runoff.

9)Establishment of tree nursery and bulking plots

-The catchment tree nursery has raised both forest and fodder (calliandra) tree seedlings. This has improved agroforestry and fodder production in the catchment. Trees check wind erosion, toots hold the soil particles well against being detached by runoff and leave droppings increase the organic matter in the soil once they rot. Fodder improves the quality of manure for soil fertility.

-Bulking of sweet potatoes and climbing beans both for cover cropping for increased water infiltration and hence less runoff has also been done.

10) Organic farming pits(*marima ma urimi*) for the production of kales Pits of 60 cm2 are dug. The top soil is mixed with FYM and put back to the pit for the production of kales whereas the sub-soil is put on the upper side of the pit to form a soil bund which acts as a soil conservation structure. The pits also harvest water in situ which infiltrates into the soil profile.

NB: Adoption of the above 10 structures is 70%.

11) Road improvement, road runoff control and harvesting;

-The community has done 3 km of various sections of the roads to be able to market their farm produce, hence increased incomes.

-Road runoff is controlled and harvested after short intervals into the farms for crop production. Harvesting channels convey runoff into coffee terraces and napier plots.

12)Spring protection -kaauni spring is in the process of being protected to supply clean water for domestic use. The beneficiaries were involved at all levels- identification, planning and implementation for ownership and hence proper operation and maintenance

13) Riverbank protection -- the portion of river Mara and other streams have their banks well protected by leaving the natural vegetation and planting napier grass (for livestock feeding) to avoid riverbank erosion. (*see figure 4*)

14) Roof water harvesting -- most farmers (80%) harvest rain water from iron sheet roofs into 200 litre drums due to high cost involved in constructing masonry tanks. However around 10% of the farmers have masonry tanks. The 200 litre drums cost Ksh 1000 ($15) whereas an average 2000litre masonry costs around Ksh20,000 ($300). Roof water harvesting reduces runoff from homesteads.(*see figure 5*)

15)Shallow wells -- these have been dug by around 10% of the catchment farmers to provide water for domestic, livestock and kitchen gardening.(*see figure 6*)

In summary, the farmers have stated that, the yields of various crops have substantially increased, hence improved incomes, road network has improved and marketing of farm produce is nowadays easy. With the protection of kaauni spring, the few shallow wells dug by the individual farmers and the roof water harvesting techniques adopted, the water resource distribution has also been substantially improved.

3.2 Case Study 2: Rwakinanga Catchment

Introduction

Rwakinanga catchment is in Tharaka Central Division. It is in the agro-ecological zone LM4(marginal cotton zone) and covers an area of about 9km2 with about 90 farms. The average slope is 6%.

Source: Rwakinanga catchment file, Tharaka Central Division.

The average annual rainfall is 700mm and is bimodal. The soils are sandy loams and clay loams.

The population density is about 200 persons per km2 with an average family size of 6 persons.

After the PRA data analysis, the following were found to be the major problems in the catchment;

a)Soil erosion- by wind due to felling of trees and hence no wind breaks and due to up & down slope cultivation,

b)Felling of trees without replacement,

c)Insufficient water sources and,

d)Poor soils due to the following;

-burning of FYM manure and non application of inorganic fertilisers and,

-burning of trash after harvesting.

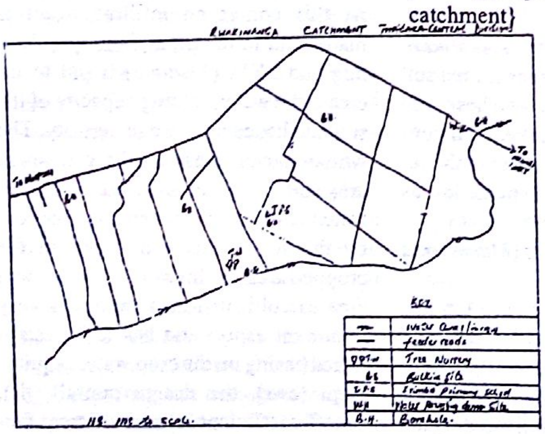
To address the above problems, the following land management plans have been carried out;

1)Fanya juu terraces, unploughed strips and trash lines.{Explanation as for Thigaa catchment}

2)Stone lines -- hipping stones along the marked soil conservation structures. These increase infiltration of the runoff and hence reduce erosion.

3)Cultural measures, Examples are;

-Contour farming. and early planting{Explanation as for Thigaa catchment}



4)Soil fertility improvement practices,

-Use of FYM(*Thuumu*) and to a small extent compost is now very popular with farmers in the catchment.{Explanation as for Thigaa catchment}

-Intercropping other crops(e.g., millets) with leguminous plants such as cow peas and green

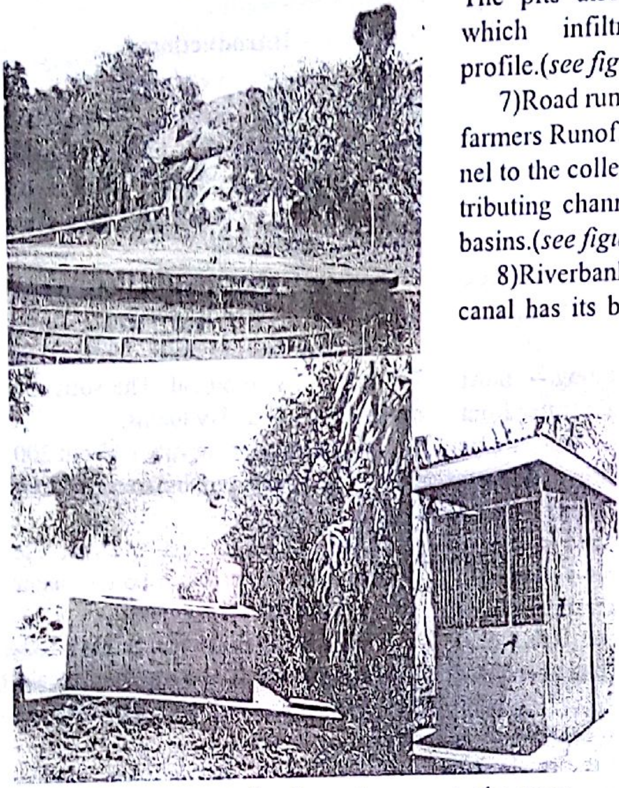


Fig.2 Rock catchment for domestic use,note the stone gutters,storage masonry tanks, the water kiosks, the washing basins and the series of sieves

grams (legumes fix nitrogen into the soil) and,

NB: Millets, cowpeas and green grams are only grown in the low rainfall areas.

-Crop rotation - millets are rotated with green grams or cowpeas. {Explanation as for Thigaa catchment}

5)Establishment of tree nursery and bulking plots

-The catchment tree nursery and a number of private nurseries have raised adequate forest trees.. This has improved agroforestry/afforestation in the catchment. {Explanation as for Thigaa catchment}

-Bulking of napier, makarikari, vertivar and kericho grasses for the soil conservation structures - These are planted either on the marked soil conservation structures or on the embankments of fanya juus. {Explanation as for Thigaa catchment}

6)Banana growing pits (*Marima ma urimi*)

Pits of 40cm^2 are dug. The top soil is mixed with FYM(*Thuumu*) and put back to the pit for banana growing whereas the sub-soil is put on the upper side of the pit to form a soil bund which acts as a soil conservation structure. The pits also harvest water in situ which infiltrates into the soil profile.(*see figure..7.)*

7)Road runoff harvesting -very few farmers Runoff is harvested by a channel to the collecting channel to the distributing channel then to the planting basins.(*see figure8*)

8)Riverbank protection-the water canal has its banks well protected by planting napier grass.

9) Five (5) borehole/shallow wells (8m deep) with casing have been sunk by Tharaka water and Sanitation Project, collaborators in this catchment. They provide water for domestic and livestock use. The farmers/land users' participation is in operation and maintenance.(*fig. 9*)

10)Contour ridging-These are hand and oxen constructed across the slope. The crops are planted on the ridges and the space between ridges form depressions or furrows in which rain water collects and infiltrates into the soil profile.

11)Water canal/furrow - The community have constructed a water canal from river kuuru to provide water for domestic livestock and small irrigation (kitchen gardening).

12)Negarims (V-shaped) for growing of mangoes, pawpaws, oranges and bananas.

Negarims are regular squares turned by 450 to concentrate runoff water at the lowest corner of the square. At this corner an infiltration pit is made, and in the pit a planting hole is dug and FYM (*Thuumu*) is put to increase the water holding capacity of the soil and hence increase its fertility. The whole square consists of a catchment area and a cropped area. Runoff is collected from the catchment area marked by the soil bunds and stored in the cropped area. In this system, catchment area to cultivated area ratio is a very important aspect and has to be established basing on the crop water requirement (cwr), the design rainfall (dr), runoff coefficient (c) and efficient factor (e). The adoption is currently low since it is a new technique but farmers have seen its benefit in that they can grow crops they cannot grow under the current climatic conditions. *[see attached for details].(see figure 10)*

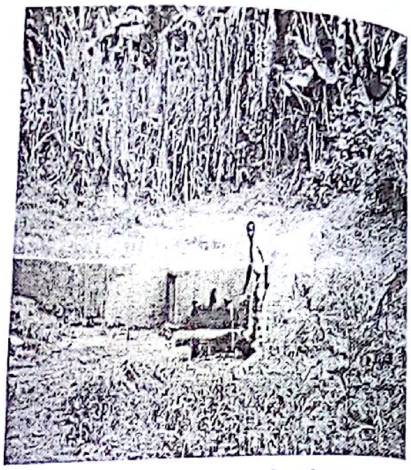


Fig.3 Spring protection for domestic water use.Note extent of protection, the draw pipes and the law water level draw pipe.

13)Roof water harvesting into water jars (ferro- cement tanks) and masonry tanks by very few farmers.

The Canadian Save the Children (CSC), an NGO has trained the users groups on how to construct these water jars. They (CSC) provide cement, chicken wire, pieces of GI pipe, and taps whereas the beneficiaries provide gutters, sand and labour.

The jars have a capacity of around 500 litres and can last an average family of 6 persons for 60 days , drinking only (water for other uses is got from the shallow wells and the canal).

The total cost of constructing one water jar is estimated to be ksh.5,000 ($70) which can be afforded by the ordinary farmer even after CSC winds up

Fig.4 riverbank protection Note the natural vegetation of lantana camara

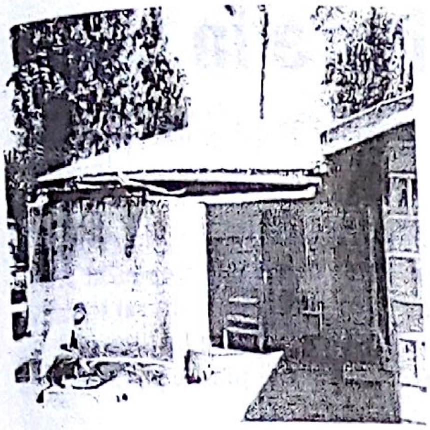


Fig.5 Roof water harvesting by use of masnory tanks

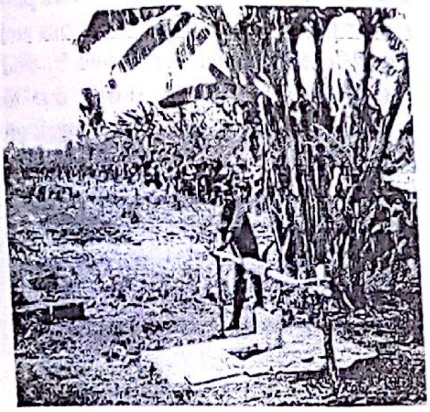


Fig.6 Shallow well for domestic, livestoc and agricultural use. Note the tomatoes grown using the water

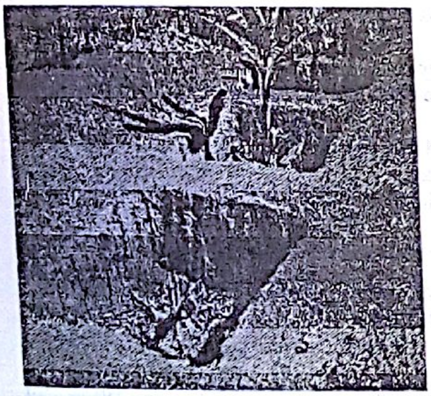


Fig.7 Banana growing pits

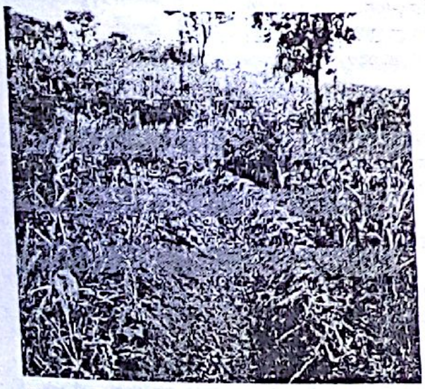


Fig. 8 Road runoff harvesting.Note the harvesting & the collecting channels

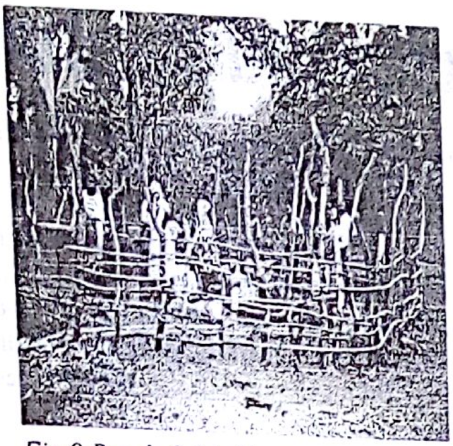


Fig.9 Borehole/shallow well casing for domestic & livestok use.Note the pump & the washing basin

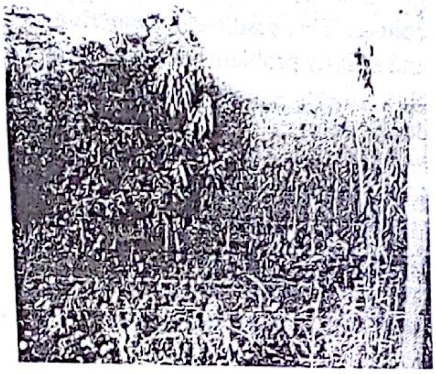


Fig.10 Negarims for the production of mangoes & pawpaws

its operations in the catchment. In contrast, the cost of constructing a 2000 litre masonry tank is around ksh 20,000 ($300) which is unaffordable by the ordinary farmer.

Conclusion

The adoption rate for this catchment is 85%. The benefits which farmers say are accruing from this are, soil erosion is now low, afforestation/ agroforestry improved, water resources at a reachable distance, and due to education on the use of FYM and non-burning of crop residues, the soil fertility has now improved and they are realising high yields.

From the two case studies and the district in general, it has been noted and concluded that it is important to involve the land users or farmers in watershed technique identification, planning and implementation to ensure ownership and hence proper operation and maintenance for sustainability. Of great importance also is to recognise and utilise whenever possible and appropriate, the traditional (local) knowledge, expertise and management practices of the land users.

3.3 Limitation/constraints

The following have however been the constraints in the implementation of watershed in the district;

a)Non-implementation of the recommended LMPs by some laggard farmers,

b)Farmers expecting more than the project can offer such as asking for an irrigation scheme and,

c)Failure by some of the collaborators to meet their commitments and requests.

Conclusion

From the two case studies, it can be concluded as follows;

I. Due to the sound watershed management adopted by farmers in the two case study catchments, crop yields have increased substantially, soil erosion managed, water sources at reachable distances, incomes of the communities improved and hence their living standards,

II. It is of paramount importance to involve the farmers/land users in any watershed management practice/technique development through the use of PRA where their innovations are improved for sustainability.

III.Involving the land users/farmers in any new watershed management technique identification, planning and implementation ensures ownership and hence proper operation and maintenance for sustainability, and

IV.With some form of assistance and education, the land users/farmers are very willing to participate in any watershed management technique due to their difference economical status.

References

Dryland Applied Research and Extension Project, KARI Regional Research Centre, Embu: Conference Proceedings: Participatory Dryland Agricultural Research East of Mount Kenya, January 21-24 1997 at Izaak Walton Inn, Embu.

Edited by: J.N Kang'ara, A. J Sutherland and M. Gethi.

Kithinji Mutunga, Paper presented at: International Soil Conservation Conference 1999 (Unpublished).

Soil and Water Conservation Branch, Ministry of Agriculture, Nairobi, Soil and Water Conservation Manual for Kenya. Edited by: D.B Thomas.

Author: Miriti Joseph Minyori

Drainage of Irrigated Agriculture in India

L. B. Roy, Associate Professor, Arbaminch Water Technology Institute, P.O.Box.21,Arbaminch, Ethiopia

Abstract

Recent efforts in the post independence era to improve the drainage condition of irrigated agriculture in India have been described in detail. These efforts include the adequate provision of fund for drainage component of any irrigation project, a network of well coordinated research activities under Indian Council of Agricultural Research and other state Agricultural Universities and adequate training programmes through State Training Institutes (STIs). the Indian industry is capable of providing drainage materials e.g. clay tiles, concrete tiles and plastic pipes and also various equipment required for drainage construction.

Introduction

Agriculture occupies a key position in the Indian economy because of its contribution to overall economic growth through supplies of food, raw materials and exports. It is a source of livelihood for a majority of the population and provides a large market for non-agricultural goods and services. It contributes about 40% to the gross national product and provides employment to over 70 percent of the working population. However, it has often been observed that the Indian economy fluctuates with the agricultural production in the country, which in turn, depends heavily on the monsoons which are often very erratic i.e. untimely, inadequate and non-uniformly distributed. Sustained agricultural production over a period is very effective in controlling the consumer price index even if there is drought in some parts of the country for 2-3 years (IMTP, 1988). Thus both irrigation and drainage have to play very important role in protecting and stabilizing agricultural production in the country.

Status of Irrigation and Drainage

After independence, India adopted the policy of planned development beginning in 1951-52. Agriculture was given very high priority and therefore, irrigation development was given a boost. By the end of seventh five year plan (1985-90), an irrigation potential of 80.80 million ha has been developed as against 22.6 million ha in 1951. The target for the ultimate irrigation potential is 113.5 million ha which is to be achieved by 2010 AD. However due to the zeal to create more and more irrigation potential, the due attention was not given to the drainage aspects of agriculture. This resulted in waterlogging and salinity problems in many irrigated areas. Table - 1 shows the command deficiencies in projects visited by the central team on water utilization (CWC, 1980). In this Table item no 5, 8 , 9 and 16 indicate the urgent need for drainage in irrigated agriculture. Bhargava (1988) has estimated that an area of 6.0 million ha suffers from partial or full waterlogging conditions and about 7 million ha is affected by soil salinity and alkalinity mostly due to poor drainage. A state-wise break up of waterlogged area is as given in Table 2. Also the area under salt-affected soils has been given in Table 2 and Fig.-1. Except for most parts of Bihar, West Bengal, Orissa and Kerala, the

Table - 1 Command Deficiencies in Projects Visited by Central Team on Water Utilization (CWC, 1980)

SL. NO	Deficiencies in Irrigation Projects	Number of deficient projects out of 25
	Engineering	
1.	Reappraisal of available surface and return flow from Irrigation	16
2.	Pumping of irrigation water and its effects	2
3..	Silting of reservoirs, conducting sedimentation surveys and measures to prevent silting	11
4..	Insufficient number of hydrological and meteorological stations in command and catchment areas	4
5.	Excessive seepage and need for determining it. Lining of canal is required	22
6.	Tail reaches do not get enough irrigation water	5*
7.	Absence of conjunctive use of ground and surface water	18
8.	Inadequate drainage system and waterlogging	19
9.	Salinity in soils and ground water	7
10.	Bad maintenance of canal system	19
11.	Improper operation of reservoir and canal system	10
12.	Canal cannot carry design discharge	5
13.	Insufficient canal structures and their improper maintenance	13
14.	Lack of communication facilities in the command	12
15.	Lack of field channels and proper maintenance	11
16.	Improper water management	25
	Agronomy	
17.	Improper cropping calendar and cropping pattern	23
18.	Lack of research to determine the water requirement of crops	12
19.	Lack of research to determine suitable types of crops to suit the soils in the command	17
20.	Poor extension services, lack of pilot projects, demonstration farms, etc.	20
21.	Lack of detailed soil surveys of command areas	16
22.	Excessive application of irrigation water to crops	10

** : Presumably at the tail of the distributory, not of water course and even then this figure seems low. At the tail of the water course, this figure would certainly be 25 (WALMI, 1989).*

Table 2 : State-Wise Distribution of Waterlogged Area in India (Bhargava, 1998)

State	Waterlogged area (in ' 000 ha)	Salt affected Area (in '000 ha)
Punjab	1090	404
Haryana	620	526
U. P.	810	1295
Bihar	117	4
Rajasthan	348	728
Gajarat	484	1214
M. P.	57	242
Karnataka	10	404
A. P.	111	240
Maharastra	339	534
West Bengal	1850	850
Orissa	60	688
Tamil Nadu	18	4
Kerala	61	16
Delhi	1	16
Jammu and Kashmir	10	-
Total :	5,986 ~ 6 million ha	7,165 ~ 7 million ha

waterlogged area is situated in arid and semi-arid states of the country, where irrigation has been developed in the recent years.

The happy development in food grain production has been associated with increase in the irrigated area, fertilizer consumption and the area under high yielding varieties as shown in Fig 2. However, the overall productivity in the irrigated areas remains quite low as shown in Table 3.

Command Area Development Programme

One of the most important steps to enhance the agricultural production is the Command Area Development Programme (CAD) which is sponsored by the central Governments with equal participation of the State Governments. Currently this programme covers an area of 17.3 million ha in 130 irrigation projects in the country. The important activities of CAD programme are: construction of field channels including its lining in vulnerable reaches, land shaping and land grading, systematic programme of land consolidation, farm roads, field drains and intermediate drains. Much emphasis has been given to the construction of field drains and intermediate drains. Therefore, yields are supposed to be improved through better soil and water management practices besides other measures e.g. credits, marketing facilities etc. In some command areas surface ditches of 2.0 m depth have been constructed to serve both as a surface drain and subsurface drain.

Table - 3 Production Levels for Rice and Wheat Crops in India (IMTP, 1988)

Crop	Year		
	1951-52	1983-84	1989-90
Rice			
A	30.8	41	21.5 [Irrigated]
Y	66.8	1458	2237.0 [Irrigated]
A			22.5 [Unirrigated]
Y			1151.0 [Unirrigated]
A			44.0 [Total]
Y			1682.0 [Average]
Wheat			
A	9.7	24.5	22.9 [Irrigated]
Y	665.0	1851.0	2210.0 [Irrigated]
A			5.1 [Unirrigated]
Y			1059.0 [Unirrigated]
A			28.0 [Total]
Y			2000.0 [Average]

A : Area in million ha , Y : Yield in kg/ha

Vertical Drainage

In canal irrigation areas, because of continuous and intensive application of surface irrigation, the subsoil water table rises up resulting in waterlogging and salinity hazards. These can be prevented by withdrawing water from ground water also, which will lower the water table and reduce the soil salinity and waterlogging hazards.

In areas where ground water is brackish and has been rising fast upward, conjunctive use of surface and ground has special importance. The upward rising trend of saline ground water can be controlled by installing augmentation tube wells and the saline water can be mixed with canal water for making its use for irrigation.

In any tube well drainage scheme, the following aspects of water quality vis - a- vis depth is considered :

In order to find out the aquifers to be tapped, investigations in respect of depth of aquifer and water quality is carried out by extensively covering the project area.

If the water quality varies with depth, only those aquifers which are with good quality water are tapped , provided these aquifers are connected to water table .

In case fresh water floats over saline water, installation of skimming wells is preferred.

Vertical drainage has been provided with the installation of shallow tube wells in some of the command areas of India. Thus the conjunctive use of ground and surface water is practiced to form a dynamic equilibrium condition i.e. to maintain the constant depth of water table. Where the ground water is saline, mixing it with good quality surface water has also been tried successfully. A few examples are as described below:

Gandak irrigation project is an international major irrigation and power project involving Bihar and UP states of India and adjacent portion of Nepal.

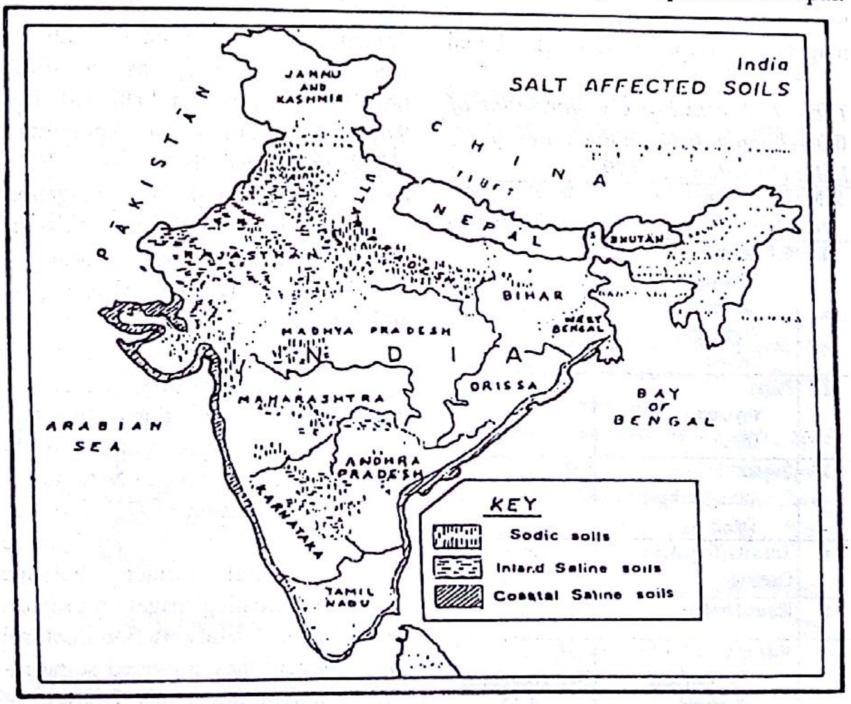


Fig.1 Salt-affected soils of India (Source CSSRI,Karnal,1986)

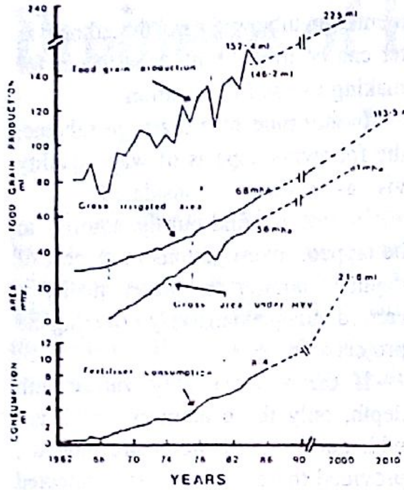


Fig 2 Progress of food production, irrigation development, area under high yielding Varieties (HYV) and fertlizer use India (Source-Randhawa and Rajput 1986)

In the eastern UP portion of the project, irrigation was first started in 1971. The depth of ground water table was high i.e. 3 to 4 m below ground surface and showed a further sign of rise. Therefore, surface drainage system was planned in the area, but very few field drains could be constructed due to extremely small sizes of land holdings. Hence, it was decided to have vertical drainage system in the area to control the rise of ground water table consisting of 2000 such tube wells. Since the ground water is of good quality , the water from these tube wells is used for irrigation (Western Gandak Canal Project Report, 1986).

Table 4 Norms For Categorization of Waterlogged Areas in the States of India (Navalawala, 1991)

SL No	Name of State	Water Table Depth below Ground level (m)
1	U. P. (Sharda Sahayak project):	
	Worst zone	<1
	Bad zone	1-2
	Alarming zone	2-3
	Safe zone	>3
2.	Punjab:	
	Very Critical	0-1.5
	Critical	0-2.0
3.	Haryana:	
	Critical Waterlogged	0-1.5
	Critical	1.5-3
4.	Karnataka (Tungabhadra Command):	0-2
5.	Himachal Pradesh:	0-2
6.	Maharastra:	
	Fully Waterlogged	Water at ground surface
	Waterlogged	0-1.2

In the state of Haryana which is situated in the semi-arid /arid zone of the country, the ground water is brackish. Therefore, a system of skimming wells has been tried with good results. Water pumped out from these skimming wells are mixed with canal water and used for irrigation. Similar efforts have been made in Punjab also (WTC, 1987).

Research Efforts in Drainage

The need for drainage in the present context was realized as early as 1865 when for the first time the then Government of Punjab drew the attention of the then Governor General to the seriousness of the problem of reh and usar in the canal commands. In 1876, the problem of soil salinity was reported from Uttar Pradesh and at about the same time from Nira canal command in Maharashtra. Alarmed by the exodus of population from Amritsar (Punjab), a tubewell drainage. experiment was started with 16 tubewells of 0.0425 cumecs capacity each. Experiments were also laid out on tile/pipe drains in Maharashtra and Punjab. Comprehen sive work on drainage was carried out in Maharashtra leading to compilation of observations and design techniques in the Technical Report No. 56 submitted to Maharashtra Government in 1937. The report is still referred to for drainage design in the state. A subsurface drainage research Institute functioned at Ibban (now in Pakistan). The Royal Commission on Agriculture (1928) mentioned "Now lessons have been learnt and in all future irrigation projects, drainage will form an essential component". However, observations were mainly confined to papers and irrigation projects continued to be commissioned without proper provisions of drainage, even after independence. The concept of irrigation and drainage to go together was religiously emphasized by the second National Irrigation Commission (1972) and National Commission on Agriculture (1976). Several surface drainage schemes in existing irrigation projects were laid out mainly as flood control measures and they provided some relief to agricultural lands. Because of realization on the part of the agricultural scientists that farm drainage and subsurface drainage will play an important role in the solution of problems related to waterlogging and soil salinity, large number of small scale experiments were carried out by various institutions throughout India as described below:

The major research efforts on agricultural drainage are being made through the state agricultural universities, various research institutions under the Indian Council of Agricultural Research (ICAR), various state training institutes i.e. water and land management institutes (WALMIs) and irrigation management training institutes (IMTIs) etc. Some of the important topics of research on drainage are :

-tolerance of various crops and crop varieties including paddy to submergence and high water table conditions.

-Estimation of drainage coefficient for different areas and crops. Gupta et. al (1971)developed drainage coefficients for surface drains for different parts of the country.

-Subsurface drainage design criteria (CSSRI, 1986)

-On farm drainage methods to meet the requirements of different crops (Rajput, 1986)

-Reuse of drainage water for irrigation paddy

-Studies on leaching of salts.

The norms for monitoring ground water table for estimating the extent of waterlogged area vary from state to state in India as given in Table 4

Central Soil Salinity Research Institute (CSSRI) Karnal, Haryana is a research institute under ICAR. The output of researches at this Institute has led to the development of effective and economically viable technologies for the management of salt affected soils. CSSRI is also researching design criteria for the tile drainage system and its effects on crop yields. Some of the results are as given in Table 5:

Studies were carried out on an experimental basis to develop design criteria of subsurface drains at Punjab Agricultural University, Ludhiana in 1966. At Jawaharlal Nehru Krishi Vishwa Vidyalaya (J. N. K. V. V.), Indore, experiments were carried out in 1970 - 71 to examine the effect of subsurface drains by installing two tile lines of 10 cm diameter and 30 cm long semi-glazed stone tiles at a depth of 1.0 m and a spacing of 14.0 m. At Pant Nagar, U. P., studies were conducted in 1972 for finding out the proper spacing of tile drains (between 15 m to 35 m) and to develop the design criteria for transient state condition. Similar works have been done and are under progress at many other state agricultural universities (Chauhan, 1988).

Training Activities

India has developed a very comprehensive programme for in service training on different aspects of irrigation e.g. operation, maintenance, monitoring, soil and water management including drainage. State Training Institutes (STIs) have been established in 12 states with the support provided by World Bank and United States Agency for International Development (USAID). These Institutes offer training to in service personnel of Irrigation Departments. Courses on surface and subsurface drainage aspects are integral parts of these training programmes. In 1988, under USAID supported programme, the Irrigation management and Training project (IMTP, 1988) prepared 'a Handbook on Drainage of Irrigated Areas in India' which is being used by State Training Institutes and many universities for their teaching and training programmes.

Drainage Materials and Machinery

India has its own well developed industry for manufacturing agricultural tractors and other equipment. Annual production of tractors (15 to 50 H. P.) has already exceeded 100,000. Heavy machines used for construction of drainage works e.g. crawler tractors, excavators, back-hoes, draglines and trenchers are also manufactured in the country. Tile drains of both clay and concrete are available almost every where in the country. Plastic pipes with perforations are also manufactured in the sizes of 25 - 200 mm. Recently, the manufacturing of perforated corrugated polyvinyl chloride (PVC) pipes has also been started in India. All these

Table : 5 Crop Yields for Different Pipe Drain Spacings (CSSRI, 1986)

Drain spacing (m)	Crop Yield (t/ha)				
	Sorghum	Mustard	Barley	Wheat	Cotton
25	0.8	2.4	4.2	4.9	1.8
50	0.7	2.0	2.9	4.0	1.6
75	0.4	0.9	2.0	2.5	1.6

manufactured materials are standardized by the National Bureau of Standard (NBS) which is an autonomous body in the country with the primary responsibility of framing standards and specifications for all kinds of goods and products.

Conclusions

Important factors which increase agricultural production in irrigated areas are proper soil and water management, quality seeds, application of fertilizers and other chemicals, credit, marketing, communication and extension. Of all these water management is vital. Poor water management results not only in lower yields but also in wastage of scarce water and creates waterlogging conditions and salt related problems.

India has made planned and concerted efforts in the post - independence era to improve crop yields in its irrigated areas by improving drainage systems and adopting better water and land management practices. These efforts are through the concept of command area development programmes (CAD). In the new projects, adequate financial provisions are made for the drainage works so as to obtain sustained production. All the above efforts are being well supported with very comprehensive and integrated research activities through Indian Council of Agricultural Research (ICAR) and other state Agricultural Universities. A well coordinated training programme has also been established with the assistance of World Bank and USAID. Indian industry is quite capable to provide materials and machinery of good quality and standard required for drainage construction.

References

1.Bhargava, G. P. (1988), ' Characteristics and Extent of salt Affected Soils,' Lecture notes of National Training course on Field Drainage for the Control of Ground Water Table and Soil Salinity in Irrigated Agricultural Lands of Semi-arid Regions, PP 1-7, Vol. II, CSSRI, Karnal, India, 1988.

2.Central Soil Salinity Research Institute (1986), ' Drainage Investigations for Salinity Control in Haryana,' Karnal, India, 1986.

3.CWC (1980),' Recommendations of Central Team on Water Utilization on 25 Existing projects', Central Water Commission of India, R. K. Puram, New Delhi, 1980.

4.Chauhan, H. S. (1988) , 'Subsurface Drainage of Agricultural Lands', National Symposium on ' Management of Irrigation System,' CSSRI, Karnal, India 1988.

5.Gupta, S. K. , K. G. Tejwani and Ram Babu (1971),' Drainage Coefficient for Surface Drainage of Agricultural Land for Different Parts of India,' The Journal of Irrigation and Power, 18(1), 1971.

6.IMTP (1988),'Handbook for Drainage of Irrigated Areas in India , ' LBII & WAPCOS (I) Ltd, New Delhi, March, 1988.

7.Ministry of Irrigation and Power, Govt of India, (1972), 'Report of the second Irrigation Commission', Vol. I New Delhi, PP. 310, 1972.

8.National Commission on Agriculture (1976), 'Report of the Commission', Part V, New Delhi, 1976,

9.Navalawala, B. N. (1991),' Waterlogging and its Related Issues in India' The Journal of Irrigation and Power, CBIP, January 1991, New Delhi.

10.Rajput, R. K. (1986), ' Research on Water Management, Progress Report', 1983 - 85, coordinated project for Research on Water Management,' ICAR, 1986, New Delhi.

11.Randhawa, N. S. And Rajput, R. K (1986) ' Irrigation Water Management Research - National Perspective', Indian Science Academy, 1986, New Delhi.

12.Water Technology Centre (1987) , ' Sixth Annual Workshop of ICAR coordinated projects on Agricultural Drainage under Actual Farming Conditions on Watershed Basis', ICAR, 1987, New Delhi.

13.Western Gandak Canal Project (1986),' Progress Report (revised) 1984-85', Government of UP, Lukhnuw, India, 1986.

Warabandi - an Effective Water Distribution Method in India

L. B. Roy, Associate Professor, Arbaminch Water Technology Institute, P.O.Box.21,Arbaminch, Ethiopia

Abstract

Food security is critically dependent on irrigation and some 60 percent of the food production is from irrigated lands in Asia. If water distribution system is well operated, many other important management objectives e.g. on farm water management can be satisfactorily realized and therefore, high water use efficiency can be obtained. Warabandi, a rigid water distribution system, is widely practiced in India to encourage farmers to make better use of their water, to add more value to their existing supplies and to release water for more pressing uses elsewhere. The 'warabandi' has been described in detail with the help of an illustrated example. Ideal situations and the major constraints of warabandi have also been described. Some important issues related with warawandi like equity and lining of water courses have also been discussed.

1.Introduction

Water has always played a central role for the existence of human being. It is linked to rituals, superstitions and attitudes and its administration is largely political. Global estimates indicate that irrigated agriculture produces 40 percent of the food and agricultural commodities from 17 percent of agricultural land. This makes food security critically dependent on irrigation. This dependence is most critical for Asia where some 60 % of the food production is from irrigated land. The relative contribution from irrigation varies from region to region and from country to country as shown in Table - 1 (DFID, 1997).

In latter 1970s and early 1980s , much attention was paid to the distribution of water among farmers below outlets for maximizing the water use efficiency in India. Sometimes this was called RWS (rotational water supply) and sometimes RWD (rotational water distribution) but the most common term was **warabandi**. This system was adopted in north west India and Pakistan since at least the second half of the nineteenth century and has been described in its contemporary form by Malhotra (1982). In the present paper, one of the tertiary distribution systems i.e. warabandi has been described in detail with an illustrated example. Apart from this its constraints and some related issues like equity and lining of water courses have also been described.

2.Existing Water Distribution Approaches

Water distribution is a two dimensional problem in time and space : **technical**, i. e. Planning, design and operation of water distribution system and **social**, i. e. literacy, lack of cooperation, lack of effective leadership, pressures from influential farmers, vested interests, etc. The main water distribution methods are the following (Meijer , 1993) :

Continuos flow or **proportional flow :** In this method water flows continuously in the entire canal network and is proportionally distributed to the irrigated farm areas. Also the flow is adjusted to match the changing crop water requirements during the irrigation season.

Fixed flow : It is similar to continuos flow but the flow size is kept constant throughout the season.

Rotational or on - off system : In this method, the farmers receive water in turn at a pre-determined time and at a fixed rate. Rotation is also applied among canals i.e. in turn these will convey either the full flow or no flow at all.

On demand : In this method, there is a continuous but fluctuating flow in all canals i.e. the farmer is free to use the water as he needs. However, to limit these fluctuations, the freedom of the farmer is often restricted in one way or another.

2.1 Requirements of a Water Distribution Method

The major requirements of a good water distribution method are:

- appropriateness,
- equity (both social and locational equity),
- predictability,
- adequacy,
- timeliness,
- flexibility,
- incentive to users and
- less scope for malpratices.

2.2 Local Names to Important Rotational Methods in India:

These are :

i) **Shejpali or Rigid Shejpali** or **Rigid Water Supply** (used in states of Maharastra, Gujarat and Karntaka),

ii)**Varavaram** (used in Tamil

Table - 1 Food Production From Irrigated Land (DFID , 1997)

Region	Food Production From Irrigated Land (%)
Asia	60
Pakistan	80
China	70
India	50
Indonesia	50
Middle East and North Africa	33
Egypt	98
Iran	50
Latin America	10
Chile and Peru (food crops for export)	50
Sub - Saharan Africa	9
Madagascar	20

Nadu) and
iii)**Warabandi** (used in North - West India)

In India, generally rotational methods are used and the rotation may be made between :

·Two water users
·Two or more groups of water users
·Outlets
·Distributories and minors or
·Definite sections of main canal

2.3 Merits and Demerits of Rotational Methods

The important merits and demerits of rotational water distribution methods are the following :

·Closure period is beneficial in lowering the ground water levels.
·Smaller cross-section of main canal, though larger cross-section of the distributory canals.
·Helps Engineer to organize his time and enables him to supervise a bigger area.
·Easy for periodical maintenance.
·Less chances of conflicts among farmers.
·If rotation period is more, it may cause water stress resulting in reduced yields.
·Low field application efficiency, if there is no control on the time of individual irrigation.
·Farmer has to adjust himself as per the rotation schedule as these are supplier controlled methods.

3.Macro and Micro Distribution System in India

Macro distribution system consists of distributories and minor off taking from main and branch canals, and micro distribution comprises water courses off taking from distributories and minors. The major differences between the two are :

Whereas capacity of a distributory / minor decreases from head to tail as the outlets take off on the way, the capacity of a water course is constant throughout its run as it serves its command area through the off taking turnouts.

Responsibility of regulating supplies to meet the demand of the command in the distributories / minors rests with the Government i.e. Irrigation Department, whereas the responsibility of distributing flows in the water courses to various holdings rests with the farmers themselves with the minimum interference from the Irrigation Department under warabandi system in which the time in proportion to the area of holding is allotted to each farm.

Maintenance of macro distribution system rests with the Government agencies and that of the micro network rests with the beneficiaries. However, the initial planning, layout, design and construction of micro system from Government controlled outlet to 5-8 ha sub-chak turnout will be borne by the Government.

Thus the micro distribution network comprises part of the canal system below the irrigation outlet. The command area of an outlet is called **chak** which is generally from 30 to 60 ha, average being 40 ha and the discharge of the water course varies from 21 to 42 litre per second, 30 litre per sec being the average value. The irrigation channels in the command area of a **chak** are:

Water course which carries water from the outlet to the turnouts for irrigating 5-8 ha size sub-chaks (Fig 1) and

Field channels carrying water from turnout to individual holdings of about 2 ha and above within the sub chak. Sometimes farm channels are also constructed within a holding to irrigate individual fields. Losses in the unlined water courses and field channels including field application constitute about 50 % of the total losses in the water conveyance system. Therefore, it is imperative that the water courses which are generally constructed by the Government, are lined to save the scarce water. It is also desirable to line the field channels but this depends upon the farmers' financial resources as these are constructed and maintained by them.

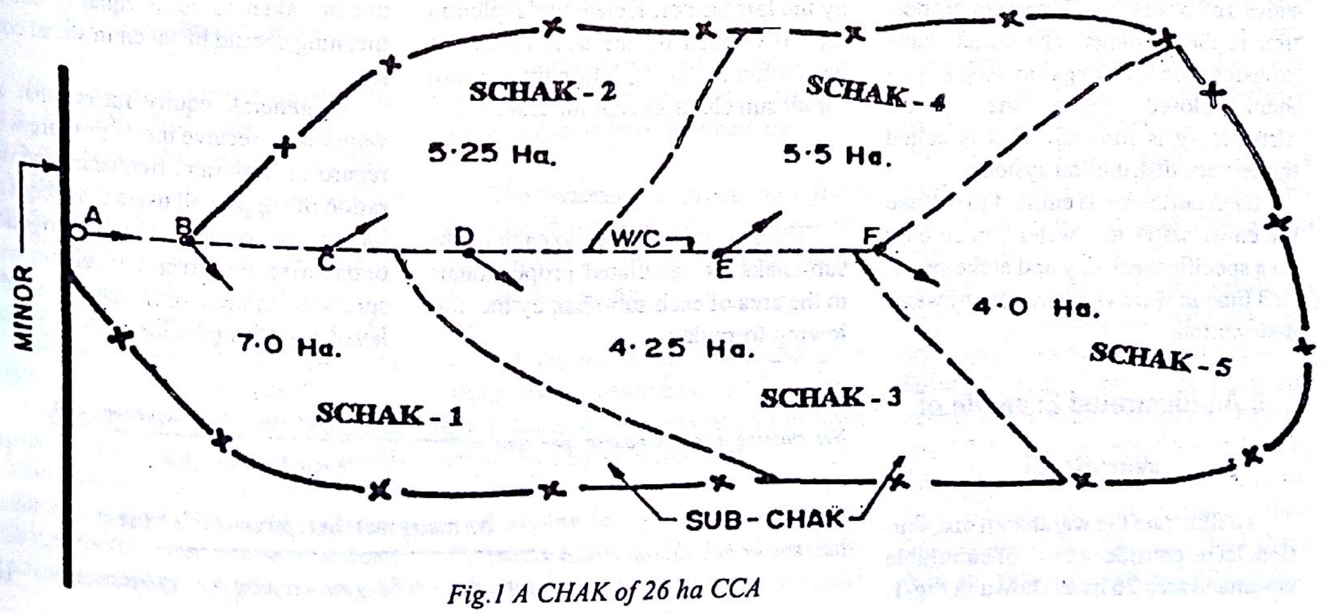


Fig.1 A CHAK of 26 ha CCA

Table - 1 Statement of Warabandi Roster Within the Specified Chak* (Fig - 1)

Sl. No.	Name of Sub-Chak	Area of Sub-Chak (ha)	Length of W/C (m)	Time Allotted Hr. Min.	Filling Time in Min.	Depletion Time in Min.	Net Time Hr. Min.	Taking Over point	Handing Over Point	Starting Day & Time	Completing Day & Time
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(1)	(11)	(12)
1	SCHAK-1	7.00	200 (AB)	45.09	10	-	45.19	Head outlet (A)	TOR - 1 (B)	MON 6-00	WED 3-19
2	SCHAK-2	5.25	150 (BC)	33.52	7	-	33.59	TOR - 1 (B)	TOR - 2 (C)	WED 3-19	THU 13-18
	SCHAK-3	4.25	225 (CD)	27.25	11	-	27.36	TOR -2 (C)	TOR - 3 (D)	THU 13-18	FRI 16-54
4	SCHAK-4	5.50	300 (DE)	35.28	15	-	35.43	TOR - 3 (D)	TOR - 4 (E)	FRI 16-54	SUN 4-37
5	SCHAK-5	4.00	200 (EF)	25.48	10	35	25.23	TOR - 4 (E)	TOR - 5 (F)	SUN 4-37	MON 6-00
	Total :	26	1075	167.42	53	35	168.00				

4. Concept of Warabandi

'***Wara***' means turns and '***Bandi***' means fixation i.e. warabandi means fixation of turns. In this method, the available water is allotted to cultivators in proportion to their holdings. The utilization of irrigation supplies is left entirely to the cultivator who is under no obligation to grow any particular crop in an area. The main canal feeds two or more branches which operate by rotation and may or may not run full. This is the primary distribution system and runs continuously throughout the irrigation season. Branch canals supply water to a large number of distributories which must run at full supply level (FSL) by rotation. This is called the secondary distribution system.

The distribution of water coming out of an outlet is managed by cultivators. The distribution of this water is done on a 7 days rotation basis with the help of an approved roster which divides 168 hours (i.e. 7 days) in proportion to the holdings. The outlets have no gates and it is illegal to keep any of them closed when the parent distributory is running. This is called the tertiary distribution system.

Each cultivator is entitled to receive the entire water in a water course only on a specific week day and at the specified time in warawandi system of water distribution.

5. An Illustrated Example of Warabandi

To illustrate the warabandi distribution, let us consider a chak of culturable command area 26 ha as shown in Fig-1. Based on topography of the area, the chak has been divided into 5 sub-chaks and each of these is served by an independent turnout. Since it is easy for even an illiterate farmer to remember the day of a week than the date, the warabandi roster is prepared for week days e.g. Monday 6 AM to Monday 6 AM (i. e. for 7 * 24 = 168 hours). Filling and depletion time of the water course is accounted for while calculating the allotment of time. Based on experience the filling and depletion times for a lined water course are taken as 3 and 2 minutes and for unlined water course as 5 and 3 minute respectively for a length of 61 m (200 feet). While working out the net time of allotment filling time is credited to and depletion time is debited from the account. Filling of water course starts from the head and proceeds towards its tail. At the end of the rotation, the whole length of water course, which has been filled with the common pool time, is utilized by the last farmer. Hence the depletion time is debited on the account of the last farmer i.e.the depletion time is zero for all sub chaks except the last .

The net time allotted to each of the sub-chaks is calculated proportionate to the area of each sub-chak by the following formula :

$$\text{Net running time in hourse per unit} = \frac{168 - \text{total filling time} - \text{total depletion time}}{\text{Total CCA of chak}} \qquad (1)$$

$$\text{Total time for each sub\_chak in hours} = \frac{\text{Net running time in hours per unit of CCA * Area of}}{\text{Sub chak} + \text{its filling time} - \text{its filling time} \quad \text{its depletion time}} \qquad (2)$$

The warabandi roster for the chak given in Fig - 1 has been prepared based on the above concept and has been given in Table - 1.

6. Equity of Water Distribution

In many irrigation projects, power, wealth and personal communications are used to exercise strong political pressure in order to favour certain water user over the others. The greater the degree of flexibility, the greater will be the opportunity for an allocation policy to be corrupted by these human factors. A demand based schedule is the most flexible allocation policy and, therefore, the most sensitive to influence (Walker , 1998). One essential criterion of well managed project is the ability to distribute water equitably to all farmers within the command area. The criterion of equity is of critical importance wherever water supplies are scarce in relation to demand. The term equity may not be taken as strict equality but its meaning should be taken in social context.

In general, equity means that all water users receive their fair share with regard to flow rate, frequency and duration of supply; all users share equally inconveniences such as night irrigation or day irrigation in certain regions with sprinkler system of irrigation or delayed supplies (Walker, 1998). Equality may be interpreted as all water users share equally surpluses and shortages. Also, it should favour the under privileged small holders over the privileged large farm holders.

Farmers who have to irrigate at night feel themselves worse off than those who can irrigate during the day. Anarchy favours the strong and ruthless, and penalizes the weak and timid. It is common for head reach or otherwise powerful irrigators to have gained the pre-emptive rights to irrigation flows during the day. However in north-west India, warabandi turns rotate each year between day and night i.e. a farmer who has day in one year, has night in the next (Chambers , 1988).

Equity can be classified into two types:

6.1 Equity Between Large and Small Farmers

If the water is allocated in proportion of the land holding, large farmers get a larger share of water as compared to small farmers (e. g. Warabandi in north-west India). Such type of allocation is inequitable from the social point of view. In Maharashtra, Shejpali system which is a sort of modified demand system, water is allocated as per the area demanded by the farmers, and if area demanded exceeds system's capacity, differential 'cut' is applied i. e. more cut to large demands and less cut to small demands (WALMI, 1989).

6.2 Locational Equity

It means the equity of water distribution in different locations of the system at macro and micro level. Following indicators can be used to judge the locational equity:

Variation in cropping pattern/cropping intensities/yields/water availability between upper one - third (1/3) , middle one third (1/3) and tail one third (1/3) of the main system.

Variation in cropping patterns/ cropping intensities/yields/water availability between upper one-third (1/3), middle one-third (1/3), and tail one-third (1/3) of water course command (outlet command).

7. Lining of Water Courses

It is generally seen that by lining about 40-50 % of the length of water course / field channels, about 70-90 % of the seepage loss could be saved. Such selective lining will also ensure adequate size of farm stream for the sub chaks / fields at the tail end. Therefore, about 50 % of the length of water courses / field channels including vulnerable reaches should lined. The vulnerable reaches will be:

Very pervious soils (full length)

Embankment of height 0.5 m and more i.e. Canal in high filling (full length)

Curves (upto 5 m on either side, in addition to the curve length)

Upstream and downstream of structures e.g. Drops, measuring devices and crossings (5 m up stream and 5 m down stream)

Black cotton soils (full length).

If the length of lining in the above reaches does not add upto 50 % length of water courses, additional lengths may be lined to make up to 20 % as follows in order :

Section with a running period of 4 days or more in each rotation

Sections with a running period of 2 to 4 days.

The factors involved in evaluating a criteria for determining the length of the water courses to be lined are :

·The increase in production from the cost of water saved by seepage reduction must justify the additional investment in lining.

·No farmer in the command of a water course would have to carry water for a distance in excess of 550 m from the water course to his field.

Thus the lining of water course in the reach AB (Fig-1) is the most cost effective (running period = 7 days) and perhaps lining beyond D (running period = 2.5 days) may not result in significant reduction of seepage loss commensurate with the extra cost of lining.

For uniformity, it may, however, be considered to line the entire length of the water course. In general, the responsibility of construction of field channels rests with farmers, whose financial condition may not permit them to line even the selected / vulnerable reaches of the field channels. Therefore, it should be decided in principle to have unlined field channels in the project with an advice to the farmers' organization to line the vulnerable reaches when the benefits of projects begin to flow and improvement in their economic condition takes place and the general awareness to derive maximum benefit in an equitable manner is realized.

8. Discussions

The idea of introducing warabandi outside the north west of India has a history. Both second Irrigation Commission of India 1972 and the National Commission of Agriculture , 1976 saw warabandi with fixed times but taking water throughout at night. Also the central Govt. of India provides support of Rs 350 per ha to state Governments for the introduction of warabandi (Chambers, 1988). However, there are few major constraints for the proper execution of warabandi, as described below :

There is shortage of identified land ownership for the allocation of timings and turns. The revenue records are generally not updated in time. Other complications arise where consolidation of holdings has started but not completed. With very small holding sizes, a warabandi schedule is likely to be complicated to draw up and difficult to implement.

For the success of any warabandi distribution system, the field channels are required to be brought direct to the farmers' fields. The construction and maintenance of field channels is the responsibility of farmers. Due to lack of financial resources and proper motivation, farmers do not construct their field channels in time. Also field channels are generally unlined and poorly maintained, therefore, it is difficult to implement warabandi.

The third condition for the success of warabandi is consistent water scarcity. If water is not scarce, there is no need for strict turns. Also, the scarcity has to be consistent. Therefore, warabandi works well in the north west part of India and its performance declines as one moves eastwards in the Gangetic plain into the areas of higher rainfall. In this part of India, majority of projects are run of the river schemes. Also scarcity is vital for enforcing night irrigation.

The fourth condition for the success of a warabandi is the constant flow through the outlet at pre-fixed times. If the flow varies, the farmers will not get equitable share and the scheduled turns will automatically lose legitimacy. Singh (1983), who undertook a much perspective research on Command Area Development (CAD) in Sriramsagar (Pochampad) project in Andra Pradesh, India has quoted a farmer saying :

·" But Sahib, when people don't get water, why should they maintain the field channels ?"

·" If there is enough water, we can manage things on our own."

·" Now I will tell you the truth. You give us the water and we will distribute it ourselves. We don't need CAD, if you really ask me."

There is no provision in this system to compensate any individual farmer, who does not receive water in his turn because of the reasons for which he is not responsible like fault in operation or breaches in the canal. This system also does not compensate for the losses in the water course.

9. Summary and Conclusions

Any water distribution system like warabandi is adopted to save the scarce water and to encourage the farmers to make better use of their canal water, to add more value to their existing supplies and to release water for more pressing uses elsewhere. For implementing warabandi, farmers need both financial and technical support from state Irrigation Departments and Command Area Development Agencies. Warabandi, if implemented properly, will reduce conflicts among farmers. Also, it will encourage night irrigation. However, the following are the four prerequisites for the success of warabandi in any command in India or elsewhere:

·Identified land ownership for the allotment of timings and turns

·Existence of field channels to individual farmer's fields.

·Consistent water scarcity

·Constant flow at the outlet at predetermined schedules.

10.References

1.Chambers, R. (1988),' Managing Canal Irrigation Oxford & IBH publishing Co Pvt. . Ltd, New Delhi, 1988 pp. 92 - 102, 146.

2.DFID (1997), ' Priorities for Irrigated Agriculture', Water Resources Occasional Paper No 1, Engineering Division, Department for International Development, 94 Victoria Street London SW 1E 5 JL, July, 1997.

3.Malhotra, S. P. (1982), ' The Warabandi System and Its Infrastructure,' Publication no 157, Central Board of Irrigation and Power, New Delhi, April, 1982.

4.Meijer, T. K. E. (1993) , ' Design of Small Holders' Irrigation Systems', Department of Irrigation and Soil and Water Conservation, Wageningen Agricultural University, The Netherlands , pp. 13 - 18, 1993.

5.Ministry of Irrigation and Power, Govt. of India,(1972),'Report of the second Irrigation Commission', Vol.1,New Delhi, 1972.

6.Natinal Commission on Agriculture (1976),'Report of the Commission', Part V, New Delhi,1976.

7.Singh, K. K. (1983),' Social Factors in Irrigation Utilization : a Dialogue with Jugga , ' National Seminar on ' Integrated Approach to Water Management in Command Areas', 6-8 Sept. , 1983, Water Technology Centre, New Delhi.

8.Walker, W. R. (1998),' Moving Towards Demand Scheduling of a Canal System,' Session Notes of 'Water Management Workshop, 1998', organized by United States Department of The Interior, Bureau of Reclamation, Denver, Colorado.

9.WALMI (1989), D. A. Concepts & Techniques,' a WALMI Aurangabad (Maharastra) Publication no - 11, pp. 62-68, June, 1989, India.

Sustainable Water Resources Development in Ethiopia Perception on approach Frame work

Tefera Woudeneh, Metaferia Consulting Engineers, P.O.Box. 3192, Addis Ababa,Ethiopia

Abstract

Sustainable development concept has evolved in the past decade as a principal guideline for efficient natural resources management. Basically the concept embodies the principle of inter generational equity in which the present society has to consider the needs of the future generation in utilizing existing natural resources in such a way that present day development should not undermine the ability of the future generation in its effort to meet its requirement. This means that in development endeavors the long term consequences has to be projected and any potential malfunctions that may jeopardize the ability of the future generation should be adjusted. While this general perception of sustainable development concept has been considered as an approach guideline, there is no agreed operational rule as to how this aspect is taken into consideration under a specific set of development activities. This has lead to wider misapplication of the concept to suit specific objectives of development planner and managers.

In Ethiopia, the concept of sustainable development might appear far fetched and perhaps luxurious mainly due to the fact that the need of the present generation is so enormous and overwhelming as result of which developments are geared to meet this requirement for survival. Ethiopia is endowed with substantial volume of water resources which if developed will contribute to the amelioration of the various needs of the present society. In this context water resources development has to be implemented in such a way that the need of the present society is met on a sustainable basis with out curtailing the ability of the future generation to cater for itself.

In this paper, the complex nature of water resources development and the application of the concept of sustainability are discussed in a general manner and suggestion on approach framework are presented as a contribution towards the understanding of the basic issues and generate wider discussion that would eventually lead to a common and acceptable formulation of sustainable development framework. The paper provides general concept of sustainable development as applied to the Ethiopian condition and on the basis of this suggestions on an initial perception of an approach framework. Some elaboration on the main element of the proposed approach has been given. Finally proposals on the immediate course of action has been outlined for the purpose of creating awareness and generating discussion on this important issue. The thrust of the paper is to provide ideas that may be strengthen by further analysis based on detailed studies and research on the state and the requirement of sustainable water resources development in Ethiopia.

Introduction

Ethiopia is one of the few African countries endowed with substantial volume of water resources. The rainfall that occurs over the extent of the country gives rise to an estimated 110 Billion cubic meter of mean annual flow. At present population level (62 million in 1999) the per capita water resources is about 1780 m3 per year which is considered to be at the upper water stress thresh hold condition. (A water stress condition is defined as existing when the quantity of naturally available fresh water supply less than 1700 m3 per capita per year). The agro-ecology of the country is such that large areas of the highland benefits from rainfall which is adequate for single or double crop production whilst vast areas of the low land needs irrigation for agricultural production.

Ethiopia is also one of the few countries in the world where the socio-economic well-being of its people is at the lower thresh hold with rampant poverty exacerbated by drought induced recurrent famine leading to starvation and death. Agricultural production mainly from rainfed does not met the requirement of its people as a result of which large portion of the population is sustained by foreign handout. Energy mainly from biomass sources has been depleted to such an extent that large part of the population barely met the food preparation requirement with no spare for other economic activities.

For Ethiopian, the choice is either to use the natural endowment such as its water resources or keep on living in abject poverty, depravation and suffering as result of low level of development. The socio-economic equilibrium is easily affected by natural occurrences such as cyclical drought which often brings the country on the brink of disaster. On the other hand, the water resources that can provide energy, increased agricultural production, improve heath and sanitation, originate in the country and traverse its international boundaries providing sustainable means of livelihood to millions of our neighbours. In this process billions of tons of fertile soil are transported out of the country turning the once fertile agricultural production area into degraded land scape of insignificant productive value. On the other hand water resources development means advancement in the use of science and

FIGURE 1 : PERCEPTION OF WATER RESOURCES DEVELOPMENT PROCESS

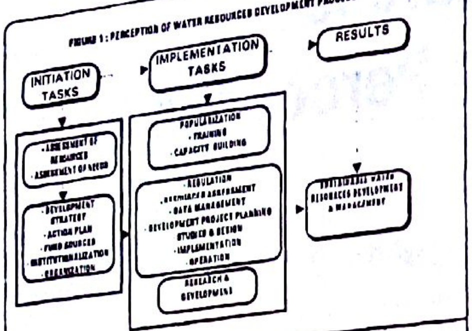
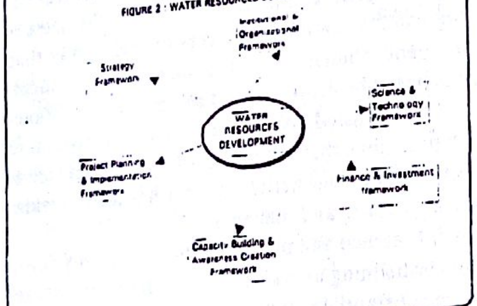
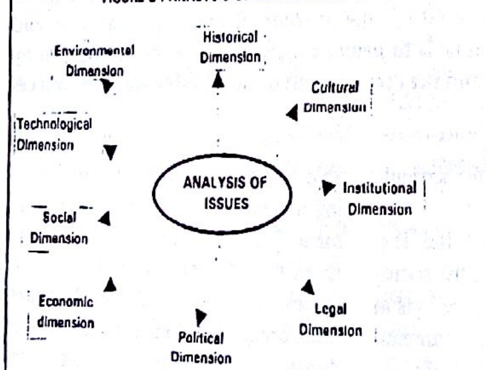


FIGURE 2 : WATER RESOURCES DEVELOPMENT FRAMWORK

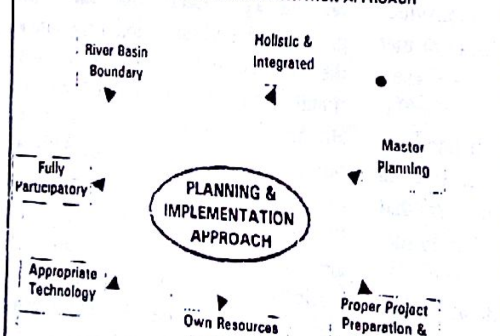


technology, increased agricultural production improved health and well being, generation of energy for various uses, containment of degradation and conservation of the land resources and generally improved socio-economic condition.

FIGURE 3 : ANALYSIS OF DEVELOPMENT ISSUES



FUGURE 4 : PLANNING AND IMPLEMENTATION APPROACH



While the need for water resources development is strikingly obvious, its undertaking requires huge effort, commitment and application of advanced knowledge. The assessment of the resources base, its potential utilisation, development planning and implementation will need dedicated organisation, skilled and experienced manpower, the full participation of informed public, strong and visionary leadership and management. Development means changing the delicate balance of the state of a given socio-ecological equilibrium and if such changes are in the negative direction, the outcome will be even more disastrous and could lead to lower level of existence. Hence sustainability of development is equally as important as initiating and implementing the development endeavour. In the context of Ethiopian reality sustainable water resources development is not a choice but the only choice.

Realising this complex situation that we Ethiopian are faced with to bring about the desired level of water resources development, as sustainable venture, some preliminary ideas on the approach framework are suggested in this paper, the objective being to generate wider discussion that would eventually lead to a common and acceptable understanding of sustainable development framework. In this paper, the general concept of sustainable development as applied to the Ethiopian condition has been cursorily examined and on the basis of this an initial perception on an approach framework has been suggested. Some elaboration on the main elements of the proposed approach has been given. Finally proposals on the immediate course of action has been outlined for the purpose of creating awareness and generating discussion on this important issue. The thrust of the paper is to provide ideas that may be strengthen by further analysis based on detailed studies and research on the state and the requirement of sustainable water resources development in Ethiopia.

The Socio-Economic Context

According to The 1994 census, the Ethiopia population is estimated to be (62 million in 1999 (CSA, 1998). This is projected to increase to 129 million by year 2030. In 1995, life expectancy at birth is 49 years compared with 72 percent for Sub. Saharan Africa (SSA) with infant mortality rate of 112 per 1000 live birth compared with 92 for SSA (World Bank 1998). The average consumption of food is estimated to be 1,770 calories per capita per day which is less than the FAO./WHO recommended calorie minimum intake of 2000 calories per capita per day. High level of malnutrition is one of the most serious problem affecting the well being of the Ethiopian people.

The per capita income was estimated to be US $100. in 1995 (World Bank 1998) and is considered to be one of the lowest in the world. About 52% of the population was earning less than US $1 per day (world Bank 1998). The deep rooted poverty is considered to be the single most important basic factor determining the present status of socio - economic and cultural condition of the people.

In 1998 the total land under temporary crops was estimated by CSA to be about 7 million ha. Of this about, 6.85 million ha was under Meher season crop while the Belg crop coverage was 0.82 million ha. The Meher production of seasonal crops which includes cereals, pulses, oil seeds and minor temporary crop was 7.4 million tons while the Belg production was 0.74 million tons. The total combined production over the 7.7 ha cultivated in that year was estimated to be about 8.1 million tons. The combined average was 10.6 qtl/ha. The per capita production for the estimated population of about 60 million in 1998 was about 1.35 quintal per person per year.

The production level indicated for 1998 season is typical of the rainfed sector and could be considered as representative of the status of the Ethiopian agriculture under rainfed condition. With increased use of modern input such as better seeds, fertiliser and improved cultural practices and land management, yield from the rainfed sector might rise to double of the 1998 level. But the fundamental constraints limiting the potential production from the rained sector is the low moisture supply at the critical crop growth cycle and the inability to produce through out the year on all productive areas due to the seasonal limitation of rainfall. It seems that all of the Meher season areas (6.85 million ha in 1998) could be double cropped if water can be made available through irrigation. The availability of moisture at critical growth stage for areas under rainfed crops could enhance the impact of the modern input packages thus. increasing yield and sustaining it at a very higher level.

In terms of food requirement the estimated calorie intake of 1770 calories per day per person would translate to 0.52 kg of cereal equivalent per person per day or 1.9 quintal per person per year. If the calorie intake is increased to 2000 calorie per person per day, the food requirement in terms of cereal equivalent would be about 2.15 quintal per person per year. If the above target is assumed to be attained say by year 2010, the total seasonal crop production need should would be about 179 million quintal as the population is expected to reach 84 million by that time. This would mean that the yield from the rainfed production has to increase to 26 quintals per ha assuming the seasonal cropped area is about 7.0 million ha,. This figure might be, the upper threshold for rainfed production and to meet the demand of increasing population say that of 2030 which is projected to be 129 million yield level of 40 quintal per ha should be attained. Again if the calories intake increases to say 2500 calories per day per person (World wide average in 1987) annual production has to increase to 346 million quintal or yield from the seasonal cropped area (7 million ha) has to be about 50 quintal per ha. This level of yield can not be attained and sustained without wide spread use of irrigation.

FIGURE 7 : PROPOSAL FOR SHORT TERM ACTION PROGRAMME

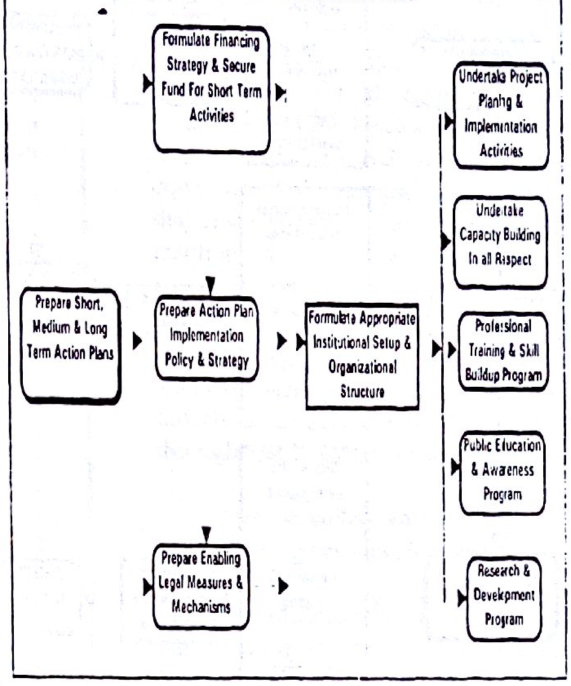


FIGURE 5 : WATER RESOURCES DEVELOPMENT TOOLS

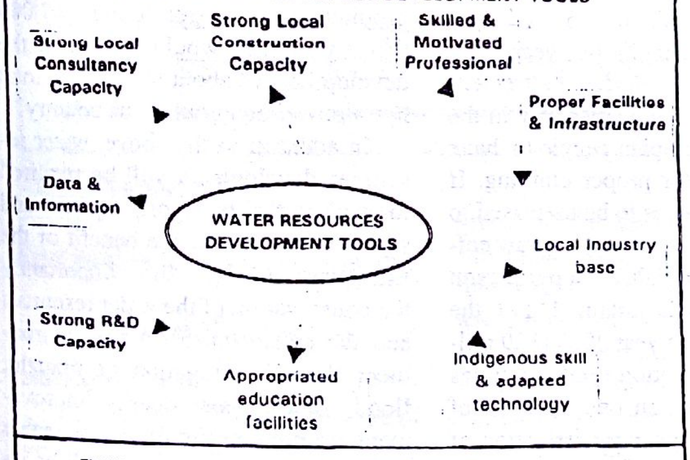
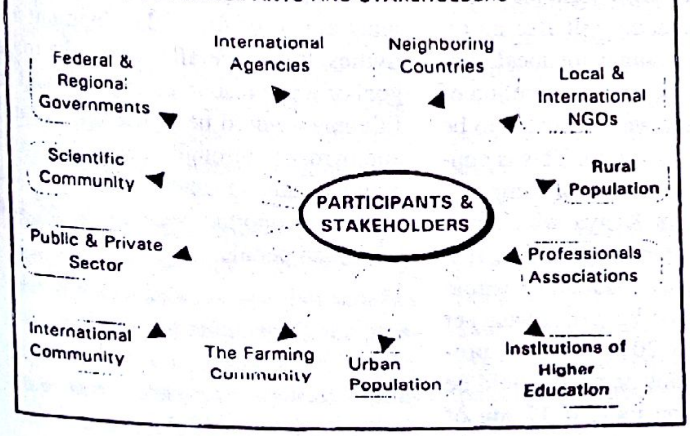


FIGURE 6 : PARTICIPANTS AND STAKEHOLDERS

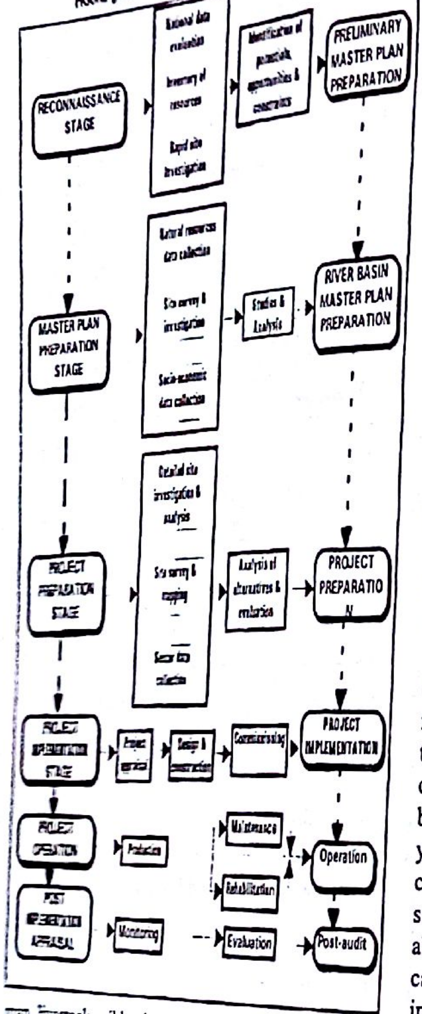


Need for Water Resources Development

The water resources potential in terms of mean annual flow is estimated to be about 110 BCM (EVDSA, 1990). The land potential suitable for large scale irrigation is put at 3.5 million ha (EVDSA, 1990) . The hydro power generating potential is estimated at 161,000 Gwh/year. Other water resources potentials include 40,000 tons per year of fish production, 1900 km of water ways suitable for transport and other immense scenic, historical and cultural resources. In terms of utilisation, 22% of the Ethiopian population has access to clean water while only about 7% has access to adequate sanitation. About 3% of large scale irrigation and 2% of the hydropower potential has been developed in the past. The aquatic resources exploitation is less than 10% and water based transport development is negligible.

First and for most, the water resources development will be required to provide clean and secure adequate water supply to meet the need of hu-

FIGURE 1: WATER RESOURCES PLANNING IMPLEMENTATION STAGES



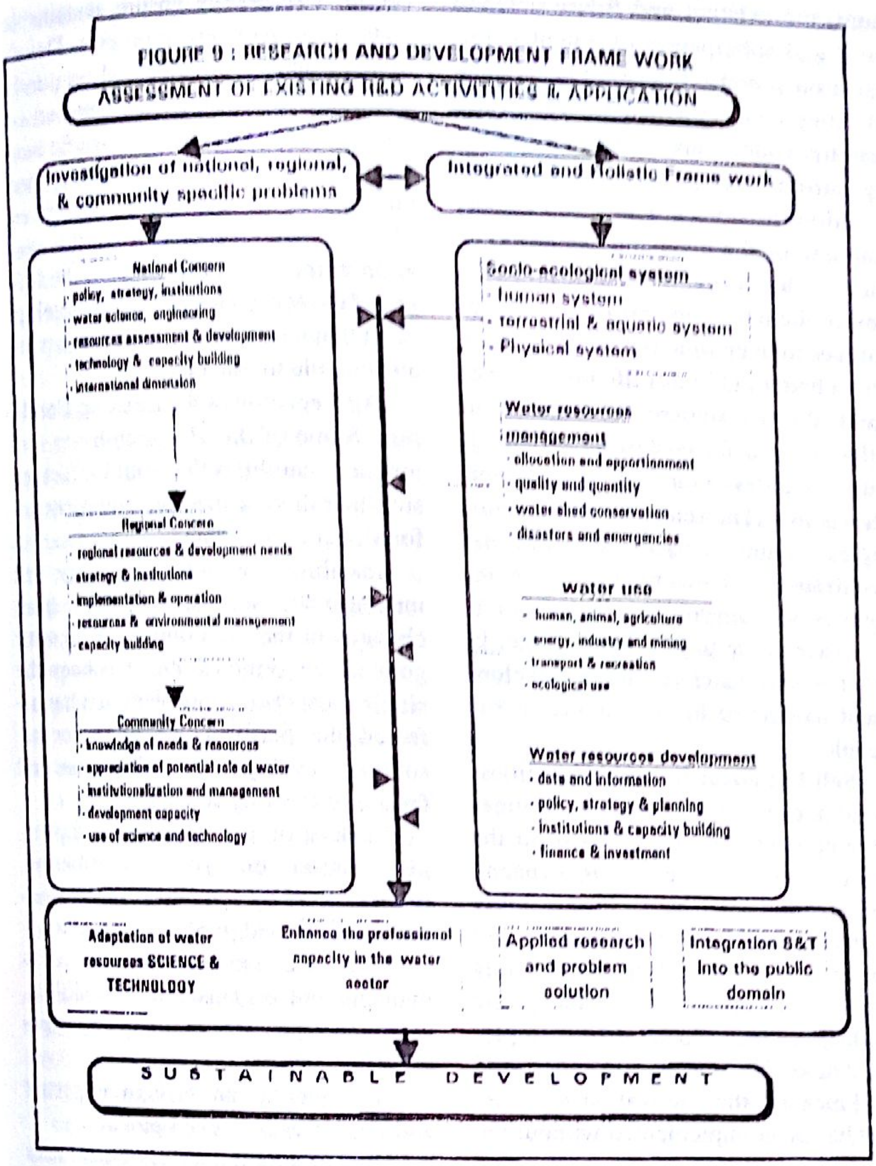
ment, livestock, wild animals and other ecological and environmental requirement. The two most challenging tasks in this sector are to initially provide the whole population with the basic coverage of about 20 litre/person/day and secondly to increase the per capita supply to WHO's standard of 50 litres per capita per day and thereafter increase the over all domestic supply to 150 litres per capita per day for the entire population. To meet this demand scenario for an increased population under a sustainable supply condition would be an enormous undertaking. Along with this, secure and sustainable supplies should be provided for animal and other environmental requirements.

The second need for water resources development is to support and augment agricultural production. The analysis in the above section has shown that, to meet a calorie intake of 2500 calories per person per day, by year 2030 yield of about 50 quintal per ha of food crops should be attained. Irrigation will greatly contribute in the increase of food production by supplying moisture at required level for areas under rainfed production, bringing more areas under production by enabling double cropping or cultivation of areas without sufficient rainfall. The other need for irrigation will be in the production of fibber and sugar crops whose consumption is at a very low level at present.

A study conducted in 1993 has indicated that the estimated per capita consumption for fibre was 7.8 m2 per year. The East African average at the same period was about 15 m2 per capita per year. This indicates the tremendous disparity in the ability of the Ethiopian people to have an opportunity for proper clothing. If the fabric required is to be increased to 15 m2 per person per year, the raw cotton production of 0.009 ton per person per year has to be attained. For the population level of year 2030 (129 million people) the cotton production has to reach 1.16 million ton. In terms of area, this would mean the irrigation of 387,000 ha assuming a yield level of 3 tons per ha. Irrigation will also be required to produce sugar for local consumption. In 1994, the consumption of sugar in Ethiopian was estimated to be about 3 kg/person/annum. This is considered to be very low when compared to consumption in Kenya which was about 20 kg per person per year. If it assumed that sugar consumption would gradually reach 20 kg per person per year, say by year 2030, the total production to meet this demand would be about 2.58 million tons. If 12 ton of sugar can be produced per ha, the total area that should be irrigated will be about 215,000 ha. The above analysis indicates that to meet the various demand for agricultural products, large areas of irrigation development has to take place over the coming 30 years.

Thirdly water resources development will be required to tap the enormous hydropower potential to supply the energy demand of the population. At present about 360 MW of hydropower production is under way and this is considered to be about 2 to 3 % of the total potential. In 1982 consumption of energy was estimated to be about 8 million tons of oil equivalent which is 95,000 GWH/year in terms of electric energy (EVDSA, 1990). Of this supply, electric power constituted about 2.5%. Fuel wood, cattle dung and cereal straw supplied about 91% of the requirement. The use of wood, cattle dung and cereal straw for fuel has resulted in sever environmental degradation from clearing of the forest cover, deterioration of soil fertility and erosion of the soil potential. If 50% of the above requirement is to be met from hydropower supply for the consumption pattern of 1982, the annual production has to reach about 47,000 GWH/year. This would translate to the development of about 30 % of the total hydropower potential of the country.

In addition to the above, water resources development will be required to exploit the transport, aquatic and scenic resources for the benefit of the Ethiopian people. More importantly the conservation of the water resources and the enhancement of the environment through mitigation of draught, flood control water quality improvement are prerequisite for a sustainable resources management and will be an integral part of future development activities. In the overall context, the main goal of water resources development in Ethiopian would be to use this natural endowment through conscious and planned human intervention for the socio - economic well being of the Ethiopian people.



TW/ DRAFT PAPER

Sustanable Development in the Water Sector

Conceptual Basis

The most widely used definition of sustainable development is that given by the Brundtland Commission on Environment & Development in 1987 in the report " Our common future". The definition given was" Sustainable development is development that meets the needs of the present without compromising the ability of future generation to meet their own needs". The world Watch Institute state that " A sustainable society is one that satisfies its needs without diminishing the prospect of the future generation." The most water resources oriented definition of sustainable development is given us" the development which ensures that utilisation of resources and the environment to day does not damage the prospects for their use by the future generation" (Day & Perks). Water resources development is considered to be sustainable if it is " socially, environmentally, economically and technically acceptable and the water resources system is in a dynamic equilibrium over along period of time. "

Sustainability embodies long term perspective, integrated approach, respect for diversity and pluralism, equity, justice and reliance on participatory development. Development has to be environmentally economically, politically, socially and culturally sustainable. Societies well being depends on good government, democratic participation, economic efficiency, equitable distribution of economic resources, cultural and other intrinsic values and balanced inter-relation with non- human species and environment. Sustainable development means optimising these values, consideration of inter-generation equity which means that the future generation will have at least equal needs for natural resources as that of the present generation. This will result in using resources on a deterministic and sustainable yield basis. Sustainable development implies that in the process of depletion of non-renewable resources, society must ensure an orderly translation to other activities through alternative development.

Sustainability and Water Resources Development

The translation of the concept of *Sustainability* in to the arena of the Ethiopian water resources development would imply the following.

The need of the present generation: Sustainability embodies two basic principles i.e. providing for the need of the present society and considering the needs of the future generation. In the context of the Ethiopian reality the need of the present society is so enormous such that if it is not met, the continuity of the society to produce the future generation that replaces it is under threat. The main focus of water resources development would then be to generate the means of livelihood primarily to stop the decline in the socio - economic status of the present generation and then provide for better socio-economic well-being.

Long term vision: Sustainable water resources development would mean long term vision and knowledge at each key step in the future time horizon. In the context of Ethiopian reality the long-term vision should at least extend over the generation time frame i.e. a minimum of about 30 years and in this time frame there should be a clear understanding of the action and activities of water resources development projected up to and beyond the set minimum time frame.

Poverty Alleviation: sustainable water resources development means that the output of the development should contribute to the enhancement of the existing socially and culturally crippling poverty situation in the country. This should be a central objective, as a poor society can not be deemed to lead a sustainable life. Poverty as manifested in Ethiopia is not to able to eat adequate quality and quantity of food for meeting the normal, need of the body, to be inflicted by various disease and not to possess the means for treatment ,to be without adequate clothing to protect from the changing condition of climate, to live in an inadequate shelter, to be directly interacting with the environment without the benefit of modern technology and to be illiterate and live in darkness away from the opportunities and benefit offered by modern knowledge. The benefit from water resources development should augment food supply, create wealth for the society to be able to produce goods and services, produce agricultural raw material for clothing and energy supply, provide clean water supply to meet the daily body needs etc. Sustainability over a generation time frame and for the future generation can only be ensured if the development of the resources is geared to contribute to the alleviation of these problems at present.

Environmental Integrity: Water resources development should be carried out within an integrated socio-ecological frame work under a constant condition of dynamic equilibrium. The overall integrity of the environment which is governed by principle of interdependence should not be violated so as to cause an imbalance and hence environmental degradation and eventually to the unsustainablity of development efforts. The human and other living communities and non living manifestation are interconnected in a vast and intricate network of relationships in a mutually dependent process. The understanding of this relationship and planning and implementing water resources development within this frame work will ensure environmental integrity and contribute to sustainability of the development.

Proper Knowledge and Understanding: Development should be undertaken on the basis of adequate knowledge of all socio-ecological factors, including the resources base, distribution, its pre development equilibrium, the existing and future demand on it and anticipation of potential impacts on proposed developments. The planning and implementation of water resources activities should be guided by sufficiently qualified and experienced professionals with clear understanding of the need and aspiration of the people on one hand and ability to device the means for exploiting the resources to overcome poverty and bring about better quality of life on the other hand. Water resources development in Ethiopia is a fairly new undertaking. The awareness of the people on its benefits is low. The scientific and technological requirements for assessing the occurrence and magnitude of the resources and carryout development has not reached the population at large. In other words water resources development has yet to be the culture of the people.

Self Reliance: It would be fruitless to think of sustainable water resources development that is not based on the use of indigenous resources, capacity and technological base. Sustainability of water resources development can not be contemplated if the major actors in the development are outside of the country such as donor driven implementation. No matter how good and well meant is the motivation, schemes that has been implemented without the major participation of the local effort are suspect to all sorts of destabilising effects.Indigenous resources utilisation means that there should a meaningful participation in the financing of the project, that the full cost of operation and maintenance should be from the local resources mainly from the output of the projects and that the beneficiaries should have full control over the planning and development based on informed and conscious appreciation of all factors. Development planning and implementation should be mainly carried out by local expertise and adopted technology suitable and modifiable to suit local condition. Sustainability in the generation time and beyond would be enhanced through this approach.

Meaningful Participation: The participation of the public in all facets of development planning and implementation based on adequate awareness information and democratic procedure will greatly ensure sustainable water resources developments. Development that is implemented on purely technocratic decision and imposed on the general public and the specific beneficiaries is prone to instability and failure without meeting its objectives. There are bitter experiences of this situation in the country as most of the failure of the few water resources development that has taken place in the part are attributable to this fact.

Appreciation of the Existing Condition: Some of the of destabilising factors or instabilities that could affect the sustainability of past development efforts could be attributed to:

Instability of policy, strategy and institutional set up arising from changes in the direction of successive government policies. This has been the single most critical problem that has affected the performance of water resources development in Ethiopia and failure of existing schemes.

Lack of broad and integrated planning based on good information, implemented by competent professionals and informed public participation

Lack of competent water resources management organisation and skilled, motivated and highly trained and experienced staff.

Dependency on foreign expertise and resources for development

Lack of adopted technological base and support of research and developments.

Lack of indigenous industrial base.

Water Resources Development Process

Development Initiation Tasks

The water resources development process in the Ethiopian context is perceived as a set of activities that would commence at given moment in time and be progressively implemented with in the general generational time frame-work of minimum of about 30 years to bring about change in the socio-economic status of the people in sustainable manner. Figure 1 shows the main elements of this process and the flow of activities leading to the attainment of sustainable development. The process is conceived as a series of activities commencing with the initiation of the water resources development plan which lead to a discrete implementation tasks over the plan period. The end result is the achievement of sustainable development in its total context.

The initiation process eventually sets the overall development framework within the envisaged time frame. The main component activities during this period are briefly outlined as follow.

Assessment of Resources: This activity aims at establishing the resources base in its spatial and temporal occurrence and the existing and projected demand on it. At present this activity has advanced with the preparation of the preliminary country wide water resources development master plan and the specific integrated river basin master plans. With some additional work, an overall assessment of the resources can be achieved.

Assessment of Needs: Need or demand, sets the utilisation pattern of the water resources and will establish the main areas of water requirement. In this analysis, all potential users on the resources will be identified. This will include human and other life forms, agriculture, energy, industry, environment or ecological needs. A substantial amount lot of work has been carried in national and river basin context and with some additional work a full planning picture could emerge..

Development Strategy: The development strategy will set the matching of the resources with the demand during the planning period. The strategy will provide an overall planning framework and will define the action to be taken at each key steps. The development goals and objectives are defined and formulated and the action required to attain them are elaborated. At present there is no comprehensive strategy on water resources development over a generation time frame.

Action Plan: The action plan follows from the strategy formulation and is an essential part of the development strategy. The action plan will elaborate specific projects that would be implemented with all the other peripheral activities and will provide the overall investment required to implement the plan. In this process, the investment budget requirement for the envisaged development over the planning period is estimated. Action plans are not in place at present.

Fund Identification And Allocation: Water resources development in Ethiopia will require enormous amount of financial resources for its implementation. The financing sources and plan has to be carefully worked out and overall allocation need to be made for the duration of planning period. Finance could be obtained from international sources, allocation of government budget, private investment, user participation, cost recovery and such like. Special water resources development taxes could even be considered. The most important aspect at this stage is to know the global financing level and availability and to allocate it to various development components set in the strategy and action plan document. There is no comprehensive direction on the identification and allocation of financial resources at present.

Institutionalisation: Institutionalisation refers to formulation of appropriate short term implementation, policies, laws and regulations governing the resource utilisation and management and the various proclamation establishing the required organisations and defining the legal relationship between the actors in the development. In this context policy is used to define short terms objectives set by the government of the day while strategy defines the overall frame work for guiding the long term implementation. Strategy may be refined but may not be radically altered while policy could be changed based on the emphasis of the government of the day but not out side of the strategy framework. There are a number of institutional measures in place at present, which need to be reviewed in the context of the envisaged plan and anticipated development need.

Organisation: This refers to the establishment of various organs of the development and engagement of the human resources and other requirement for implementing the envisaged strategy in all sectors of the society. The government has established the Ministry of Water Resources as the Federal organ in Water Resources Development and Regional Bureau to take care of regional concerns. While this by itself is step forward, the present organisational arrangement is not considered to be adequate. A more elaborate and comprehensive structuring covering all actions, stakeholder and all water resources development activities need to be formulated and implemented.

The successful implementation of the initiations tasks will lay the foundation on which the implementation of the water resources development will be based. These aspect needs careful consideration and sufficient time and resources should be used to prepare the component tasks and the overall framework considering the generational time frame. For this purpose, year 2000 could be, for example, taken as the starting point in time and extend to year 2030 as the period over which development in a sustainable frame work could be considered .

Implementation Tasks

The implementation tasks deal with the operational aspects of water resources development activities. The main implementation activities are briefly elaborated as follows.

Awareness And Capacity Building: This includes creating or enhancing the awareness of the public about water resources through public education, popularisation, training at all level to create the necessary skill and profession, and undertaking overall capacity building in all aspect and at all level. Capacity building has to be on continuos basis and has to cover all participating actors. At present the capacity building is skewed in that it is mainly catering for with government establishments. There is no visible capacity building activity in the public and private sector. As the overall national capacity is very low, whatever development is taking place is mainly being planned and implemented by foreign organisation.

Regulation: Regulation refers to the administration of the set of policies, laws and other institutional measures mainly by the government. This is a policing activity to ensure that water resource development takes place within the envisaged parameters such that sustainable results are obtained.

Data Management: Date management includes the collection of all types of data in all relevant sectors and subsector, processing, storage and distribution for project planning and implementation. Certainly basic data will be required at the initiation stage for resources assessment need evaluation and preparation of strategy and action plan. This aspect of data management will be a necessary pre-requisite for completing the initiation phase tasks.

Resources and Needs Assessment: The potentially utilizable water resources under a given technological and management framework should be established. The need of the society and other user should be assessed and matched with the resources in a given time frame. The river basin based master plan is the most appropriate approach for this aspect.

Project Planning and Implementation: This aspect deals with project identification, preparation and implementation including operation. Project ideas are drawn from the strategy consideration and the action plan. Hence the project planning and implementation by itself is a huge under taking and will require efficient organisational set-up and management. Details on proposed approach are discussed.

Research and Development: Research and development should be considered as an integral part of the implementation process. This aspect is completely missing from the Ethiopian Water Resources Development scene. Research and Development under pins sustainability in that solution to instabilizing factors could be sought or obtained and appropriate adjustments can be made to ensure that the process of development is taking place to attain the set objectives without deteriorating the environment.This aspect is presented in more detail in Section 7.4.

The implementation process will be demanding and require the integration of human ingenuity, technology and vast financial resources to develop water resources for various uses. The imbalance in the system as a result of improper action in implementation could have a disastrous consequences on the natural system. The end results of the implementation process is envisaged to be sustainable water resources development that has attained the objective set in the plan period.

Water Resources Development Perspective

Component of Sustainable Development Framework

In general terms water is required as an economic, social and environment good subject to private and public use under sustainable management. Water resources development and management is always carried out within a given socio-economical and socio-ecologicl sphere of influence facilitated by the technical and institutional infrastructures organised by development managers. The above condition calls for the formulation of a multi faceted framework that integrates the social, economic and environmental aspects into an efficient management process. Figure 2 shows five main components of an integrated sustainable water resources development approach frame work for which outline discussion are given.

The Development Frame-work

The organisation of water resources development in the Ethiopian context should be under pinned by six main approach frameworks as shown on Figure 2 so that the fundamental relationship between the socio-economical and socio-ecological interdependence can be properly understood. These development frameworks as foresee are briefly discussed as follows.

Strategy Framework: This sets the discrete global and local objectives and provides the general direction and plan during the envisaged development period. Strategy sets the states long term goals while policy sets the governments short term objectives.

Institutional and Organisation Framework: The short term policy objectives, the legal and regulatory aspects are defined and appropriate organisational arrangements are devised.

Project planning and Implementation Framework: The procedures for project identification preparation and implementation are defined and set. Figure 4 provides the proposed planning and implementation stages for which elaboration are given in section 7.3.

Capacity Building and Awareness Creation Framework. In this frame work the approach and actions required to create strong and efficient organisational set-up will be defined. A long term public education and awareness creation strategy will be formulated and implemented.

Finance and Investment Framework: The level of investment required in the plan period and allocation of sources will be defined.

Science and Technology Framework:Research and development for supporting the with planning and implementation process will be institutionalised. The proposed research and development framework is discussed in section 7.4 and illustrated on Figure 5.

Development Issues And Context

There are multitudes of issues that should be properly understood and addressed in the process of water resources development in Ethiopia to safe guard the sustainability of the system. The issue should be analysed in a structured manner covering all development influencing factors. Figure 2 provide an overview of the aggregation of the issue under a set of important factors affecting or influencing water resources development as described below.

The Environmental Dimension: The natural resources particularly forest and soils are severely degraded. This situation has to be contained and possibly reversed as it affects water resources development tremendously. The effect of water resources development on the environment should also be clearly identified and minimised. Development may disturb existing equilibrium and trigger a process that may set a new equilibrium. Sustainable development means that the new equilibrium should be in a dynamic balance without creating a net negative effects.

Historical Dimension: The history of water resources development should be understood over the recorded period of history. Knowledge of history will enable us to understand as to why significant water resources development has not taken place in the past and to build the finding into future development framework.

Cultural Dimension: In Ethiopia there is a more direct dependence on nature i.e rainfall for agriculture, springs, streams and rivers for water supply, wood straws, dung for energy etc.. Even under the most severe condition, people do not seen to revert to the use of the abundant water resources in the country. The cultures of water resources development has not grown and thrived. The issue should be analysed to understand the apparent lack of water resources development values in the Ethiopian culture and to draw appropriate approaches for the future efforts.

Institutional Dimension: In the past there has been a considerable instability in the institutional set-up of water resources development. It seems on the average every 10 years, institutional change takes place resulting in enormous set backs in terms of destructive effect on organisational capacity. Sustainable development means stable and strong institutional set-up and organisational capacity.

Legal Dimension: The legal issue immanent from either the lack of appropriate legal measures needed for sustainable water resources management or changes triggered by the unstable institutional condition. The regulatory framework can not function without the appropriate legal provision.

Political Dimension: The political environment sets the umbrella for any water resources development effort. Stability, democratic participation, good governance will greatly enhance water resources development. The physical occurrence of the resources is such that there is an international connection over the political boundary and claim to the use of the resources by other nations. Significant volume of water originating from Ethiopian is being utilised by Sudan and Egypt to sustain the life of millions of their citizens. Increased use in Ethiopia would result in reduced use elsewhere as the resources is finite. This could be a source of instability and conflict unless an amicable environment for water resources management created with the concerned countries.

Economic and Financial Dimension: Financing of water resources development in Ethiopia would involve huge capital investment each year if the need of the population for clean water supply, agriculture and energy is to be met. Poverty alleviation which is the central theme of any WRD in Ethiopia would mean subsidy to create the necessary infrastructure to convert water into an economic good and social services. Cost recovery under the existing economic situation might be difficult to implement. Allocation of finance for water resources development will compete with other equally important development such as education, transport, health, defence etc. There is a need to look into the economic and financial condition under which water resources development will take place.

Social Dimension: The present tendency in water resources development is to provide for the need of the urban population more than for the rural sector. Development of water supply, energy and agriculture are all skewed in favour of the urban centres. The issue of equity is of paramount importance for sustainable development. Large water resources development will displace existing settlements which should be redressed fairly and equitably. There is a need for change in the cultural perception and to create acceptability leading to meaningful participation in the development. Water resources development should be geared to enhancing the health and education status of the population. There will be a need for identification and analysis of all social issues so that appropriate solution could be devised and integrated in to the development plan.

Technical Dimension: Indigenous water resources science and technology is lacking. Traditional water resources development is limited and where such exists detailed investigation should be carried out for possible development. Since the main sources of technology is from the developed countries, adoption to suit the condition of the country will be a major exercise. Appropriate research and development will enable the adaptation and indiginization of technology needed for water resources development. Use of inappropriate technology will be expensive and will render development effort fruitless and unsustainable . Technology has to be manageable at the level of the common man if water resources at the desired scale has to take place.

Planning and Implementation Approach

Planning of water resources development can be regarded as a continuous process of making choices between many desirable activities, alternatives and approaches and allocating resources to achieve the set goals and objectives. Planning is a means of achieving goals and objectives by alternative course of actions. Planning is carried over a given time horizon say a minimum of 30 years. In the overall context implementation is an execution of the desired activities to produce the anticipated outputs for use by the society to meet the various demands as set in the definition of goals and objectives. More often implementation involves the design and construction of engineering infrastructures and commissioning of facilities. The basic approaches that should be followed in the planning and implementation of water resources development to obtain sustainability over the generation time are outlined in Figure 2, while details are discussed below.

River Basin as a Resources Management Boundary: In Ethiopia, the occurrence of the water resources is such that rainfall on the highlands gives rises to runoff that flow in streams and river courses in the valleys towards the border of the country thereby crossing the plains that are considered to be suitable for large scale irrigation. The river basin which represents the natural boundary of the resources occurrence, is an appropriate functional region established by physical relationships which can serve as spatial unit for scientific understanding of natural processes. The biophysical and socio-economic linkages of upland, valleys and plain can be logically analysed and understood. Water is the most important resources in the river basin system that can be directly used or serves as an input for the development of other resources. Water transfers energy in the river basin system through the hydrological cycle and matter from the highland to lowland through erosion and sediment transport.

Holistic & Integrated Development: In the holistic and integrated approach, the development has to take into consideration all possible human and environmental requirements in the river basin system. All aspect of the occurrence, distribution and potential uses are analysed and development intervention in all sectors including human, agriculture, energy, mineral, industrial, infrastructural and social areas can be planned and implemented with water as the core resources. Essentially holistic refers to the consideration of all aspect of water resources development and integration refers to the harmonisation and balancing of the various areas to which water can be used.

Master Planning: The master plan approach provides a long term integrated resources development plan considering the spatial and temporal occurrence of the resources over the management boundary i.e. the river basin. At present river basin master plans have been prepared for Omo- Gibe, Baro Akobo, Abbay and Tekeze river basins. This process has to be completed for all river basin in the country followed by legal measures for their use as basic plans for the development of the water resources of the country

Appropriate Project Planning & Implementation Procedures: Appropriate project planning and implementation procedures based on the project cycle concept should be applied. The conventional project cycle includes identification, reconnaissance, pre-feasibility, feasibility, design, construction, operation and monitoring and evaluation. If the master plans are prepared in sufficient details the process of identification, reconnaissance and pre-feasibility may not be required. Feasibility studies will be undertaken to ascertain the alternative possibilities and analyse the social, economic, environmental and technical aspects of the projects. Proper design and construction, efficient operation and consistent moniforing and evaluation will greatly contribute to the sustainability of the development endeavours. Figure 4 in Section 7 provides the stages of proper project preparation and implementation process.

Use of National Resources: In the past foreign financial resources and expertise has played prominent roles in the development of water resources of the country. Foreign financing comes with conditions that may not be favourable to our situation and foreign experts lack the political, economical, social and cultural appreciation of the country. Sustainable development presupposes the substantial use of own financing and manpower expertise and idignization of water resources development technology.

Appropriate Technology: Technology has to be adopted, indiginized and grow with in the framework of the objective realities of the country. In this context, there is need for a comprehensive and concerted efforts for technology transfer and development in the water sector.

Fully Participatory Development: The achievement of water resources development at the desired scale will require the full participation of all the stake holder in their respective areas of interest. Full participation means well informed and concerned public, transparent planning and appropriate institutional and organisational mechanisms for ensuring the participatory process on a continuous basis. In section 6.6 details on the stake holder and the general areas of participation are presented.

6.5 Water Resources Development Tools

The envisaged water resources development are enormous and are anticipated to contribute to the socio- economic transformation in the country in a sustainable manner. Along with appropriate planning and implementation approach, appropriate tools need to be used at all stages of resources management. The main tools as identified in Figure 2 are briefly presented as follows.

Data & Information: Data of sufficient coverage and appropriate quality is a basic input for water resources development planning and implementation. Various types of data and information need to be collected, processed stored and distributed for use in the process of development. Basic data should be collected at a national level on a continuous basis. Collection of soil, topographic, climate, vegetation, animal, water resources etc. data, preparation of maps at the required scale are very important planning tools. The preparation of at least the 1:50,000 scale maps for topography, soils, land use & cover etc. could be a priority area of interest. Data for specific project planning and implementation purposes should also be collected.

Skilled & Motivated Professionals: A cadre of highly trained, skilled and motivated professional will be required to plan and implement water resources development. The past human resources management approaches has not created the required base and level of skilled manpower. The state of the water resources development at present could be mainly attributed to the lack of adequate trained manpower which has been exacerbated by the inability of effective use of the scant existing manpower base.

Proper Facilities & Infrastructure: This include laboratories, information centres, study and design facilities, data collection and analysis equipment and instrument, education and training facilities, offices etc. Water resources development will require the placement of huge facilities and infrastructure for undertaking the various development process and activities.

Indigenous Skill & Technology Adaptation: Indigenous skill has to be developed at a wider scale. Construction skill and manufacturing of basic components and equipment capacity has to be developed. Technology has to be transferred at the appropriate scale and popularised such that it becomes part of the indigenous skill and continue to be used on a sustainable basis.

Local Industrial Base: The industrial base for producing components and application for water resources development has to be created and widely developed. Sustainability of water resources development can not be ensured when major technologies and application are imported from various sources. This renders the application non interchangeable and eventually useless. The efficiency of existing water resources schemes is being affected by this situation. The other aspect of industrial development is the use of water resources based products such as crops, energy etc. as an input for industrial processes. Water resources development has to be integrated with industrial development and vice versa.

Appropriate Education Facilities: Education facilities for training from basic skill to advanced level professionals should be established. At present advanced water system planning and implementation is being carried by foreign experts. Institutes of higher learning should be strengthened and new once established to cater for the high demand of skilled manpower that would be required to undertake development at envisaged scale. Training facilities for basic skills in construction, manufacturing and other fields of importance should be established all over the country.

Strong Research & Development Capacity: There is a need for a strong research and development capacity in the water sector. More discussions on this aspect is presented in Section 7. Figure 5 shows the R & D activity flow.

Strong Local Consultancy Capacity: Meaningful development of local consultancy capacity has to take place to undertake planning, project preparation and supervision of development implementation. In the past and at present, consultancy services have been provided by foreign consultants. All major water resources planning and implementation has been carried out by these group. Local consultancy capacity is presently being created and is at its infancy. This sector has to grow and government support will be required for a meaningful capacity to be created. The major portion of the water resources planning and implementation has to be carried out by local consultants if sustainability is to be practically ensured.

Strong Local Construction Capacity: This is another important area that should be established with adequate capacity to undertake the construction of advanced water resources facilities and infrastructures. The past and present experience shows that major water construction has been undertaken by foreign contractors. Local capacity for construction of small and medium level infrastructure is growing but need be to strengthened.

6.6 Stakeholders In Water Resources Development

Sustainable water resources development in Ethiopian attracts a number of interests, involves large number of participants and will directly or indirectly affect various stakeholder. Figure 2 lists the main participants and stakeholder that may have influence and direct impact on water resources development and its sustainable management. The indicative but in exhaustive areas of involvement and responsibilities of the various stakeholders are presented as below.

Federal & Regional Government

As stakeholders the Federal and Regional governments will participate and have responsibility for the following main aspects;-

Primary responsibility for the assessment of resources potential and development need

Primary responsibility for data collection, analysis, storage and dissemination

In consultation with other stakeholders, setting of goal, objectives and strategy and legalising them as development guiding principles

Primary responsibility for preparation and legalisation of action plans

Primary responsibility for fund raising and allocation for various purposes.

Establishment of appropriate institutional and, policy mechanisms and issuing of regulating measures and overall organisational set up

Participation in project preparation, implementation, operation monitoring and appraisal with other stakeholders.

Ensuring equity through fair distribution of the benefits to various sectors

Primary responsibility for creating local capacity, establishment R&D, creating awareness and training of manpower.

6.6.2 Public & Private Sector

Participate in goal objective and strategy setting directly or by democratic representation

Participation in resources potential and need assessment

Undertaking project preparation, implementation operation and monitoring

Direct users of accrued benefits

Undertake adaptation of technology, establishment of industry etc.

6.6.3 Urban & Rural Community

Participation in goal objective and strategy setting

Support resources potential and need assessment and action plan preparation.

Participate in project preparation, monitoring & appraisal

Undertake project implementation

Primary responsibility for operation

Direct beneficiary of development

6.6.4 Professional Associations & Scientific Community

Assist and participate in need and resources assessment, goal, objective and strategy setting and preparation of action plan

Undertake R&D activities and promote technology transfer and indignation

participate in project preparation and implementation

Undertake monitoring and evaluation

Support capacity building particularly in human resources development

Undertake preparation of guidelines, standards and other applied hand books.

Institutions of Higher Learning

Primary responsibility for human resources development

Undertake R & D activities and project related scientific analysis

Participate in public education and awareness creation efforts

Undertake monitoring & appraisal

Assist in goal, objective and strategy setting and preparation of action plan

International Community

Support harmonisation efforts on international water resources allocation and development

Provide financial support for development planning and implementation

Participate in general development efforts

Support technology transfer and indignation efforts

Support human resources development and other capacity building measures

International Agencies:

This includes multilateral, bilateral and international agencies. Their role is set as follow.

Support need and resources assessment efforts, goal, objective and strategy setting

Participate in action plan preparation

Provide financial support for general and specific development efforts

Participate in project preparation and implementation

Support capacity building and technology transfer efforts.

Support harmonisation efforts on international water use

Neighbouring Countries

Create conducive atmosphere for amicable utilisation of transboundary resources

Participate in and support the creation of enabling environment and institutional arrangement for equitable utilisation of transboundary water resources.

Undertake data collection and create exchange mechanisms for development planning

Local & International NGO's

Participate in need and resources assessment and setting of goal and objectives

Support action plan and project preparation

Implement water resources development

Support project operation and undertake monitoring and appraisal

Support capacity building, adaptation of technology and human resources development

Participate in public education and awareness activities.

Conclusions

General

The important issues related to sustainable water resources development is the establishment of proper and appropriate development framework. Some general ideas has been put forward in this paper on the approach framework that are considered to be essential for the planning and implementation of future development. The presentation is not exhaustive and comprehensive enough to cover all aspect at the required detail and depth. In this frame work sustainable development is conceived to be attainable if the resources and needs are properly know and an all inclusive integrated development plan is prepared and implemented with full the participation of all potential stakeholders with adequate and continuous financial allocation under an efficient, professionally guided management system. Proposals on a course action for laying the foundation for sustainable development are outlined in the following sections as partial recommendation of this paper.

Proposal for Short Term Start UP Activities

Figure 3 shows a series of tasks that would constitute a start up activity for laying the foundation for sustainable water resources development over the comings 30 years. The start up activities could commence for example in year 2000 and be implemented up to year 2005 as a five year programme. The start up programme are presented in four discrete but interrelated activity components as indicated in the following paragraphs.

Preparation of Action Plans:

At present the master plan for four of the river basin has been completed. For the remaining basins basic plans on water resources are available except for Genale Dawa basin which is the least studied basin in the country. With concerted effort and allocation of resources the master plans for all river basin and the preparation of an action could be completed with in a period of 2 to 3 years. The action plan should cover a minimum of 30 year development time frame.

Pre Action Plan Implementation Activities

The result of the action plan shall lead to the preparation and enactment of three important implementation strategies.

Formulation of financing strategy and securing of financial sources for project to be implemented in the short to medium time frame, say 5 to 15 year after year 2000.

Preparation of action plan implementation policy to suit the general development frame work of the Government. For example at present, the Government follows a five year development plan period set in the ruling party program. The policy formation could be integrated with the programme of the government.

Preparation of enabling legal means and mechanism necessary to implement the action plan.

Institutional Set Up

The institutional set up emanates from the enactment of the policy and legal measures and should include the establishment of appropriate organisational structure in the government, public and private sector, to create the organisation base for implementing the action plans.

Action Plan Implementation Programme

A set of six programme component are envisaged to implement the action plan.

The Development Planning & Implementation Programme: This includes project identification, preparation and implementation activities and the operation of the schemes as provided for in the action plan.

Capacity Building Programme: This is geared to create the necessary capacity in terms of facility infrastructure, technology and manpower.

Training & Skill Build-up Programme: The programme will deal with the training of highly advanced professional to low level skilled manpower needed for implementing the action plan.

Public Education & Awareness Programme: The objective is to educate the public and create the necessary awareness to enable the meaningful participation of the public in water resources development

Research and Development Programme : This is geared to create the capacity with the necessary infrastructure to support the implementation of the action plan.

Proposal on of Water Résources Development Implementation Stages

The planning and development of a water resources requires extensive and enormous amount of data collection, complex analysis and evaluation of alternative plans, huge investment for implementation and institutional, organisational and financial commitment of a nation for operation. For this reason a staged planning and development approach need to be applied to ensure that planning is correct to the extent possible. Water resources development should be planned and implemented in six stages as shown in Figure 4 for which the general activities and output for each stages are discussed below based on the integrated river basin development master plan approach.

Reconnaissance Stage: The reconnaissance work consists of field and office studies with the objective of preparing a preliminary river basin development master plan. Initially the available national data is studied and analysed followed by rapid field study and site investigation in which the assessment of the natural resources are made. An inventory of the resources in terms of quantity and quality, occurrence, prospective use, limitation constraints, etc. will be produced as a result of the initial attempt. Further site investigation, observations and data collection will be made in order to refine the initial inventory. The final result of these activities is to produce the preliminary master plan report which will indicate the resources potential, development prospects and the global level of financing requirement. The social, environmental technical and economical aspects are assessed at preliminary level to identify potential issues, combats and benefits.

Master Plan Preparation Stage: This stage is the most important planning stage in which fundamental decision on the development of river basin and therefore of the alteration of the socio-ecological balance are taken. The studies and analysis should be of wide coverage and of adequate depth and the decisions at each phase and at the final plan should involve wide sector of the public and private interest. Essentially the master plan will present the magnitude of the available resources, comprehensive need assessment on the resources, the development options and recommendation over a long period time frame i.e. from 30 to 50 years. The completion of master plans for all the river basins of the country will be necessary for the preparation of development strategy and action plan.

Project Preparation Stages: At this stage specific development projects such as irrigation, power, soil conservation, drainage, flood control etc. or programmes like livestock improvement, environmental health control, wildlife conservation etc. are prepared for implementation. The projects or programmes are studied and prepared in the sequence and in accordance with the River Basin Development Master Plan. The main objective at project preparation stages is to make a detailed investigation and analysis of physical, environmental, social and economical aspects and make alternative technical analysis in order to determine the most effective method of implementing the project.

Implementation Stage: Implementation is the activity concerned with the execution of the project or programme that has passed through preparation stage. Implementation may involve structural or non-structural measure or combinations of both, as determined from the project preparation report.

Operation Stage: At the operation stage the development is giving fruit. The main activities at this stage is to institute the management systems for enabling the production or performance at predicted level. Maintenance, rehabilitation and production are the main elements of this activity. Successful operation will depend on appropriate management, institutional set-up, organisational structure and financial source and commitment.

Monitoring Stage: This is post auditing activity of monitoring and evaluation of the executed works of planning and development with the objective of making critical analysis and review to present a reliable status report on the achievement of development programmes. Monitoring and evaluation will inform planners, developers and the general public on the positive and negative aspects of planning and operation, on the achievement of intended objectives, on unforeseen effects or impacts and so on.

Proposal on Research & Development Frame Work

Research and development (R&D) in the water sector is lacking at present. There is no institutional responsibility and what ever little activities that are being carried out in this area are geared to meet the individual research objectives. R & D in the water sector will be an important part of the overall development efforts as this aspect will deal with the scientific and technological requirement for the envisaged water resources development. Without it, sustainable water resources can not be contemplated. In view of the importance of R & D work in the water sector, a proposal on approach frame work is presented as shown on Figure 5. Three basic steps are envisaged which will lead to meaningful contribution of R & D to sustainable water resources development.

Assessment of the Existing Situation

This step is basically an entry point and the objective is to know the existing activities if any and rationalise them in the context of the proposed frame work.

Approach Framework

R&D in the sector should be aimed at identifying water resources development constraining problems and seeking solutions at all levels and in all water resources development activities. There are two main components that should be analysed and integrated into an overall R & D frame work and operational direction. These are:-

Investigation of National, Regional & Community Specific Problem: The main problems constraining water resources development should be identified at national, regional and community level and the role of R & D in bringing about solution to development problems should be defined. Specific areas of concern are indicated in Figure 5.

Integrated & Holistic Research: R & D has to cover all aspects of water resources development in a multi-disciplinary approach and present an integrated solution to the problems hindering sustainable development. The specific areas of interest would be the analysis of the socio ecological, water resources management, water use and water resources development systems to study links, interdependencies and disturbance level and provide solution within this frameworks.

The expected out put

Having assessed the problems in the context of the two main approach parameters R & D would be carried out to provide appropriate solutions for integration in planning and implementation of water resources development activities. Basically R & D will lay the base for the adoption and indigenization of water technology, build up professional capacity in the sector, provide solution based on applied research and will assist on the integration of science & technology into the public domain. The end result of properly implemented R & D undertaking would be to underpin sustainable development on robust scientific and technological base. In the final analysis R & D in the water sector has to be institutionalised, with the institutes of higher learning and government establishment taking leading roles. This aspect needs commitment and urgent attention.In the preceding sections the issue of sustainable water resources development in Ethiopia has been discussed in a broader and general context. For Ethiopia, sustainability has to be realised in the generation time frame . The crippling poverty and the general dependence of the Ethiopian agriculture, energy sources and lack of water for health and biological requirement has put the present generation at risk. A generation at risk may not be able to ensure the need of the comings generation even if the need is considered to be equal to that of the present one. Sustainable development has to operationalized with in this existing reality. The immediate task would then be to gear water resources development to over come the existing socio-economic problems so that the basis for the ability of the future generation to meet its own need can be achieved. This might mean that development would be sub-optimal in the inter-generational time frame even through it could be justified in the context of ameliorating the problems of the present generation.

Reference

Berhanu Adugna, 1997. *Sustainable water Resources Development of Ethiopia, A prospective Approach.* proceding of the symposium on sustainable water Resources Development in Ethiopia, Ethiopian Journal of water Science and Technology Vol. 1, Arba Minch.

Capra, F., 1996. *The Web of Life.* Doubledy Dell Pab Group , New York.

Central Statistical Authority, 1998. *Summary Report at country and Regional Level.* The 1994 population and Housing Census of Ethiopia, Addis Ababa.

Central Statistical Authority, 1998 : *Report on Area and Production of Belg season crops.* Agricultural sample survey 1990 EC, Statisticai Bulletin 196, Addis Ababa.

Central Statistical Authority, 1998. *Report on Land Utilisation U& IV.* Agricultural Sample Survey 1990 EC, Addis Ababa.

Central Statistical Authority, 1998. *Area and Production For Major Crops.* Agricultural Sample Survey 1990 EC, Vol1, Statistical Bulletin 189.

Central Statistical Authority, 1998. *The 1994 population and Housing Census of Ethiopia.* Result at country level, Volume 1, Statistical Report, Addis Ababa.

Easter, K.W Dixon, I.A and Hufschmidt, M.M (eds.), 1996. *Watershed Resources Management:. An integrated Framework with stadies from Asia and the Pacific.* Westview press, Boulder R London.

Ethiopian Valleys Development Studies Authority, 1990. *Preliminary Water Resources Development.* Master Plan For Ethiopia V II, Addis Ababa.

Newson, Makolm ,1992. *River Basin System and Their Sustainable Management.* Routledge Natural Environment, London.

Tefera Woudeneh, 1997. *Water Demand Scenario For the Ethiopian portion of the Nile Basin.* A paper presented on the Vth Nile 2002 conference, Addis Ababa.

Tefera Woudeneh, 1990. *River Basin Planning & Management - An outline Review, Concepts and issues for Condition of Tropic Africa.* (MSC theses). Institute of Irrigation Studies, University of Southampton.

Titi, V and Singh, N, 1994. *Adaptive Strategies of the Poor in Arid and Semi Arid Lands.* Search of Sustainable Livelihoods, Working paper International Institute for Sustainable Development , Canada.

World Bank, 1998. *Ethiopia Social Sector Report.* Washington D.C.

Effect of Soil Quality on the Decomposition of Urea Fertilizer

Abraham Meressa, Lecturer, Arbaminch Water Technology Insitue, P.O.Box. 21, Arbaminch Ethiopia

Abstract

To sustain the productivity of soils is one of the main issues in agriculture all over the world. One way to increase soil productivity is through the application of fertilizers. Urea is the most extensively used nitrogen fertilizer in the world. Unfortunately, the nitrogen bound in urea can not be taken up by plants as it is applied, for it has to be decomposed to ammonia and nitrate first. Hence special attention should be given to the problems encountered with the utilization of urea as fertilizer in order to match the decomposition of urea to ammonia and nitrate with the demands of the plants and to avoid pollution of the atmosphere as a result of ammonia volatilization and pollution of water as a result of Nitrate leaching. In turn, the decomposition of urea depends strongly on the chemical, biological and physical properties of the soil it has been applied to. The knowledge of the pathways of urea decomposition and the transformation in a soil is a necessary requirement for the effective utilization of urea fertilizer. The release of ammonia and nitrate available for plants after the application of urea has been investigated in three soil samples. The chemical analysis of the soil samples were carried out by the classical standard methods and in comparison with another method for nitrate determination developed in the laboratory. The results are discussed on the basis of the chemical properties of the soil samples.

1.Introduction

The experience of farmers has established that the progress of science and technology, the use of fertilizers, intensive agriculture and improved animal husbandry create favourable conditions for a steady increase in the productivity of the soil.

Application of nitrogen fertilizers has particular importance. This is because nitrogen is one of the basic mineral elements required by plants. Unfortunately in most soils there is not enough nitrogen to provide high yields. Application of nitrogen fertilizers in soils enables to increase crop yields rapidly and to improve their quality appreciably. However, only about one half of the fertilizer nitrogen is taken up by plants during the year of application. This value may be as low as 25%. About 25% of the nitrogen applied is lost from the soil plant system and about 25% of the nitrogen applied is immobilized in soil the first season of its application .

Urea is the dominant nitrogen fertilizer in world agriculture. Consumption is estimated to be fifty million metric tons annually. Hence special attention should be given to problems encountered with the use of urea as a fertilizer. These problems result largely from the rapid enzymatic hydrolysis of urea to ammonia and carbondioxide .

The chemical, biological and physical properties of different soils strongly influence urea transformations and nitrogen loss from soils . knowledge of the basic urea- nitrogen path ways and transformations is needed to improve its fertilizer use efficiency in agriculture. Therefore it is necessary to know the urea release pattern in a given soil so that it matches the plants need for nitrogen.

1.1 Determination of nitrogen in soils

There are several methods for the determination of ammonium and nitrate in soils. The standard method used for the determination of ammonium and nitrate in soils is the Kjeldahl distillation method .

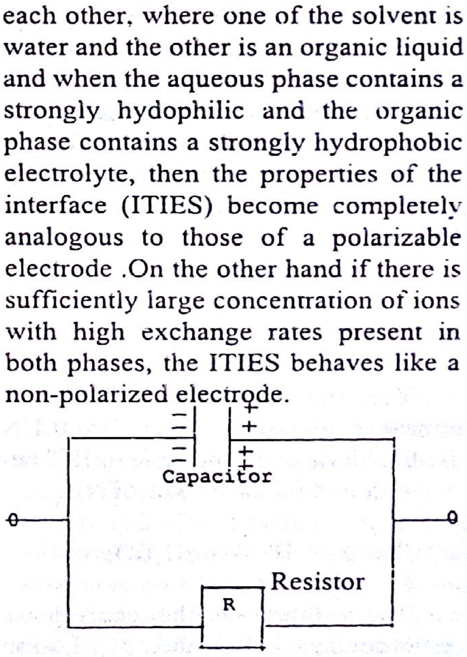
Electrochemical studies over the last 20 years on ion transfer across the polarized oil/water interface have shown that this interface can be employed for voltammetric and amperometric determination of ions.

2.Theory

Electrodes are devices with which one can detect the movement and separation of charges occurring at phase boundaries, as well as induce and vary such processes by means of a forced current flow. An electrode can be a metal wire immersed into an electrolyte solution or two immiscible electrolyte solutions in contact with each other. The electrodes are referred to as metal/electrolyte solution electrode and electrolyte solution/electrolyte solution electrode respectively .

2.1.Analogy Between Metal/ Electrolyte Solution and Electrolyte Solution

When two immiscible electrolyte solutions are brought in contact with each other, where one of the solvent is water and the other is an organic liquid and when the aqueous phase contains a strongly hydophilic and the organic phase contains a strongly hydrophobic electrolyte, then the properties of the interface (ITIES) become completely analogous to those of a polarizable electrode .On the other hand if there is sufficiently large concentration of ions with high exchange rates present in both phases, the ITIES behaves like a non-polarized electrode.



R---->0 ideally non-polarizable electrode
R -----> ¥ ideally polarizable electrode

Fig.1.Electrode surface model on the corresponding equivalent circuit.

In both the metal/electrolyte solution electrode and electrolyte solution / electrolyte solution electrode a potential difference will occur between the two phases which is called the Galvani potential difference (GPD). The magnitude and sign of the GPD depends on the composition of the two phases in contact with each other. Inorder to measure this galvani potential difference one has to build up an electrochemical cell. This is done by employing reference electrodes. A reference electrode is an electrode which possesses a constant GPD at the interface between the metal and an electrolyte solution .

3. Experimental

3.1. Standard (Kjeldahl) Method

Kjeldahl flasks and condensers used for this experiment were made (in the chemistry department glass blowing workshop).

Five soil samples were brought from Gojam (Angenea) in co-operation with the Ethiopian soil conservation project.

3.1.1.Determination of total nitrogen

10 grams of each soil sample was taken and the nitrogen of the nitrogenous substance in the soil was converted into ammonia by boiling with concentrated sulphuric acid, which was fixed by the excess of acid as ammonium sulphate. The latter was determined by adding an excess of 40% sodium hydroxide solution and distilling of the liberated ammonia into excess boric acid mixed indicator solution to be absorbed as follows

$NH_3 + H_3BO_3$ ---->$NH_4^+ + H_2BO_3^-$

The borate ion formed was determined by titration with standard 0.1 N hydrochloric acid, one mole of HCl being required for each mole of NH_3.

$H_2BO_3^- + H^+$ ----->H_3BO_3

The solution at the equivalence point contains H_3BO_3 and NH_4Cl, so an indicator in the pH range 5-6 was necessary. A mixed indicator (Bromocresolgreen-methylred) was satisfactory.

3.1.2. Determination of Available Nitrogen.

Available (nitrate and ammonium) nitrogen in the soil sample was determined as follows:

10 gram of each soil sample was added to 100 ml of 10 mM CuSO4 solution into an Erlenmeyer flask and was shaken for 1 hour using Gallenkamp flask shaker. After filtering, the extract was transferred into the Kjeldahl flask for the determination of ammonium-nitrogen and nitrate-nitrogen by distillation with MgO and Devarda's alloy-MgO mixture respectively. The remaining procedure was the same as 3.1.1.

3.2.Electrochemical methodu

Fig.7 and 8 show the block diagram of the experimental set-ups for the electrochemical method used in the experiment.

3.2.1. The flow system and the sample

The flow system was realized by utilizing a gravity flow. A container filled with 10 mM copper sulphate solution was positioned at the required height and the carrier solution (10 mM copper sulphate) was made to pass through a tubing to the sample loop. The sample loop injects 25ml sample solution to the carrier stream.

A dialysis membrane (PT-600) having a thickness of 45 m was used to stabilize the water/nitrobenzene interface.The membrane was fit on to a teflon tube by the help of a plastic O-ring. The teflon tube was filled with 10 mM solution of EtVTPB in nitrobenzene which was used as a supporting electrolyte in the organic phase. The supporting electrolyte in the aqueous phase was 10 mM copper sulphate solution.

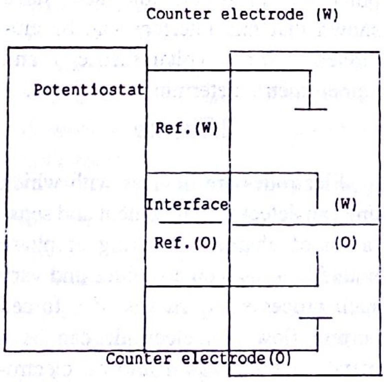


Fig. 2. The four-electrode potentiostat

The dialysis membrane lasted from three to four weeks. The deterioration of the membrane was characterized by a shift in electrode potential, drift and poor response. Membrane

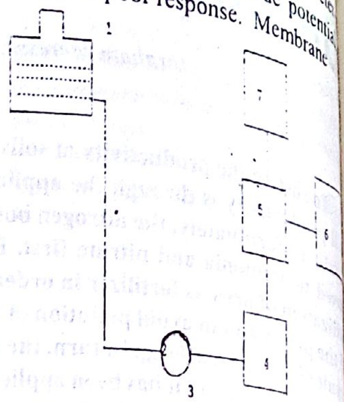


Fig.3. Block diagram of the flow-injection system

failure was sometimes apparent on visual inspection as blue spots on the membrane.

1. Reservoir of the carrier solution
2. Sample loop
3. Mixing coil
4. Detector
5. Four-electrode potentiostat
6. Variable voltage supply
7. XY/t recorder

3.2.2. The ammonia sensor

The ammonia electrode ORION uses a hydrophobic gas-permeable membrane to separate the sample solution from the electrode internal solution.Dissolved ammonia in the sample solution diffuses through the membrane until the partial pressure of ammonia is the same on both sides of the membrane. In a given sample the partial pressure of ammonia will be proportional to its concentration.

Ammonia diffusing through the membrane dissolves in the internal filling solution and, to a small extent reacts reversibly with water in the filling solution.

$NH_3 + H_2O$ - $NH_4^+ + OH^-$

and

$[NH_4] . [OH^-]/[NH_3]$ = constant

The internal filling solution contains NH4Cl at a sufficiently high level so that the ammonium ion concentration can be considered fixed. Thus:

$[OH^-] = [NH_3]$. constant

The potential of the electrode sensing element with respect to the internal reference element is described by the Nernst equation:

$E = E_o - S\log[OH^-]$.

where:

E = measured electrode potential

E0 = reference potential

OH^- = hydroxide concentration in solution

S = electrode slope.(~60 mv/decade)

Since the hydroxide concentration is proportional to the ammonia concentration, the electrode response to ammonia is also Nernstian.

$E = E_o - S\log[NH_3]$

The reference potential Eo, is partly determined by the internal reference element which responds to the fixed level of chloride in the internal filling solution.

4. Results and Discussion.

4.1. Transfer of nitrate across ITIES

The transfer of nitrate across the membrane stabilized ITIES was investigated using flow injection amperometry. In this method, the axial concentration profile of the ion being investigated, which is caused by dispersion of the injected sample plug in the laminar flowing carrier stream, is monitored by the current- time response.

When 25 ml of the standard solution of nitrate was injected into the carrier solution at different applied potentials with in the polarization range of the supporting electrolytes, different current-time responses were observed.

For potentials sufficiently negative from the half-wave potential, a limiting diffusion current is obtained. This limiting current is given by

$i_l = kZD^{2/3}C_b$

where,

Cb = the bulk concentration

D = the diffusion coefficient

Z = charge of the ion

k = a constant which depends on the flow rate, the viscosity of the carrier solution, the geometry of the wall-jet arrangement and the dispersion of the injected sample.

For the determination of nitrate, a potential in the limiting range was chosen so that any change introduced in the potential does not seriously affect the current. Having chosen this potential a calibration curve was obtained for the transfer of nitrate across a membrane stabilized ITIES.

4.2. Application of the method to soil samples

Five different soil samples were determined for their nitrate and ammonium content using the flow injection amperometry (FIA) and ammonia sensor respectively. The values obtained were in good agreement with the values obtained by the standard (Kjeldahl) method (Tables 1 and 2).

Since only ammonium and nitrate can be taken up by plants from urea, it is of great importance for farmers utilizing urea as fertilizer to know the time when these two ionic species are present at maximum concentration after the application of the fertilizer.

The aim of this investigation was two fold:

i) the determination of ammonium and nitrate in soils by electroanalytical methods and to compare the results with those obtained by standard methods used for the determination of ammonium and nitrate in soils.

ii) A search of the literature has revealed that little has been done on the time dependence of the decomposition of urea into ammonia and nitrate in the soils of Ethiopia. Therefore the time dependence of urea decomposition into ammonia and nitrate in selected soil samples has been investigated employing the electroanalytical methods

The electrochemical method was then applied to the determination of nitrates and ammonium in three selected soil samples with low, medium and high total nitrogen contents. Samples were analyzed for pH, moisture content and carbon content.

Sample	1	2	3	4	5
Kjeldahl	6.8	7.0	7.5	6.8	11.2
FIA	6.6	6.7	7.4	6.7	11.1

Table 1. Nitrate content (in 10^{-5} M) of soil samples determined by the standard(Kjeldahl) method and FIA

Sample number	Total carbon (%)	Total nitrogen (%)	C/N ratio	Moisture content (%)	pH	Avail.N. (%)x10^{-+3}
1	0.28	0.03	9.3	10.2	5.8	2.34
2	1.06	0.13	10.6	11.5	6.5	22.7
3	4.08	0.28	14.6	8.4	5.4	29.7

Table 2. Ammonia content(in 10^{-5} M) of soil samples determined by kjeldahl method and ammonia sensor

Sample number	Total carbon (%)	Total nitrogen (%)	C/N ratio	Moisture content (%)	pH	Avail.N. (%)x10^{-+3}
1	0.28	0.03	9.3	10.2	5.8	2.34
2	1.06	0.13	10.6	11.5	6.5	22.7
3	4.08	0.28	14.6	8.4	5.4	29.7

Table 3. Total carbon, total nitrogen, available nitrogen, C/N ratio, Moisture content and pH of selected soil samples.

From Table 3, it is shown that the amount of available nitrogen in sample no. 1 is very low. This may be due to the low total nitrogen content. The available nitrogen in sample no. 3 is less than that of sample no. 2 though the total nitrogen in sample no. 3 is much greater than that of sample no. 2. The possible explanation for this is that nitrogen mineralization is a microbiological process controlled by several factors such as pH, temp, moisture,...etc. Several studies have shown that the soil pH is known to be the limiting factor for nitrogen mineralization. This process has been found to be minimal at low soil pH. As result, nitrogen mineralization in sample number 3 is slower due to the lower soil pH, and consequently lower nitrogen availability.

To the above soil samples, fertilizer urea was added (4 mg/kg soil) and its decomposition studied by measuring the total nitrogen, nitrate-nitrogen and ammonium-nitrogen daily for 32 days. All values reported were the average of at least four measurements.

As can be seen from Figures 4,5,6, there is a large increase of ammonium concentration in all the soil samples one day after the application of urea. This increase in ammonium concentration suggests that urea hydrolysis occurred rapidly.

Compared to the other samples, the increase in ammonium concentration in sample no.3 is slow. A possible explanation for this is that, the overall rate of urea hydrolysis in sample no.3 may have been slower due to the lower soil pH and lower moisture content.

Urea is hydrolysed by the enzyme urease and the optimum pH for the activity of this enzyme has been reported

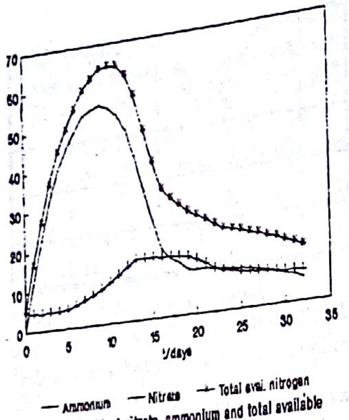


Fig. 4 Amount of nitrate, ammonium and total available nitrogen vs time after application of urea.

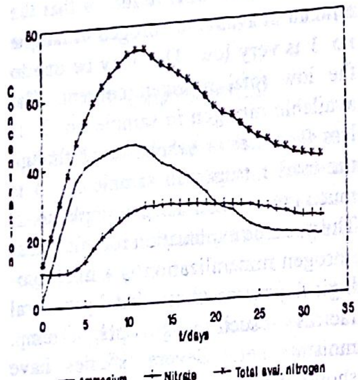


Fig. 5 Amount of nitrate, ammonium and total available nitrogen vs time after application of urea.

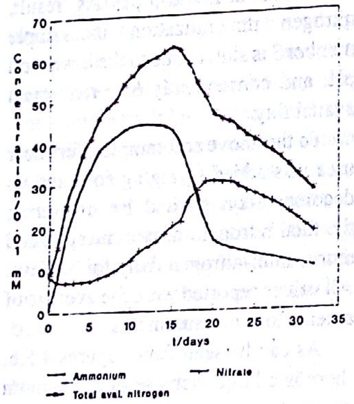


Fig. 6 Amount of nitrate, ammonium and total avail. nitrogen vs time after application of urea.

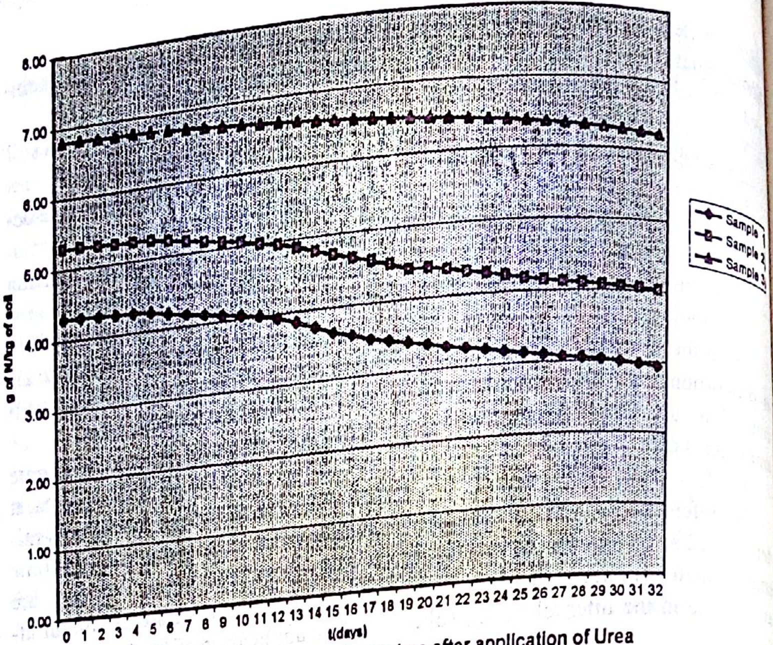


Fig.7. Total nitrogen of the soil samples vs tme after application of Urea

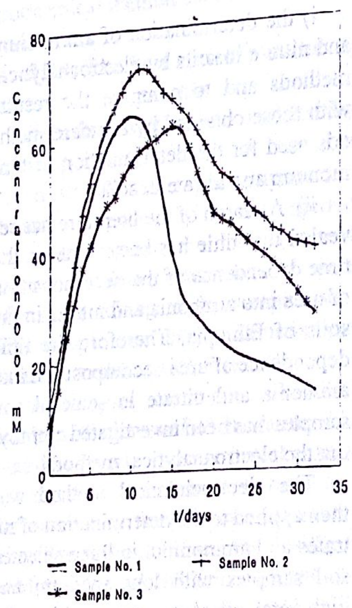


Fig. 8 Total available nitrogen vs time of the soil samples after application of urea.

to range from 6.5 to 9. It has also been found that greater soil moisture content promoted hydrolysis of urea.

In the first 5 days after the application of urea, the nitrate content in all the soil samples showed little or no change . This could be due to the nitrification inhibiting effect of high pH resulted from the fast hydrolysis of urea. The activity of nitrifying bacteria is found to be inhibited at soil pHs below 6 and above 9.

The NH_4^+ concentration started to decrease quickly in samples 1,2 and 3 respectively 9,10 and 12 days after the application of urea. This decrease in NH_4^+ concentration may be due to ammonia volatilization, nitrification and immobilization.

The driving force for ammonia volatilization is the ratio of NH_3 to NH_4^+, which increases with pH.

Urea hydrolysis can be represented as follows.

$CO(NH_2)_2 + 2H^+ + 2H_2O \rightarrow 2NH_4^+ + H_2CO_3$

The net result of the above reaction is the consumption of 2H+ ions from the soil for each mole of urea hydrolysed. As a result of this H+ consumption, soil pH increases substantially and the proportion of NH_3 increases promoting ammonia loss to the atmosphere.

From the curves, it can be seen that the amount of plant available nitrogen content in soil samples 1, 2, and 3 started to decrease respectively 10, 11 and 15 days after the application of urea. This may be due to the loss of nitrogen to the atmosphere, as a result of ammonia volatilization and denitrification, and immobilization of nitrogen.

As a result of the loss of nitrogen to the atmosphere the total nitrogen content of all the soil samples is expected to decrease. However, Fig.7. shows that the decrease in total nitrogen content in soil no.3 is not significant compared to the other two. From this observation it is possible to conclude that the major reason for the decrease of available nitrogen in sample no.3 is not loss of nitrogen to the atmosphere but incorporation of the available nitrogen into the organic mater of the soil.

This could be explained by the high carbon content and high C/N ratio. High level of available carbon in soils encourage proliferation of soil microorganisms that are capable of rapidly immobilizing the available nitrogen present. Microbial nitrogen demand is mainly determined by the amount of carbon present in the soil. And the high C/N ratio indicates a higher rate of nitrogen immobilization than mineralization.

5.Conclusion

The membrane stabilized interface between two immiscible electrolyte solutions in a flow system and the ammonia sensing electrode have been used for the determination of soil nitrates and ammonium respectively. These techniques have been found to be very fast and the results obtained were in a very good agreement with those obtained employing the standard method. Application of this electrochemical method could save the time and chemical wasted in comparison to the standard (kjeldahl) method.

This method was then applied to investigate the decomposition of urea with time in selected soil samples. knowledge of the basic urea-nitrogen path-ways and transformations is needed to improve fertilizer use efficiency in agriculture. Therefore it is necessary to know the urea release pattern so that it matches the plants need for nitrogen.

Since only ammonium and nitrate can be taken up by plants, it is of great importance for farmers utilizing urea as a fertilizer to know the time when these two compounds are present at a maximum concentration after the application of the fertilizer.

The investigation showed that the time when the plant-available nitrogen reaches at a maximum concentration after application of urea varies from soil to soil. Thus farmers must adjust their fertilizer application so that the time of maximum fertilizer release and maximum nitrogen uptake by crops coincide, inorder to insure maximum utilization of the fertilizer applied.

6.References

Kaures A. Malik and M. I. H. Aleem, *Nitrogen and the environment*. (1985)

D. A korenkou ,*Nitrogen fertilizers*.(1983)

I. Yamada, S. Shoji, *Soil Sci. Soc. Am. J.*, 55(1991) 1462.

B. Hundhammer and S. Wilke, *J. Electroanal. Chem.*, 266(1989)

A.A.U., Department of chemistry, *workshop on modern electroanalytical methods*., 1992.

Masakazu Aoyama and Tomhiro Nozawa, *Soil Sci. Plant Nutr.*, 39 (1993) 23.

Masahito Hayatsu, *Soil Sci. Plant Nutr.*, 39 (1993) 219.

S.S. Malhi M. Nyborg and M. S. Aulakh, Commn. *Soil Sci. Plant Anal.*, 23 (1992) 1119.

M.L. Cabrera, *Soil Sci. Soc. Am. J.*, 57 (1993) 62.

D.M. Sullivan and J.L. Havlin, *Soil Sci. Soc. Am. J.*, 56(1992) 957.

R.E. Brown, G.E. Vasvel, and C.A. Shapiro, *Soil Sci. Soc.Am. J.*,57 (1993) 121.

Kevin A.Handreck,*Commn.Soil Sci. Plant Anal.*, 7 (1992) 201.

R.D. Hauck, *Soil use and management*. 6 (1990) 66.

R.Sylvester Bradley, *Soil use and management*.9 (1993) 112.

D.S.Powlson, *Soil use and management*., 9 (1993) 86.

A.Lindloft,R.Nieder and J.Richter, *Soil use and management*, 9 (1993) 120.

G.B.Reddy and K.R.Reddy, *Soil Sci.Soc. Am.J.*, 57 (1993) 111.

R.E. Brown and G.E. Varvel, *Soil Sci. Soc. Am.J.* 57(1993) 121.

Small-Scale Sand Filter as a Method of Appropriate Treatment for the Removal of Biological, Physical and Chemical Impurities at Household Level

Esayas Alemayehu, Kebede Faris, Gebre Zeleke, Jimma Institute of Health Sciences, P.O.Box. 973 Jimma, Ethiopia

Abstract

Small-scale sand filter as a method of appropriate treatment for the removal of biological, physical and chemical impurities at household level In an attempt to test the effect of samll-scale sand filter in the reduction of fecal coliform, turbidity, color, Iron, manganese and effects on pH and temperature; initial laboratory examinations of samples taken from smiche stream was conducted after initial examination was made. Representative samples was filtered through small-scale sand filter from Nov. 10,1998-Jan 8, 1999.

Small-Scale sand filter was made from a 160 litre barrel. A half inch out let pipe with its accessories was fitted to the barrel. A 10cm deep well-washed coarse sand (dia. 1-2mm)was laid over the layer of gravel; And 60cm deep very clean fine sand (dia. 0.2 -1mm) was laid over the layer of coarse sand. The max. Filtration rate was set at 0.15m/h. Intended for the unit to filter up to 150 liters of raw water per day provided water is added at reasonable intervals.

Laboratory test, methods and instruments used are:- determination of fecal coliform by multiple tube method (MPN); turbidity by turbidimetric; color, Iron and manganese by palin tests; pH and temperature by electro-meteric methods were conducted, in SHE laboratory in JIHS.

The initial laboratory test resulted an average concentration of fecal coliform to be 2004.0 MPN/100mL; turbidity 116.1 NTU; color 108.3 TCU; iron 0.26 mg/L; manganese 0.169 mg/L; pH 6.43-8.7; and temperature 18,.5°C - 23.5°C. Sample which was filtered from the same source shows that very good reduction of contaminants was achieved. After 1-4 weeks of operation, the average concentration of fecal coliform was lowered down to 1.5 MPN/100mL (99.925% redu.); turbidity 3.32 NTU (97.14% redu.); color 4 TCU (96.31% redu.); iron 0.07 mg/L (73.08% redu.); manganese 0.071 mg.L (58.0% redu.); pH 6.98-7.56 and temperature 20.1°C -21.7°C.

This study has revealed that filtration of raw water through small-scale sand filter of the type used for the study can remove contaminants upto the recommended vaues by WHO and/or standard books. As the number of operation days increased the efficiency of the filter increases.

Communities, whose water sources are unprotected and not treated, can use the method adapted for this study. Larger families may require larger filter which can hold more filter media and water. Larger filter can be built with bricks and mortar in the same way, or even traditional pots or cement jars can be used.

I. Introduction

Water is life, and one needs to look broadly at the indispensable nature of it to human life, because with out which life is not possible (1,2). It is a unique substance and one of the most important natural resource but its amount in nature is fixed ; of all the water available on earth only 0.007% is fresh water that is renewable and available for use on a sustainable basis (3). Its availability alone is insufficient to support life . Its quality is also of supreme importance.

Of course, more than 25 millions of people lose their precious lives each year in the world due to diseases spread through consumption of unsafe water(3). It has been reported that, of the 4.5 billion population of the developing world, more than a billion have no access to supply of safe drinking water(4), with the result that diseases related to water are the major causes of high morbidity and mortality in developing countries.

In Ethiopia, up to 1990 the estimated coverage of urban and rural population with safe drinking water was 18.8% (5).On the other hand data obtained from the UNICEF, for the year 1992 indicate that more than 87% of the total population live in rural areas. Out of these only 19% get access to safe water, with the remaining 81% drawing their water supplies from contaminated sources. Apparently, water from these sources has a large chance of being contaminated with the fecal matter as well as other impurities, provided by the fact that about 80% of diseases prevalent among the people of the country are water- related(6). All these signify that much of the world population and much more of Ethiopians are suffering from luck of safe water and water borne diseases. In this case water to be used by a community needs some method of eliminating contaminants.

Although safe and reliable water supply is badly needed, the installation of conventional water treatment plants in rural and suburban area of developing countries is, at present, impractical due to operational consideration, economic reasons and the settlement characteristics of the population. In such cases the development and popularizing of small-scale water treatment processes which dose not demand much money and skilled manpower is important.

Who, through its program in the International Drinking Water Supply and Sanitation Decade encourages the search for low cost solution which is more suitable to local socio- cultural conditions(7). One of such uncomplicated technology in which most people can afford is small-scale sand filter. The method of small-scale sand filter dose not demand much money, skilled manpower, sophisticated equipment and chemical disinfectants. Hence, especially the poor will benefit from this technology.

This simple technology is not studied in detail in its efficiency of contaminants reduction. Therefore, the aim of this project is to ensure removal of solids, organic matter, pathogenic organisms and some chemicals in the raw water.

Theory of biological filtration

The removal of contaminants in biological filter is by a combination of the principal processes by which the particles are brought into contact with the sand grains consists of straining or screening, sedimentation, inertial and centrifugal forces, diffusion, mass attraction, adhesion, electrostatic and electrokinetic attraction as well as biological action. As the depth from the surface increase the quantity of organic food decreases and the struggle among the various organisms becomes fiercer. As a consequence the raw-water, which entered the bed laden with a variety of suspended solids, colloids, microorganisms and complex salt in solution, has, in its passage through some 40-50cm of filter medium, become virtually free of all such matter, containing only some simple (and relatively innocuous) inorganic salt in solution. Not only has practically every harmful organism been removed but also the dissolved nutrients that might encourage the subsequent growth of bacteria or slimes(8).

The biological processes that take place in the filter skin (SCHMUZDECKE) of the filter are capable of reducing the total bacteria content by a factor of 1000 to 10000 and the E. coli content by a factor of 100 to 1000 (9). The bacterial activity described is most pronounced in the upper part of the filter-bed and gradually decreases with depth as food becomes scarcer. When a filter is cleaned by scraping off the top layer, the bacteria in the layer are also removed, and a further ripening period is necessary to bring the population up to the required strength (10).

Filter operation needs care in some aspects, scouring of the filter bed and resuspension of settled matter, due to uncontrolled addition and drained of water, must be avoided. This will cause surges of water through the sand. By careful addition and draining of the filter, water quality can be improved significantly. Drying of filter bed should be prevented between filter runs. If it occurs, the filter media should be taken out completely and replaced again. If not, cracks, will be formed that act as a conduit allowing short-circuiting of raw water. The filter should be cleaned when the flow is reduced, normally after a few months. To clean the filter, drain out the water and scrape off a very thin layer, about 10mm. thick from the sand surface and thoroughly washed and replaced in the filter. For sufficient treatment by filtration the initial water source should be selected if available, other wise if the source water is too muddy, it must be allowed to settle in a drum or tank before adding it to the filter (8,9,10).In a properly operated sand filter, the filtered water may be safe for drinking, there by avoiding the need for chemical disinfection.

2. Objectives of the Study

2.1 General Objective

The general objective is to determine the efficiency of small-scale sand filter using microbiological, physical and chemical parameters before and after filtration process and make recommendation based on the result.

2.2 Specific Objective

1. To detect the load of fecal coliform organisms of water samples and after filtration.
2. To determine the level of turbidity and color of water samples before and after filtration.
3. To measure the temperature and pH of water samples before and after filtration.
4. To determine the level of concentration of iron and manganese of water samples before and after filtration.
5. To formulate recommendations based on the results on its applicability, construction, cost and the need for further in depth study.

Limitation of the study

- The study is limited only on those parameters found more indicative for the efficiency of small- scale sand filter.
- Since there is no established national water quality standard in the country, the data analysis and interpretation will be based on guideline values recommended by WHO and/or drinking water standards recommended by several developing countries.
- Shortage of materials and reagents.
- Time was a limiting factor to perform a detail analyses.

3. Methodology

3.1 Study Design:- An experimental study was conducted from NOV. 10,1998 to JAN.8,1999 in Environmental health school(SEH) laboratory, Jimma Institute of Health Sciences (JIHS), Ethiopia.

3.2 Design and Preparation of the small-scale sand filter:-

Filter Barrel :- small-scale sand filter was made from a 160 liter barrel. It was cleaned out and painted with none water soluble anti-rust paint. A half inch out let pipe with its accessories was fitted to the barrel. The under drain pipe which was perforated and covered with wire mesh(dia.<1mm.) was fitted horizontally with the water delivering pipe as shown in figure 1, so that the out let pipe rises 3cm above the top of the filter sand. This ensure that the existence of some layer of supernatant water on top of the sand bed at all times to keep the biological film active and alive. The cost of materials required for a single filter barrel as of NOV.1998 market prices(Jimma town) is Birr 225.

· Filter arrangement and operation principles:- A 10cm. deep well-washed gravel (dia.5-8) was laid over the bottom of the barrel; A 5cm. deep well-washed coarse sand (dia.1-2mm.) was laid over the layer of gravel; And 60cm. deep very clean fine sand (dia. 0.2 -1mm.) was laid over the layer of coarse sand. After the sand is filled, care is taken not to damage the bed during pouring water. A washed flat stone was laid above the sand layer, directly underneath the hole in the lid, thus distributing the water slowly on the sand bed.

· Filter capacity and filtration rate control:-With such arrangement the barrel will have a 25 liter capacity, which will be ready for use after 4 to 5 hours of operation. If water is added at reasonable intervals, the unit can treat up to 150 liters of raw water pre day, which is sufficient for an average family of 10 persons at the demand indicated (4,11). Although the filter work under declining rate of filtration, it is essential to control the maximum rate of filtration to get an effluent of good quality. This is provided by fitting a faucet (Tap) on the out let line as shown in figure1. And the head is regulated by opening or closing the Tap by half or full round to have the maximum filtration rate of 0.15m/h

3. 3 Survey and measure the water quality

In developing national standards, it will be necessary to consider a variety of local, geographic, socioeconomic, dietary, and industrial conditions. This may lead to national standards that differ appreciably from the WHO guideline values. For small community water supplies only a limited selection of parameters could possibly be used to survey and measure the water quality for public supplies. The WHO guidelines suggests that the main emphasis be placed on microbiological quality, followed by aesthetic considerations. Furthermore, the removal of many chemicals constituents from water requires sophisticated treatment processes that are beyond the economic capability of people in developing countries (9,12). So, this project concentrates mainly on the removal of pathogen, solids, organic matter and some chemicals in the raw water.

3.4 Laboratory test , Methods and Instruments used

Determination of fecal coliform by multiple tube method(MPN); turgidity by turbidimetric; color, iron and manganese by the palin tests; pH and temperature by electro-metric methods were conducted, in SEH laboratory in JIHS. In attempt to test the effect of small-scale sand filter in the reduction of fecal coliform, turbidity, color, Iron, manganese and effects on PH and temprerature; initial laboratory examination of samples takent from samiche stream was conducted after initial examination was made. The sample size for each parameters was determined based on the analytical methods and procedures employed for each parameters.

3.5. Frequency of Analysis:-

To observe how the filter bed of the small-scale sand progresses with time, the bacteriological quality of the raw and filtered water is analysed weekly. A total of seven samples with an interval of one week for six consecutive weeks were collected. For other paramenters, a total of 13 samples with an interval of three days for six consecutive weeks were collected.

4. Results and Discussions

The efficiency of small- scale sand filter to eliminate fecal coliform, turbidity, color, Iron, manganese and effects on pH and temperature were measured. The effect of the treatment on each parameter are discussed in the respective headings.

4.1 Microbiological test:-

According to the study findings the load of fecal coliform bacteria in the raw water on average decreased to only 28.26 (98.64% reduction) before amonth of operation (table 1). This is probably because of the principal processes by which particles are brought into contact with the sand grains. But, after a month of operation on average it decreased further to 1.5 (99.925% reduction). This is due to the formation of filter skin (SCHMUIZ DECKE) on the surface of the sand.

Tabe 1Microbilogical test results before and after a month of operation

Sample number	Date	MPN/100mL F.C		
		Raw Water	Filtered water	% redu.
I -V	Before a monthe	2030.84	28.26	98.64
VI-VII	After month	2004.11	1.5	99.925

4.2. Physical test

The physical parameters have been improved greately by increasing the number of operation days.

Turbidity:- Before a week of operation it decreased to mean 24.1 (86.4% redu) (Table 2) This may be noticable and consequently objectionable to consumer as well as it can stimulate the growth of bacteria. But, after a week of operation it decreased further to 3.32 (97.1% redu.). This is because of the principal processes, such as screening, sedimentation, mass attraction and adhesion are increased once the sand bed is matured.

Color:- Filtration of raw water, which had on average of true color of 108.3 TCU resulted in the reduction of color to 4 TCU (96.3% redu) (table 2). This is probably because organic matter (primary humic substance) and metals such as iron and manganese (which are the major causes of color) are brought into contact with the sand grains . This met the drinking water standard of WHO (12) But, for the first week of operation, it did not achieve the recommended value. I.e. 28.3 TCU.

Temperature:-The initial temperature of the samples varies between 18.5-23.5Oc (table 2). But, after filtration in the filter the temperature level of the filtered water was on average of 20.9 oC . This is probably because the adsorptivity of sand media increases as the temperature drops and temperature increases as the rate of sedimentation and filtration decrease (12)

4.3 Chemical tests

The removal of many chemical constituents from water requires so-

Sample No	Date	Mean level of						
		Turbidity (NTU)			Color (TCU)			Temprature
		WBF	WAF	%redu	WBF	WAF	%redu	^{o}C
I -II	before week	163.3	24.1	86.4	165.3	28.3	81.7	18.5 - 23.5
III -VII	After week	116.1	3.32	97.1	108.3	4.00	96.3	20.9

Table 2.Physical test results before and after a week of operation.

phisticated treatment processes that are beyond the economic capabilities of people in developing countries. Therefore, chemical considerations such as Iron, manganese and hydrogen ion concentration (pH) of the samples are the limited selection of parameters could be used to survey and measure the efficiency of small - scale sand filter as the removal of such chemicals

In this study iron and manganese were decreased to mean 0.136 mg/L (25.7% redu) and 0.153 mg/L (12.6 % redu.) respectively (table 3) before a week of operation. The concentration at this level may couse unpalatable and objectionable taste to beverages such as coffee and tea as well as it promotes the growth of "iron bacteria" that cause taste, odor, color problem. But, after a week of operation, the filtered water have met the drinking water quality standard that became 0.07mg/l of Fe and 0.071mg/l of Mn. This is probably because the electrostatic attraction between a negative charged particles of colloidal matter and a cations of iron and manganese increased, once the sand matured.

According to the study finding the initial hydrogen ion concentration(pH) of the sample varies between 6.43 to 8.7pH; but after filtration, which have met the WHO recommended standard value of pH for drinking water supply (12), i.e. between 6.98-7.56pH (table 3). This is probably because in most natural water treatment processes, pH is controlled by the carbondioxide-bicarbonate-carbonate equilibrium system(8,10).

Conclusion and Recommendation

- The finding of this study proves that, the small-scale sand filter to be efficient in reducing the fecal coliform bacteria, turbidity, color, iron, manganese, hydrogen ion concentration(pH) and temperature levels to their recommended values by WHO and/or standard books. However, full ripening of the filter bed and hence its efficiency may take up to a month. As the number of operation days increased the efficiency of the filter increases.
- This simple technology has been designed that can be made from locally available materials, and that can be operated and maintained by the householders as well as it is affordable by most of them. Therefore, in most rural and suburban communities, whose water sources are unprotected and not treated, water quality can be achieved by filtering raw water in small-scale sand filter.
- Larger families may require larger filter which can hold more filter media and water. Larger filter can be built with bricks and mortar in the same way, or even traditional pots or cement jars can be used.
- The impurities removal efficiency of the filter will be analyzed for the filter media used during the second cycles(Fine sand:- dia. 0.2-1mm; activated carbon: dia. 8-10mm and crushed bricks: dia. 1mm.-2mm.

Table 3. Chemical test results before and after a week of operation.

Sample No	Date	Mean level of						
		Iron (mg.L)			Mangance (mg/L)			pH
		WBF	WAF	%redu	WBF	WAF	%redu	
I -II	before Week	0.183	0.136	25.7	0.173	0.153	12.6	6.43- 8.7
III -VII	After week	0.26	0.07	73.1	0.169	0.071	58.0	6.98 - 7.56

Acknowledgement

My sincere acknowledgment goes to my advisors Ato Kebede Faris, Assistant Professor, Head, SEH, JIHS, and Ato Gebre Zeleke, Head Faculty of Technology and Lecturer,JIHS, for their continuos support and guidance through out this work.

I am also grateful to my alma mater for the financial and material support made to me the fulfillment of this study.

References:-

1.Ricards A. Bartram J. Drinking water monitoring and surveillance. Africa Health 1993; 16(2):12-15

2.WHO,WHO News Letter 1994;9(1):2-3

3.IRC,The World's Water: Is there enough? World day for water 1997. Water News Letter February 1997;247:1

4.IRC, Two billion and counting. Water News Letter. October 1997; 251:1

5.A News Letter of NETWAS, Nairobi; 1995

6.UNICEF,1992. Govemment and public organizations WATSAN Directory-Ethiopia. Addis Ababa.

7.Water lines, July 1990, 9(1)

8.L.Huisman and W.E.Wood, Slow sand filtration WHO Geneva, 1974.

9. Schulz, C. And Okun, D. 1984. Surface water treatment for communities in developing countries. Wiley, New York.

10. Peter Morgan, Rural Water Supply and Sanitation, Blair Research Laboratory, MOH, Harare 1990:256:9

11. Yayeyiral Kitaw, Water supply in small village in Western Ethiopia. Ethio. Med. J. 1980, 18(4): 165-169

12. WHO, guidelines for drinking water quality , vol.3, WHO,Geneva 1985.

WHO, guidelines for drinking water quality 2nd edition vol.2. Geneva 1995

An Objective Approach to Drought Management in Ethiopia

Berhanu Adugna, Arbaminch Water Technology Institute, P.O.Box 21 Arbaminch Ethiopia

Abstract

Ethiopia is one of the most drought-affected countries in Africa and has faced the blunt of drought/famine many times in recent years. Nowadays, due to the alarming trend of population, increasing demand for more food from year to year is becoming more apparent than ever before. In the study done by the National Meteorological Service Agency (NMSA) an attempt was made to quantify the intensity and severity of drought for the country as whole. It was observed that the worst period appears to be the 1980's and the worst drought year happens to be 1984. Northern part of the country was mainly affected severely by droughts/famines.

Drought need not lead to panic among the people nor it is linked automatically with the famine. Early warning systems, droughts prone area programmes to relieve the misery of the victims, drought management and mitigation measures, drought preparedness etc., are, currently, always there with the planners. Long- and short-term measures on integrated basis will provide relief to the solution to withstand the impact of drought. Water resources developments for drought management in Ethiopia is an essential step. Irrigation plays a vital role in mitigating the vigorous of drought.

The main objective of this paper is to better understand the factors predisposing people and landscapes to heightened drought vulnerability and actions which can reduce drought vulnerability and move towards sustainable development in Ethiopia.

Introduction

Hurricanes, cyclones, floods, earthquakes and tidal waves are natural disasters which are more or less sudden and occur in a short time but drought is a worst disaster because it comes on slowly and causes cumulative loss and suffering over a long period of time over a wide area. Since the beginning of humanity the drought throughout the world had severe and sometimes catastrophic effects on vital activities of people. It is a phenomenon which occurs in different parts of the world with unpredictable frequency with the result that the countries concerned are often unprepared for the eventuality. It is generally viewed as a sustained and regionally extensive, occurrence of low precipitation. It is a creeping phenomenon; its accurate prediction of either onset or end is a difficult task. Drought severity too, is difficult to determine. It is dependent not only on duration, intensity and geographical extent of specific drought episode, but also on the demands made by human activities and by the vegetation on a regions, water supplies, soil moisture, evapotranspiration rate, etc.

Nearly 80-90 % of the annual rainfall in Ethiopia falls in the months of February to September due to Inter Tropical Convergence Zone (ITCZ). Hence, this rainfall is quite erratic in space and time, leading to extreme situations of floods and droughts in the country. The span of rain season is regarded as critical in Ethiopia and a negative deviation from normal during this period is supposed to have serious repercussions on the crop productivity. Consequences of droughts are many: economic, social, and political. Impacts on agriculture and rural populations are of particular importance that can result in tragic consequences frequently occurring in Ethiopia. An adverse impact of drought on agriculture produces a chain reaction on all other sectors of economy. The food production declines, shortages lead to more dependence on food imports. The share of agricultural commodities in export trade also decreases. Every incidence of drought to be more or less severe blow to Ethiopian economy which has its own in built weakness. Drought is not an autonomous problem. It is closely linked to the larger problem of our approach to the management of the country's land and water resources potential as the components of an interacting ecosystem.

The main objective of this paper is to understand more fully the factors predisposing people and landscapes to heightened drought vulnerability and actions which can reduce drought vulnerability and move towards sustainable development in Ethiopia.

Country Background

Ethiopia covers approximately an area of 1.1 million Km^2 of which 53% are under pasture, 12% are arable, 7% are covered by forest, 10% covered by lakes and rivers and 18 percent are desert or swamps. Ethiopia is a country of great ecological diversity, located in North East Africa, between 3^0N and 15^0N latitudes and 33^0E and 48^0E longitudes.

Ethiopia is physically and ecologically situated in an environmentally rich geographical regime. The natural resource base that includes significant flora and fauna enabled the country to be one of the best and most significant biodiverstiy areas of the world. It owes its diversity mainly to its contrasting altitude, climate, geology, soils and vegetation. The variations in these parameters are quite wide resulting into many agro-ecological zones in the country. But ask virtually any one in the world what they know about Ethiopia and they will point out famine, drought and starving people. This im-

Year	1988-89	1989-90	1990-91	1991-92	1992-93
Food Grain ('00t)	6230	6736	6952	6440	6953
Population (million	46.7	48.3	49.9	51.6	53.3

Table 1: Food grains Production and Population of Ethiopia (Survey of Current Economic Condition in Ethiopias)

Year	Food Aid (MT)
1984	114.065
1985	1,272,221
1986	928,250
1987	278,812
1988	1,096,205
1989	460,599
1990	657,464
1991	926,400
1991/92	927,313
1992/93	1,176,220

Table 2. Toyal General Food Aids (Source: World Bank, 1992)

pression is largely based on media images of Ethiopia's catastrophic droughts. One of the English dictionary has used Ethiopia as example to explain drought and famine. Considering of the vast potential of this country, it is a paradox that the society is confronted with disaster. But one should not forget the fact lies here is the combination of economic mismanagement, a rapidly expanding population, wars and of course the recurring drought.

As can be seen from statistics released by the National Bank of Ethiopia (1991/92) agriculture is the dominant sector of the economy accounting for about 50 per cent of GDP and 76 per cent of export revenue in 1991/92. It is estimated that it provides livelihood for 85 per cent of the total population. It is estimated that there are more than seven million predominantly subsistence farm families who, on average, have a holding of 1.5 ha or even less per family to cultivate. Despite such a relative importance of agriculture, growth in agriculture was nominal during the eighties, whereas the population growth was unabated, with consequent food shortages. During the past three decades African food production has achieved a growth rate of about 2 % per year, while the population has risen at the rate of 3 % per year (DFID, 1997). The estimated food grain production in Ethiopia and population over the last few years are as shown in Table 1. The growth of agricultural production has not kept pace with the growth of population in Ethiopia.

Expressed on a per capita basis, the 1988/89 production was only 151.1 Kg a year. This believed to be 25 per cent below the nutritionally minimum calorie requirement for the population. If the total production and nutritional requirement are disaggregated, the North and North Central regions are seen to be the poorest in terms of per capita production and hence also in terms of calorie intake. Table 2 shows the annual food aid to Ethiopia, which indicates that a sustained program of agricultural development is needed to overcome the need of prevailing food aids. A strong national policy and commitment to tackle the root causes of drought could lessen this problem. As many of the largest markets for food exports were once food aid recipients, countries like Taiwan, South Korea, Mexico and China, there is no reason that Ethiopia can turn into food self-sufficiency. Some former recipients even have become donor nations.

Drought Overview

Ethiopia is one of the densely populated countries in Africa. It has often suffered from acute droughts and famines causing unprecedented misery to people. Droughts are reported as early as 253 BC over the country (NMSA, 1989).

Danielov (1987) prepared a drought probability (P) map of Ethiopia based on decile method as suggested by Gibbes and Maher (1975). The analysis was done based on 137 stations for the main crop growing season. Some stations have observation of up to ten years only. According to him a year was considered to be a drought year if two months were with rainfall less than their second decile value during the vegetation period, that is from March to October. Also a year was a non-drought year in case the monthly rainfall is close to or more than the value of its potential evapotransiparation. The areas with $P < 0.3$, $0.3 - 0.5$ and $P > 0.5$ are marked as low, transition and high drought probability zones of the country, respectively. They cover mostly western, central and eastern, and southeastern and northern parts of the country, respectively.

The occurrence of meteorological droughts, their intensity, frequency and spectral coherence besides drought years for Belg (small rainy seasons), Kirmet (main rainy seasons) and both seasons together during the period 1969 - 1987 had been analyzed over Ethiopia by the NMSA (NMSA, 1989). Generally, the study revealed that the northern and southeastern parts of the country are highly drought prone. Belg season is more susceptible for droughts suggesting the uncertain behavior of the rains in the season. Among the regions Tigrai is the most affected area in all the seasons. Worst droughts are 1975 for Belg, 1987 for Kirmet and 1984 for both seasons when more than 60 % of the country was affected by drought.

Kirmet is the main rainy season, in which 85 - 95 % of the annual food crops are produced. The percentage of rainfall during this period (June - September) to the annual mean values varies from 10 to 90 %. The Belg season covers the period from February to May and accounts for 5 - 15 % of the annual food crop production. The contribution of Belg rainfall to the annual total varies from 5 to 50 %. Belg and Kirmet are the two important rainy seasons of the country.

Definitions of Drought

There is no universal definition of drought as it is location specific and random one. It is so uncertain event too. It varied from field to field and place to place. Definitions of drougly are difficult and controversial as they depend on a professional viewpoint or economic activity. Many of the definitions of drought are based purely on rainfall status. However, all definitions of drought make it clear that "Want of rain" lies at the root of all drought situation since a long period of time many attempts have made drought precisely, but so far nobody has been able to give a definition which is acceptable to all concerned. The following are few definitions which are given to understand what is drought.

Droughts are periods of abnormally dry weather that are sufficiently prolonged for the lack of precipitation to cause serious imbalance in the hydrologic cycle. They result in water shortages, crop losses, reduced stream flow, diminished ground water resources and depleted soil moisture.

Droughts are distinguished from dry spells, which are periods of approximately 14 days with little or no precipitation. They may be classified according to climate conditions in the affected areas. Thus *permanent drought* exists where the climate is perpetually dry and agriculture can be carried out only with constant irrigation. *Seasonal droughts* exist where wet and dry seasons regularly alternate. The farming is done during the dry season, and must also rely on irrigation.

Contingent or unpredictable droughts exist where normally expected rainfall fails to occur most characteristically in humid and sub humid areas, they tend to be most severe when they coincide with the increased water needs of the growing season and are thus the most serious of the physical hazards to farming. A fourth type of drought called *invisible drought* is harder to recognise. It occurs where precipitation fails to counter balance the moisture lost by crops through evapotranspiration and it makes itself felt by reduced crop yields rather than by wilting or some other observable form of crop damage.

Definition by:	Description of Drought
GUMBEL	Drought is the smallest annual value of mean daily stream flows. This results in one occurrence of drought event per year and limits its application in daily management of drought.
CHANG	Drought is a measure of stream flows, i.e. stream flows are below specified truncation levels. The truncation method is to abstract drought events from a time series.
DRACUP et al.	A shortage with reference to a specified need for water in a conceptual supply and demand relationship.
LINSLEY et al.	A period during which stream flows is inadequate to supply established uses under a given water management system.

Table 3: Drought Definitions

Event Based Definitions

When dealing with droughts, practical, realistic, and workable operation of water resources projects is to be scheduled based on the past experiences of such events. Toward this, a few definitions that are based on events and experiences of the people are worth to be quoted herein in a tabular format (Table 3). More detailed description /definition of drought has been dealt by Yevjevich (1967) and Dracup *et al* (1980).

Definition by : Description of Drought

GUMBEL Drought is the smallest annual value of mean daily stream flows. This results in one occurrence of drought event per year and limits its application in daily management of drought.

CHANG Drought is a measure of stream flows, i.e. stream flows are below specified truncation levels. The truncation method is to abstract drought events from a time series.

DRACUP et al. A shortage with reference to a specified need for water in a conceptual supply and demand relationship.

INSLEY et al. A period during which stream flows is inadequate to supply established uses under a given water management system.

According to Tannehill " drought belongs to the class of phenomenon which is popularly known as spells of weather." Indian Meteorological Department has defined drought as a situation occurring in any area when the annual rainfall is less than 75 % of the normal. British Rainfall Organization (1936) has defined absolute drought as a period of at least 15 consecutive days to none of which is credited a rainfall of 0.1" or more. The U.S. Weather Bureau has defined a drought as a lack of rainfall so great and long continued as to affect injuriously the plant and animal life of place. And to deplete water supplies both for domestic purposes and for the operation of power plants, especially in those regions where rainfall is normally sufficient for such purposes. For management purpose in Australia, drought is broadly defined as a severe water shortage typified by a prolonged period of rainfall deficiency. The Ethiopian NMSA considered that drought occurs over a region if the seasonal rainfall is less than 19 % or more of its mean. Further, a drought is classified as moderate and severe if the seasonal rainfall deficiency is between 21 to 25 % and more than 25 %, respectively. A year is considered to be drought year for the country as a whole, in case the area affected by one of the above criterion for drought, either collectively or individually is more than 20 % of the total area of the country. This criterion has been considered due to meager irrigation and high dependence of crops on rainfall (NMAS, 1989).

The term drought has different connotations in various parts of the world. In Bali, a period of 6 days (one week) without rain is a drought. In parts of Libya, droughts are recognized only after 2 years without rain. Droughts in many parts of Saudi Arabia are recognized after 2 or 3 years without significant rainfall occurrence. In Egypt, many years the Nile River does not flood are a drought regardless of rainfall.

However, drought could be seen generally as a period of extreme dryness due to lack of sufficient water. It is associated with prolonged and abnormal deficiency in the rainfall amounts over a wider area.

The various professionals view drought as *context based* are given below. For a Meteorologist, it is reduction in rainfall due to various meteorological mechanisms. A Hydrologist considers it to be associated with depletion of surface water and runoff from lakes, rivers and reservoirs for generation of power and other uses. Hydrological drought is concerned with the shortage of water in rivers. For Groundwater Hydrologists abnormal falls in groundwater levels because of over-pumping are the start of drought periods. An Agriculturist feels its impact when there is lack of soil moisture to the crops which could ultimately result in a decrease of crop yield. An Economist defines drought as a low water supply affecting the society's productive and consumptive activities. One may add to the above list, the concern of the sociologist and animal husbandry personnel. A Sociologist can view the drought event as the society is starving with famine and no food. The professional of Animal Husbandry can view the drought as the live stock population is dwindling and perishing. All these definitions, since based on their experiences, merit full consideration by the researchers who are working on drought management models. Among the various definitions of droughts, the meteorological drought is important as it leads to other kinds of drought if it persists for a longer period over wider area. An accurate prediction of them is still unsuccessful.

History of Droughts/Famines in Ethiopia

Drought in Ethiopia is not a new phenomenon. The NMSA attempted to collect and document the history of drought and famine and their impact on various regions of Ethiopia from different national and international documents. Droughts are reported as early as 253 BC over the country. Analysis of the chronological events of Ethiopia's droughts/famines has been divided into four parts and the analysis suggested some interesting features. During the period from 253 BC to AD, one drought/famine was reported in seven years period. From the beginning of AD to 1500 AD, there were some cruel famines known as ASAH, FASSAS and HGLAH which killed millions. In this period, there were 177 droughts/famines, about one in nine years, was reported in the country. From 1500 to 1950, the information's relatively based on recorded data and is more reliable. From 16th to the 1st half of the 20th century, 10, 14, 21, 16 and 8 droughts/famines were reported, respectively, suggesting 69 events in a period of 450 years. This signifies that on an average the occurrence of one drought in 7 years. The two notorious famines known as QUACHINE and KIFUKEN which devastated major areas of the country were reported in this period. The reports from 1950 onwards are well documented with scientific data. The analysis of the rainfall data in this period indicated 18 droughts/famines in 38 years, suggesting the occurrence of drought in every two years.

The decadal analysis shows that the decade 1970 - 1979 was the worst having 7 disaster years in terms of frequency. The highest frequency of droughts/famines occurred in the 2nd century AD followed by the 1st part of the 20th century and an increasing trend from 16th century onwards. Twenty thousand people were thought to have lost their lives by the 1973/1974 famine and eighteen percent of the total population was affected by the 1984/1985 famine in which over a million people are said to have lost their lives. The worst period appears to be the 1980's and the worst drought year happens to be 1984. The northern parts of the country appeared to be highly vulnerable to recurring drought and famine. An examination of the chronology of disaster events reveals that there is an increasing trend in the occurrence of droughts over the country. Nearly 60 % of the total area and 25 % of population live in drought-prone zones of Ethiopia.

The Causes of Drought

The critical factors that predispose people and landscape to drought vulnerability are many. Some of the factors that generally promote deficient rains over an area are attributed to the lack of adequate water vapor, the absence of optimum number of condensation nuclei, presence of sinking motions, absence of organized synoptic weather systems, etc. Other suggested possible causes include changes in surface properties such as reflectivity or soil moisture, presence of deep layer of dust, the amount of green house gases in the atmosphere and the warming up of tropical sea surface temperatures (WMO, 1983). The principal causes of drought is quasi-periodic oscillation of rain producing weather systems, trigered by the combined effects of the so-called EL-NINO ("the Christ Child")/Southern Oscillation (ENSO) events. The ENSO phenomena are produced as a result of the changes of the ocean-atmospheric interaction over the eastern equatorial pacific ocean induced by the anomalous behavior of the sea surface temperature. Recent finds have revealed that ENSO events have great impacts on the recurrence of drought in Ethiopia. Ininda *et al.* (1987) concluded that on qualitative basis that warm ESNO events are generally characterized by drought in Ethiopia. Quinn (1992) found that the high (low) Southern Oscillation Index SOI is related to anomalously high (low) rainfall over the Ethiopia highlands region.

Some of the other Ethiopia's concomitant factors responsible for the increase in vulnerabilities include rapid population growth, land degradation, war, wrong policies and unstable political situation, very weak economy, etc. Therefore, the cause of drought has complex nature.

Impacts of Drought

Drought produces a complex web of impacts that spans many sectors of the economy and reaches well beyond the area experiencing physical drought. Impacts are commonly referred to as direct or indirect. Direct or primary impacts are usually biophysical. The few examples of direct impacts include reduction of crop, rangeland, and forest productivity; increased fire hazard; reduced water levels; increased livestock and wildlife mortality rates; and damage to wildlife and fish habitat. The consequences of these impacts illustrate indirect impacts. For example, a reduction in crop may result in reduced income of farmers and agribusiness, increased prices for food, unemployment, reduced tax revenues, increased crime, migration, etc.

The prolonged drought periods had a significant impact on national economy and severe consequences for human life. The impacts of drought can be listed as economic, environmental or social.

Economic

·loss from crop production
. annual and perennial crop losses; damage to crop quality
. reduced productivity of crop land (wind erosion, etc.)
. insect infestation
. plant disease
. wildlife damage to crops

·loss from dairy and livestock production
. reduced productivity of rangeland
. forced reduction of foundation stock
. closure/limitation of public lands to grazing
. high cost/unavailability of water for livestock
. high cost/unavailability of feed for livestock
. high livestock mortality rates
. increased perdition
. range fires

. loss from timber production
. forest fires
. tree disease
. insect infestation
. impaired productivity of forest land

·loss from fishery production
. damage to fish habitat
. loss of young fish due to decreased flows

·loss of national economic growth, retardation of economic development
·income loss for farmers and others directly affected
·loss from recreational businesses
·loss to manufactures and sellers of recreational equipment
·increased energy demand and reduced supply because of drought-related power curtailments
·costs to energy industry and consumers associated with substituting more expensive fuels (oil) for hydroelectric power
·loss to industries directly dependent on agricultural production (e.g., machinery and fertilizer manufactures, food processors, etc.)
·decline in food production/disrupted food supply
. increase in food prices
. increased importation of food (higher costs)
·unemployment from drought-related production declines
·strain on financial institutions (foreclosures, great credit risks, capital shortfalls, etc.)
·revenue losses to federal state, and local governments (from reduced tax base)
·revenues to water supply firms
. revenue shortfalls
. windfall profits
·loss from impaired navigability of streams, rivers and canals
·cost of water transport or transfer
·cost of new or supplemental water resource development

Environmental

· damage to animal species
. wildlife habitat
. lack of feed and drinking water
. disease
. increased vulnerability of perdition (e.g., from species concentration near water)

·wind and water erosion of soils
·damage to fish species
·damage to plant species
·water quality effects (e.g., salt concentration)
·air quality effects (dust, pollutants)
·visual and landscape quality (dust, vegetative cover, etc.)

Social

·food shortages (decreased nutritional level, malnutrition, famine)
·loss of human life (e.g., food shortages, heat)
·public safety from forest and range fires
·conflicts between water users
·health-related low-flow problems (e.g., diminished sewage flows, increased pollutant concentrations, etc.)
·inequity in the distribution of drought impacts/relief
·decreased living conditions in rural areas
·increased poverty
·reduced quality of life
·social unrest, civil strife
·population migration (rural to urban areas)

Natinal Policy Objectives and Directions

The National Policy on Disaster Prevention and Management has been developed so that relief assistance is provided to the affected population in a manner which ensures that such efforts contribute towards disaster prevention and sustainable growth and development, and that disaster prevention activities get due attention in the government's development efforts. Drought plans should be incorporated into general disaster and/or water management plans wherever possible.

These are indicated briefly as collated points as under:

·Root causes of famine are identified and appropriate measures are taken to eradicate them.
·Relief plans are drawn-up with development aims.
·Any plan should include measures for disaster preparedness.
·Full community participation is vital to make use of grass root knowledge, local expertise and to ensure sustainability.
·Region is responsible for early warning systems, identifying problem areas and drought severity levels
·Implementation of training programs (skill upgrading) at regional level.
·Emphasize the need on economic sustainability of both relief and development plans.
·Operations are to focus building up an economic infrastructure.
·Give an economic buffer to the people against future disasters.

MAIN AIMS	POLICY DIRECTIONS
No human life shall perish for want of assistance in times of disasters.	The community shall have a leading role to play.
Disaster affected should get adequate incomes through relief programmes.	Professionals respond to the needs of the community spontaneously.
Better access to food and other basic necessities.	Resources shall be allocated on a priority basis.
Swift recovery through employment generation schemes.	Relief to the most needy on free basis.
Assets and economic fabric be preserved.	Clear defined action plans, responsibility, structure, empowerment for relief works.

Table 4: National Policy and Policy Directions

...Relief efforts should safeguard human dignity and promote self-reliance.

Salient Features of the Plan

Table 4 gives the important policies and directions in the drought preparedness plans. These are needed, with sustainable development, for the country to finally lay rest the famine haunting for almost two decades. Sharply focused ***contingency plans***, prepared in advance, could greatly assist government and others in the early identification of drought, lessen personal hardship, improve economic efficiency of resource allocation, and, ultimately reduce drought-related impacts.

Main Aims of Policy Directions

No human life shall perish for want of assistance in times of disasters.

The community shall have a leading role to play.

Disaster affected should get adequate incomes through relief programmes.Professionals respond to the needs of the community spontaneously.

Better access to food and other basic necessities.Resources shall be allocated on a priority basis.

Swift recovery through employment generation schemes.

Relief to the most needy on free basis.

Assets and economic fabric be preserved.Clear defined action plans, responsibility, structure, empowerment for relief works.

Mitigation Measures for Drought management in Ethiopia

Drought is inevitable, a normal part of virtually every climate on the planet, even rainy ones. Drought is a menace. Its effects on the society are dangerous. Past experiences of the effects of droughts of Ethiopia are the pointers for sustained measures to be taken at all levels to contain and control the evils of droughts. During periods of droughts, professionals of water resources developments are to address themselves with various queries under uncertainty conditions. How long the drought will continue?, How severe a drought will be? and What inflows a reservoir will obtain? Thus, planning ahead to mitigate drought which gives decision makers the chance to relieve the most suffering at least expense is essential.

Floods and droughts are the two extremely varied hydrological processes. More pronounced and established control and relief measures are available for the former case. For the later, there are currently slowly and steadily a mechanism is being developed with the help of radar and satellite communications for the developing countries. The existing awareness is not enough in some of these countries.

The major objective is to control the severity and reduce the period of drought. Toward this, proper management to reduce the impact of drought on the society, reduce the damage and minimise the negative consequence is the need of the hour. Small period drought will have a great damaging impact on the agriculture and society. Continued period of drought might even lead to abandoning society itself. So the major objective is the quick relief and long term preventive measures with development aims.

The followings are suggested as key combatant/mitigation measures to reduce drought vulnerability in Ethiopia:

(1) Meteorological assessment of drought can play a vital role in management and mitigation plans of drought, in the planning and management for various socio-economic activities. The knowledge of volume of rainfall is useful in problems related to water management, crop planning, hydroelectric power generation and assessing the availability of water for human consumption. The Palmer Drought Severity Index (PDSI) can be used to describe the characteristic of drought events in time and space and as support for drought management in areas.

Enhancements in computing capabilities, modernisation of data collection equipment, improved communication, better prediction algorithm, development of better structural technology, and better management of water resources should all improve the effectiveness of drought forecasts.

The experience of USA, Australia, China or India for meteorological assessment of drought can be utilised for better forecasting, to gain some experience and to have a better vision. It is inevitable to look for experiences some where else where there are only little at home.

(2) Deep comprehensive understanding and integrated approach for watershed management that goes beyond mere soil and water conservation to promoting production and economic benefit to create sustainable livelihood is required.

Watershed management is integration of technologies within the natural boundaries of a drainage area for optimum development of land, water, and biomass resources to meet basic needs of the people in sustained manner. It takes the physical and biological conservation and biological production in a system framework. The main principles of participatory integrated watershed management (PIWM) includes: utilisation of land according to its capacity; maintaining adequate vegetative cover for erosion control; conserving maximum rainwater at the place where it falls through physical (ditches, bench terraces, etc.) and biological conservation (planting of grasses, trees in bench terraces, waste land reclamation to raise production of crop, fruit and plants to generate income for living, etc.); draining out excess water with a safe velocity and storing it in ponds, dams, check dams, shallow wells, etc. for future use; preventing erosion in water courses and gullies through various measures and increase groundwater recharge; controlling floods and reducing sedimentation; increasing soil nutrients using organic (compost, manure, crop residues) and chemical fertilisers; developing and creating high production micro-environments within the watershed; maximising productivity per unit area of rainfall and per unit of water; and maximising the combined income from the interrelated crop-tree-livestock-labour complex over years in a sustainable manner.

(3) Agricultural aspects (plant manipulation for drought resistance, crop modelling in relation to water stress, soil management for soil and water conservation, and crop management

related to drought and water stress) to be combined with irrigation to coping with droughts. The introduction of modern inputs, such as fertilisers and seeds, can radically improve land use – the increased yields obtained allow farmers to adopt more appropriate farming techniques that protect the soil better and put new heart into the land. Land degradation rates then reduce.

Sustained agricultural activities will bound to thwart and mitigate the ill effects of drought on the society. The ability to anticipate draughts have strong implications on farm assistance programs, agricultural trade, and relief programs (agricultural policy).

(4) To eradicate famine and secure food-self sufficiency based on rainfed agriculture is impossible in Ethiopia. Testimonies oh this have been the series of recurrent droughts, famines and consequent massive deaths. This is mainly due to two reasons. The first one is that in most areas of the country, the rainfall situation is highly erratic and usually results in crop failure. The second reason is the very high population growth. It then follows that whatever expansion and intensification are carried out under rainfed agriculture, food self-sufficient can not be achieved unless adequately augmented by irrigated agriculture. Therefore, to eradicate famine, to increase and sustain food production, irrigation development is of urgent necessity.

Irrigation is an important tool to minimise the effects of agricultural droughts and improve agricultural conditions in water-stressed environments. This considers irrigation management techniques under water deficits, irrigation techniques to achieve water savings, improvements in the management of irrigation systems. Management - at the crop, the farm or the project level - is the area where there is the most potential to help irrigated agriculture withstand drought. Irrigated agriculture is more productive than rain-fed agriculture and contributes nearly 40 % of the world food production on 17 % of cultivated land.

(5) Drought preparedness by the people, as always, is a key issue to the success of managing a drought.

(6) Awareness should be made at various level of the people, about the effect of natural calamity like drought to understand its impact, severity, causes, intensity, effect on social life, etc. Natural disaster like floods, earthquakes, etc. are studying in depth and introduced in textbooks at various levels of studies, but the natural disaster, like drought has not been included in any levels of the study. Hence it is preferably recommended that the topic related to drought should be added in textbooks at various levels to give awareness.

(7) Water resources developments for drought management is essential (dam construction to reduce drought impacts and increase agricultural production through access to irrigation water, distribution of water availability, water sharing and use management, etc.). Inter-basin transfer of resources and conjunctive uses of surface and ground waters should be encouraged to augment low flows. Productive groundwater development as a means of coping with drought should get due attention as groundwaters fluctuate less than surface flows. Further the role of wetlands in drought mitigation should also be not forgotten.

(8) A comprehensive resource analysis should be conducted for drought prone areas which should take into consideration of cropping pattern, water resources and other land use pattern of the area. To achieve food security, the resource base for food production must be sustained, enhanced, and where it has been diminished or destroyed, restored (The World Commission on Environment and Development, Our Common Future, 1987). For example, land degradation is caused primarily by the misuse of land. It follows that an examination of misuse is essential if lasting solutions to country-wide degradation are to be found. The analysis of current realities in Ethiopia leaves us no option but to be committed to environmentally sound management of our natural resources.

(9) Great emphasis should be given to the generation of appropriate technology which is based on indigenous knowledge supported by a strong basic and applied research. This will improve the crop varieties, response to different formulas of fertilisers (type of fertilisers, method of application and time of application), use of different mulching (crop residues, plastic mulches) and water harvesting methods as a means to drought mitigation problems. Research on tree and fruit crops basically focuses on indigenous species with less emphasis on exotic species should be encouraged. Research should be conducted on soil and water conservation, fertility management, crop improvement adapted for drought prone and low rainfall areas. Research on national resources management (soil, water, forestry, dry land agriculture and agroclimatology) and irrigated agriculture should not be fragmented and need to be coordinated.

(10) The country should develop the drought policy that specifies the general purpose for the drought plan. Also drought considerations should be well integrated into others' sectorial polices wherever possible.

(11) Relocating land users- where all else fails, consideration must sometimes be given to relocating land users to areas where degradation is less severe and yields potentially higher. Relocation schemes need to be voluntary but should be backed by attractive economic incentives. An FAO assessment mission to Ethiopia's central highland area in 1993 reported: "Clearly the land has a finite human capacity ... it is doubtful that technology can both catch up and stay ahead of current population growth in the highlands and adequately provide for basic human needs and environmental stabilization. This is an inescapable reality." Climate is often blamed by those who fail to appreciate land use - runoff relationships: "The drying up of streams and the wilting of crops are such convincing symptoms of drought." The misconception that wet years are 'normal' and dry years are 'bad' has frequently been behind the failure of development projects in the tropical drylands.

(12) The non-structural measures are summarized below:

- Immediate movement and distribution of food grains to the disaster affected through a network.
- Deployment of relief personnel at all identified drought areas.
- Removing fears and panics from the

minds of the people hit by drought.

- Urgent supply of drinking water through transport of water by trucks.
- Swift recovery plans to reduce the period of drought.
- Raising confidence of the drought stricken people by personal contact and media.
- Preventive actions as well as control measure for the spread of diseases.
- Control of exodus of people from one region to the other.
- Establishment of realistic reservoir operating policies and fair allocation among various uses.
- Adoption of extensive irrigation practices into the farming methods.
- Advocating of irrigation scheduling in conformity with the low flow condition of the irrigation canal.
- Post drought restocking.

The above points are a few hints and there could be many more to add to the list of strategies to reduce drought vulnerability in Ethiopia. The lessons of past efforts strongly suggest in Ethiopia that the '*risk management*' or proactive approach (involving contingency planning and consideration of reasonably foreseeable futures) to drought management is a more effective mitigation tool than the '*crisis management*' or reactive approach (short-range preoccupation and 'technological fixes', which often do not work, to problems as and when they arise). In the light of continued deforestation and frightening imbalances - in the food-population equation, and to combat our twin enemies - poverty and environmental degradation - it is believed that if we make water and drought management our common mission in Ethiopia, this can become one of the strongest binding factors in Ethiopia.

Conclusions

Ethiopia, with an area of 1.05 million square kilometers, is the largest and most populous country in the Horn of Africa. With a very ancient history that dates back to many millennia, the country has recently been verified to be the place of the origin of mankind. But its long history has dotted with alternating periods of wars, famine and relative peace.

Drought is a normal feature of climate. The occurrence of drought appeared to be a random phenomenon. Among natural disasters, only drought has produced more deaths, property damage, and human misery than floods. Everybody knows that drought need not be always linked with famine. Drought Planning ahead to mitigate drought is important as it gives decision-makers the chance to relieve the most suffering at least expense. Government policy must promote a greater self-reliance in drought management, including the use of risk management strategies rather than crisis management. Drought plans should be incorporated into general disaster and/or water management plans wherever possible. Drought preparedness by the people is a key issue to the success of managing a drought. The experiences of the droughts of 1973/74 and 1983/84 of the country have given the people a strong basis that was instrumental in greatly averting the drought recurrence in the year 1994. The year 1984 was found to be the worst drought in Ethiopia. About 60 % of the total area and 25 % of population live in drought prone zones of Ethiopia. In future, irrigation may assume greater responsibility for drought security in Ethiopia. The prime responsibility for halting the drought in Ethiopia rests with the government.

Acknowledgment

Special thanks to Ato Miskir Tesfaye for his review of this manuscript.

References

1.Chang, 1995. Use of Flood Control Reservoir for Drought Management. ASCE J. of Irrigation and Drainage. Vol. 1.

2.Danielov S.A., 1987. Preparation of Drought Probability Map of Ethiopia. NMSA, Addis Ababa, Ethiopia.

3.Department for International Development (DFID), 1997. Priorities for Irrigated Agriculture, Water Resources Occasional Paper No. 1, DFID 94, Victoria Street, London.

4.Dracup, J. A., Lee, K. S., Paulsen, E.G.Jr., 1980. On the Definitions of Droughts. WRR. 16(2), 297-302.

5.EPA & MoECD, 1997. Environmental Policy of Ethiopia. Addis Ababa, Ethiopia.

6.FAO, 1990. The Conservation and Rehabilitation of African Lands: An International Scheme. Rome, Italy.

7.National Meteorological Services Agency of Ethiopia, 1989. Assessment of Drought in Ethiopia. Addis Ababa, Ethiopia.

8.RRC, 1994. National Policy on Disaster Prevention and Management and Preparedness, 1993/94. Policy Planning and Programme Department, RRC, Ethiopia.

9.Pereira, L.S., 1989. Mitigation of Droughts. ICID Bulletin, Vol. 38 No. 2, New Dehil, India.

10.______, 1997. Executive Summary: Report on the Study Tour to India and China. Vol. I. Nov. 1997.

11.______, 1994. Survey of Current Conditions in Ethiopia. In: Roy, L.B and *et al*, 1999, Farmers' Participation and the Hare Irrigation Project. A paper submitted to the WEDC Conference to be held in Addis Ababa.

12.World Bank Report, 1992. Ethiopia towards Alleviation and a Social Action Program. In: Roy, L.B., 1998. Estimation of Drainage Coefficient for Surface Drainage Systems in Ethiopia- A Case Study (Unpublished).

13.Yevjevich. V, 1967. An Objective Approach to Definitions and Investigations of Continental Hydrological Droughts. Hydrology Paper 23. Colorado State University, Fort Collins, USA.

14.Yilma Seleshi, 1997. Causes and Variability of Summer Rainfall and Runoff Over the Highlands of the Nile River Basin, Paper Presented at Vth Nile 2002 Conference, Feb. 24-26, 1997, Addis Ababa, Ethiopia.

Raw Water Storage and Simple Fluoride Filters as Methods of Appropriate Treatment for the Removal of Biological, Physical and Chemical Impurities

Argaw Ambelu, Jimma Institute of Health Sciences, P.O.Box. 973, Jimma, Ethiopia

Abstract

Because of the absence of appropriate technology, that addresses the socio-cultural condition of the community, the majority are consuming non potable water. Storage of raw water in local vessels and filtration of fluoridated water in crushed bricks is simple methods of treating water.

Samples of water from stream, spring and fluoridated water was used to see effect of storage and appropriate home made filters in the reduction of fecal coliform, turbidity color, and fluoride. The respective samples with initial number of fecal coliform 578 MPN/100ml; turbidity 61.2NTU; color 90 TCU; and pH 6.4 at a temperature of 20 oC, have been stored fore one, two and three days in clay pots, plastic (jerrycan) and metal bucket. The fluoridated water that was prepared in the laboratory was also filtered through crushed brick and porous clay pot filters. The result showed very good reduction of contaminants after three days of storage, where, fecal coliform was reduced to 0 MPN/100ml in metal bucket, 60 MPN/100ml in jerrycan and 147 MPN/100ml in clay pot. Turbidity was lowered to 29.3 NTU in metal bucket; Color to15 TCU in plastic and clay pot and to 20 TCU in metal bucket. On the other hand storage of fluoride water sample with 6 mg/l in clay pot was reduced to 4.22 mg/l; 2.43 mg/l and 1.4 mg/l after one, two and three days of storage respectively. There was no change of fluoride concentration after storage in plastic jerrycan. A sample with a fluoride content of 8.23 mg/l became 3.52 mg/l when filtered through crushed brick. Another sample with 10 mg/l fluoride concentration was reduced to 0.62 mg/l, when filtered through porous clay pot.

It is found that different containers have different efficiency in the reduction of contaminants, as metal bucket is best for fecal coloiform organisms, plastic jerrycan for turbidity, and clay pot and plastic jerrycan for color reduction. This study has revealed that storage of raw water and using clay filters can remove biological, physical and fluoride contaminants (fecal coliform, color and fluoride) up to a level recommended by WHO. It is believed that with further perfection communities who lack safe water source can use the method just mentioned to improve the quality of their water in their homes.

Introduction

All Water that appear in public or private supplies has been exposed to pollution while falling as rain, running over the ground surface or in stream, or percolating through soil. In addition the increase of population and technological development brings about the problem of wastes which will pollute land water and air, which has direct or indirect impact in the deterioration of water quality. Because of these problems the majority of the world population suffers with lack of potable water sources.

To alleviate the problem and make water safe for users there are different water treatment methods. But due to the absence of appropriate treatment methods in urban and rural areas of developing countries, including Ethiopia, water is often remote and unsafe. In areas where conventional treatment plants are available, all of the community at the vicinity are not capable of utilizing the system. For example study done by Sisay Wondimagn (1994) has showed that the majority (76.5%) of the people in Jimma town, in which water treatment plant is available, use from unprotected sources (2).

This could be, as suggested by Okun and Ernest (3), socio-cultural and economic conditions have an influence on water use and willingness to support and pay for community water systems. On the other hand, in areas where municipal and public water supply or protected springs and wells are absent, consumption of raw water from any source is the major problem. In this case, careful selection of the proper treatment unit, which will solve the particular pollution problem, in addition to cost required for maintenance and operational control, must be considered (4). World health organization also encourage the search for law cost solution of water treatment system; which is more suitable to the local socio-cultural conditions, because inaccessibility could be in most case due to low socioeconomic standards. Anyhow to make water safe for consumption, need some method of treatment for the removal of biological, physical and chemical contaminants.

Studies show storage of raw water can eliminate contaminants like silts and pathogenic microorganisms. For example schistosome cercariae is nonineffective if the water is stored for 48 hours (5). Research conducted in Somalia at Magany camp showed storage of water in a tank for 1.5 to 4 days has eliminated about 37% of turbidity and fecal coliform reduction of 43-84% were obtained (6). Wood, C.H. et al.(7) have recommended about the use of storage using three pot system for the removal of harmful organisms and suspended matter. WHO guide line also indicates removal of 80 to 90 percent contaminant after 10 to 30 days of storage in the reservoirs and sedimentation tanks(8). On the other hand the study done by Hauge-s; et al (9), have showed that effective reduction of fluoride concentration was achieved by storing fluoridated water for 30 minutes to 20 days in ordinary clay pots and crushed brick that are fired at an optimum temperature.

Methodology

An experimental study was conducted in the laboratory of Environmental Health school, Jimma institute of health sciences.

Sample source: Samples of raw water were collected from unprotected spring and stream for fecal coliform, turgidity and color tests using Jerrycans washed with deionized water. These sources were selected because of the need of getting considerable amount of contaminants for the laboratory test. In addition, since the majority of Ethiopian communities are using from such unsafe water sources, it will be possible to imitate the result of the study for the users. For fluoride test, fluoridated water was prepared in the laboratory; by adding 0.221gm of Sodium fluoride (NaF) salt in to 10 litters of tap water to get 10 mg of fluoride per litter, or adding of 0.0663 mg NaF in to 10 litters to get 3 mg fluoride per litter and the like. The study was devided in to three.

1. Storage of raw water in different containers

Storage of samples were made in ordinary clay pot (pots which are made by local potters), plastic jerrycan and metal bucket, because these containers are most commonly used vessels for transporting and storage of water by the majority of the Ethiopian communities. So based on the finding of the study, it will be possible to recommend how to purify their water by the material they have.

After initial measurement of fecal coliform, turbidity, true color (color determined after filtration through filter paper), pH and temperature, samples were stored in each vessel. To know the effect of clay pot on the reduction of fluoride concentration, three samples having different concentration of fluoride (10,5,and3mg/l each) were stored to the three respective clay pots. Plastic jerrycan was also used to store fluoridated water as control, since clean plastic containers have no effect in changing fluoride concentration as fluoride standard solutions are stored in plastic bottles.

2. Filtration of fluoridated water through crushed brick

A conical filtration apparatus which was made of sheet metal was prepared for holding the filtration media. The apparatus has an internal diameter of 50 cm top, 25 cm bottom and 75cm height. The bottom part was covered with aluminum sheet which is perforated using 2.5mm diameter nail for the passage of filtered sample. The filtration media was prepared by crushing bricks (those which are used for construction purpose) to a size from powdery form to1cm across. Generally a total of 0.046 cubic meter. of crushed media was used for filtration.

Different samples having different concentrations of 12.7mg/l, 5.5mg/l, and 6.5mg/l fluoride were poured to the vessel to be filtered through the media. After the test of each sample the media was rinsed and washed with deionised water. The need for variation in concentration from 12.7 mg/l to 3 mg/l is just to know the effect of defluoridation at different fluoride concentration. In addition the ground water of the Ethiopian rift valley area which has caused endemic fluorosis has an average fluoride concentrations of 10 mg/l; so the study will give relevant solution based on the results achieved, and it will be possible to seek a solution (12).

3. Clay pot filtration

An ordinary clay pot, which is made by local potters around Jimma, was used to filter the sample. It is known that after local clay pots are bought from the market, user should glaze the pot using fire to make it strong and water tight, unless there will be leakage when they are using to store water. This principle is used in this study. The clay pot bought from the market was directly used to store 5 litters of fluoridated water having fluoride concentration of 10 mg/l. The pot has started to ooze 3ml/min through its bottom part. The filtrate was collected, analyzed and compared with the fluoride concentration of the sample before filtration.

Procedures and methods used to determine fecal coliform, turbidity, true color, and fluoride were Multiple tube test (MPN), turbidimetric, palin test, and SPADNS respectively as recommended by STANDARD METHODS.

Sample size for a single test of fecal coliform, Turbidity, Color and Fluoride were 105, 25, 10 and 8 ml of water respectively.

Three tests were done for each study parameter with the same step and procedure. Arithmetic mean was computed from the results of each test made for each variable. The most probable number (MPN) of fecal organisms in 100 ml of the original sample was estimated using statistical table of probability table with confidence interval of 95%.

Data were collected from laboratory results of individual values and analysis made after one, two and three days of storage. In addition fluoride data were the result of analysis made after the water has filtered through the crushed brick and clay pot filers. Data were processed using handhold calculator. Tables are used For compilation, summarization and comparison of data.

Result

The average number of fecal coliform, turbidity, and color before storage were 578MPN/100ml, 61.18NTU and 90TCU respectively with average pH of 6.44 at a temperature of 20.6 0C.

After one day of storage contaminants has reduced at different degree except the fecal coliform count stored in clay pot. As shown in table 1, metal bucket has reduced the fecal coliform load to 4 MPN/100ml(99.3% redn.) and 0(100% redn.) after two and three days of storage respectively. After third

	Study parameter	container type	Day of storage						
			0 (initial)	1	% redn.*	2	% redn.	3	% redn.
1	fecal coliform (MPN/100 ml)	clay pot	578	578	0	177	69.4	147	74.6
		plastic jerrycan	578	375	35.1	118	79.6	60	89.6
		metal bucket	578	272	52.9	4	99.3	0	100
2	Turbidity (NTU)	clay pot	61.2	48.8	23.5	39.6	35.4	28.3	53.8
		plastic jerrycan	61.2	45.5	26	38.5	37	24.4	60.2
		metal bucket	61.2	46.6	23.8	41.2	32.6	29.3	52.1
3	color (TCU)	clay pot	90	55	38.9	40	55.6	15	83.3
		plastic jerrycan	90	68	24.4	42	53.3	15	83.3
		metal bucket	90	68	24.4	45	50	20	77.8

** percent reduction*

Table 1.The average results of the study parameters after samples are stored in different containers for different days, JIHS, Oct. 1997.

Container type	Day of storage and % redn.						
	0 (initial)	1	% redn	2	% redn.	3	% redn.
Clay pot 1	10	7.15	28.5	4.25	57.5	2.3	77.0
clay pot 2	5	3.5	30.0	1.99	60.2	1.2	76.0
clay pot 3	3	2.0	33.3	1.05	65.0	0.7	76.7
average value	6	4.22	29.7	2.4	59.5	1.4	76.7
plastic jerrycan	10	10	0	10	0	10	0

Table 2. Fluoride concentration (mg/l) and percent reduction (% redn.) of samples after storage in different container, Jimma, oct.1997.

water sample	initial F^- conc.* (mg/l)	F^- conc. after filtration(mg /l)	% redn.
I	12.7	5.85	53.9
II	5.5	2.05	62.7
III	6.5	2.65	59.2
Average	8.23	3.52	57.2

** fluoride concentration*

Table 3. Fluoride concentration of different water samples after filtration through crushed brick filter media, Jimma,oct.1997.

Water sample	initial F^- conc.*	F^- conc. After filtration	% redn.
I	10	0.65	93.5
II	10	0.62	93.8
III	10	0.60	94.0
average	10	0.62	93.8

**fluoride concentration*

Table 4. Reduction in fluoride concentration (mg/l) after filtration of water samples through clay pot, Jimma, Oct 1997.

day of storage fecal coliform count became 147MPN/100ml (74.6%redn.) and 60MPN/100ml (89.6% redn.) in clay pot and plastic jerrycan respectively. In the same day of storage turbidity became 28.3NTU, 24.4NTU and 29.3NTU in clay pot, plastic jerrycan and metal bucket containers respectively. And also color became 15 TCU both in clay pot and plastic jerrycan, and 20 TCU in metal bucket after three day of storage.

Clay pots have shown removal of fluoride from fluoridated water sample stored in them. Clay pot1 having water sample with 10 mg/l of fluoride was reduced to 7.2 mg/l, 4.25mg/l and 2.3mg/l after one, two and three days of storage respectively. The other two different samples with fluoride concentration of 5 mg/l and 3 mg/l that are stored in clay pot1 and pot2 were reduced to 1.2 and 0.7 mg/l respectively. No concentration change was observed from the samples that were stored in the plastic jerrycan. (Table 2)

In the filtration process, water sample with fluoride concentration of 12.7 mg/l was filtered through crushed brick media . The filtrate tested for fluoride concentration, was found to be 5.58mg/l(53.9% redn.). The other two samples, having fluoride concentration of 5.5 and 6.5 mg/l, filtered through the same media, have also showed considerable reduction.(Table 3)

The three water samples with initial fluoride concentration of 10 mg/l. When filtered through the clay pot showed average fluoride concentration of 0.62 mg/l which is 93.8% reduction (Table 4).

Discussion

Storage of raw water is advocated as one of the simplest method of treating water by eliminating fecal organisms, turbidity, color and fluoride(5-7, 9). On the other hand filtration of fluoride water through clay material is also known in removing fluoride concentration (9). The efficiency of removing chemical, physical and biological contaminants depend on the duration of storage and type of container used to store the sample.

Fecal coliform removal:

Among containers metal bucket is significantly better than clay pots and plastic jerrycan (p.<0.005). And also plastic jerrycan is significantly better in removing fecal coliform organisms than clay pot in fecal coliform removal (p.<0.005). The complete elimination of the organisms in the metal bucket could be due to the sterilizing nature of metals as suggested by Hobbs (10).

As also indicated by Wood. C. H. et al. (7) the reduction in all storage vessels is achieved mainly because, micro-organisms are likely to settle in to the bottom together with settleable particles when water is stored in a container. The other possible reason is that, the available food for microorganisms will be diminished when storage time increase, hence the bacterial growth decline.

Color and turbidity removal:

Color and turbidity reduction was achieved in different degrees according to the day of storage and containers used. Even though storage is blamed as it has no much effect on turbidity removal, in this study reduction is achieved by 52.1% to 60.2% in both containers after three days of storage.

Better reduction was found in the plastic jerrycan which is 24.4 NTU, after three days of storage. Generally after these days of storage the turbidity below 30 NTU in both storage vessels. Even if this did not fulfill WHO guide line value, in some African countries like Tanzania, as their temporary drinking water quality standard show, turbidity below 30 NTU was acceptable(11). The better reduction in plastic jerrycan could be most probably due to the sampling technique conducted to each storage vessel. When samples are taken by dipping, as in the case of clay pot and metal bucket, the water may get disturbance and the settled materials suspend and get in to the sampled water. But in plastic jerrycan sampling was by pouring and relatively clear water sample might be found. This Systematic error was not happened in the true color test, because samples are centrifuged and filtered so there is no possibility for any suspended particulate to get in to test sample.

Color reduction that is recommended by WHO which is 15 TCU (8), was achieved in clay pot and plastic jerrycan after three days of storage. How ever in both containers color reduction by 77.8 % to 83.3% is achieved in the same day of storage.

Fluoride removal:

Storage of fluoridated water in clay pot and filtration through crushed bricks and clay pot have showed elimination of fluoride in different degrees. As the day of storage increase from 1 to 3 fluoride concentration of different aliquots that are stored in different clay pots decrease by 28.5 to 76.7 percent. Better reduction of fluoride is achieved from the aliquot whose initial fluoride concentration is least. The unchanged fluoride concentration of samples that are stored in the plastic jerrycan in each day of storage reveals that the fluoride concentration reduction is due to the effect of clay pots.

Filtration of fluoridated water through clay pots and crushed brick media have eliminated much of the fluoride by an average reduction of 57.2 and 93.8 percent respectively. Purdom (12) have explained that, water with more than 1.5 mg / l fluoride can be defluoridated by 100 percent using ion exchange method which is comparable with the results of this study obtained from the filtration though clay pot. The finding showed defluoridation of water up to the value recommended by WHO, using clay pots and crushed bricks. Study done by Hauge-S; et al. Also have showed that, ordinary clay pots and crushed bricks fired at an optimum temperature are efficient to bind fluoride from water.

Water sources that have high concentration of fluoride can be removed best using clay pot filter. This simple defluoridation method is applicable in any community whose water sources are fluoridated above the recommended limit like Wonji Showa (13).

As the study showed selection of containers in respect to the contaminants to be removed should be made for the better treatment of raw water. Metal bucket for biological contaminant (fecal coliform) removal, plastic Jerrican For Turbidity, and clay pot and plastic jerrycan for color removal can be used.

Teaching institutions and rural development enterprises can develop the technology as approached by this study. Further studies are warranted to evaluate its practical application and social acceptance. The investigator would like to acknowledge research and publication office of JIHS for financial support to under go this study.

References

1. Duerden, B.I. et.al. 1993. Microbial and parasitic infection. 7th ed.

2. Edward Arnold. London. pp. 361- 364

2. Sisay Wondimagegn. 1994.Institute of Health Sciences bulletin, 4(1).

3. Okun, DA. and Ernest,WR. 1995. Community piped water supply.A news letter of ETWAS, Nairobi.

4. World Health Organization (WHO). July - august, 1992. Water!. World health.WHO. Geneva. pp. 27

5. CAIRNCROSS S. and FEACHEM R. 1997. Environmental health engineering in tropics. An introductory text. 2nd ed. John and Sons publishers. England. pp. 81

6. Kerr, Charls. 1991. community health and sanitation. Selected and Edited by Charles. Intermediate technology publications. London. pp. 104

7. Wood, C.H. et.al.. 1985. community health. Published by African research foundation. English press. Nairobi, Kenya. pp. 191 - 192.

8. World Health Organization (WHO). Recommendation. Volume 1. Guide line for drinking water quality. 2nd edition. WHO. Geneva.

9. Hauge-s; et al. Dec. 1994. Defluoridation of drinking water. Scand. J. Dent. Res. 102 (6): 329 - 333

10. C. Hobbs, Betty. 1976. Food poisoning and food hygiene. 3rd edition: pp. 44.

11. Christopher R.Schulz and Daniel A.Okun. 1992. Surface water treatment for communities in developing countries...Great Britain. pp.14.

12. Purdom, P. Walton. 1980. Environmental health, 2nd ed., Academic press, New York. PP.196

13. Haimanot-RT, et.al. July, 1987. Endemic fluorosis in Ethiopia Rift valley. Trop-Geog-Md. 39(3): 209-217

Environmental Information System for the Study of Anthropogenic Stress on lake Abijata

Gezahegne Gebremeskel, Ethiopian Mapping Authority, Remote Sensing Department Addis Ababa, Ethiopia

Abstract

This study reports on an investigation carried out pertinent to the eutrophic state of Lake Abijata employing Remote and Proximal sensing techniques. The Remote method is based on image ratio of two visible bands of Landsat TM data. A new proposal has been presented on the potential application of Non-imaging system for parametric analysis. The parametric analysis renders ease of interpretation whether or not the lake is productive. The study of both proposals were carried out at Lake Abijata. The Abstract of the study was selected by NASA and ERIM sponsored 4th International Remote Sensing conference held in Orlando, Florida(USA). Lakes including both exorheic and astatic alimented by centripetal drainage are repository bowls for myriad of nutrients. Nutrient influx to a lake basin is one of the leading causative agents of eutrophication. Eutrophication Is a process in which natural and man-induced nutrients are funnelled into a lake to the effect that, the physical, chemical and biological structures of a lake show a marked qualitative change. Apart from climatic caused, catchment morphology and lentic morphometry, lacustrine productivity heavily depends on the diffusion and accretion of alloctonous and autochthonous nutrients. Algal gross-production is subject to the Leibig's law of the minimum. The law states that, nutrients which are highly needed, but are found in minimum quantity are the controlling factors of growth. The proper dose of nutrients intake by algal crop is 'In the ratio of 100 units of Carbon, 10 units of Nitrogen and 1 unit of phosphorous' (Ryther, 1981). Some limnologists according to their finding, 'The ratio of nutrients extracted by phytoplankton are C:N:P = 10:16:1 and Si:N:P = 20:16:1(Sverdrup,1942, Richards, 1965). Some of the conventional methods used to estimate lacustrine eutrophic state are:

Ceiving with a mesh-net for microscopic, chemical and photometric analysis;
The Carlson's Trophic Status Index, which is a mathematic model based on Secchi disk depth, Chl-a amount and Total Phosphorous:
The Vollenweider-Rigler Approach which is based on phosphorous loading for a later implementation of a mathematical model.
The study overhauls the following proposed technical approach and the impacts of eutrophication on birds, fish and trona crystal being produced at the Abijata soda-ash plant.
To test the validity of the newly proposed Normalized Difference Lacustrine Productivity Index(NDLPI) for the estimation of the trophic status of Lake Abijata;
To test the validity of the newly proposed Non-imaging system for lacustrine productivity;
To examine the impact of eutrophication on birds, fish and trona crystal being produced at Lake Abijata.

1.Introduction

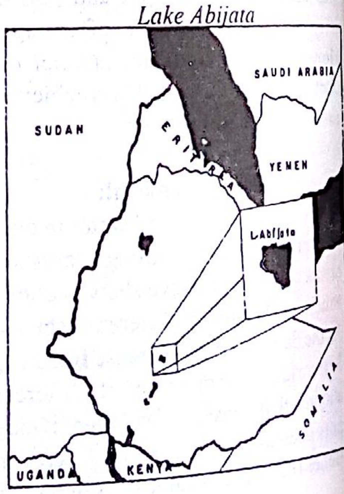
1.1 Background

The Ethiopian Rift Valley is one of the richest regions of the nation in natural resources. Owing to its unique tectonic formation, it amasses varied mineral resources. Satellite sensed data of the rift depict multiple megalineaments and so called 'ring-like structures'. These are credible indicators of accreted minerals, sometimes also called '**geochemical barriers**', which form ore bodies and mineral aureoles. The presence of fertile alluvial soil, ubiquitous water resources with bright sunshine hours almost throughout the year have imparted the region its high '**bioclimatic potential**'. The hot springs do have significant scenic and therapeutic role as a result of which tourist and agro-industry is getting momentum.

Agro-industrial development in the Ethiopian Rift has been impinging upon the environmental status of the region. By and large, the following tendencies have been observed.

1. Rise in salinity of irrigated land and deflocculation of soil;
2. Increased ago-industrial plumes in lakes and reservoirs;
3. Persistent deflational and riverine erosion leading to soil loss due to forest clearance and the appearance of Bold watersheds;
4. Shore recession of lakes resulting from pumping for irrigation and soda-ash extraction;
5. Man- induced eutrophication and siltation of lakes.

Lake Abijata



In order to study resource abuse, nowadays, the implementation of remotely sensed data and technique have become effective panacea. Space borne multi-spectral sensors, passive microwave radiometer, radar and Lidar Sensing have been used for non-contact terrain data acquisition. Over and above these, proximal sensing using non-imaging systems loaded on low hovering platforms like helicopter or truck have augmented the ways and means of remotely sensed data acquisition.

Space borne data have been used in many fields, among which hydrology constitutes a part. In the field of hydrology, remotely sensed data are being applied for:

1. Ice pack analysis;
2. Watershed management;
3. Drainage network analysis;
4. Water quality assessment;
5. Trophic status estimation;
6. Hydrogeological studies, especially to detect 'hydrothermal areas';
7. Wetland and flood susceptible area analysis;
8. Irrigation network and crop yield estimation, including salinity problem analysis.

Environmental Information System (EIS) integrates the current geo-information triad RemoteSensing, Geographic Information System (GIS) and Global Positioning System (GPS). **Environmental Information System (EIS) is an automated data capture, display, retrieval and analysis of a spatially indexed data to extract meaningful environmental information.** In order to make use of the maximum vantage of Environmental Information System, the study attempts to overhaul the anthropogenic stress on Lake Abijata.

1.2 Location

Lake Abijata is one of the lakes constituting the **'Lakes Region of Ethiopia'**. Lake Abijata is found some 225 km south of the capital; Addis Abeba. The geodetic frame of reference of the study area is:

= 7° 30' 32" N to 7° 50' 5" N
= 38° 30' 5" E 38° 40' 24" E

As per Landsat TM Reference Trapezoid, the study area is within the 160 path and 055 row.

1.3 Geological Structure and Lithology.

The Ethiopian Rift System is part of the Afro-Arabian rift system "The Afro -Arabian Rift system is one of the long-est ; more than 6000 km. with an intricate structural arrangement of intercontinental link of the world Rift system. Its formation on the whole relates to the anthropogeny, but in some instances, more ancient manifestation of riftogenesis were observed" (Belousov , 1974).

The Ethiopian Rift System is a typical belt of 'Wilson's cycles of opening '.In the lake region there are active volcanoes . Earthquakes and tremors are frequent. Hotspring and fumarole are ubiquitous. In the lake region, the subsurface temperature is exceedingly high. For instance, the **"subsurface temperature in the thermal spring of Wondogenet and Wesha from SiO_2 contents and Na/K ratio is about 2000°C"**.(Chernet, 1982).The region has a high geothermal potential. The Aluto peak north of Lake Langano is a good instance.

After the regression of the Mesozoic sea to the southeast, there was a major tectonic uplift called the **' Ethio-Arab swell'**, especially the Tertiary uplift had resulted in the four major sectors of the Afro-Arabian Rift belt. These echelon like articulated rift sectors are the Western (Rukwa-Nyasa-Tanganyka) , the Eastern (Gregory-Ethiopian), the sub latitudinal Rift (Gulf of Aden-Carlesberg ridge) and the Northern (Gulf of Suez-Levant).The **'Afar triangle'** is a tectonic knot of three rifts; Red sea-levant, Aden and the Ethiopian Rift.During the end of pluvial period which extended between 7000 to 12000 years, the Rift Lakes Region level was higher than its present level. At this time, Lakes Ziway, Langano, Abijata and Shalla used to be a single macro lake (Grov, 1970). According to Chernet, abandoned lake terraces are found at levels 150 m, where Ziway became a separate lake larger than its now. An additional 60 m drop resulted in the separation of Langano and in a further drop of few meters Abijata and Shalla separated (Chernet, 1986).

1.4 Climate and Climax Vegetation

Lake Abijata is at the leeward side of the two rain bearing prevailing wind in Ethiopia, namely the South westerlies and the South easterlies. since it experience a double leeward, usually foëhn condition prevail. "The amount of mean annual precipitation ranges from 200-600 mm, while mean annual temperature is 19.3°C" (Gamechu, 1986). The area has a semi-arid climatic condition.

When considered as a 'biome' , the study area is within a woodland savannah belt. Along river courses riparian galleries are common The main species of trees include Acacia albida, Acacia senegal and Acacia tortillas. Grass species include, Cenchurus cilaries, Chrysopogon aucheria and Hyparahenia ruffa (Amharic senbelet) are the dominant cover types. Hydrophilous include Typha thoningi, Shefflera abyssinica.

1.5. Faunistic Resources

The Lakes Abijata and Shalla are the habitat for migratory birds of Palaearctic and Ethiopian faunistic realms. Some of the Palaearctic realm birds have most of their residence time at Lakes Abijata and Shalla. Some of the bird species include Ostrich (Struthio camelus), Lesser flamingo (Phoenocopterus phoniconais, Cormorants (Phalacro corax carbo), Grebes (Podicerps), Pinkbacked pelican (Pelicanus rufescens), the Great white pelican (Pelicanus onocratalus), African fish eagle (Heliatus vocifer), Pied Kingfisher (Ceryl rudis), Darter (Anniga rufa), Sagittarius serpentarius, Black storck (Cironia nigra L.). wart hog and antelope are common in the Abijata-Shalla park.

1.6 The Morpphometric Parameters of Lake Abijata

The year 1972 is noted for the acquisition of aerial photographs for the Lakes Region for the 1:50 000 topographic map production. Better results on the morphometric parameters of Lake Abijata were achieved using this map. In this study, however, the morphometric indices were determined by digital planimeter and GIS analysis. Some of the morphometric parameters are given in (Table 1).

Name	Type based on water exchange	Surface area (A) in Km^2	Volume (V) in m^3	Maximum Depth (Z) in m	Width (w) in m	Shoreline length (SI)	Shoreline Development (DL)
Abijata	Endorheic	199.614	-	10	21.37	64.6	1.29

Table (1) Morphometric indices determined by X-plan 360. The maximum depth of Lake Abijata is as per the data acquired from the soda-ash plant in 1995.

1.7 Soil and Edaphic Conditions

According to the soil classification of Ethiopia given in the National Atlas of Ethiopia, the soil type is grouped within the 'andosol '. Andosols (humic, molic and vitric) with a sodic phase in the south are the main soil types. At riverine flood plains, azonal type soil are common.

2. Objective

Employing Environmental Information System (EIS), the study attempts to take a diagnosis on the degree of anthropogenic impact on Lake Abijata and its catchment. In view of this, the study attempts to treat the following ecological issues.

1. To take a diagnosis on the actual ecological status at the lentic environment and the catchment;
2. To assess the water quality of Lake Abijata;
3. Estimation of the Trophic status of Lake Abijata and treat eutrophication as an environmental problem;
4. Shore recession analysis on a multi-date data caused by soda-ash extraction and irrigation;
5. To suggest effective meliorative measures to reinstate the ailing ecosystem of Lake Abijata to its pristine status.

3. The Ecological Degradation of Lake Abijata and its Catchment

Ecological degradation. Is the temporary of permanent loss of good and acquiring poor status of an ecosystem due to natural or anthropogenic causes. Persistent follow up through surveillance and monitoring are of prime importance. They help to detect the quantitative and qualitative changes resulting from anomalous or emergent characteristics of the given system. Like other ecosystems, lacustrine ecosystem has an elastic behavior or resilience. It has a tendency to show Lechatellier's response to a stressful conditions. With recurrent stress (chronic stress), however, its elastic rebound property can't be maintained. Before irreversible conditions prevail, it is imperative to detect anomalous conditions at an earlier stage. This Ecological Degradation Analysis (EDA) uses Environmental Information System (EIS) with the incorporation of Lake truthing and collateral information to make the study through. Some of the diagnostic syndromes of the malfunctioning ecosystem of Lake Abijata identified in the Pilot Study (Gezahegne, 1986) include the following.

1. Water quality change resulting from autochthonous nutrients. The lake has a higher Dissolved Organic Matter (DOME). Owing to eutrophication, The lake is pigmented;
2. Vegetation clearance and the appearance of bold watersheds followed by increased eolian and fluvial erosion. Leachate contribute nutrients influx to the lake resulting the chemical, physical and biological structures of the lake;
3. Increased salinity as a result of the lowering of discharge by rivers, Horakelo, Bulbula and Gogessa;
4. Shore recession due to coupled anthropogenic (soda ash extraction) and natural (climatic) factors;
5. Landuse change around the lake basin, especially expansion of livestock feedlots, tillage and quarrying activities on lacustrine deposits around bird's habitat.

3.1 Diagnosis of the Ecological Status with Tct and Tndvi

3.1.1 Data Transfer and Subscene Extraction

The acquired GEOCODED Landsat TM scene was recorded in Dec., 21, 1989. The acquired raw data were previewed so as to ascertain whether or not they are free from crossover and cloud contamination. After a thorough previewing, the data were found to be free from cloud contamination, but have a limited horizontal streaks. Since they were noise free, they were found to be workable.From the total scene, a database as it is called in ERDAS (Earth Resources Data Analysis System), a Subscene (data file) pixel spatial coordinate were fixed. The Abijata image file has a 1194 column by 1668 row pixel window.

3.1.2 The Tasselled Cap Transformation for Forest Removal Diagnosis from the Catchment

The lentic environment of Lake Abijata and its catchment area are interwoven by a web of ecological factors. Lake Abijata is an endorheic lake whose water quality is determined by the influx of autochthonous materials from its catchment. Three rivers act umbilical chords via which nutrients are funnelled into it. River Bulbula and Horakelo in the northeast and river Gogessa in the west aliment Lake Abijata.

The rate of soil loss on a bold watershed is significantly higher than a vegetated one. Leachate from rocks and soil colloid play their part in determining the physical, chemical and biological structures of the lake. The Tasselled Cap Transformation (TCT) and the Transformed Normalized Difference Vegetation Index (TNDVI) offer the best feasible means for phytomass diagnosis at Abijata's catchment.

The Tasselled Cap Transformation (TCT)optimizes the hyperellipsoid multi-spectral image to the viewer's X and Y axes. The TCT is based on three data structures axes, the Greenness, Brightness and Wetness. The TCT is a linear combination of TM bands except the thermal infrared band excluded for its course resolution. The TCT is mathematically expressed as:

$$TCT = a1 x 1 + a2 x 2 + a3 x 3 + ... + a6 x 6$$

The brightness is the weighted sum of all the bands except the far infrared. The Brightness is represented by positive TCT coefficients (Table 2). Positive TCT coefficients signify positive loading to maintain brightness. On a Cartesian plane, the brightness is the

Layer-1	Layer -2	Layer –3	Layer - 4	Layer - 5	Layer -6	Additive
+ 0.2909	+0.2493	+0.4806	+0.4438	+0.1706	+0.1706	+10.3695
-0.2728	-0.2174	+0.5568	+0.7221	+0.733	-0.1648	-0.7310
+0.1446	+0.1761	+0.3322	+0.3396	-0.6210	- 0.4186	- 3.3828

Table (2) The Tasselled Cap Transformation coefficients for Lake Abijata's image frame.

column (x-axis). Orthogonal to it is the Greenness axis, which is the row (y-axis). the visible bands, especially Blue and Red have negative loading i.e., negative TCT coefficients. This is attributed to the absorptance for photosynthesis from the PAR (Photosynthetic Active Radiation). The value of Green band is greater than either Blue or Red. This is due to the medium green reflectance by terrestrial healthy phytomass. The infrared bands have positive TC coefficients owing to peak infrared reflectance by the healthy green vegetation and to a certain extent MIR-1 and MIR-2 vegetation vigor.

The Wetness axis lies somewhat between the two axes. All the visible bands and the reflective infrared have two positive coefficients. The Mir-2 has negative loading. The negative TC coefficient in the case of Mir-2 is due to the absorption by the hydroxyl ion (OH) in the soils. Pertinent to Mir-1 positive coefficient is due to the fact that vegetal stressful condition in wetland is non-existent. The statistical extract of the six TM bands on TCT algorithm is given in (Table 3).

On the color composite output, the deep to light . iolet color hue is vegetated area. The reddish brown to lightbrown color signifies the abandoned shoreline and exposed area. Wetland and waterbodies are yellowish green to various shades of green. Well

Layer-1	Layer-2	Layer -3	Layer -4	Layer-5	Layer –6
X 76.821	36.70	57.20	48.96	85.17	46.88
Min 96.00	46.00	68.00	68.00	123.00	64.88
0 45.76	23.40	35.38	35.38	65.91	36.98
Max 255	181.00	217.00	223.00	240.00	151.00

Table (3) The TCT statistical extract of six TM bands of the Abijata image frame.

protected forest is confined within the Abernosa ranch and at the aviculture center. At the Jebule-Chebi, patches of the remaining forest are in violet color. Scattered trees at the catchment are found at the Lencha peaks rimming Lake Abijata at its southwest

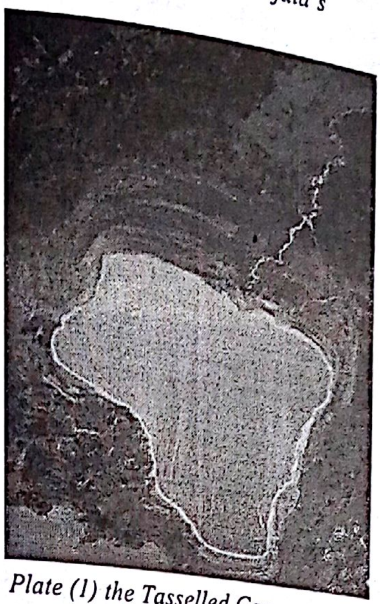


Plate (1) the Tasselled Cap Transformation (TCT) Color composite output.

embayment. Bare areas, tillage and exposed soil are in reddish brown. the receding shoreline of Lake Abijata appears in orange to reddish brown. A considerable portion of this bare area is being used as tillage and cattle feedlot (Plate 1)

3.1.3 The Transformed Normalized Difference Vegetation Index(TNDVI)

The Transformed Normalized Difference Vegetation Index (TNDVI) is an absorbed wavelength and the Infrared as a reflective wavelength. The new monochromatic band discriminates vegetated areas as bright tones and bare areas in grey. The TNDVI is expressed mathematically

as:Where: $$TNDVI = \sqrt{\frac{IR-R}{IR+R}} + 0.5$$

TNDVI = Transformed Normalized Difference Vegetation Index;

IR & R = Infrared & Red bands

0.5 = constant

The monochromatic TNDI output is given in (Plate 2). Analogous result was reached as that of the TCT output. Vegetated areas are bright signifying higher digital value, while degraded ar

Plate (2) The TNDVI monochromatic output of the Abijata image frame.

eas are darker in tone. Vegetal cover high digital value is attributed to peak infrared reflectance of healthy green vegetation.

3.1.4 The Normalized Hadamard Transformation

The Normalized Hadamard Transformation (NHT) algorithm discriminates aerial green phytomass. The Normalized Hadamard Transformation represents "The ratio of Hadamard (HI) to Hadamard O(HO), (Wiersema, 1982)". With this algorithm, the author was able to discriminate aerial green phytomass for the Alpine Ibex habitat.

$$NHT = \frac{H1}{H0} = \frac{B7+B6-B5-B4}{B7+B6+B5+B4}$$

The NHT is given by the formula:

Where:

NHT= The Normalized Difference Hadamard Transformation;

B4 ... B7 = Landsat TM bands.

3.1.5 Principal Component Analysis

Multi-spectral image data have negative inherent qualities. One of such qualities is that, thy are correlated. This stems from the fact that, the variables (digital values) on the axes are not independent. Therefore, the Probability Density Function (PDF) are not orthogonal to reduce dimensionality. The PC analysis like other canonical transformation is a multivariate statistical technique, where data are steered to

Plate(3) Vegetal status analysis based on TNDVI, NHT and PC output in a composite form.

principal axes (components) to maximize data variance. The new images which are formed are the linear combinations of all the input bands. the transformation reduces the number of correlated bands. The Principal Component Analysis is based on eigen values and eigen vectors. In ERDAS axial data transformation is realized through the variance instead of the correlation coefficient. the row (Table 4) represents the TM bands, while the columns are Principal Components. The eigen vectors are loading factors. Negative loading renders the images a darker tone while the positive loading increases the brightness, thus improves the image contrast.

The first principal component contains 85% of the information. Although some disciplines like geology employ PC2 and PC3, for aerial green phytomass study, PC1 was chosen. the TNDVI, NHT and PC1 image color composite output (Plate 3) clearly discriminates the status of vegetal cover at Abijata's catchment.

Based on TCT, TNDVI and PC analyses, the vegetal cover at Abijata's catchment is suffering from chronic stress. The spatial coverage of bare areas by far exceeds vegetated on. Tree stands had already been substituted for tillage and cattle feedlots. Forest clearance is chiefly attributed to charcoal burning for income. The other reason is population pressure, where farmland and cattle rearing had already encroached on the Abijata-Shalla National Park.

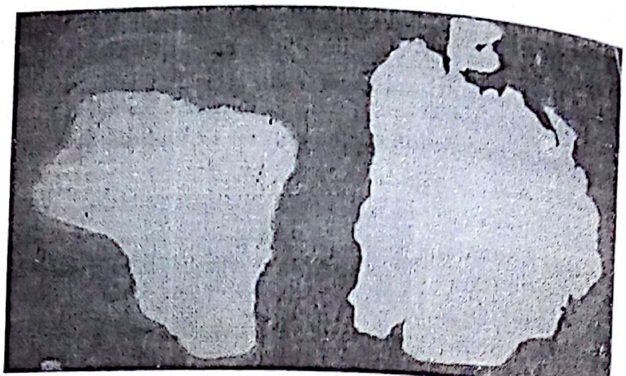


Plate (4) The IHSRGB color composite output of lakes abijata and Shalla.

4. Remote and Proximal Sensing for Eutrophic State Estimation of Lake Abijata

4.1 Methods and Techniques

4.1.1. Imaging System

A GEOCODED Landsat TM image was used for the analysis. For comparison, an image frame containing of the two juxtapose lakes; namely Abijata and Langano were extracted from the total scene. To test the physical status of the lakes, the **IHSRGB** enhancement technique was implemented.

4.1.1.1. Ihsrgb Enhancement

Owing to the influx of nutrients and higher Dissolved Organic Matter (**DOM**) and Suspended Organic Matter(**SOM**) productive lakes are always pigmented. Their color appears to be in green hue. To identify the physical structure of the lakes, the **IHSRGB** enhancement was executed. The algorithm offers the best way to discriminate the subtle physical structures of the two lakes.

Lake Langano receives quite a number of rills, streams and rivers from the adjacent slopes of the Arsi massif. It is highly turbid. The disperse are chiefly soil colloids and silt. Due to the presence of ironoxide, the lake appears to be reddishbrown. Since the disperse phase's Reinold's number is small, particulate most of the time remain in suspension. "Suspensoid at Lake Koka settle ready while Langano do not settle readily" (Tefera, 1994). The IHSRGB discriminates, the physical state of the two lakes, especially their color which is partly the reflection of physical state. The IHSRGB has rendered Abijata its green hue and Lake Langano reddish brown(Plate.5). The color composite exactly depicts the physical appearance of the two lakes to the naked eye. Therefore, with the help of IHSRGB one can determine the physical structure of the lakes, without laketruthing. The green hue of Lake Abijata is accounted for its fertility, while Langano's turbidity has imparted to its reddish brown color.

4.1.1.2 The Normalized Difference Lacustrine ProductiveIndex

The newly proposed Normalized Difference Lacustrine Productivity Index (NDLPI) is based on band ratio technique. The idea steamed from the fact that there is a subtle difference between aquatic (phytoplanktonic) and terrestrial vegetation (higher forms) in reflectance characteristics. Both higher forms and phytoplankton absorb the Blue and Red spectra from the incoming **Photosynthetic Active Radiation (PAR).** The photosynthetic Active Radiation spans from 0.38 m to 0.72 m. According to Ilyansky, "Maximum absorption at = 0.59 m to 0.59 m at the red region of the spectrum (Ilyansky, 1986). A marked difference yet exists between higher forms and most algal species in the reflective wavelengths. Most higher forms reflect maximum in the near infrared region of the spectrum, but medium in the green. Most algal species of the chlorophyll-a group exhibit maximum reflectance in the green wavelength and medium in the reflective infrared region. The most frequently applied technique in Remote sensing for green biomass detection is band ratio. For instance, Vegetation Index (VI), Transformed Normalized Difference Vegetation Index

(TNDVI), Perpendicular Vegetation Index (PVI), Green Leaf Area Index (GLAI) and Vinogradov's Zonal Brightness Index (k) all render a contrasted green phytomass in images. All employ band ratio between two visible bands i.e, Landsat TM Green (0.52) m-0.68 m and Red (0.63 m - 0.69 m). For band ratio ERDAS IMAGINE offers a modeller. For Chl-a pigment detection in Lake Abijata, the following algorithms was used.

$$NDLPI=((B2-B3)/(B2+B3)+1)*(127)$$

Where:

NDLPI = The Normalized Difference Lacustrine Productivity Index;

B2,B3 = Landsat TM spectral bands;

1&127 = Constants to saturate data value to the dynamic range i.e. 8 bit (256) level.

The output of NDLPI is a monochromatic image which is analogous to a Vegetation Index output. However, there is a marked difference between them. In the case of VI, higher form phytomass signatures have a lighter tone, while other signatures have a darker tone. In the case NDLPI output, the lentic environment of Lake Abijata has lighter tone signifying the presenceof Chl-a pigment (Plate 5). A color composite where band 1(blue) is coded to the blue color gun and NDLPI to the green color gun and band 3(red) to the red color gun is shown in (Plate 6).

Plate (5) The monochromatic NDLPI output of Lake Abijata.

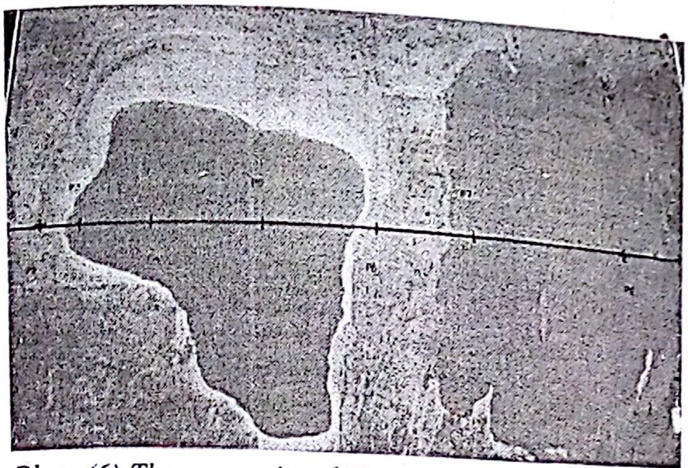


Plate (6) The composite of Blue, NDLPI and Red bands.

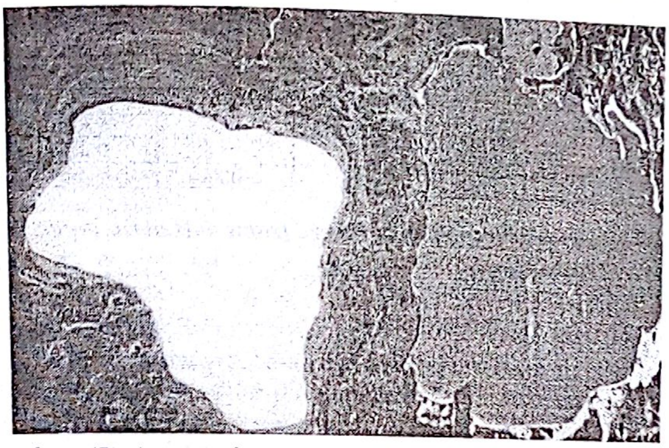
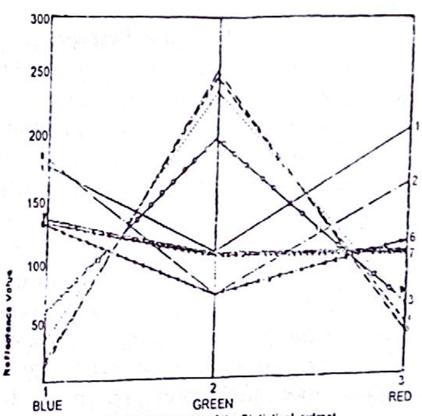


Plate (7) A monochromatic image of Abijata and Langano.

For comparison, the NDLPI algorithm was executed for Abijata and Langano image frame. The monochromatic output (Plate 7) shows that Lake Abijata is lighter in tone while Lake Langano in grey. The multi-spectral interpretation of the tonal difference between the two lakes is that, the NDLPI enhances the green reflectance. This means where green reflectance is peak, the lentic environment would have a lighter tone. If the green reflectance is low, the lentic environment would appear to be grey or black. Abijata's peak green reflectance is accounted for the presence of Chl-a (green pigment) in the lake. Most species of bluegreen algae exhibit peak in the red and medium reflectance in the infrared. This indicates that Lake Abijata is highly productive lake (eutrophic lake). Lake Langano by contrast has a darker tone. This shows that Langano has alower Chl-a (green pigment), therefore it is an oligotrophic lake. The coastal wetland of Langano has a lighter tone due to the presence of terrestrial algae (Plate 7).

A transect (AB) was drawn across the Plate-6 color composite. At intervals nine points were annotated. The intention was to extract their respective statistics. Accordingly, their respective statistical data is shown in (Table 4). A scatter plot of the transect is shown in (Fig.2). Based on the statistical extract, **Point - 3** has a mean reflectance value of 237, **Point - 4** has a mean reflectance value of 250, and **Point - 5** has 253 points 3,4 and 5 represent the lentic environment of Lake Abijata. Peak reflectance of the three points is due to the Chl-a pigment in the lake. Point 1 is an exception. It has a mean reflectance value of 206. The main reason for its elevated digital value is that, it represents a wetland where wetland algae behave in the same way as aquatic. **Point - 6** has a medium green reflectance which is a characteristics of most terrestrial higher green biomass.Fig (2) Scatter plot of statistical extract. **Points 7,8,9** represent Lake Langano. On the green band axis, they have a lower reflectance. This is attributed to the absence of or insignificant pigment (Chl-a) presence in the lake. By and large, the scatter

Fig (2) Scatter plot of statistical extract.



Fig(2) Scatter plot of the Statistical extract

Principal Components File: Abijata

Covariance Matrix						
1	2	3	4	5	6	7
741.17	453.76	770.58	736.88	1383.88	289.08	813.73
435.76	282.20	482.67	467.56	879.47	182.60	513.21
770.58	482.67	852.24	857.91	1652.25	352.58	951.21
736.88	467.56	857.91	927.43	1823.00	403.64	1023.74
1383.88	879.47	1652.25	1823.00	3729.36	854.82	2113.51
289.08	182.60	352.58	403.64	854.82	225.20	490.02
813.73	513.21	951.21	1023.74	2113.51	490.02	1232.55
	Eigen values	Var. %	Total %	Angle	Scale	
1	7587.47	94.96	94.96	33.75	1	
2	325.46	4.07	99.03	82.37	1	
3	46.38	0.58	99.61	78.57	1	
4	19.62	0.25	99.86	59.97	1	
5	6.26	0.08	99.94	89.91	1	
6	3.90	0.05	99.99	87.94	1	
7	1.04	0.01	100.00	89.62	1	
Eigen vectors						
1	2	3	4	5	6	7
0.28	0.66	0.25	0.16	-0.55	-0.23	-0.21
0.18	0.37	0.03	0.00	0.11	0.11	0.89
0.32	0.41	-0.13	-0.05	0.49	0.56	-0.39
0.35	0.04	-0.58	0.20	0.30	-0.64	-0.05
0.70	-0.42	-0.21	-0.12	-0.43	0.29	0.09
0.16	-0.23	0.32	0.88	0.15	0.11	0.02
0.40	-0.17	0.66	-0.37	0.35	-0.34	-0.06

Table (4) The Principal components of the Abijata image frame based on eigen value and eigen vectors as loading factors.

plot manifests one important regularity. Productive (eutrophic) lake appear to have 'and' sign ( ) while sterile (oligotrophic) lake have 'or' (V) sign. In view of this, Lake Abijata is productive; it has ( ) on the scatter plot while oligotrophic Lake Langano has (V) sign.

From **NDLPI Green Axis Decision Rule,**

we can classify lake into the following groups.

1. Oligotrophic; sterile or unproductive would have a digital value ranging from 90 to 125;
2. Mesotrophic; moderately eutrophic would have a digital value between 125 - 200;
3. Eutrophic; productive lakes would have digital value from 200 - 256

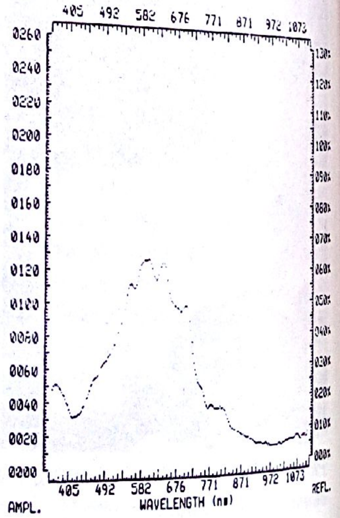
4.1.2 Non-Imaging Systems

Proximal sensing is a technique which makes use of non-imaging system like spectroradiometer. The grating spectroradiometer renders target reflectance data in the form of a profile for the subsequent parametric analysis. so far spectroradiometer has been applied in forestry and agriculture to detect chlorosis and senescence of vegetal covers. Spectroradiometer is usually deployed on low hovering platforms like helicopter or may be mounted on a truck. In this study, however, the spectroradiometer was mounted on a boat platform. Hemispheric scanning of the littoral zone of Lake Abijata was conducted to record algal reflectance data. The main reason for choosing the littoral zone is that dense algal crop usually occupy the littoral zone of a lake. In the earlier periods, there was consensus that in a lake's water mass nutrient influx takes place in gross diffusion. This, however, is an erroneous vision of the past. "Nutrients accrete at the littoral zone of a lake" (Addamenko, 1985). the density of algal crop at the littoral zone of a lake is much greater than the pelagic zone. In view of this, hemispheric scanning were taken at the littoral zone of Lake Abijata. Scanning were conducted at different points of the littoral zone, but the spectral profile acquired were similar. A randomly selected spectral profile is shown in (Fig. 3). The associated reflectance data is given in (Table 6).

The parametric analysis of the spectral profile is accounted as follow. The amplitude of the profile is lowest at 20 and maximum at 130. Almost 60% of the reflectance data's peak is confined within the green region of the spectrum. At the blue region (405 nm), the slope is at its depression owing to absorptance from the photosynthetic Active Radiation for photosynthesis. The curve gradually shows a recovery from 407 nm to 497 nm, reaching peak green reflectance at 583 nm. This is mainly due to the pigment (Chl-a) presence in the lake. From 585 nm to 626 nm, the slope shows a recession. Then from 629 nm to 643.7 nm shows a slight elevation imparting the slope a bimodal nature. This is because of the prevalence of other pigments. Within the red wavelength region, the slope shows a nose dive due to absorption of the region for photosynthesis. At the reflective infrared, the slope flattens with insignificant rise from 972 nm to 1073 nm. The spectral profile data indicates the productivity of Lake Abijata. The lake is highly pigmented; rich in Dissolved Oxygen Matter (DOM).

Fig. 3.A randomly selected spectral profile

REFL. CURVE PAIR	A	A
MAXIMUM SIGNAL	158	247
INTEGRATION TIME	08	01
DATE- MON/DAY/YR	02/15/95	02/15/95
TIME- HR:MIN:SEC	11:19:37	11:18:07
IDENTIFICATION #	1009	0006
# OF SCANS AVG'D	4	4
AUTORANGING MODE	YES	YES
SEQUENCING MODE	NO	NO
CAMERA SPECTRUM	VIS/PIR	VIS/PIR
NORMALIZE TO MAX	NO	NO
PERCENTAGE(+OR-)	+00%	+00%
MULTIPLY FACTOR	8	8
OFFSET BY (+OR-)	+00	+00



Series No	Layer	x-axis value	Profile	X(mean)	Min	Max	Q(sd) below
1	1	1.00	197.00	187.11	181.00	200.00	182.88
	2	2.00	155.00	107.22	98.00	115.00	104.19
	3	3.00	223.00	206.89	195.00	226.00	202.19
2	1	1.00	176.00	179.11	133.00	203.00	136.01
	2	2.00	90.00	72.56	64.00	94.00	67.13
	3	3.00	182.00	161.89	132.00	182.00	154.55
3	1	1.00	37.00	39.00	37.00	43.00	32.76
	2	2.00	235.00	237.56	222.00	247.00	218.53
	3	3.00	66.00	64.66	63.00	69.00	61.64
4	1	1.00	19.00	18.33	16.00	19.00	16.35
	2	2.00	247.00	250.00	230.00	255.00	230.17
	3	3	36.00	47.67	36.00	52.00	26.10
5	1	1.00	16.00	14.11	11.00	16.00	12.20
	2	2.00	247.00	253.22	247.00	255.00	239.94
	3	3.00	44.00	41.11	36.00	44.00	39.37
6	1	1.00	144.00	136.89	93.00	173.00	101.02
	2	2.00	98.00	106.56	85.00	141.00	65.30
	3	3.00	151.00	146.33	110.00	173.00	116.37
7	1	1.00	133.00	131.22	128.00	133.00	128.90
	2	2.00	102.00	109.00	94.00	124.00	84.68
	3	3.00	105.00	105.22	102.00	107.00	100.90
8	1	1.00	133.00	132.00	125.00	136.00	127.00
	2	2.00	102.00	104.11	94.00	124.00	84.61
	3	3.00	99.00	106.67	99.00	113.00	89.15
9	1	1.00	59.00	54.89	29.00	104.00	60.56
	2	2.00	158.00	187.89	124.00	222.00	90.23
	3	3.00	66.00	60.11	41.00	88.00	31.61

Table(5) The Profile's Tabular Data Input Annotation Layer

#	no.	AMPL	#	no.	AMPL	#	no.	AMPL	#	no.	AMPL	#	no.	AMPL	#	no.	AMPL	#	no.	AMPL
002	366.4	46	038	463.7	54	074	564.8	109	110	670.2	98	146	777.1	37	182	890.1	16	218	1003.6	[illegible]
003	371.0	50	039	466.5	55	075	567.6	111	111	673.1	98	147	780.1	35	183	893.3	16	219	1006.7	[illegible]
004	373.6	51	040	469.3	55	076	570.5	113	112	676.0	97	148	783.2	35	184	896.4	16	220	1009.9	10
005	376.2	51	041	472.1	56	077	573.4	116	113	679.0	97	149	786.2	35	185	899.6	15	221	1013.0	10
006	378.8	51	042	474.9	57	078	576.2	120	114	681.9	96	150	789.2	35	186	902.8	15	222	1016.2	11
007	381.4	50	043	477.7	59	079	579.1	123	115	684.9	95	151	792.2	35	187	906.0	15	223	1019.3	11
008	384.0	45	044	480.5	61	080	582.0	124	116	687.8	95	152	795.3	35	188	909.1	14	224	1022.4	11
009	386.6	46	045	483.3	62	081	585.0	125	117	690.7	96	153	798.3	35	189	912.3	14	225	1025.6	12
010	389.2	46	046	486.1	63	082	587.9	126	118	693.7	97	154	801.3	36	190	915.4	13	226	1028.7	12
011	391.7	45	047	488.9	64	083	590.9	126	119	696.6	98	155	804.3	35	191	918.6	12	227	1031.9	12
012	394.3	44	048	491.6	65	084	593.8	126	120	699.6	98	156	807.4	35	192	921.7	12	228	1035.0	12
013	396.9	42	049	494.4	65	085	596.7	126	121	702.5	98	157	810.4	35	193	924.9	12	229	1038.2	[illegible]
014	399.5	40	050	497.2	67	086	599.7	127	122	705.5	97	158	813.6	34	194	928.0	12	230	1041.3	12
015	402.1	39	051	500.0	68	087	602.6	126	123	708.5	94	159	816.8	33	195	931.2	12	231	1044.5	12
016	404.7	36	052	502.8	69	088	605.5	124	124	711.5	89	160	820.1	31	196	934.3	12	232	1047.6	13
017	407.3	34	053	505.6	70	089	608.5	121	125	714.4	83	161	823.3	30	197	937.5	12	233	1050.8	13
018	409.9	32	054	508.4	72	090	611.4	119	126	717.4	76	162	826.5	28	198	940.6	12	234	1053.9	13
019	412.5	31	055	511.2	74	091	614.4	116	127	720.4	69	163	829.7	26	199	943.8	11	235	1057.1	13
020	415.1	31	056	514.0	75	092	617.3	115	128	723.4	63	164	832.9	24	200	946.9	11	236	1060.2	13
021	417.7	32	057	516.8	75	093	620.2	114	129	726.3	59	165	836.1	23	201	950.1	11	237	1063.4	14
022	420.3	32	058	519.6	80	094	623.2	115	130	729.3	56	166	839.3	22	202	953.2	12	238	1066.5	15
023	422.8	32	059	522.4	82	095	626.1	117	131	732.3	53	167	842.5	22	203	956.4	12	239	1069.7	15
024	425.4	33	060	525.2	84	096	629.0	120	132	735.3	51	168	845.7	21	204	959.5	11	240	1072.8	15
025	428.0	33	061	527.9	86	097	632.0	122	133	738.2	50	169	848.8	21	205	962.7	10	241	1075.9	15
026	430.6	34	062	530.7	88	098	634.9	124	134	741.2	49	170	852.0	21	206	965.8	11	242	1079.1	14
027	433.2	35	063	533.5	90	099	637.9	125	135	744.2	48	171	855.2	20	207	968.9	10	243	1082.2	13
028	435.8	37	064	536.3	92	100	640.8	124	136	747.1	47	172	858.4	29	208	972.1	10	244	1085.4	12
029	438.6	38	065	539.1	96	101	643.7	122	137	750.1	45	173	861.5	20	209	975.2	10	245	1088.5	14
030	441.4	40	066	541.9	100	102	646.7	119	138	753.1	43	174	864.7	19	210	978.4	10	246	1091.7	14
031	444.2	42	067	544.7	105	103	649.6	114	139	756.1	39	175	867.9	19	211	981.5	10	247	1094.8	14
032	447.0	13	068	547.5	109	104	652.5	109	140	759.0	37	176	871.1	18	212	984.7	10	248	1098.0	15
033	449.8	45	069	550.4	111	105	655.5	106	141	762.0	36	177	874.2	18	213	987.8	10	249	1101.1	14
034	452.6	47	070	553.3	112	106	658.4	103	142	765.0	35	178	877.4	18	214	991.0	10	250	1104.3	15
035	455.3	50	071	556.1	111	107	661.4	101	143	768.0	36	179	880.6	17	215	994.1	10	251	1107.4	13
036	458.1	51	072	559.0	110	108	664.3	100	144	771.1	37	180	883.7	17	216	997.3	10	252	1110.6	14
037	460.9	53	073	561.9	109	109	667.2	99	145	774.1	37	181	886.9	16	217	1000.4	11	253	1113.7	16

Table(6)

Plate(8)Photograph taken from acomputer's screen showing the shore recession of Lake Abijata

4.1.3 The Causal Factors of Abijata's Eutrophication

The major causal factor of Lake Abijata's eutrophication are the following.

1. The sodic phase of the lake's basin water. Lake Abijata's $_pH$ is 9.9. The sodic phase of the lake is an optimum medium for algal growth and reproduction.

2. The shape of the lake's basin. The shallow water column and the gently sloping nature of the basin are the ideal conditions for Leachates influx and accretion.

3. Cattle rearing at the adjacent lands. At the adjacent land of Lake Abijata, cattle rearing is being practised. At the abernosa area, there is a state ranch. Animal waste as manure are excellent natural fertilizers. The gently sloping nature of the adjacent land whose average declivity is 2°, creates a favorable condition for nutrient transportation. During wet seasons, the natural fertilizers are flashed into the lake. Nutrient influx has been inducing algal bloom in the lake. Therefore, the utilization of the juxtapose land as cattle feedlot is one of the major causative agents of Abijata's eutrophication.

4. Farming practices . At Lake Abijata, the adjacent land is either farm or cattle feedlot. Tillage contributes nutrients which are useful for plant growth. Leachate during rainy seasons bring nutrients into the lake. Farming activities at Lake Abijata also contribute nutrients which are extracted by phytoplankton.

River	HCO_3	CO_3	Cl	NO_2	SO_4	NH_3	Ca	PO_4
Bulbula	120	Nil	12.5	0.36	2.0	0.76	20.0	0.1
Horakelo	600	400	400	0.41	15.0	0.67	4.0	0.28

Table (7). Findings on the chemical structures of the indicated rivers (water Resources Authority, 1984).

5. Abijata's watershed ratio. The watershed ratio (WL) is the lake's drainage area to the lakes's surface area. Lake Abijata's drainage area according to the data acquired from the Ministry of Water is 10744 km^2. Considering the fluctuation, the surface area is 205 km^2. Therefore, the WL ratio is 50:1. This offers a favorable condition for its productivity.

6. Riverine influx. Rivers Horakelo and Bulbula with their rich nutrients aliment Lake Abijata (Table 7).

The parametric analysis done using proximal Sensing · (Grating spectroradiometer) showed peak reflectance in the green region of the spectrum. This shows that Lake Abijata is a productive (eutrophic) lake.

4.1.4 Iimpacts of Eutrophication

Eutrophication has its merits and demerits. Ethiopian productive lakes support fish to satisfy local consumption. Crocodile nursery lakes have become pivotal hard currency generating centers. High productivity (hyper-eutrophication), however, has a serious drawback. Hyper-eutrophication lowers the Dissolve Oxygen(DO) in a lake. Phytoplankton would begin to die and decompose, subsequently followed by NH_3 and CH_4 emission. This condition creates oxygen sag(anoxia) in a lake, thus increasing the Biological Oxygen Demand(BOD). At this time the rate of algal bloom surpasses their rate of removal by lacustrine fauna. As algae die, they would start to precipitate to the lake's bed with the eventual decomposition.The first victims of oxygendepletion are schools of fish. As fish die, their decay and decomposition supplies rich nutrients again to the algae. Hyper-eutrophication also favors the reproduction of toxic species. According to Ehrhardt. "If mass death of birds, dogs, ducks, grazers occur through the ingestion of lake's water, nearly twelve species of bluegreen algae may be found. Ingestion of bluegreen algae, especially Anabaena, Aphanizomenon and Microcystis are highly fatal to fauna" (Ehrhardt, 1984).

Eutrophication has been one of the causal factors of Water hyacinth(Icornia crassipes) invasion of the Ethiopian Rift Lakes. Lakes Aba-Samuel, Koka, Ziway have been carpeted by water hyacinth and algal crop. Periodic mass zebra death at the Abaya is perhaps due to algal ingestion during their bloom.Uncontrolled nutrient influx from Abijata's catchment, especially from its east and southwestern embayment favors algal growth. From successive observations carried out at different seasons, rills and minor streams descending from the Lencha peaks at the southwestern embayment appear to be tar-like rich in nutrients. Coupled natural and anthropogenic causes, the sodic phase of the water have created the ideal condition for eutrophication of Lake Abijata.

5. Finding and Recommendation

Applying the environmental information system(EIS), the lentic environment and ecosystem status of abijata's catchment were overhauled. To ascertain the findings insitu tests using the proper limnological equipment and post laketruthing laboratory analyses were carried out. Collateral information were incorporated to make the analyses more comprehensive. By and large, important findings of the study include the following .

5.1 The Biogeocoenosis Status at the Catchment

Abijata's water quality depends on the ecological status at its catchment. In order to determine the vegetation status at the catchment, three diagnostic algorithms were executed. The Tasselled Cap Transformation (TCT), the Transformed Normalized Difference Vegetation Index (TNDVI) and the Normalized Hadamard Transformation (NHT) had rendered the vegetal status at the catchment. The TCT had discriminated vegetated from bare (cleared) areas. Nearly 70% of the image frame shows poorly vegetated and cleared areas. Owing to population pressure, farmlands have been encroaching on the National Park. Intensive charcoal burning is being practised within the Abijata-Shalla National Park. Intensive charcoal burning is being practised within the Abijata-Shalla National Park. The Abernosa forest reserve whose undergrowth is a ranching field has been suffering from chronic stress by the inhabitants. The inhabitants have been dismantling fences as an expression of discontent for the lack of enough land. On the TCT color composite, the damaged Abernosa at north and east shows anomalous condition caused by human stress. The drier (semi-arid) climatic condition has favored top soil loss. Frequent dust storms during the long dry seasons and sheet wash during wet seasons have created a favourable condition for soils erosion and the appearance of ' bad land'. This inturn has an impact on the water quality of Lake ABIJATA. To conclude, the biogeocoenosis of the Catchment has been suffering from chronic stress.

5.1.2 The eutrophic Status of Lake Abijata

Based on the Remote and Proximal sensing techniques used to determine the eutrophic status of the Lake, it is eutrophic lake. The two proposals new approaches handy for limnologists to determine the productivity of a lake. It was also discovered that the green hue of the lake has a serious drawback on the trona crystal being produced by soda ash plant at Abijata.

5.1.3 Shore Recession

According to the study carried out by Gezahegne (EST, 1988) using GIS, Lake Abijata has been showing fluctuation. For the GIS, multi-date and multi-data planes were implemented. Some of the data planes included a digitized 1974 was 16798.6 ha. In 1976, it was 19825.66 ha in 1989, it was 14797.89 ha, and in 1998 it was 15586.44 ha. A facsimile of the GIS output is shown in (Plate 8).

Plate (8) Photograph taken from a computer's screen showing the shore recession of Lake Abijata.

Recommendation

To reinstate the ailing ecosystem to its pristine status, the following meliorative measures have overriding importance.

Reforestation of the bold watershed with tree species appropriate for the edaphic condition of the area;

Cattle rearing within the reserve center and around the lake's basin must be abandoned;

Sand exploitation (lacustrine deposit) around birds feeding area must be abandoned;

Bad farming practice at the catchment must be substituted for systematic farming with the implementation of terracing and intercropping method;

Any means of forest resource abuse including cutting and charcoal burning must be abandoned. Especially, in the National Park, the protection measure requires law enforcement to penalize any intruder;

Owing to its lower level (depth) and high Dissolved Organic Matter (DOM), the soda-ash plant must be transferred to Lake Shalla. The depth of Shalla is 266m, its $_pH$ is 10. Since the lake is relatively transparent, a better soda-ash (crystal) can be produced.

So long as the water budget of Ziway has an impact on Abijata, rational water utilization must be maintained. This is to reinforce the Bulbula river which has almost become an intermittent stream.

Pertinent to eutrophication problems which is usually accompanied by lower Dissolved Oxygen, it is imperative to apply aeration. During low Dissolved Oxygen, it is better to apply mechanical mixing and hypolimnetic aeration. A lower 'DO'results in poor fish population, but a higher algal bloom. Therefore, mechanical mixing of the pho tic zone with aphotic zone helps to redistribute the photosynthetically produced oxygen. Since lake Abijata is ventilated, the wind also stirrs it, thus eases the mixing process. Hypolimnetic aeration is also a good method. Oxygen must be supplied to the oxygen sag hypolimnion without mixing nutrients into the epilimnion. Hypolimnetic aeration removes iron and manganese which precipitate as redishbrown stains. Nutrients released from micro zone and toxic ammonia may be converted back to useful nitrate. The most unpleasant and repulsive odor of H_2S which is associatedd with decay and decomposition would reduced.

Countries like Ethiopia which are pinched by poverty may not offer the financial demand for the implementation of chemical extradiction of hyper algal reproduction, but it is an effective panacea. Copper sulfate is very toxic, thus weedsout nuisance algal bloom.

Bibliography

1. Belousov v.v(1974)**The East African Rift system**, USSR Academy of science, Nauka Publishers, Moscow
2. Daniel Gamachu (1977)**Aspects of climate and water budjet in Ethiopia**, technical monograph published for Addis AbebaUniversity.
3. Dilon P.J (1974) **The phosphorus-chlorophyll relationship in a lake**, Limnology and Oceanography
4. Edelstein K.K (1972) **Limnological practice** Moscow State University Publisher, Moscow.
5. Ehrhardt. J.P(1982) **LE plankton Ecology, pollution, Paris**
6. Emily K.V (1974)**A Checklist of the birds of Ethiopia** Hailesillassie I University Publishers, Addis Abeba
7. Kelecha W.M (1987) **A glossary of Plant names**, Addis Abeba.
8. Longhlin W(1991) **Principal component Analysis for alteration Mapping**, USA..
9. Gerbrandt Wiersema (1973)**Ibex habitat analysis using Landsat Imagery**, ITC, Enschede, the Netherlands.
10. Nazarove I.M (1973)**Bases of Remote methods for Environmental pollution**, monitoring, Gidrometeoztdat, Leningrad.
11. Vollenweder R.A (1975) **Input and output model with special reference to phosphorous loading concept in Limnology**, scweis.z.
12. Tefera Getachew (1972) **Impact of irrigated agriculture and soda ash extraction on fish and Birds In two Ethiopian Rift Lakes**, AAU, Addis Abeba.


ARBAMINCH WATER TECHNOLOGY INSTITUTE
COMPUTER & DRAFTING ROOM
ADMINSTRATION
LIBRARY
DORMITARY
DORMITARY II
DORMITARY III
CAFITERIYA
LECTURE HALL