water

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Arbaminch

19 - 20 May 2003

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.

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Dr.-Semu Ayalew
Guchie Gulie
Fesseha G/selassie
Dr.Mekonen Ayana

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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.

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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.

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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.

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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: Dr.Mekonen Ayana Assistent Editor: Feseha G/slassie DTP: Feseha G/slassie
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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.

Editorial
Dear Reader,

Arba Minch Water Technology Institute used to organize the symposium on "Sustainable Water Resources Development" Consistently for the last seven years. This has been special year for the institute, which has been celebrating its transformation to full fledged University.

This proceeding contains about 20 papers that were presented on the 7th symposium, which was held on 19 - 20 May 2003 at Arba Minch. The broad focus areas of the papers are Water supply & Sanitation, Water & Environment, Irrigation and Drainage, Hydrology, Hydropower & water Resources etc.

The papers are the results of case studies and research works that address directly the issues related to Sustainable Water Resources Development. We hope that the discussed problems with their alternative solutions will be valuable references.

The editorial board would like to thank all authors for their contributions. We are thankful to GTZ for sponsoring the symposium.

Welcoming Address For the 7th Symposium on "Sustainable Water Resources Development,"

19-20 May 2003

Arbaminch

By Dr. Mekonen Ayana

Distinguished guests
Dear participants
Ladies and Gentlemen,

At the onset, on behalf of the organizing committee and on my own behalf, I wish to welcome you all to the 7th Symposium on Sustainable Water Resources Development.

Let me first register my sincere appreciation and thank to the Vice Minster to have found time to be with us on this occasion. Your presence with us today assures us that the ministry of Water Resources continues to support our Institute in its effort to train professional for the water sector.

Distinguished guests and participants
Ladies and Gentlemen

An increasing trend of drought on one hand, flood and soil erosion on the other hand has been observed in the country and it is regarded as a recurring hazard. When the next drought does come there is every reason to believe that it will be perhaps as bad or even worse than the one before it, not only because of an increasing climatic change but also because of the vulnerability of the society which tend to magnify the effects of drought.

This symposium on sustainable water resources development under increasing victims of drought in the country will examine the hydrological conditions of the country, its utilization and management options that provide the scientific foundation for sustainable use of water resources.

Distinguished guests and participants
Ladies and Gentlemen

The purpose of this Symposium is, therefore, to bring together researchers, practitioners from Governmental and non-governmental organization, consulting offices, research institutions and universities to exchange current research results and valuable findings from practical activities.

Thus, we believe that this Symposium will serve and facilitate the dissemination of results as well as transfer of technology.

Once again on behalf of organizing committee, I would like to thank all researchers who have responded to our call by sending us their research papers and have appeared to present their papers in the Symposium. I wish to take this opportunity to express my very sincere thanks for GTZ and AWTI for sponsoring the Symposium, without which the Symposium would not have been organized.

I would like at this stage to take this opportunity to request Dr. Ing. Seleshi the Dean of the Institute to make opening speech and thereby formally open the 7th Symposium on Sustainable Water resources Development.

I thank you all for your attention and wish your comfortable stay and fruitful discussion during the Symposium period.

Opening Address For the 7th Symposium on " Sustainable Water Resources Development," 19-20 May 2003 Arbaminch

By Dr. Ing. Seleshi Bekele

Distinguished Guest
Dear participants
Ladies and gentleman

On behalf of Arbminch Water Technology Institute, I am very glad to have this opportunity to make an opening speech and to welcome you on the symposium of Sustainable Water Resource Development (WRD). This symposium marks the 7th cycle in which Arbaminch has been delivering.

We are happy to consistently sustain this annual symposium without interruption. Thanks to your active participations without which such event can't happen. Thanks also to the support of the GTZ, who have been behind our efforts through financial support.

The objectives of this symposium can be described as:

- To provide, professionals in the water and related natural resources and environment sector, a platform in which they can communicate.
- A platform to present research findings and study result
- Produce the proceedings of the presentation; thereby information can be disseminated to those who have not been part of this symposium. This also has an added value in obtaining reference document for researchers, educators and planners.

Even though these have been the been the objectives, on the other hand, a symposium in this form is the only one in Ethiopia addressing the water sector that is ongoing consistently. Thus, our Institute, given the short period since establishment, is proud of delivering such reputation.

Water resources development, management and sustainability is a crucial issue and should be one of the most important agenda to bring about socio-economic development in Ethiopia as well as secure growth.

The basic definition for sustainable development is: " the ability of the present generation to use its natural resources without putting at risk the ability of future generations to do similarly". Sustainable development is making efficient use of natural resources for economic and social development while maintaining the resource base and environmental capacity for the coming generation. This resource base should be widely interpreted to contain besides natural resources: knowledge, infrastructure, technology, durables and people. In the process of development natural resources may be converted in to other durable products and so remains part of the overall resource base.

The failure of our nation to sufficiently, appropriately and efficiently utilize the water and land resources has led us to innumerable catastrophes. We face time and again in the agonising poverty, inability to feed ourselves, inability to get adequate and clean water to drink. For example we are now having not enough food for almost ¼ of our population.

Adequate water supply coverage is not in place because of lack of adequate financial and human resources, technical known how, etc. Thus, sustainability of health of people, education of women and development of or society is affected.

Our past rich forest resource cover is vanishing from our face leaving us to heavy erosion, land degradation, environmental impact because on one hand the natural resource couldn't provide the necessary demand, which is called for energy, construction, etc. The alternative would have been to utilize other renewable energy resources, among others water resource as energy resources is the most important in Ethiopian context.

In many parts of the world, fresh water resources are scarce and usually finite. Consequently, there are may ways to jeopardize the future use of water, either by over exploitation of resources or by destroying resources for future use. Our case is somewhat different at least for most part of the country. Although it is imbalanced and erratic in its spatial and temporal distribution, our country is blessed with ample amount of water resource, that can be developed and utilized for our nation and societies well being. Limitation of resources is thus not a serious problem, but the muscle to develop the resource is not there. Our ability in Ethiopia to use and enhance the positive role of water and reducing the negative impacts has been very limited.

This inability is described in terms of lack of adequate development and sustainability of development commensurate with the growth of population. Besides physical aspects of sustainability mentioned above related to the resources base there are social, financial and institutional aspects of sustainability. Aspects of sustainability can be identified as: technical sustainability (balanced demand and supply), financial sustainability (cost recovery), social sustainability (stability of population, demand and willingness to pay), economic sustainability (sustaining economic development or welfare and production), institutional sustainability (capacity to plan, manage and operate the system) and environmental sustainability (no long-term negative or irreversible effects).

We are simply not adequately utilizing our resources (example water) or not appropriately utilizing our resources (example forest, land resources, manpower etc). A number of aspects of sustainability mentioned above in fact are not well developed nor well considered in our endeavours s of development.

Today, water sector is given higher consideration than ever by our government. This awareness, I hope remains consistent to bring fundamental change in future. There is strong believe how that, even if we overcome our current food crises through the usual quick fixes, the efforts to use water as a means and driving forces for development is indicated in the sectoral policies and strategies. Even the other sectors like agriculture etc has realized that using water on a house hold level is an alternative almost second to none.

It is very important and correct to give due emphasis on small and household level water usage. That way production can be enhanced by individual farmers and production can be more reliable than the purely rain fed option. However not just small and house hold level approach is the key to all success but medium and large scheme projects are very useful areas and worth considering for development. These are the vehicle to influence and support the macro-economy, job opportunity and industrialization of agriculture. As seen in the Water Sector Development Program and emerging activities, I hope aspects of medium and large scale irrigation will be adequately addressed in parallel to other sub sector developments.

Most of us who are gathered here today, no doubt would like to see that on going development endeavours in Ethiopia, would lead to a significant change and leap forward so that Ethiopia exists as a self fulfilling nation, none synonymous to various tragedies through which the rest of the world see us.

It is obvious that such gathering and presentations provide opportunities to exchange views, interchange ideas, and learn from one another. This symposium is expected to provide us an opportunity of presenting our research outputs, study results, etc in the sector and associated sectors. In effect, we fill this symposium fills the gap in the information exchange leading to sustainable water resources development in part. The themes covered here, in the two days length can't cover all aspects, but a portion of the large set.

Distinguished Guest
Dear participants
Ladies and gentleman

In theses two days of deliberations, I hope that useful papers be presented, discussions would be made in an enthusiastic manner, and participants gain considerably from the forum.

May I take this opportunity to extend my thanks to those of you who are prepared to present the papers, who have travelled a long journey to participate in the symposium as well as to those of you who have been involved in organizing the symposium.

With this brief remark, I now declare that the symposium is open.
Thank you!

Analyses Of Multiple Variable Water Quality Data In the Time and Specral Domain For Water Quality Monitoring

Ababu Teklemariam, AWTI, P.O.Box 21
Arbaminch, Ethiopia.

Abstract

This report summarizes the results of the application of multivariate analysis and time series analysis of water quality data. The analyses was based on data collected from rivers and lakes of the Abaya – Chamo drainage basin during a 3 months field work in the area during the period June 2001 – September 2001. The application of principal components Analysis on river water quality data reduced the data dimensionality from 17 to 5 at most. Subsequent application of factor analysis on the same data revealed that few factors (2-5) account for the data variation. Rainfall appeared as the major factor on which other variables were loaded. Application of cluster analysis on Lake Abaya water quality data revealed that TDS and conductivity form few clusters while pH, redox potential and Dissolved Oxygen form several clusters. There were few clusters across the lake than along the longitudinal axis. Time series analysis on the river water quality data produced long term seasonal trend as well as periodic variation. Both variations are explained by the rainfall regime. ARIMA model and spectral regression were used for the periodic analysis. State – Space model was used adequately for relating water quality data among two rivers Harie and Kulfo.

Introduction

Multivariable analyses of water quality data such as Principal Component Analysis and factor Analysis have been applied in water quality studies as part of the effort to establish inter – relationship among water quality variables, for establishing the cause – effect relationship between pollutants and as a cost reduction mechanism for the optimum design of water quality monitoring system. They can also be employed for identifying possible errors in water quality data and for checking the integrity of the data.

Principal Components Analysis

Principal Components Analysis investigates the data dimensionality by a linear transformation of the original data variables X in to a set of independent variables called principal Components through the following equation:

$$Y_j = a_{1j} X_1 + a_{2j} X_2 + \ldots\ldots + a_{pj} X_p$$

The a values are determined by solving the equation

$$(\Sigma - \lambda I) a_i = 0$$

where l are the eigen values of the original correlation matrix.

The diagonal matrix L is the equivalent of the original covariance or correlation matrix S and the two are related through the equation:

$$\Lambda = A^T \Sigma A \text{ or}$$

The component loadings are given through the covariance between Y and X variables and are given through the equation.

$$COV(Y_j, X_i) = Cov\left(Y_j, \sum_{K=J}^{P} A_{ik} Y_k\right)$$
$$= a_{ij} Var(Y_j)$$
$$= a_{ij} \lambda_j$$

Common Factor Analysis

Factor analysis extracts common factors amongst variables through the model:

$$X_1 = \sum_{J=1}^{m} \lambda_{1j} F_j + e_1 \quad \ldots \quad X_p = \sum_{J=1}^{m} \lambda_{pj} F_j + e_p \ ,$$

Where l_{ij} are the constants and m is generally much smaller than p. The variables F_1, ….., F_m are called common (primary or latent) factors. Since they are common to all p response variables. They are assumed to be uncorrelated with unit variance. The variables e_1, ……, e_p are called specific (or unique) factors, since they are unique to each response variable. They are assumed to be uncorrelated with:

Called the specific variance or the

$$V(e_i) = \zeta_i, \quad i = 1, \ldots p$$

specificity of the I the response. The variables F_i and e_j are assumed to be uncorrelated, I = 1, …..m, j = 1, ….P. The constants l_{ij} are called the factor loadings

Cluster analysis

Cluster Analysis is a Technique that Groups Samples Objects with SIMILAR characteristics. Cluster Analysis Visually Displays the Relationship Between Samples as Well as Among Variables. The Sample Points are Defined by the Standard Eucleadian Distance (SED). The SED is the Square Root of the Sum of the squares of the Standardised Variables included in the Analyses. The clustering criteria uses either th nearst neighbour criterion or the largest dissmilarity criterion.

$$C1(A,B) = \min d(a,b)$$
$$C2(A,B) = \max d(a,b)$$

Time Series Analysis

Time series analysis of water quality data is carried out for the detection of trends, the determination of periodic fluctuations and Estimation of Mean Values of the Stationary Component.

The trend of water quality data is detected through the power tred equation

$$P_w = 1 - \beta = F(n_T - t_{\alpha/2})$$

The periodic sampling frequency is determined through spectral analysis of the detrended data and using the Nyquist frequency:

$$f_p \geq 2f_s$$

The frequency variation of the water quality data is detected through the spectral density function which is the Fourier transform of the auto covariance function of the water quality data

$$f_x(\nu) = \sum_{m=-\infty}^{\infty} R_x(m)\, e^{-2\pi i \nu m}$$

The periodic relationship amongst sets of water quality variables is determined through the spectral regression equation:

$$A(V) = \frac{f_{xy}(\nu)}{f_x(\nu)}$$

Where A(v) is the Fourier transform of a(t) in the equation

$$y(t) = \sum_{s=-\infty}^{\infty} a_s x_{t-s}$$

Time domain regression is carried out using ARIMA model from the general equation:

$$\phi_p(B^s)\phi(B)\Delta_s^D \Delta^d x_t = \alpha + \theta_Q(B^s)\theta(B)w(t)$$

For water quality variables the ARIMA model is developed for each variable and the regression is done on the residuals of the respective ARIMA models. State space methodology can be employed for determining the spatial relationship amongst water quality data in a region employing the state space relationship:

$$Yt = AtXt + Vt$$

$$Xt = \phi Xt\text{-}1 + Wt$$

Where Y is taken as the observed water quality variable at space and X is the unobserved state variable. The coefficients unknown in the equations are determined through the Kalman filter recursion.

Description of Site, Data Collection and Organisation

The Abaya Chamo drainage basin in which this study is based is a sub basin of the rift valley that crosses through Ethiopia midway in the north south direction. The basin comprises mainly the two lower lying lakes. Lake Abaya and lake Chamo and rivers like Gelana, Bilate, etc the drain in to lake Abaya. The rivers kulfo and Sile enter in to Lake Chamo and the overflow from lake Chamo drains in to the sagan river which in turn drains finally to the Chew bahir

Figure -1shows the layout of the two lakes Abaya and Chamo together with the with rivers Kulfo and Hare that drain in to the lakes and from which the water samples were taken for analyses. The dots on the two lakes indicate the sampling location for the lake water quality surveys.

Sampling and Testing of the Water Quality

The sample for testing in the laboratory were transported within 6 hours and analysis in most cases were started immediately. Because of the greater number of parameters to be analyzed it was not possible to analyze for all parameters on the same day. Therefore, samples that had to be analyzed on subsequent days were appropriately conserved in a refrigerator and as stipulated in the standard operation procedure for the parameter in question.

For water quality parameters such as the pH , conductivity, dissolved oxygen, redox potential, water temperature, on site testing is the preferred method since the water quality changes between sampling and analysis in the lab. Field testing equipment that were available in the water quality laboratory of the institute were used for these analyses. Every day before departing for the field work the equipments used for the field tests, i.e., the pH meter, TDS meter and conductivity meter were calibrated using known standards. This daily operation was necessary as it was found out that the performance of the instruments were not stable and calibration was needed almost on a daily basis.

Turbidity was measured using the HACH model turbidimeter. The standards for this turbidimeter were available and the equipment is found to be functioning adequately. Dissolved Oxygen was measured on site by the use of dissolved oxygen sensitive electrode. Later a counter check was carried out in the laboratory using the Azide modification of the winkler method. The sample dissolved oxygen was fixed on site for this test. The pH test was also made on site using the pH meter testing kit . Redox potential was made using the field testing kit. So also were the water temperature, conductivity and total dissolved solids measurements. . Chloride was determined by the argentometric titration method using silver nitrate as a titrant. Calcium and Magnesium as well as Hardness were all determined by the EDTA method using EDTA as a titrant. Bicarbonate and carbonate alkalinities were determined titrimetrically using hydrochloric acid as a titrant. Total sol-

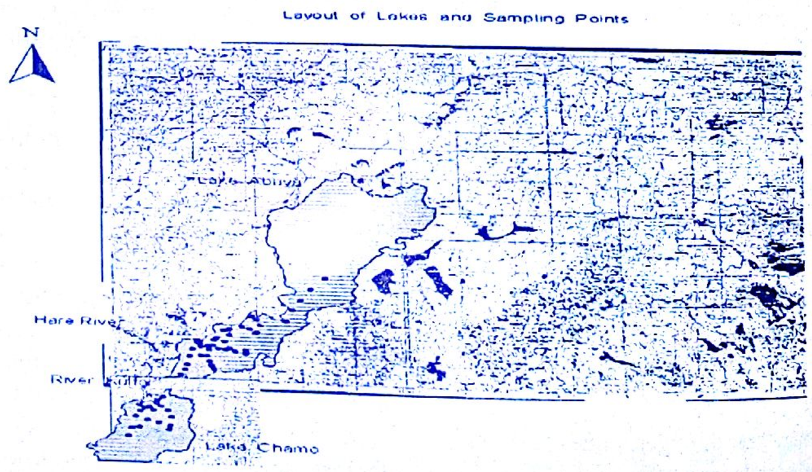

Fig. 1 Layout of lakes & sampling points

ids were determined at 105° using a laboratory oven. Volatile solids were determined at 550° using a furnace.. Colour was determined visually by a comparator as well as spectrophotometrically at several wavelengths. Sodium and Potassium were determined by flame photometric procedure.

Data Validation and Quality Control

Before embarking on the analysis attempts have been made to validate the test procedure through the use of known and relatively stable standards. The turbidimeter have been calibrated before every measurement using the appropriate standards. The spectrophotometer measurements have been evaluated with respect to standard solutions and in most cases it has produced consistent results. The field testing equipments have also been calibrated each time a field study was conducted. All of the titration methods employed in these studies have also been standardized through the titration of known amounts of relative stable analytes. Mass and volume measurements have been measured as accurately and carefully as possible. Sufficient number of samples have been analyzed for each test parameter as stipulated in the procedure and in order to arrive at the desired statistical accuracy of the results obtained. With all samples at least duplicate samples from the same point have been analyzed.

Integration of Water Quality Data with a GIS.

The GIS software used in this research is the ArcView version 3.0 developed by the Environmental Systems Research Institute (ESRI). The scanned images of the area map containing the rivers and lakes were imported to the arcview and the maps were georeferenced to an acceptable accuracy with points on the map that have known UTM (Universal Transverse mercator) coordinates (ground Control Points). The UTM coordinates of the sampling points along with the associated water quality data were imported to the ArcView from a Microsoft Access Data Base File Containing these Data. The results of cluster analyses of lake water quality data were linked to the data base and the resulting clusters were mapped in to the GIS through various themes.

Analysis of Data

PCA analysis was done on the water quality data. Figure-2 shows a plot of the Eigen values (Scree Plot). I is clear that the data dimensionality is significantly reduced from 17 to about 5 or less.

Subsequent common factor analysis using varimax rotation produced factor loadings given in the table 1. The bold face prints in the figure show the comoponent loadings that are significant. Factor 1 is associated with rainfall. Factor two with soil constituent. Factor 4 is a weather factor. Facotr 5 is a turbidiy factor somehow related with rainfall. Factor 3 is not apparent as it appears related with pH water temperature and chloride.

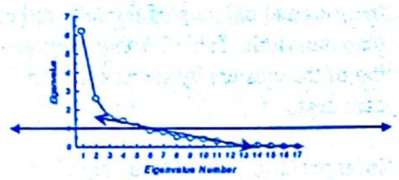

Fig. 2 Scree Plot

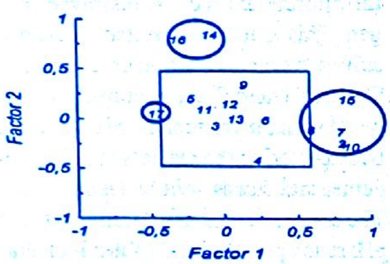

Fig. 3 factor loadings: factor 1-factor2

An example of factor loadings of variables is shown in the above figure. Factor analyses works on the premise that variables are explained in terms of common factors. As can be seen from the figure above, variables 1,2, 7, 8, 10 and 15 are explained in terms of higher loading on factor 1. These variables are respectively conductivity, TDS, Calcium, magnesium Alkalinity and Sodium. On the opposite side to these are variables 11 and 17 load negatively high on factor one. These are respectively, chloride and rain fall. Variables 16, 18 and 14 load higher on factor 2. These variables are Total solids, Potassium and suspended solids. The correlation of total solids with suspended solids is spurious as the latter is derived by calculation from the former. PH also load slightly high on factor 1.

Cluster Analysis of Lake Abaya Water Quality Data

The result of the hierarchical cluster analyses for the water quality data of lake Abaya is presented in figure 4. The variables included in the cluster analyses are : air pressure. Air temperature, water temperature, dissolved oxygen, TDS, conductivity, redox potential, and pH. 44 sampling points have been considered in the cluster analyses. The vertical dendrograms of the cluster agglomeration are presented in figure 5.

It is seen from the cluster agglomeration that, variables 1,2,5 and 6 are considered as homogenous. Their clustering may have been caused by temporary variability factors. On the other

Results after Varimax Rotation (Orthomax with Weight=1)							
	Factor1	Factor2	Factor3	Factor4	Factor5	Uniqueness	Commmality
X1(Conductivity)	**0,813**	-0,259	0,397	-0,074	-0,204	0,067	**0,933**
X2(TDS)	**0,803**	-0,248	**0,441**	-0,025	-0,174	0,069	**0,931**
X3(Redox Potential)	-0,058	-0,072	-0,375	-0,225	-0,002	**0,800**	0,200
X4(Dissolved Oxygen)	0,225	**-0,418**	-0,065	0,167	-0,087	**0,735**	0,265
X5 (Turbidity)	-0,225	0,201	0,059	-0,123	**0,943**	[redacted]	[redacted]
X6(pH)	0,281	-0,015	**0,557**	0,240	0,006	0,552	0,448
X7(Calcium)	**0,794**	-0,132	0,260	0,123	**-0,498**	0,022	**0,978**
X8(Magnesium)	**0,592**	-0,114	0,123	0,209	0,004	0,578	0,422
X9(Hardness)	0,139	0,339	0,258	-0,108	-0,052	**0,785**	0,215
X10(Alkalinity)	**0,865**	-0,285	0,343	0,121	-0,164	0,011	**0,989**
X11(Chloride)	-0,132	0,088	**-0,666**	-0,054	-0,010	0,528	0,472
X12(Water Temperature)	0,040	0,144	**0,466**	**0,765**	-0,093	0,167	**0,833**
X13(Air Temperature)	0,081	-0,005	0,126	**0,948**	-0,070	0,074	**0,926**
X14 (Potassium)	-0,088	**0,840**	-0,096	0,267	0,048	0,204	**0,796**
X15 (Sodium)	**0,841**	0,190	0,187	0,087	0,003	0,215	**0,785**
X16 (Total Solids)	-0,307	**0,788**	-0,207	0,183	0,328	0,100	**0,900**
X17 (Rain fall)	**-0,465**	0,045	0,161	0,081	0,048	**0,747**	0,253
Proportion	0,252	0,116	0,110	0,109	0,081		
Cumulative Proportion	0,252	0,368	0,478	0,587	0,667		

Table 1

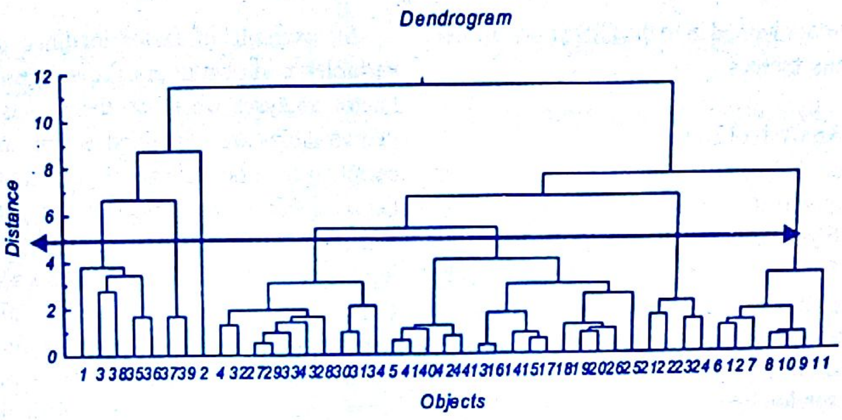

Fig. 5 Vertical Dendrogram of Sample Clusters

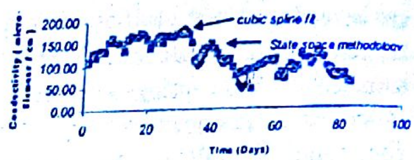

Fig.7 Comparison of cubic spline with state space methodolgy for missing data

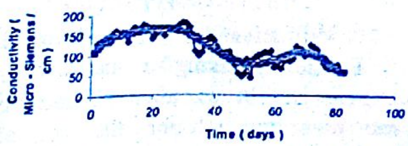

Fig. 8 Trend curve fit to the conductivity data (7 degree polynomial)

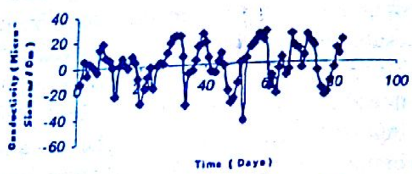

Fig. 9 Detrended plot of the conductivity data

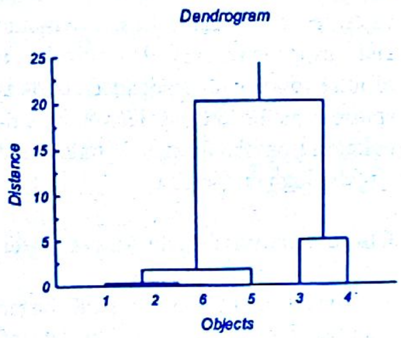

Fig. 4 Vertical Dendrogram of Variable Clusters

hand variables 3 and 4 (TDS and conductivity) are clustered together and separate from the others. This may have been due to the fact that these variables measure long term effects of water quality. However, the higher cluster distance of 5 between these variables (3 and 4) is unexpected as the two variables measure more or less the same thing. It may point to errors in the instrumentation used to measure these variables.

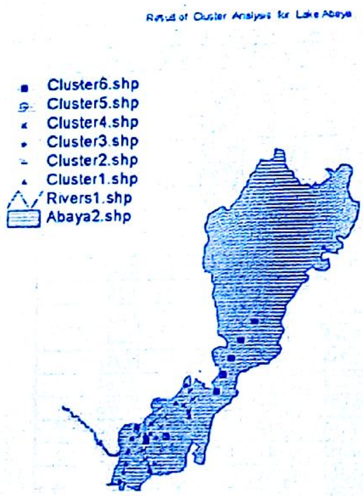

Figure 6 Cluster Analysis

The figure 6 shows the layout view of the Cluster Analysis Results when superimposed on the Lake view. The analysis have been done on a GIS arc view software. It is clear from the graph that the cluster variation occurs along the longitudinal axis of the lake rather than the width. Table 2 shows regrouping of the clusters by statistical significant tests.

Interpretation of Reclustering of Lake Area

The one variable that varied across the clusters the most is dissolved oxygen. This is to be expected as the dissolved oxygen is a dynamic variable. Clusters 1 and 3 are grouped together by all variables except the pH. This is to be expected as the clusters are close together and can as well be taken as one. The next most dynamic variables are the pH, redox potential and Water Temperature. Conductivity was found to be the least dynamic of all. All the clusters belong to one group and it appears that there is little variation in conductivity across the lake.

Time Series Analysis of River Water Quality Data

The state – space methodology was tried to fill in the missing data. The figure 7 shows the comparison of the conductivity data one graph corresponding to data filled with a cubic spline and another one with the state – space methodology. As can be seen clearly in the figure, the cubic spline gives a wide fluctuation while the state-space fit is follows the curve closely. It appears that the state space methodology is the preferred method for filling the missing data.

Since the data shows a discernable trend over the time of sampling a polynomial was fitted to get rid of the long-term trend as shown in figure 8 the conductivity data.

Figure 9 shows the detrended plot of the conductiity data which is more or less sationary.

The spectral density plots of TDS and conductivity data are presented below. The peak values occur at around 0.06 and 0.12 cycles per day. These cor-

Variable	Group1 Cluster	Group2 Cluster	Group3 Cluster	Group4 Cluster
Dissolved Oxygen	1,3	4	6	5
PH	1	3,4,5	6	
Redox Potential	1,3,5,	4	6	
Water temperature	1,3,6	4	5	
TDS	1,3,4,6	5		
Conductivity	1,3,4,5,6			

Table 2 Regrouping of the Clusters by Statistical Tests

respond to sampling frequencies of 16 days and 8 days respectively. Since the Sampling frequency is twice this value sampling over 4-8 days is likey to detect the peak vales. The estimate of TDS from conductivity using spectral level regression is also shown in figure 10.

Similar analysis done on the periodic data of total solids and rain fall produced figure 11. It is seen that the periodic variation in total solids can be explained mainly in terms of rain fall data.

Application of the state-space model for predicting the water quality of Kulfo river from Hare river using variance ratios is shown in figure 12. As can be seen from the graph the modl predicts adequately the data. The variance ratio between the two rivers is held constant for the prediction. This analysis can be extended for all the rivers that drain within the Abaya – Chamo basin.

Conclusion

Principal component and Common factor analyses were applied to identify underlying factors for the water quality variables. The results revealed that 47 % of the data variation could be explained in terms of two factors and 62 % of the data variation in terms of 5 factors. With a 5 factor analyses several variables were shown to show high correlation with the first principal factor. These variables are Total Dissolved Solids, Conductivity, Calcium, Magnesium, Alkalinity and Sodium. On the same factor rain fall was shown to be also some what correlated with negative loading. This factor is believed to be the dilution factor due to rainfall. Potassium and total solids were correlated with the second independent factor. This factor could be more related to the soil constituent and erosion. PH and Chloride were correlated with a third factor, while water and air temperature were identified with a 4th factor. Dissolved oxygen, redox potential, and hardness share little in common with other factors as well as turbidity. This is not expected and, therefore, the data shall be checked for possible errors. Plotting the factor scores against the common factors showed several outliers which when checked against the data values appeared to have been caused by errors.

The lake water quality data consisting of six variables were analyzed with the help of a cluster analyses. It was found out that two variables, conductivity and TDS for a cluster group through in which there was little variation across the lake area. There was a significant variation in dissolved oxygen across the lake sampling points followed by pH, water temperature and redox potential. The result overall suggest that the lake water quality is dynamic and shows spatial as well as timely variation. This result has an implication on the extent of monitoring of the lake water quality.

Time trend analysis revealed that for variables belonging to the respective principal components the time trend as well as the periodic relationship was strong. The sampling interval for these set of variables was more or less the same. Examination of the spectral density curve of the set of variables revealed that they are more or less similar in shape and position with respect to time (no time lag). These curves were shown to be coinciding with the spectra of the rainfall.

The water quality time series data relationship between rivers Hare and Kulfo was modeled using spectral level regression, time domain regression using ARIMA models and the state space methodology. Due to the proximity of the two rivers and similarity more or less of the catchment characteristics both the trend component as well as the periodic component of the water quality data of these two rivers displays strong relationship. The time trend portion was modeled adequately by a polynomial regression. The periodic relationship was modeled preferably using spectral level regression. By far better relationship

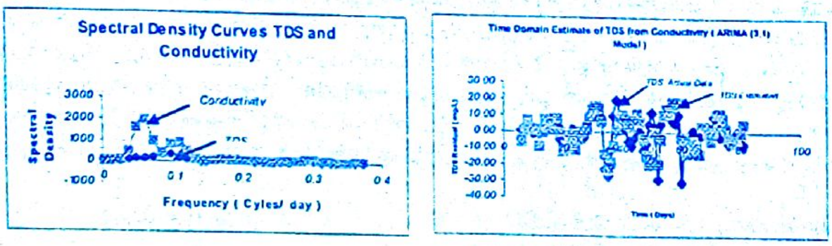

Figure 10

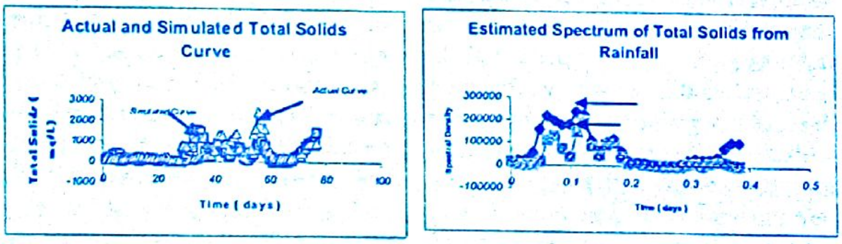

Figure 11

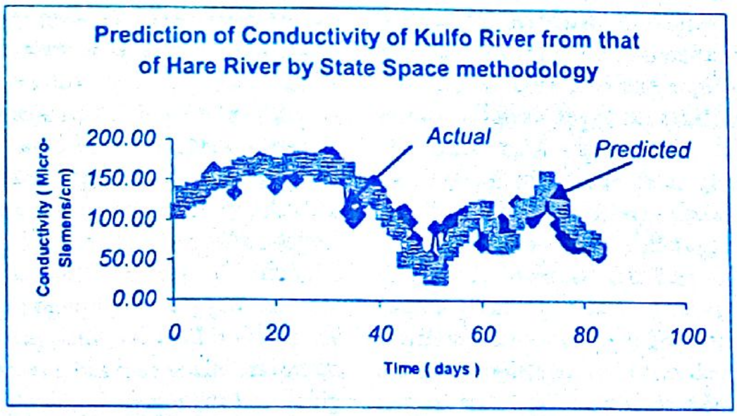

Figure 12

between the water qualities of these two rivers was obtained with the state space modeling. It is recommended that the time variable dynamic state space methodology be extended to the rivers existing in the Abaya-Chamo basin so that cost-effective modeling of the river water quality and prediction can be accomplished using this state-space methodology specifically developed.

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Watershed Thinking in Natural Resources Conservation for Sustainable Land-Use: - Constraints Associated with Planning and Technical Backstopping

Eylachew Zewdie, PhD; Researcher; Ethiopian Agricultural Research Organization; National Soil Research Center; P.O.Box 147, Addis Ababa

Abstract

The nation is becoming increasingly worried about the current soil and water conservation method that is not effective in terms of achieving sustainable and productive land-use. The conflict between the current soil and water conservation technologies and the people's desires has to be studied carefully. Unfortunately, at policy level, no strong association between soil and water conservation and other development activities has been realized in the past. Successful natural resource (soil and water) conservation in watershed does not encourage for a detailed master plan at the initial period. The pure techno-bureaucratic land-use planning approach can work only if the watershed is considered as a reference framework. One-sided treatment, for example soil and water conservation only, cannot serve as a means for sustainable land-use and must follow a holistic approach (integrated approach). The farm household must be encourage to focus on soil and water conservation program since communal action at local level is an important entry point for watershed management under Ethiopian condition. Lack of secure land tenure was a major cause of low interest of farmer in environmental conservation. Improving tenure security may be the main intervention needed for farmers to adopt reasonable watershed management technologies. The top-down approach in soil and water conservation planning has resulted into failure in soil and water conservation. In most of watershed/catchments the soil and water management did not address farmers' need and farmers were not willing to adopt technologies.

Introduction

In Ethiopia, the nation is becoming increasingly concerned about the current soil and water conservation approach that is not effective in terms of achieving sustainable and productive land-use. There were also efforts to develop organizations at different levels to arrest the soil erosion and harvest water to create stabile eco-system. During the last thirty years researches were conducted on different soil and water conservation methods and based on findings recommendations were made. However, most of the recommended practices were not adopted by the farmers and become part of the land-use or land management. Thus, in many places of the country where population growth is high land degradation has continued and currently the rate has reached at alarming stage. In this regard the degradation in northern part of Ethiopia, where topography is rugged and reserves of agricultural land is extremely low or absent, has reached its maximum and in some area croplands are going out of production. CFSCDD/ERCS (1986) identified that environmental (soil, water and climate change) degradation, overgrazing and back warded non-conservation based resources utilization are caused of famine and disaster that has lead to weak socio-economic structure and low agricultural productivity. The situation has been even worst in area where there is a lack of administrative structures dealing with these problems. The few activities carried out in the country were not well coordinated.

To achieve meaningful impact from agriculture and conserve the natural resources for sustainable use it may be necessary to get out of the current soil and water conservation approaches and try to handle resources (soil, water, vegetation etc.) conservation around the rim of watershed or catchments thinking, which can allow us to see the farming systems from different viewpoints with especial emphasis on resources management. The points, which we must look in either direction, are the people's attitude and demands, natural set-up in relation to calamities and the available indigenous catchments management technologies. Thus, the objectives of this paper are to indicate some of the major constraints associated with planning that were found to be the causes for the failure of watershed management and technical backstopping that lead to rejection of the approach in the past.

People's Attitude and Demands

The conflict between the current natural resources (soil, water, vegetation, etc.) conservation technologies and the people's needs has to be studied carefully. In number of occasions the conflicts developed as a result of low resources potential and severe socioeconomic problems. Under these conditions even if the technology were appropriate to the eco-system it would be difficult to implement and demands the allocation of high external inputs to motivate farmers. In the past introduction of material assistance in form of food for work in soil and water conservation activities was considered to serve as motivation and means of curbing down the socioeconomic problems.

But created dependence of farming population on the government and reduce the search of other alternatives.

In the past under forcefully imposed farmers' cooperative system farmers were dissatisfied with land ownership and, therefore, were not motivated to involve in activities that conserve natural resources and increase production. They were complaining that all soil and water conservation methods are not profitable or physically impossible and questioned also the ownership right of plantation forest. This was because farmers do have their own subsistencially understandable priority and feel that natural resources (soil, water, vegetation etc) conservation is not their activity. Therefore, they gave small marginal to activities related to resources conservation and aversion of risk. This was due to lack of knowledge about the cause and importance of land degradation. On the other hand the blue print project operation calendar (operation rule book) that was worked by techno-bureaucrat did not allow the integration of farmers' needs. Moreover, most of conservation project gave little attention to farmers' education and explain the problems related with degradation. The technologies introduced were not giving also higher production, i.e. over 50%. The 10% yield increment did not persuade the farmers to commit themselves in soil and water conservation program.

The extension system of the country was giving more attention to cropland and less to the grazing, forest and bush lands. Thus, for long period the eco-system under pastoral communities (range and bush lands) or grazing land in mixed farming was degraded easily and even in some area it has reached at irreversible situation. Extension was not conducting resources conservation as a necessary prerequisite for agricultural improvement. Thus, in the past conservation campaign were conducted in isolation and mostly done on the basis of a prohibition policy. The condition is more aggravated by the lack of clear and appropriate land-use policy. Unfortunately, at policy level, no strong linkage between soil conservation and other development activities has been realized in the past. The dynamic and threatening nature of natural resource degradation was also found to be obstacle to create government awareness. Thus, government considers it as catastrophic event and does not take it as long-term uses

Natural Set-Up and Calamities

The country has rugged topography with diverse climatic zones. These conditions have caused different forms of environmental degradation that are considered to be the causes of drought in the area. Engida (2002) indicated that conditions such as climate change and variability, method of cultivation, deforestation and livestock density and grazing patterns were found to be the root causes of environmental degradation. The recent data indicted that agricultural drought started in 1900 in the country and reached its climax in 1971-75. The 1971-75 droughts in the northern part of the country have affected 100,000 people in Wollo. During the same period about 80% of the cattle, 50% of sheep and 30% of the goats of the area were perished. The frequency of drought is between 15-40% and has very close relationship with the stages of environmental degradation. The environmental degradation due to soil-water and ground cover loss is increasing yearly and it looks that it does not have any boundary unless serious consideration is given at the national level. The current drought that affected 14 million people is also the reflection of resources (soil and water) degradation.

Catchments Management

A successful project on natural resource conservation in watershed does not advocate for a detailed master plan at the initial period. But, requires only clearly identification of each catchment within the watershed. Watershed management plan must be an output of farmers' based participatory rather than a blue print manual of the project funding organization or the government. To reach on the final working document it requires a sequence of planning-implementation-planning loops in the presence of concerned farmers, who are target group. The activities in the watershed should not be delivery system with pre-fixed targets and achievements must not be measured in terms of monitory gains. Donor agencies or government must be in the position to monitor if planned activities brought social change rather than squeezing activities in the convenient phasing of formal government's office activities. If government is involved actively in the watershed management project departmental approach should be avoided for the fact that it reduce people's participation to little more than a symbolic action. In the development and implementation of activities care must be taken to avoid the difference between rich and poor farmers. Rich farmers are always active to utilize new intervention faster than resource poor farmers and this is dangerous because it could change the watershed development to narrow target group. Moreover, this situation can be more awful if the pure techno-bureaucratic land-use planning approach, which refute the farmers the access to formerly used resource, is adopted. For example Celander, T. and Kassaw Aragaw (1984) and CFSCDD (1988) recommended the reduction of grazing land, increasing the forest cover while retaining the same scale of cultivated land area. But this was not acceptable by the farming communities. Such pure techno-bureaucratic land-use planning approach can work only if the watershed is considered as a reference framework. On all activities of the watershed conservation wise utilization and access to the use of natural resources must remain open. Otherwise the planned watershed management will be affected. The above options were not strictly followed. Thus, the efforts were not successful in most parts of Ethiopia.

The design of watershed management is based on its' potential and limitations. Thus, its' identification, which indicate productivity, equity and sustainability, will be the most important component. One-sided treatment, for example soil and water conservation only, cannot serve as a means for sustainable land-use and must follow a holistic approach (integrated approach). Otherwise it creates conflict between people and project objectives like it happened in most places of Ethiopia.

Soil and water conservation was

taken as a single means to combat resources degradation without considering important issues. The followings are the most important points to be well thought-out: -

The farm household must be encourage to focus on soil and water conservation program since communal action at local level is an important entry point for watershed management under Ethiopian condition.

Farmers cannot ignore the short-term benefits of the land use decisions they make. Only those production strategies that will provide a reasonable return on the labour and other resources have a chance to be adopted. Farmers do not accept watershed management strategies or technologies that do not meet this criterion.

Lack of secure land tenure was a major cause of low interest of farmer in environmental conservation. Improving tenure security may be the main intervention needed for farmers to adopt reasonable watershed management technologies.

Watershed/catchments management programs have often led to 'pseudo-adoption' if strong political pressure, subsidies or other government incentives were used to support adoption of practices.

For farmers loss of soil productivity is often much more important than the loss of the soil itself, since it causes yield reduction. Thus, introduced technologies must solve this problem.

In upland systems, plant yields are reduced more by a shortage or excess of soil moisture or nutrients rather than by soil losses *per se*. Therefore, there should be more emphasis on *rainwater management*, particularly water conservation, and *integrated nutrient management* and less on soil conservation per se. For farmers agronomic process that maintain infiltration rates are more useful than mechanical measures blocking the path of water flowing at the soil surface in preventing erosion and runoff.

Erosion is a consequence of how land and vegetation are managed, and is not itself the cause of soil degradation. Therefore prevention of land degradation is more important than attempting to develop a cure afterwards.

Erosion is a top-down process, because gravity determines the direction of water flow. Soil conservation programs focused more on land degradation than on the land use, and used a top-down approach in 'dissemination' and 'extension' of 'best-bet' practices that were considered to be applicable for a wide range of farm situations. Top down programs tend to focus primarily on the symptoms of erosion through subsidised terracing, promotion of hedgerow intercropping systems or other measures which have had mixed success when introduced by outside agencies.

Soil conservation programs that aim to reduce land degradation problems through treatment of causes, require *a long term, bottom-up approach* supporting farmers who generally have detailed knowledge of their farm, know a wide range of potential interventions (although they can still learn new ideas from experiences elsewhere) and choose between these interventions on the basis of the resources and pressures on the farm household

Lesson Learnt

During the last two decades there were a lot of efforts to reduce soil and water loss and integrate conservation in different farming systems. However, all these efforts were not in the position to overcome shortage of food crop and fodder. Currently, the integration of fodder crops in Ethiopian farming systems is not considered. The activity of pasture development is extremely low. The conflict between non-profitable interventions (land capability classification for soil and water conservation) and people's need is not resolved at all and the socioeconomic problem is becoming more severe. The ecological degradation is advancing. The motivation and support approach is leading the farming communities dependant on the government. The top-down approach in project planning has resulted into failure in soil and water conservation. Some of the causes for the failure are given below.

In most of watershed/catchments the soil and water management did not address farmers' need. Thus farmers were not willing to adopt technologies.

Introduced technologies were not attractive and do not bring significant yield increments.

The technologies used in conservation are not indigenous and not supported by training. Thus, farmers have difficulty in adoption. Indigenous knowledge was not considered as solution to problems and the focus was only on introduced once.

Most of the physical and biological treatments were interfering with the interest of the farmers. For example physical major reduces cultivable area and biological major harbors pest.

The treatment does not cover the whole part of the watershed/catchments, so that it has negative effect on down slope area. Some time the treatment on upper slope could also cause strong gully erosion within and outside the area.

Putting treated area as area closure reduces the grazing area. Thus, farmers reject technologies without compromising. This activity increase pressure on the adjacent open lands, which can cause accelerated erosion. This has been observed in several locations.

Forage (grass land) development is not considered at all. But, there was introduction of legumes and legumes fodder trees. However, these materials were not used as a result of knowledge gap.

The plans were not worked out by the target society and were top-down command. They do not include the needs of the farmers in watershed/catchments.

There was a weakness in the long-term monitoring and evaluation of the activities and the change in attitude.

Conclusion and Recomendation

Watershed based natural resource conservation for sustainable land-use was found to be successful approach in various parts of the world. In our country even if the approach was introduced recently the outcomes for the few activities was not attractive to the farming communities. The source of the failure in most places was the planning steps and planning approach. To be successful in watershed management it requires an integrated planning approach consisting two different groups, i.e. the government exports and the target group. Under this situation the government experts can present the draft proposal and forward it to the target group for discussion. But after the discussion the needs of the client must be integrated. As much as possible experts should try to base their activities on indigenous knowledge.

The current catchments treatments in this country gave emphasis only for soil and water conservation, which is based on land capacity classification, and does not take care of the needs of the farmers. It would be also difficult for the farmers to accept the capacity classification for the fact that it reduces crop production area and creates pressure on the remaining. In most case such undertaking will not also give a due attention to the development of grazing land and this is important particularly in mixed farming.

Training of farmers on the concept and importance of watershed management was not given consideration in the past and this has contributed to failure. Thus, in the near future training of farmers must be prerequisite before initiation of watershed/catchments management for sustainable land-use.

Currently all watershed/ catchments management or soil and water conservation projects are being strongly supported by food for work in order to motivate the farming population. But, this has changed the attitude of farming communities and created dependence on the government. Thus, the approach, food for work, has to be changed to other forms such as agricultural inputs (fertilizer, herbicides, insecticides etc.).

Exotic grasses or trees are being used to stabilize soil bunds. These materials do not have any role in increasing food production of the area or immediate monitory returns to the farming communities. Thus, most of the time they are not welling to accept biological conservation. In Ethiopia in every agroecological zone there are number of fruit trees that could be used in the conservation projects. Projects must be encouraged to use them.

In the traditional Ethiopian farming systems there is no grassland development and, thus, cattle are allowed to graze on bottomlands where there is water logging problem or degraded uplands. The increase in population has forced the community to use bottomlands for crop production. Therefore, in watershed management the development of pasture or grazing land must be given a due consideration. Otherwise, it will be difficult for the community to accept the technologies.

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Evaluation of the Performance of Furrow Irrigation System in the Middle Awash Valley

Kassa Tadele, AWTI, P.O. Box 21, Arba Minch

Abstract

Knowledge of the performance of existing irrigation methods can help in improving the design and management of the system, and could give information for the design of new similar irrigation systems.This Paper describes the performance of furrow irrigation system on some performance indices: application efficiency, storage efficiency, distribution uniformity, and uniformity coefficient with other irrigation water loss indicators viz., deep percolation and run-off fractions which were determined using a computer program, FURDEV.Field parameters and variables were either determined (measured) or estimated for the fields, which were considered to be representative of the irrigated farms at the study area.The response of each dependent irrigation parameter to variations in inlet flow rates has been evaluated. It was found that the maximum possible attainable application efficiency with the present practices was 63% for furrow irrigation system. Irrigation water loss due to deep percolation and run-off was considered to be the cause for the minimum application efficiency The results of this study indicated that the design and management of furrow irrigation system in the Middle Awash Valley should be reconsidered and methods of improvement must be devised.

Introduction

Modern irrigation in Ethiopia was started at the beginning of the 1960's by private investors in the Middle Awash Valley, which currently comprises about 48 % of the total irrigated area of the country (FAO, 1995).

The ever growing demand for water among competing societal activities has put undue pressure on the resource base to the point that the need for sagacious use of water became global concern (Zerihun and Feyen, 1995).

The mission of increasing agricultural productivity to sustain food requirements of rapidly increasing populations could be facilitated through the management of water and land resources. Realistically, the cost of developing irrigation technology is often prohibitive in the less endowed countries where more food is painfully needed (Perrier and Salkini, 1987).

Irrigation technology has advanced significantly during the past two decades, but many existing projects and on-farm irrigation systems have not been improved significantly for decades. However, one of the first priorities in agriculture today is the development of irrigation design that are more efficient in the use of both water and energy resources for the varieties of crops and farming practices (Jaynes, 1989).

FAO (1995) pointed out that the efficiency of surface irrigation systems was low. Only 40% to 60% of the water is effectively used by the crop, the reminder of the water is lost in the system, in the farm and on the field, either through evaporation, through run-off or by percolation into the ground water. Brut and Styles (1999) indicated that the annual project efficiencies of irrigation systems of some selected 16 countries ranges from 13 % (Saldana in Colombia) to 99 % (Tadla in Morocco). Similarly, Tessema (1986) also assessed that over all efficiency of state farms in the Middle Awash was about 40 %, and particularly that of Melka Werer state farm was 42 %.

On the other hand, application of irrigation water beyond the crop need has contributed to the rise of ground water table to the effective plant root zone. On some farms of the Middle Awash, about 30 % of the area has gone out of production due to accumulation of excess salts on the surface caused by the rise of ground water table (Geremew and Fantaw, 1994).

Theoretically, however, farm irrigation systems are designed and operated to supply the individual irrigation requirements of each field on the farm while controlling deep percolation, run-off, evaporation and operational losses (Hart et al., 1983). Beside this, the objective of any water application is to uniformly replenish the root zone moisture with enough percolation for the effective leaching of harmful salts (Perrier and Salkini, 1987).

Zerihun and Feyen (1995) argued that the performance of furrow irrigation scenario (event) can be evaluated from three distinct but complementary perspectives: efficiency, adequacy and uniformity.

Generally, the basic objectives of evaluation of surface irrigation performance is to identify the types and magnitude of losses that are occurring, and then devise ways and means to improve the system and/or its operation (Merriam et al., 1983).

Field evaluation of all possible combinations of factors affecting performance of surface irrigation would be virtually impossible and hence the development and application of computer simulation models in irrigation have a great role to play. But the development of software for the specific utilization of computer models in irrigation systems has been moving very slowly compared to other sectors (Burt and Styles, 1999).

Recent advances in the theoretical description and model simulation of surface irrigation permit the evaluation of existing procedures and development of new and improved procedures for the design, management and evaluation of surface irrigation systems (Basset et al., 1983).

Over the last 20 years or so, various detailed simulation models have been developed, some of which have now come to a stage where they can be called user-friendly computer programs. The FURDEV program is one of them, (FURDEV stands for FURrow irrigation Design, operation and Evaluation), (Jurriens et al., 2000).

There is hardly any information on evaluation studies conducted on furrow irrigation methods at Melka Werer irrigated farms, which is the area selected for this study. The only information available is for the design and operation of furrow irrigation systems for cotton crops that can be used only on a tentative basis (Kandiah, 1983).

Therefore, information on the performance of surface irrigation methods in the Middle Awash, namely, furrow, border, and basin irrigation for wheat, sesame, and maize crops respectively, is of a paramount importance for improving the existing irrigation systems and assist in designing other systems.

The objective of this study is thus to evaluate the performance of furrow irrigation system at Melka Werer and asses methods of improvement.

Design, Management and Evaluation of furrow Irrigation System

The design of furrow irrigation system first involves assessing the general topographic conditions, soils, crops, farming practices anticipated and farm operators desires and finance for the field or farm in question (Bishop et al., 1987).

Design can be viewed as the process of making decisions concerning the values of flow rate (Q_o), length of channel (L), and time of cutoff (t_{co}), prior to the onset of every irrigation season and during the project development phase (Zerihun and Feyen, 1995).

The on-farm irrigation systems and operations need to be measured to determine the potential efficiency of the systems as designed and the actual efficiency that is obtained with present management (Merriam et al., 1983).

Irrigation water management is defined by the US Soil conservation Service (USDA, 1974) as "the use and management of irrigation water, where the quantity is determined by the water holding capacity of the soil, and the need of the crop, and where the water is applied at a rate and in such a manner that the crop can use it efficiently and significant erosion does not occur". Burt and Styles (1999) indicate that crop yields are definitely tied to field water management, and field water management is related to the quality of water provided.

Evaluation on the other hand, deals with the analysis, estimation of performance as well as advance and recession of existing situation given the values of the system variables and parameters. It involves measurement at one or more points in a field selected to be typical or representative locations. Value judgments or additional measurements must be made to correlate these data to an overall field, farm or project efficiency (Zerihun and Feyen, 1995).

For evaluating the design of surface irrigation systems, irrigation efficiency can be adequately characterized by the application and requirement coefficient. Several researchers, notably Hart and Heerman (1976), and Karmeli et al. (1978) have investigated the correlation between these parameters for numerous different sets of data. The merits of a design or management scenario can be judged in terms of either direct economic returns, such as profit, gross benefit, cost or using certain efficiency indices (application efficiency, uniformity of irrigation water application and adequacy of applied irrigation water).

Zerihun and Feyen (1995) summarized that the performance of furrow irrigation system is dependent on three sets of variables: design, management, and field variables (system parameters) which are shown in the following functional relationship.

$$P = f(I, S_o, n, Z_r, G, q_o, L, t_{co}) \ldots\ldots\ldots\ldots\ldots (1)$$

where

P = performance of surface irrigation

I = symbolizes the infiltration parameters

S_o = channel bed slope

n = hydraulic resistance

G = symbolizes furrow geometry parameters

Z_r = required amount of application

q_o = unit flow rate at the head end of the channel

t_{co} = time of cut off

L = furrow length

Design, Management, and Evaluation Criterion

Farm irrigation systems are designed and operated to supply the individual irrigation requirements of each field on the farm while controlling deep percolation, run off, evaporation and operational losses (James, 1988).

The basic objective of evaluation is to identify the types and magnitude of losses that are occurring, and then determine how to improve the system and /or its operation. The irrigation condition can be evaluated by determining certain ratios or efficiencies (Merriam et al., 1983).

Zerihun and Feyen (1995) indicated that the performance of a surface irrigation event can be evaluated from three distinct but complementary perspectives.

(1) *Excess application* of irrigation water, though unavoidable in real life situation must be minimized (minimum loss). Application efficiency (E_a), is the index which is used as a measure of how effective an irrigation is in minimizing unavoidable losses.

(2) *Adequacy of irrigation*, evaluated in terms of a perceived requirement is necessary to sustain normal crop growth and result in satisfactory yield. Water storage efficiency (E_s) uses how close the applied amount is to the perceived requirement.

(3) *Uniform (even)* application of irrigated water over the entire subject area not only enhances productive use of available water by spreading deficit, if any, over the subject area but also helps minimize losses. Distribution uniformity (DU) and Christiansen's uniformity coefficient (UC) are the most commonly used indices in surface irrigation application.

Moreover, deep percolation and run-off losses are vital in constraining as well as guiding operational decision making processes. It nonetheless is appropriate to threat them as performance term as per se (Karmeli et al., 1978; Zerihun and Feyen, 1995).

Water application efficiency

Water application efficiency for an irrigated area (E_a) is the ratio, expressed in percent, of the volume of beneficially used by the crop to the volume of water delivered to the area (Zerihun and Feyen, 1995).

The expression for E_a can be given as follows:

$$Ea = \frac{\left[\int_0^L Zdx - \int_0^{L_{ov}} Zdx + ZL_{ov}\right]}{\int_0^{t_{co}} Q_o dt} \times 100. \quad \text{.............(2)}$$

Where

Z = amount infiltrated ($m^3.m^{-1}$)

L = channel length (m)

Q_{oi} = inlet flow rate during time interval period t_i

L_{ov} = length of that part of the channel that received an amount of water equal to or in excess of the perceived requirements (m)

t_{co} = cut-off time (min)

Water storage efficiency

Water storage efficiency (Es), is the amount of water actually stored in the subject area expressed as a percentage of the volume of water that can be stored (Walker and Skogerboe, 1987; Zerihun and Feyen, 1995).

The general form of the Es equation is given as follows.

$$ES = \frac{\int_0^L Zdx - \int_0^{L_{ov}} Zdx + Z_r L_{ov}}{Z_r} \times 100 \quad \text{..........(3)}$$

Where

Z = amount infiltrated ($m^3.m^{-1}$)

L = channel length (m)

L_{ov} = length of that part of the channel that received an amount of water equal to or in excess of the perceived requirements (m)

Z_r = required amount of application (perceived requirements) ($m^3.m^{-1}$)

Irrigation uniformity

Uniformity of infiltration under surface irrigation depends on the spatial and temporal variability of surface and sub-surface hydraulic characteristics such as field slope, furrow geometry, surface roughness, field length, flow rate and soil pore size distribution (Sirjani and Wallender, 1989).

Two parameters are used to evaluate distribution uniformity. The first parameter is ***distribution uniformity coefficient*** DU, and is defined as the ratio of the minimum infiltrated amount expressed as percentage of the average infiltrated amount over the subject area

A general expression for DU is

$$DU = \frac{Z_{min}}{Z_{av}} 100 \quad \text{....................................(4)}$$

Where

Z_{min} = minimum infiltrated amount over the length of the run of the subject area ($m^3.m^{-1}$).

Z_{av} = average infiltrated amount over the length of the run of the subject area ($m^3.m^{-1}$) and

Z_{av} is expressed as, $Z_{av} = \frac{\int_o^{Lov} Zdx}{L}$

The second parameter is ***Christansen 's uniformity coefficient***, (UC), defined by Chistansen (1942), as the ratio of the difference between the average amount applied and the average deviation from the average amount applied to the average amount applied. It is given by the equation:

$$UCC = \left[1 - \frac{\sum_{i=1}^{N} \left|Z_i - Z_{av}\right|}{Z_{av} N}\right] \times 100 \quad \text{..............(5)}$$

Where

Z_i = infiltrated amount at point i ($m^3.m^{-1}$)

N = number of points used in the computation of UCC

Zerihun and Feyen (1995) indicated that application efficiency, though indirectly, is a measure of the total irrigation water losses. Thus, indices used to quantify losses can not be used as performance parameters per se, as this would mean double accounting. Nevertheless, information on both the relative proportion of surface run- off volume to that of deep percolation volume as well as the magnitude of the individual quantities are important from the view point of constraining and guiding design and management decisions.

Deep percolation fraction

Karmeli et al. (1978) defined deep percolation (Df) as the ratio of the volume of water percolated below the bottom boundary of the subject area to the volume admitted in to the subject area. This can be expressed as: .

$$Rf = \frac{\int_{t_a(L)}^{t_r(L)} Q_L(t)dt}{\sum_{i=o}^{I} Q_{oi} \Delta t_i} \times 100 \quad \text{.................(6)}$$

Run-off fraction

Run-off fraction (R_f) is a measure of the relative proportion of the losses attributed to run off to that of the total volume of water delivered to the head end of the subject area (Walker and Skogeboe, 1987), and given by

$$Rf = \frac{\int_{t_a(L)}^{t_r(L)} Q_L(t)dt}{\sum_{i=o}^{I} Q_{oi} \Delta t_i} \times 100 \quad \text{———(7)}$$

Where

$t_r(L)$ and $t_a(L)$ = rescission time and advance time at down stream end of the channel (m)

$Q_L(t)$ = time dependent run off rate function at down-stream end ($m^3.min^{-1}$)

Surface Irrigation Models

Changes in the dependent surface irrigation parameters induced by variation in the variables can be evaluated through one or more of the following two methods: (1) Using field experiments and (2) Using simulation models. However, the prohibitive cost and overwhelming practical difficulty associated with the first method makes the second, i.e., simulation models, the only feasible option (Zerihun et al., 1996).

A description of surface irrigation hydraulics provides a useful, even necessary, framework for mechanics (models) that can tell us quickly, reliably and economically where irrigation water will go under a given condition. All mathematical models of the surface irrigation process utilize the volume balance or continuity equation, and differ from one another primarily on the choice of motion equation (Basset et al., 1983).

Mathematical modeling of surface irrigation hydraulic processes has been the subject of many research works in the last three decades. The models vary in complexity and accuracy, rising from the complete hydrodynamic, zero-inertia and kinematics wave models based on the numerical solution of the partial differential equations of mass and, in one or another form of, momentum conservation equation in open channel (Elliot and Walker., 1982), to the simplified models based on the algebraic solution of a spatially and temporally lumped mass conservation equation under the assumption of average flow depth and power law or exponential advance functions (Levien and Sauza, 1987).

The full hydrodynamic model was proposed by Basset and Fitzsimmons (1976) and uses mass and momentum conservation equations. The model is accurate over a wide range of conditions (wide slope, roughness, inflow rate and infiltration) but the computation is complex, expensive and delicate.

Eventually, the zero-inertia model which was proposed by Strelkoff and Katapodes (1977) for free draining irrigation which solves mass and momentum conservation equations parabolic rather than hyperbolic so that the equations are locally linearized which obviates the need for iteration solution. The model examines irrigation as a deforming control volume bounded by the field inlet or receding front at the left, the advancing tip or the end of the field at the right, the water surface profile at the top and the infiltration front at the bottom.

Further simplification could still be achieved with a concomitant narrowing of the scope of application. Such model include the kinematic-wave model which essentially is a normal realistic assumption under conditions in which the channel bed slope is high enough to dominate the flow. The volume balance model (Walker and Skogerboe, 1987) neglects the momentum equation in its entirety and replaces the dynamic behavior with gross assumptions in the mathematical sense.

Of all the four major classes of surface irrigation models, the zero-inertia model is the preferred choice (by modelers) for use in theoretical and practical studies. This is because of the considerable lower execution time it requires, compared with the complete model, while offering reasonable accurate results (Zerihun et al., 1996). Oweis, 1983 applied and verified the zero-inertia model for furrows.

FURDEV: A computer package for furrow irrigation

The design and operation of furrow irrigation system has continued to receive substantial attention in irrigation research, as evidenced by the literature of the later half of the twentieth century. For a long time, however, surface irrigation theories and practical guidelines have been rather simple and approximate.

It was until personal computers became more widely used that it became possible to simulate this process more adequately. The FURDEV program provides a set of user-friendly simulation programs for the design, operation, and evaluation of furrow irrigation system. (Jurriens et al., 2000).

The FURDEV model was first developed at the Institution for Land Water Management (ILWM) in Leuven, Belgium. It was modified and completed in a collaboration effort between International Institution for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands and ILWM, Leuven, Belgium. It is based on a variant of the Eulerian controllable-volume principle, and uses a simplified zero-inertia approach. As far as the advance phase is concerned FURDEV is based on a volume balance model. It uses the approach and techniques described by Walker (1989) and by Walker and Skogerboe (1987).

The FURDEV program was tested in numerous runs, after which the result were compared with those from the SRFR programs (Strelkoff, 1990) with the 1999 Windows version. This program was based on zero-inertia model and has been tested in field trials. For all practical purposes, the results appeared to be identical (Jurriens et al., 2000).

The design and management approach which governed the design of the structures of the FURDEV program was based on the notation that a design or a management scenario must be able to maximize E_a, given the system parameters, while maintaining the other two indices (E_s and Du) above a certain acceptable level. The program can be run in four calculation modes. Characteristics of the four modes are summarized in Table 1.

In all modes, the field parameters are given (i.e. infiltration, flow resistance, and required depth), as well as some specific parameters for furrows and borders. Decision variables such as the dimensions, the flow rate, and the cut-off time are input parameters when the purpose of the calculation (program) is for evaluation of surface irrigation systems.

Materials and Methods

Description of the study area

Location

This study was conducted in the Middle Awash Valley, namely at Werer Research Center (WRC) in the main and off seasons of 2000/2001. Werer Research Center is located 280 km east of Addis Ababa in the Afar National Regional State about 54 km from Awash railway station on Addis-Asab road.

Table 1 Calculation modes with their input and main output variables.

Calculation Modes	Given field parameters	Decision Variables		Performance indicators	Remark
		Input	Output		
		L, W	Q, Tco	Ea	$D_{min}=D_{req}$; Es=1
1	I, n, Dreq	Q	L, W, Tco	Ea	$D_{min}=D_{req}$; Es =1
2	I, n, Dreq	L, W, Q	Tco	Ea	$D_{min}=D_{req}$; Es =1
3	I, n, Dreq	L, W, Q, Tco	Q, Tco	Ea, Es, Du	Es<>1
4	I, n, Dreq	L, W		Ea	$D_{min}=D_{req}$; Es=1

I = infiltration characteristics; n=flow resistance; L=field length; Q = flow rate; D_{req} = required net application depth; W = field width; Tco = cut-off time; Ea = application efficiency; Es = storage efficiency; DU = distribution uniformity; D_{min} = minimum infiltrated depth.

The Altitude, Latitude and Longitude are about 750 m above mean seas level, 10^0 N and 40^0 E respectively. The annual potential evapotranspiration estimated for the Middle Awash area is 1922 mm, while the total annual rainfall recorded was as low as 564 mm. From this, the annual effective rainfall was calculated to be 246.3 mm (Appendix Table 1). This data reveals that crop evaporation greatly exceeds precipitation and the soil water balance would be compensated from irrigation for successful production of crops in the Middle Awash Valley.

Irrigation practices and crop production

The irrigation methods practiced in the study area are furrow, border, and basin irrigation systems, of which furrow irrigation has the greatest share. The source of water for irrigation in the study area is the Awash river whose flow is controlled at the Koka dam.

The potential crops that can perform well in the region are cotton, banana, groundnut, sesame, maize, citrus, tomato, papaya, onion, wheat, sweat potato and various forage crops. Until recent years, cotton was the most widely grown crop in the Middle Awash Valley that occupied most of the irrigated land. Despite adequate irrigation water throughout the year, crop growers in the Middle Awash region practiced mono-cropping by growing only cotton during the summer (May-Nov.). Taking into account the risk of mono-cropping, intensification of irrigated agriculture and nutrient depletion, double cropping is being initiated in the Middle Awash.

Soils

The predominant soil types in the Middle Awash Valley are brown alluvial Fluvisol (70%) and dark Vertisol (30%). The available water content for these soils ranges from 150 to 250 mm. m^{-1} (Haider, 1986). Hence, the values of the total available water taken for evaluation purposes are 220 mm m^{-1} for Vertisol and 175 mm m^{-1} for Fluvisol (Israelson and Hansen, 1962; FAO, 1974).

Methodology

The methodology used in this study involved the intensive utilization of the FURDEV computer program. The specific procedures followed to carry out this study consisted of field measurements to collect primary data, secondary data from research reports, assembling the data into the FURDEV program, analyzing and interpretation of the outputs, and reporting of the results.

The FURDEV program has four calculation modes (refer to Table 1), out of which calculation modes 1-3 are used for designing new irrigation systems, whereas, calculation mode 4 is used for evaluation of existing surface irrigation system Therefore, calculation mode 4 of the program was used to determine the performance of furrow irrigation system at the study area.

The outputs from FURDEV program are presented both in tabular and graphical forms. This includes: (1) performance indicators, application efficiency (E_a), surface run-off ratio (SRR), deep percolation ratio (DPR), and storage efficiency (E_s). Appearing also in this group are some indicators of the distribution of the infiltrated depths over the field length. Used for this purpose are distribution uniformity, DU and Christiansen's uniformity coefficient, CUC (2) Time parameters such as, advance time, depletion time, recession time, and infiltration opportunity time. (3) Information on the length and amount of under- and/or over irrigation. The FURDEV program computed the above performance indicators: E_a, E_s, Du, Uc, D_r and R_f according to equations 2, 3, 4, 5, 6, and 7 respectively.

To determine the linear relationships (associations) between input and output parameters, a correlation analysis was carried out. Moreover, the responses of the output parameters to changes in input parameters were estimated by employing regression analysis.

The program has two types of data inputs: field parameters and field decision variables. *Decision variables* can be manipulated by the user and are the heart of the programs. They include flow rate, the field dimensions and cut-off time. *Field parameters* can not be influenced by the user or the program; they are measured or assumed properties of the given situation. They primarily consist of the soil infiltration characteristics, the flow resistance, the required net application depth, and the field slopes (for borders and furrows). All decision variables and field parameters required by the programs have been put into the input data files of the programs for specific cases and conditions.

A representative location was identified in the field that was typical of conditions over the whole irrigated area. For the evaluation purpose, nine alternative but uniform 300 m long furrows were prepared with the required slope (0.001m/m) following the conventional tillage practice for the area, Fig. 1 of the Appendix. Since there was no standard furrow spacing for wheat already practiced for the study area, the nine furrows were divided into three sets having a furrow spacing of 70 cm, 80 cm and 90 cm, which have more or less a parabolic cross-section. Maximum widths and depth of flow were measured after germination and at flowering stages of the crop. Stakes were set along the test furrows at intervals of 25 m to determine the advance and recession times.

The soil of the field was alluvial soil having loam texture and estimated to have 162 mm/m available moisture (Haider, 1986). Wheat was grown on the furrows during the cooler season (Nov.-Feb.) of 2000. Data were collected at two growing stages of the crop, immediately after germination and during flowering. On farms that have land leveling problems, the use of lower application depths, less than 60 mm, is not advisable and rather higher water depths depending on soil type and crop growth phonology could be practiced (Geremew and Fantaw, 1994). Based on the root depth of wheat two water depths were applied during the two selected growth stages of the crop.

To determine the infiltration parameters of the soil, the method used by Elliot and Walker (1982) was adopted. Three adjacent furrows having a spacing of 80 cm were chosen for conducting the infiltration test and all the furrows received equal flow rates of 2.5 l/s. The length of run was restricted to 200 m. Times to advance to the half- and full-filed length of the furrow were recorded. Out-flow at the end of each furrow was measured volumetrically. The average values of the advance times to the half- and full-filed, and that of out-flow were used as data input of the FURDEV program which is capable of calculating infiltration parameters k, a and f_o internally using equations 22 and 23.

After calculating the maximum possible inlet flow rate for the given slope and soil type (Withers and Viopod, 1980, James, 1988), three flow rates namely 3.5 l/s, 2.5 l/s and 1.5 l/s were selected to include the possible ranges in stream sizes. Each one of these flow rates were turned into each furrow of the selected spacing that is measured at the inlet of each furrow with a combination of pre-calibrated siphon tubes which have inside dimeters of 6.8cm, 4.1cm and 2.4cm. Water advance time to each station along the furrows and recession times from each station were recorded.

The quantity of water applied during the two stages of the crop was based on refilling the root zone to field capacity. During the first test, the crop was at its seedling stage and the required water application depth was estimated to be 75 mm. Soil samples for the determination of Soil Moisture Deficiency (SMD) were taken using a soil auger before irrigation in 30 cm increment to a depth of 90 cm from three randomly selected locations. After determining the soil moisture gravimetrically, the average values of the respective depths of the three locations were used to calculate SMD and resulted in 32.0 mm, 21.3 mm, and 17.7 mm giving a total of 71.0 mm per meter depth. Since the estimated SMD was nearly equal to the Management Allowed Deficit (MAD), the time to irrigate was on the test day or the day after.

To determine SMD during the second test, the procedure used for the first test was followed. During the test the crop was at its flowering stage and the root depth of the crop was estimated to be 105 cm. Soil samples were taken in 30 cm increment to a depth of 120 cm from three randomly selected locations. SMD was found to be 43.0 mm, 32.5 mm, 11.5 mm and 6 mm at each depth increment giving a total of 92 mm per meter depth. For this soil, climate, and crop with an expanding root zone, p (fraction of TAW) may reasonably be 60%. Hence; D_r*(TAW * 60 %)= 100 mm. Since the estimated SMD was nearly equal to the MAD, the time to irrigate was on the test day or the day after.

Table 2. Summarized information of input parameters to the FURDEV program on wheat cultivated crop during the first irrigation period at Melka Werer Research Center

		FURROW SPACING								
		90 cm			80 cm			70 cm		
INPUT PARAMETERS	Units									
Flow rate	l/s	1.5	2.5	3.5	1.5	2.5	3.5	1.5	2.5	3.5
Length	m	300	300	300	300	300	300	300	300	300
Cut off time	min.	584	215	173	552	192	156	526	181	147
Required depth	mm	75	75	75	75	75	75	75	75	75
Flow resistance	-	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Furrow slope	m/m	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Furrow spacing	m	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
maximum velocity	m/min	13	13	13	13	13	13	13	13	13
Max. depth	m	0.15	0.15	0.15	0.12	0.12	0.12	0.08	0.08	0.08
Max. width	m	0.5	0.5	0.5	0.35	0.35	0.35	0.27	0.27	0.27
Trial flow rate	l/s	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Run off rate	l/s	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85
Adv. time (L)	min.	64	64	64	64	64	64	64	64	64
Adv. time (L/2)	min.	23	23	23	23	23	23	23	23	23
Trial length	m	200	200	200	200	200	200	200	200	200
Trial bed slope	m/m	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Table3. Summarized information of input parameters to the FURDEV program on wheat cultivated field during the second irrigation period at Melka Werer Research Center.

		FURROW SPACING								
		90 cm			80 cm			70 cm		
INPUT PARAMETERS	Units									
Flow rate	l/s	1.5	2.5	3.5	1.5	2.5	3.5	1.5	2.5	3.5
Length	m	300	300	300	300	300	300	300	300	300
Cut off time	min.	644	286	235	602	248	183	565	229	178
Required depth	mm	100	100	100	100	100.	100	100	100	100
Flow resistance	-	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Furrow slope	m/m	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Furrow spacing	m	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
maximum velocity	m/min	13	13	13	13	13	13	13	13	13
Max. depth	m	0.15	0.15	0.15	0.12	0.12	0.12	0.08	0.08	0.08
Max. width	m	0.5	0.5	0.5	0.35	0.35	0.35	0.27	0.27	0.27
Trial flow rate	l/s	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Run off rate	l/s	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85
Adv. time (L)	min.	64	64	64	64	64	64	64	64	64
Adv. time (L/2)	min.	23	23	23	23	23	23	23	23	23
Trial length	m	200	200	200	200	200	200	200	200	200
Trial bed slope	m/m	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Having found the intake rate of the soil, the cut-off times to produce least run-off during the two tests were determined for the two depths of application corresponding to the selected flow rates. The maximum flow velocity in furrows was estimated to be 13 m/min. for the given soil and the Manning's roughness coefficient, n, was taken as 0.04. The summary information of the inputs parameters to FURDEV program for the three furrow spacings is presented in Tables 2 and 3.

Results and Discussion

The effects caused by the difference in inlet flow rates (1.5 l/s, 2.5 l/s and 3.5 l/s) and their corresponding cut-off times, and the three furrow spacing (70 cm, 80 cm and 90 cm) with other assumed and derived parameters on the resulting performance parameters of furrow irrigation were evaluated based on the performance indices as obtained from the soft ware package FURDEV, with two irrigation depths (75 mm and 100 mm). The performance parameters were evaluated separately and the results presented and analyzed for the two irrigation depths independently.

Although observations made on the response of system performance indices to changes in inlet flow rates and length of furrows would be more desirable and informative they are difficult, so were also beyond the scope of this study. Instead the effect of three inlet flow rates and a fixed furrow length (300 m) on the performance indices have been investigated with two irrigation depths.

The summaries of output values from the FURDEV program for each case considered are presented in Tables 7 and 8. For more details, the computation results were also presented in graphical forms indicating the relationships between performance indices and flow rates, and that of the infiltration depth profile along the length of each furrow (Figures 1-9).

Application Efficiency.

The term application efficiency (E_a) indicates that the percentage of water applied that is stored in the root zone for crop use. Despite the fact that high application efficiency can be obtained by excessive under-irrigation even when water was distributed non-uniformly, irrigation water was applied to meet the requirement depth for wheat crop with the least watered areas just receiving the required amount of water during the two irrigation periods.

A desired application efficiency (70% and above) was assumed during designing furrow irrigation systems in the Middle Awash Valley. This same desired E_a (using Z_{min}/Z_{av} and assuming the deficit was just satisfied by the minimum infiltrated depth) at which the system operates, was considered for the furrow irrigation evaluation.

Correlation coefficients ($r = 0.67$ and $r = 0.68$) were obtained that indicates there existed association between application efficiency and flow rate. Similarly, the associations of application efficiency with deep percolation and runoff were expressed by the correlation coefficients -0.91 & 0.63 and -0.87 & 0.67 at p u□ ≤ 0.05 during the first and second irrigation periods respectively. Furthermore, from the regression analysis, the t-test values (2.41 and 2.42) indicate that the response of application efficiency was significant to changes in inlet flow rate at $p \leq 0.05$ during the first and second irrigation periods respectively. On the contrary, however, from these Tables, it is very evident that furrow spacing had no significant effect on application efficiency.

The application efficiency, E_a, was in the order of 30-60% for all conditions considered (Tables 7 and 8). The maximum application efficiency computed was $E_a = 64.5\%$ for the inlet flow rate 2.5 l/s and the 0.8m furrow spacing which was less than the design value, 70% and above.

There were variations in application efficiencies achieved between the selected inlet flow rates. Of the three furrow spacing considered, during the first and second irrigation periods, the largest variation in application efficiencies were 26.3% and 20.2 % for the in inlet flow rates of 1.5 l/s to 2.5 l/s and for the 80 cm furrow spacing. The variations in application efficiency when the flow rate changed in the same order for the 90 cm and 70 cm furrow spacing were in the same range, 24.3% and 24.7% as well as 19.8 % and 16.3 % during the first and second irrigation periods respectively. The variation in application efficiency (1.8-4.8 %) for the inlet flow rates of 2.5l/s was not significant ($p \leq 0.05$) among the 90 cm and 70 cm furrow spacing.

The results clearly indicate that the largest variations of application efficiencies occurred due to variations in inlet flow rates rather than furrow spacing. Equally important, however, are the probable fluctuation in the corresponding design cut-off times for each inlet flow rate, which are the main aspects of the management of any irrigation scenario. Although, not a rigorous comparison of the application efficiency during the two depths of application, the computed values were of similar magnitudes.

Storage Efficiency

Storage efficiency, which is the measure of adequacy of applied water was the primary criteria used in selecting the appropriate cut-off time for the three inlet flow rates. The minimum applied depth (Z_{min}) was found to be greater than the required applied depth (Z_r) almost in all cases under consideration. Therefore, E_s was computed to be 100%, the case when over-irrigation existed. The optimum level of E_s to sustain crop growth is 100% so that the natural inefficiency of the system was sufficient to leach salts from the least watered area. To this effect, as indicated in Tables 7 and 8, there was no change in storage efficiency for all cases considered.

Irrigation Uniformity

Two parameters were used to evaluate irrigation uniformity. The first parameter was distribution uniformity (Du) and the second was uniformity coefficient (Uc). The results on the infiltrated water depth profile along the furrows from the FURDEV program during the two irrigation periods are presented in Figures 2, 3, 5, 6, 8 and 9. As indicated in these figures the applied depths were non-uniformly distributed and the distribution had a shape skewed towards the inlet end of the field. That is, the maximum and minimum depths of irriga-

Table 4 Correlation coefficients for the first irrigation

	Spacing	Qo	tco	Ea	Du	Uc	Df	Rf	Opp time	Zav
Spacing	1.00	0.00	0.09	0.19	0.08	0.10	-0.15	0.050	0.68	-0.15
Qo		1.00	-0.90	0.67	0.96	0.97	-0.91	0.98	0.68	-0.87
tco			1.00	-0.89	-0.97	-0.95	0.97	-0.86	-0.53	0.97
Ea				1.00	0.84	0.87	-0.91	0.63	0.55	-0.95
Du					1.00	0.98	-0.99	0.94	0.71	-0.97
Uc						1.00	-0.92	0.93	0.82	-0.94
Df							1.00	-0.89	-0.72	0.99
Rf								1.00	0.74	-0.84
Opp.time									1.00	0.68
Zav										1.00

Table 5 Correlation coefficients for the second irrigation

	Spacing	Qo	tco	Ea	Du	Uc	Df	Rf	Opp time	Zav
Spacing	1.00	0.00	0.15	0.09	0.07	0.26	-0.09	0.08	0.85	-0.11
Qo		1.00	-0.91	0.68	0.96	0.98	-0.95	0.99	0.45	-0.91
tco			1.00	-0.87	-0.97	-0.99	0.97	-0.90	-0.33	0.96
Ea				1.00	0.85	0.89	-0.87	0.67	0.42	-0.91
Du					1.00	0.99	-0.99	0.95	0.53	-0.99
Uc						1.00	-0.97	0.98	0.68	-0.97
Df							1.00	-0.94	-0.53	0.99
Rf								1.00	0.52	-0.91
Opp.time									1.00	0.54
Zav										1.00

Table 6 Performance parameters from FURDEV program for furrow irrigation system with an application of 75 mm depth of water on wheat cultivated field at Melka Were Research Center.

		FURROW SPACING								
		90 cm			80 cm			70 cm		
		1.5	2.5	3.5	1.5	2.5	3.5	1.5	2.5	3.5
OUTPUT PARAMETERS	Units									
Application eff.	%	38.5	62.8	55.8	36.2	63.5	54.3	33.3	58	51
Storage eff.	%	100	100	100	100	100	100	100	100	100
Uniformity coeff.	%	79.7	92.5	98.5	78.8	91.2	95.9	77.9	90.1	97.5
Distribution uniformity	%	39.3	81.3	96.9	37.1	78.1	90.5	34.4	75.2	94.5
Deep percolation ratio	%	59.7	23.1	14.6	61.1	23.8	23.9	63.9	29.6	22/2
Run-off ratio	%	1.8	14.1	29.6	2.1	12.7	21.8	2.8	12.4	26.8
Advance time	min.	512	137	84	496	137	98	482	136	83
Depletion time	min.	593	224	182	561	200	166	533	189	155
Recession time	min.	642	288	256	605	260	232	570	243	222
Opportunity time	min.	130	151	172	109	123	134	88	107	139
Avg. infiltration depth	mm	191	103	95	203	105	108	219	113	108
Max. infiltration depth	mm	232	112	96	248	116	113	270	126	111
Min. infiltration depth	mm	75	83	92	75	82	98	75	85	102
Surface runoff	mm	3	17	40	4	15	30	6	16	39
Over-irrigation	mm	116	28	20	128	30	33	144	38	33
Under-irrigation	mm	0	0	0	0	0	0	0	0	0
Over irr. length	m	300	300	300	300	300	300	300	300	300
Under-irr. length	m	0	0	0	0	0	0	0	0	0

Table 7 Performance parameters from FURDEV program for furrow irrigation system with an application of 100 mm depth of water on wheat cultivated field at Melka Were Research Center.

		FURROW SPACING								
		90 cm			80 cm			70 cm		
		1.5	2.5	3.5	1.5	2.5	3.5	1.5	2.5	3.5
OUTPUT PARAMETERS	Units									
Application eff.	%	46.6	62.9	54.7	44.3	64.5	62.5	41.3	61.1	56.2
Storage eff.	%	100	100	100	100	100	100	100	100	100
Uniformity coeff.	%	82.2	94.7	99.1	81.3	93.8	98.6	80.3	92.9	98.2
Distribution uniformity	%	47.5	87	98.5	45.2	84.6	97.1	42.3	82.4	96.2
Deep percolation ratio	%	51.7	18.1	9.7	53.9	18.6	6.5	56.5	22.8	13
Run-off ratio	%	1.7	19	35.5	1.9	16.9	31	2.3	16	30.8
Advance time	min.	512	137	84	496	137	83	482	136	83
Depletion time	min.	653	295	244	611	257	191	573	237	186
Recession time	min.	706	365	323	661	323	266	618	298	257
Opportunity time	min.	195	227	239	165	186	182	136	162	174
Avg. infiltration depth	mm	211	129	118	222	129	110	237	137	123
Max. infiltration depth	mm	250	137	119	265	138	112	286	149	126
Min. infiltration depth	mm	100	112	116	100	109	107	100	113	119
Surface runoff	mm	4	30	65	4	26	50	5	26	55
Over-irrigation	mm	111	29	18	122	29	10	137	37	23
Under-irrigation	mm	0	0	0	0	0	0	0	0	0
Over irr. length	m	300	300	300	300	300	300	300	300	300
Under-irr. length	m	0	0	0	0	0	0	0	0	0

tion occurred at the head and tail end of each furrow respectively. The underlying reason for this was the difference in infiltration opportunity time along the length of each furrow.

The correlation coefficient (Appendix Table 5 and 6) indicate that there existed strong associations of flow rate with both distribution uniformity ($r = 0.96$ and $r = 0.96$) and with uniformity coefficient ($r = 0.97$ and $r = 0.98$) at $p \leq 0.01$ during the first and second irrigation periods respectively. Similarly, the correlation coefficients ($r = -0.97$ and $r = -0.99$) clearly indicted that there existed strong relationship between average infiltrated depth and distribution uniformity at $p \leq 0.01$ during those periods respectively. Moreover, from the regression analysis, the t-test values (8.54 and 9.55) indicate that the response of distribution uniformity was highly significant to changes in inlet flow rate at $p \leq 0.01$ during the first and second irrigation periods respectively. From these results it is also evident that furrow spacing had no significant effect on distribution uniformity.

As indicated in Tables 6 and 7, the uniformity coefficient (Uc) increased linearly with inlet flow rates reflecting that the ratio of the difference between the average amount applied and the average deviation from the average amount applied to the total amount applied was minimum for the 1.5 l/s and maximum for the 3.5 l/s of flow rates respectively. A similar trend was observed for distribution uniformity (Du) which was also linearly increased as the inlet flow rate increased and reflecting that the ratio of the minimum infiltrated amount, expressed as percentage of the average infiltrated amount over the furrows, was minimum for the 1.5 l/s and maximum for the 3.5 l/s. These results show that Uc can be taken as a good measure of uniformity over the entire length of the furrows, whereas, Du was a more appropriate indicator of irrigation uniformity over the reach closer to the points where the required application depth was equal to the minimum application depth. Moreover, it appears from Figures 1, 4 and 7 that Du was more sensitive parameter to changes in inlet flow rate than Uc.

Irrigation Water Losses

The difference between 100% and application efficiency (E_a) is the measure of total irrigation water losses (deep percolation and run-off losses) occurring during operation of the system. Tables 7 and 8 and Figures. 1, 4 and 7 show the relationships of inlet flow rates to that of deep percolation ratio and run-off ratio.

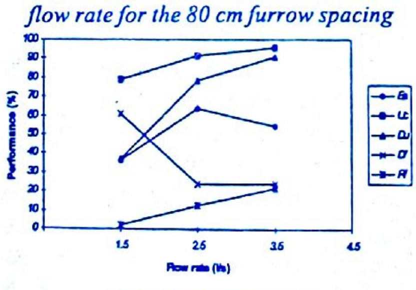
The correlation coefficients (Appendix Tables 5 and 6) clearly indicate that there exist strong association of flow rate with both deep percolation ratio ($r = -0.91$ & $r = -0.95$ and run-off ratio ($r = 0.98$ & $r = 0.99$) at $p \leq 0.01$ during the first and second irrigation periods respectively. Similarly, strong associations ($r = -0.89$ and $r = -0.94$) were observed between deep percolation ratio and runoff ratio at $p \leq 0.01$ during those periods. Moreover, from the regression analysis, the t-test values (5.75 & 12.92 and 7.83 & 22.6) indicate that the linear responses of deep percolation and run-off to changes in inflow rate were highly significant at $p \leq 0.01$ during the first and second irrigation periods.

The results in Figures 1, 4 and 7 indicate that as inlet flow rate increased steadily from the minimum value (1.5 l/s) to the maximum value (3.5 l/s), the deep percolation ratio also steadily declined. On the other hand, a steady increase of inlet flow rate generally resulted in increase of run-off ratio. The combined irrigation water loss, which is represented by the sum of D_r and R_r decreased as Q_o increases from the minimum value (1.5 l/s) to the optimum value (about 2.5 l/s in most cases) and then started to increase as Q_o increased beyond the optimum value. It can be noted from these results that at the optimum flow rate, deep percolation ratio equals run-off ratio and the optimum flow rate corresponds to minimum values of the combined surface run-off and deep percolation losses. Moreover, an over-irrigation as much as 144 mm and 137 mm for the 70 cm spaced furrow were observed at the upper ends of each furrow during the first and second irrigation periods respectively.

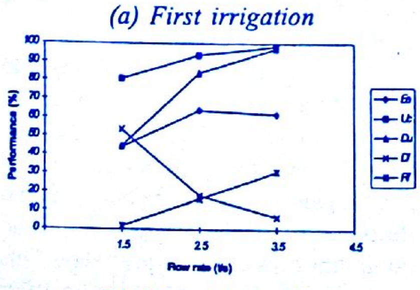
Similarly, Tables 6 and 7 indicate that, the higher amount of percolation water decreased the application efficiency, and might have contributed to the rise of the water table of the study area.

(a) 1.5 l/s

Fig. 4 Performance indices versus inlet flow rate for the 80 cm furrow spacing

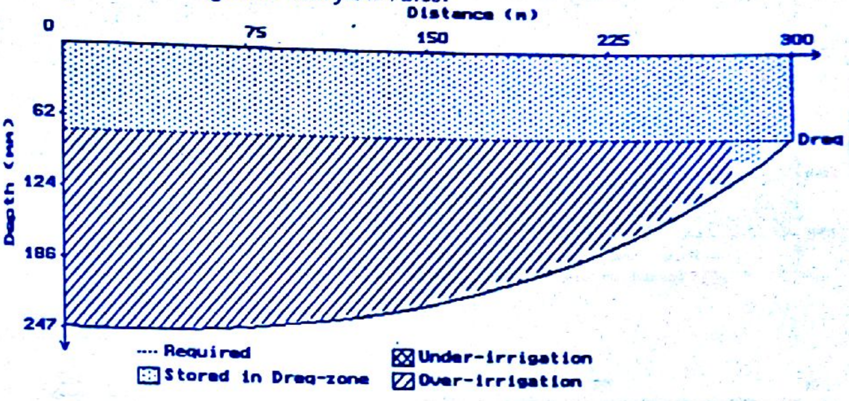


(a) First irrigation

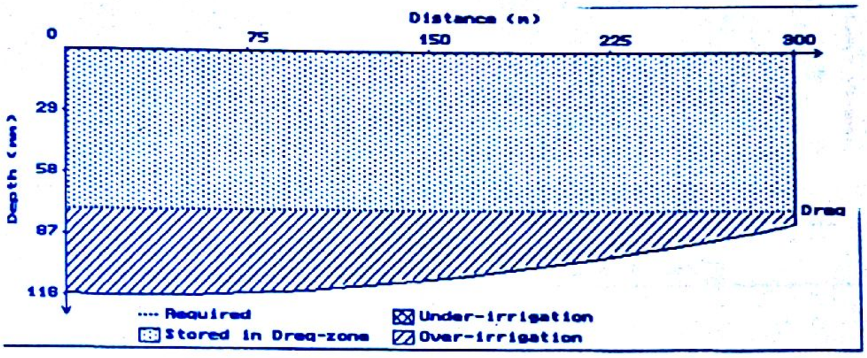


(b) Second irrigation

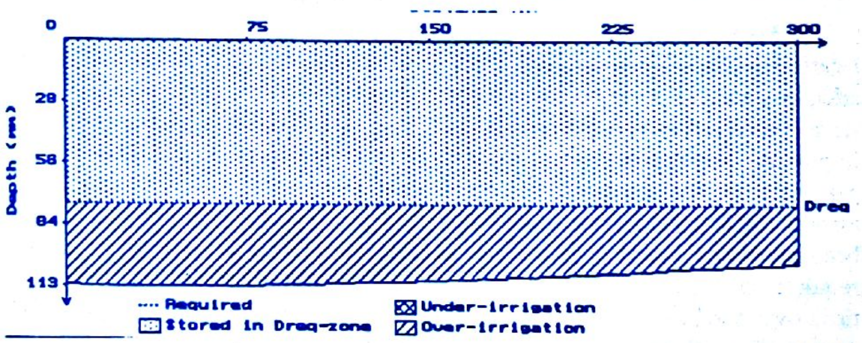
Fig. 2 Infiltrated depth profile of furrow irrigation for the 80 cm furrow spacing during second irrigation with flow rates:



(a) 1.5 l/s

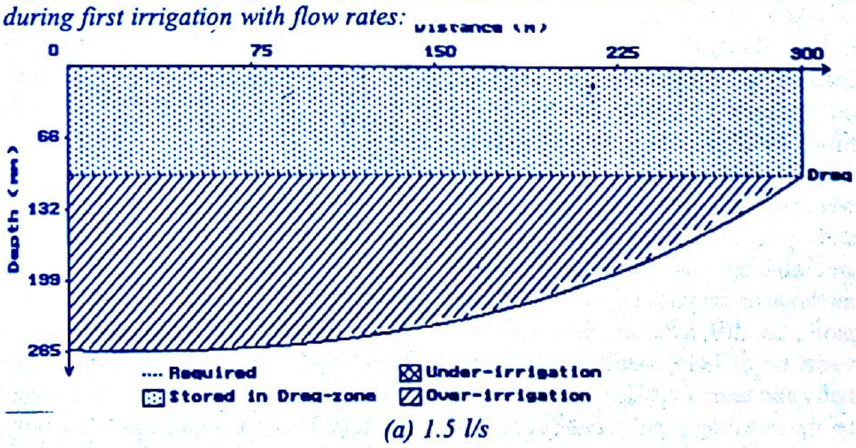


(b) 2.5l/s

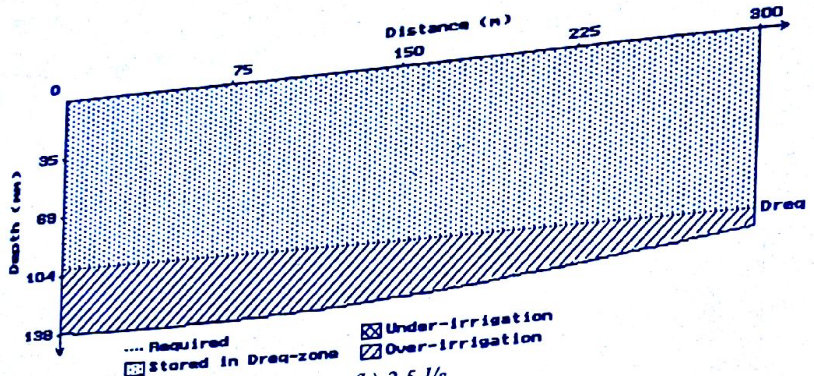


(c) 3.5 l/s

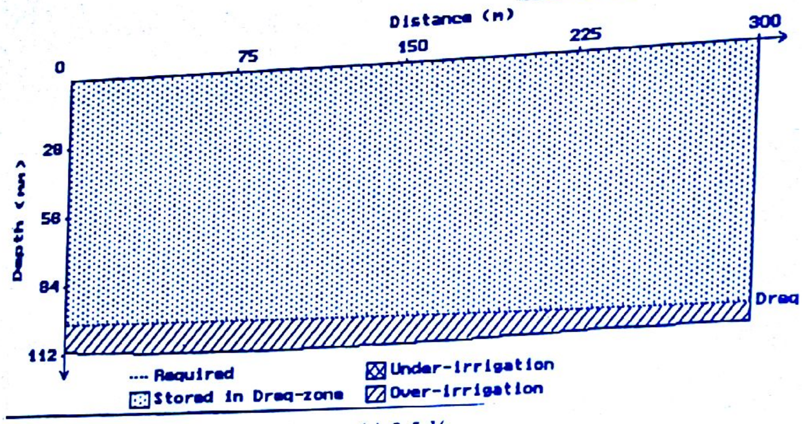
Fig. 3 Infiltrated depth profile of furrow irrigation for the 80 cm furrow spacing during first irrigation with flow rates:



(a) 1.5 l/s



(b) 2.5 l/s



(c) 3.5 l/s

Summary and Conclusion

Evaluation of the performance of irrigation methods in terms of efficiency, adequacy and uniformity of applied water is considered as an important step in improving existing on-farm irrigation performance. Performance indices corresponding to each of those terms have been computed in terms of perceived requirement for a specific field conditions over a subject area under consideration. Terms that are related to irrigation water loss have been computed and their influences on system design and management decision have been explored.

On-farm measurements were carried out to identify field parameters such as infiltration characteristics of the soils, field slopes, advance and recession times, field geometry, and soil moisture deficit before irrigation. Then decisions were made on system variables (Q_o, L and t_{co}) based on the field conditions and assumptions made for the three methods of irrigation systems. Furthermore, the difficulty to characterize the variation of field conditions both spatially and temporally has a great impact on the resulting performance of surface irrigation. Therefore, it should be noted that, the effectiveness of surface irrigation does not only depend on the relationship between flow rate and performance indicators but also on the accuracy and dependability of determining system parameters and system variables.

The study quantified the performance of furrow irrigation system based on the performance indicators E_a, E_s, Du, Uc, D_f and R_f values from the FURDEV computer soft-ware package.

In general, the result indicates that, the maximum attainable application efficiency of furrow irrigation system was in the order of 62-64 %. On the other hand, however, irrigation losses due to deep percolation and runoff were found to be the major problems that reduced the application efficiency at the study area.

Moreover, E_a and total irrigation water loss (deep percolation plus runoff) were found to be uni-modal functions of flow rate (provided that all other variables remain constant) so that for the given level of parameter combination there existed a value of Q_o at which the efficiency was maximum. Conversely the total loss was minimum. Generally, the potential application efficiency is entirely dependent on system parameters because of the assumption that storage efficiency, E_s =100 %, is satisfied.

Uniformity of irrigation water application was found to be strictly an increasing function of inlet flow rate. It appears from the results obtained that Du seems to be more sensitive to changes in inflow rates than UCC. Moreover, the storage efficiency was computed to be 100 % because of the minimum applied depth was greater than the required depth of application during the evaluation of the three irrigation systems.

Although it is difficult to substantiate the objective of this study with a year data, it is, nevertheless, imperative to present the results in the utmost generality, if they are to be of any importance in improving the existing on-farm irrigation performance and serves as a basis to design new irrigation systems with similar conditions. With this respect however, the performance indicators obtained from the program might shed valuable light on the performance level of existing irrigation systems in the Middle Awash Valley with respect to their attainable potentials. Nonetheless, with the objective of bringing some generality to the presentation of the results, the following conclusions were reached.

1. The FURDEV program, which is a very user-friendly and provides output performance indices for a given set of input parameters, was a useful tool and avoided tedious calculation procedures while the study was undertaken.

2. Since the assumption that E_s = 100 % was satisfied, it was recognized that application efficiency was entirely dependent on system parameters, mainly inlet flow rate. Thus, strategies on the improvement of performance of surface irrigation depend mainly on seeking for (designing) the right combination of flow rate and cut-off times.

3. Considerable amount of irrigation water losses (deep percolation and runoff) were observed that reduced application efficiency. The underlying reason for those extremely high run-off and deep percolation were maximum and minimum flow rates respectively. This excessive application of irrigation water

is believed to be the major cause for the serious soil salinity problem in the absence of a drainage system, which became a very sensitive issue of the study area.

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Water Harvesting And Ground Water Recharge

Dr. L. B. Roy AWTI, P. O. Box –21, Arbaminch, Ethiopia

Abstract

The scarcity of water for drinking and other purposes in summer is commonly as demand increases and supply sources start drying up simultaneously. This problem is even more acute in urban areas. The overexploitation of surface and ground water in urban areas results in continuous lowering of ground water level and low yield of surface water sources which makes it more difficult to meet the required demand during lean periods. As urban areas provide little opportunity for replenishment of ground water reserves, there is a need for augmenting the recharging of aquifers and conserving the rainwater. This paper aims at reporting the initiatives taken by various governmental, non-governmental and voluntary organizations in different cities of India for rainwater harvesting and its conservation. It also includes the beneficial effects of rainwater harvesting and its conservation especially in urban areas. Apart from this the artificial recharge techniques practiced in various mega cities of the world and the status of water harvesting techniques used in Ethiopia have also been included. Finally it has been concluded that the judicious mix of ancient knowledge, modern technology, public and private investment and above all people's participation will go a long way in reviving and strengthening water harvesting and ground water recharge practices in countries like India and Ethiopia.

Introduction

Water sustains plants and plants sustain life on the earth. Thus water is life and basis of all activities on the earth; decrease in its availability causes drought, desertification and famine resulting in hardship. The overexploitation of this important resource may disturb the hydro- ecological balance of any area. Although water is a renewable resource, yet its distribution over time and space is too uneven and uncertain.

Water harvesting technique includes a wide range of methods, which are based on the basic points, namely, source of water available, required storage duration and the intended use of the harvested water. Water harvesting includes stream flow in creeks and gullies, not just rainfall at point where it falls; therefore water-harvesting term is used to indicate the collection of any kind of water. The sources of water that are harvested are the roof water, sheet flow or intermittent or even perennial rivers. The harvested water can be used for various productive purposes such as domestic water supply, creating stock of water for irrigating the crops, orchards and also for fishing. A review of the existing water harvesting and ground water recharge practices in India is presented in this paper. It is felt that similar practices can be quite useful for Ethiopian conditions to augment ground water and alleviate the water supply problems for drinking purposes as well as for the agricultural use.

In large part of the world, water harvesting is best known as practiced in the semi-arid areas, where mean annual rain fall is in the range of 400 to 600 mm. Owing to low rainfall and erratic distribution of rainfall, the crops in semi-arid areas suffer due to moisture deficit at critical stages of crops leading to low crop yields or sometimes complete failure of crops. Under such circumstances, it is better to increase runoff of the rainwater and collect it at convenient points for use by crops at most critical stages rather than spreading water thinly over large surface of lands

The traditional rainwater harvesting systems of South India, called *'Eris'* were designed and developed 1000 years ago. Further more, in several places embankments were constructed to catch the monsoon runoff from catchments area so as to collect water in bed of the storage reservoir itself.

The area irrigated by ground water resources has increased five times during the past four decades in India. The share of ground water in irrigation sector has also increased to more than 50% as of date. As per India's National Water Policy, development of ground water resources is to be limited to the utilization of the dynamic component of ground water, which is replenished annually. The dynamic resource has been assessed as 43.189 million ha m. After making a provision of 7.093 million ha m for domestic, industrial, and other uses, the available ground water resource for irrigation is assessed as 36.096 million ha m. Though, based on norms of Ground Water Estimation Committee, the level of ground water development is only around 35% and still a large volume of replenishable ground water resources is available for future use, but in number of areas, high stage of ground water development has been registered. About 7.5% of artificial recharge assumes its importance in augmentation of ground water storage, conservation of surface runoff in subsurface aquifers, preventing evaporation losses from surface water reservoirs by diverting a part of it to ground water, improving the quality of ground water as well as prevention of saline water intrusion in coastal areas.

On one hand, experts from the donor agencies like World Bank are arguing to shift the focus from resource development to resources management. On the other hand we have eminent persons advocating the revival of the traditional systems of water harvesting to cope up with the alarming situation. *'Catch the rain when and where it falls and do not allow even a drop to be lost'* is another suggestion being suggested by many intellectuals. The utter confusion prevailing among the opinion makers- the planners, academicians, intellectuals and the stakeholders about the approach to be adopted in dealing with water has been the root cause for the slow progress in harnessing this resource. The above aspects have been described in detail in this paper.

Need For Artificial Groundwater Recharge

The aim of artificial recharge of ground water is to reduce, stop or even reverse the declining levels of ground water, to protect fresh ground water in coastal aquifer against saline water intrusion and to store the surplus water including monsoon runoff and waste water for the future use. The need for artificial recharge was never felt till the middle of 20th century, as the exploitation of ground water was limited. The rapid increase in population, large scale cultivation of cash crops requiring irrigation and rapid industrialization are responsible for the heavy demand of the ground water resources. The number of ground water abstraction structures during the period 1951-1990 has shown a phenomenal increase in India.

As per Central Ground Water Board's National Report on "Ground water Resources of India" several blocks/ *mandals/ talukas/* watersheds fall under 'dark' category (utilization greater than 85% but less than 100%) in 12 states of the country viz. Uttar Pradesh, Bihar, Andra Pradesh, Madhya Pradesh, Tamil Nadu, Kerala, Karnataka, Maharashtra, Gujarat, Rajasthan, Haryana and Punjab. In such areas, declining water levels necessitates deepening of existing abstraction structures thereby increasing cost of pumping and sometimes quality deterioration.

Ground water levels have also shown more than 4 m decline on long term basis in parts of Uttar Pradesh (24 districts), Bihar (2 districts), West Bengal (1 district), Assam (4 districts), Orissa (2 districts), Andhra Pradesh (6 districts), Madhya Pradesh (22 districts), Tamil Nadu (10 districts), Karnataka (11 districts), Maharashtra (1 district), Gujarat (7 districts), Rajasthan (26 districts), Punjab (9districts) and Haryana (12 districts) during pre monsoon season.

The main reasons for lowering of ground water table are:

- Increased area under irrigation,
- Diversification of cropping systems towards more water requiring crops,
- Improper management of surface water resources and
- Over –draft of ground water for agriculture, industrial and domestic uses.

The decline in water levels has resulted in failure of wells/ tube wells, shortage in water supplies, increase in pumping costs and higher energy consumption. Unscientific development of ground water in some coastal areas in the country has led to landward movement of sea water-fresh water interface resulting in contamination of fresh water aquifers. Problem of salinity ingress has manifested in Minjur area of Tamil Nadu and Mangrol- Chorwad-Porbandar belt along Saurashtra coast. This has rendered a number of tube wells out of use. Thus there is an urgent need of artificial recharge of ground water.

Artificial Ground Water Recharge Techniques

Artificial recharge is the process by which the ground water reservoir is augmented at a faster rate than natural replenishment by putting excess runoff water into the aquifer itself. Aquifers best suited for artificial recharge are those, which absorb large quantity of water and do not release too quickly i.e. the vertical hydraulic conductivity is high while the horizontal hydraulic conductivity is low or moderate. The factors, which must be considered in selecting the proper location of sites for artificial recharge, are:

- Geological structure of ground water reservoir,
- Pattern of pumping draft,
- Movement of water within the water table,
- Surface soils and substrata including antecedent moisture conditions, thickness and the nature of the unsaturated zone,
- Water supply source, turbidity and quality and
- Social and economic considerations.

The artificial recharge techniques can be broadly categorized in four groups as:

- Direct surface techniques,
  - Flooding,
  - Basins or percolation tanks,
  - Stream augmentation,
  - Ditch and furrow system and
  - Over irrigation.
- Direct subsurface techniques,
  - Injection wells or recharge wells,
  - Recharge pits and shafts,
  - Dug well recharge,
  - Bore hole flooding and
  - Cavity fillings,
- Combination of surface and subsurface techniques,
  - Basin or percolation tanks with pit shaft or wells
- Indirect techniques
  - Induced recharge from surface water source and
  - Aquifer modification

Besides above, the ground water conservation structures like ground water dams, roof top rain water harvesting and rainwater runoff harvesting, subsurface dykes or locally termed as Bandharas, are quite prevalent measures to arrest surface or subsurface flows. Similarly in hard rock areas rock-fracturing techniques including sectional blasting of boreholes with suitable technique has been applied to interconnect the fracture and thereby increasing recharge in countries like India and Ethiopia.

Artificial Recharge Practices in Various Mega Cities of the World

The intensive ground water development is causing decline or depletion of ground water in many parts of world, which is a cause of concern to every one. Planners and policy makers are worried about the challenging situations of water crisis in future, so appropriate and suitable ground water recharge techniques are being recommended by them for adoption at various locations in the world. Chadha et. al (1998) reported many recharge practices, which are being followed in many mega cities of the world to solve the problem of drinking water in terms of quantity as well as quality. These practices along with purposes are as given in Table-1 so that these may be used as guidelines while planning for artificial recharge.

City	Type of artificial Recharge structure	Purpose
California	Spreading basins, injection of treated waste water	To eliminate the overdraft and reverse seawater intrusion, improving water quality.
Paris	Spreading basins	To ensure sustainable water quality in over drawn alluvial aquifers, where tank filtered water is limited in quantity and quality.
Kuwait	Waste water recharge through infiltration ponds	To tackle the problem of depletion of brackish ground water
Amsterdam	Injection wells	To maintain water supply to the city
South Australia	Aquifer storage and recovery injection of treated waste water	Sustaining ground water systems, reducing reliance of urban areas on imported water
Israel	Soil aquifer treatment	Urban waste water treatment and water reclamation for agricultural use
Vienna	Recharging wells	Rise in water level and improvement in water quality
Oman	Recharge dams	Improve ground water potential
Finland	Sprinkling infiltration	Dilution of nitrates
United States	Aquifer storage recovery	Storing large volume of water to meet peak, long term and emergency demands
England	Aquifer storage recovery	Decrease in concentration of Fluoride and denitrification

Table-1: Recharge Practices in various Mega Cities of the World (Chadha et. al, 1988)

Artificial Recharge Practices in India

Construction of percolation tanks, check dams, subsurface dykes, underground bandharas, infiltration galleries and different types pf weirs besides watershed management and rain water harvesting through other traditional methods have been in practice in various parts of the country especially in the state of Maharastra, Andra Pradesh, Karnataka, Madhya Pradesh and Rajasthan. A brief review of the case studies and the experience gained in the various parts of the country is as described below:

Mohan (1980) suggested use of surplus monsoon water in river Ganga at Hardwar for developing and augmenting rice irrigation. In the process the recharge to ground water increases, which can be used for *rabi*(winter season) crops.

Mathur (1983) carried out artificial recharge studies in Ghaggar river basin. In the induced recharge studies in Kurukshetra it was established that if exploitation by creation of well fields is carried out, a substantial quantity of surface flow from recharge through injection wells at the rate of 57.7 1ps or even more is feasible and the process can be continued even for 15 days.

Sikka et al. (1998) mentioned significant lowering of ground water levels in most parts of Delhi during past two decades and suggested de-watering and refilling of unconfined aquifer system underlying the Yamuna flood plain, roof top rain water harvesting construction of small check dams at favorable locations, recharging through on-channel storage of water, recharge structures such as dug wells and village ponds.

Khepar et al. (1998) reported that there is a great potential for artificial recharge through the drainage system in Punjab. A case study conducted at Rohti drain revealed that by constructing series of check structures across the drain at suitable intervals and provision of recharge shaft under specific hydrological conditions enhanced the recharge capacity of drains.

Raju (1998) pointed out that in the state of Gujarat there are thousands of tanks including minor irrigation projects, which are either defunct or their capacity has reduced due to silting. He suggested that top priority should be given to revive these structures. In the areas having deep water table, percolation ponds with recharge tube wells are suggested, whereas in the rivers of North Gujarat subsurface dykes for artificial recharge may be appropriate.

Jain and Jain (1998) studied the possibility of artificial recharge in Nagpur city, Maharashtra and found that artificial recharge through recharge wells using surface runoff has immense scope for implementation keeping in view the land use and hydro geological setup. It is one of the most effective alternatives for mitigating the pollution observed in ground water of the city.

Rao et al. (1998) reported that both in red soil and black soil areas of Andhra Pradesh, the rainwater harvesting structures (check dams) with storage capacity in range of 0.02 to 0.134 million cubic feet contributed to additional ground water recharge, rise in water levels and improvement in well yields.

Thambi et al. (1998) reported that subsurface dykes are ideal ground water storage structures for Kerala, particularly along the higher elevations where wells go dry during the summer. Since individual land holding is very small, subsurface dykes can be beneficial when it is accepted for community irrigation projects.

Rainwater Harvesting Techniques

There are a large number of indigenous, advanced and combined technologies available for rainwater harvesting – both ex-situ and in situ for multifarious 'on farm' and 'off farm' use. The rainwater harvesting structures used in different agro-climatic zones of India are as given in table-2. Also the following is the summary of some of the important rainwater harvesting technologies for their suitable testing and promotion and adoption in micro watershed (Uphadhya et. al, 2001 and Dingre, et. al, 2001):

Farm Ponds:

Farm ponds are small storage structures used for collection and storing runoff water. As per the method of construction and their suitability for different topographic conditions farm ponds could be classified into three categories viz., excavated farm ponds suited for flat topography, embankment ponds for hill and rugged terrains with frequent wide and deep water-courses; and excavated-cum-embankment type ponds.

Cistern/ Tank System:

Tank is a local name for cistern in the arid zone of Rajasthan, which implies covered underground tank, generally constructed of masonry or concrete for the collection and storage of surface runoff.

Nandi System:

Nandi is a small-excavated village pond or embankment village pond, used for harnessing meager precipitation in arid-desert tracts to mitigate the scarcity of drinking water. This is an ancient practice and an important mechanism of harvesting rainwater in Jodhpur region of Rajasthan state.

Dugout Tanks:

Dugout tanks are popular in the *Kandi* area of Punjab, Haryana, Jammu and Kashmir and Himachal Pradesh because in spite of moisture conservation measures, water stress conditions prevail during long rainless periods.

Sunken Structure/ Dugouts

Sunken structure/dugouts are recommended practice in treatment of the upper, middle and lower reaches of drainage lines and accompany the other conservation measures such as contour vegetative hedges, vegetative filter strips, bank-erosion stabilization, gully plugging, loose-boulder checks etc.

Godha system in *Chitagong* Hills

This indigenous technique enhances efficiency of water use and maintains water availability round the year by conserving the runoff from the hill slopes. This system is called *Godha*. As a further refinement to the indigenous technology generally a dam is built on a small stream (4 m wide x 3.5 m deep) creating an upstream reservoir.

Roof-Water Harvesting

In the lower hills of Himachal Pradesh, during the rainy season, roof water is collected in a dugout structure, known as diggi in Kangra District and Khati in Hamirpur and Bilaspur Districts. These structures are excavated into the hard rocks. In addition to roof water surface runoff is also collected into the dugout structures for multifarious uses.

For example in Mehrauli area of Delhi, the depth to ground water table was six meters in 1960 but today one has to go up to 43 m below ground level for getting ground water. In south Delhi many residential colonies where people depend on bore wells for water are gravely concerned about the declining ground water level The people in urban areas have now started to understand the alarming dimensions of the problem

Agro-climatic zone	Type of structure	Recommendations
1.Humid Northwestern Himalaya	Roof water harvesting diversion of perennial springs and streams in storage structure, village pond, collection from hill slope	Improvement in roof structures and use of proper material such as corrugated sheets for generation higher runoff and with arrangement of foul slush diversion system and proper storage structure for checking Water from contamination.
2.Himalayan foothills	Collection from hill slope, village ponds	Improvement in rooftop harvesting system as above.
3.Humid high rainfall northeastern zone	Roof water harvesting, diversion of perennial springs and steams in a storage structure (tank)	Improvement in rooftop harvesting system as above.
4.Humid Assam-Bengal plains	Tank, anicut/check dam, gully plugging, contour bunding	Improvement design of tank for minimizing evaporation and seepage losses, control of sediment load and water pollution.
5.Semi-arid Sutlej-Ganga alluvial zone	Pond, check dam, gully plugging, contour bunding	Improvement design of tank for minimizing evaporation and seepage losses, control of sediment load and water pollution.
6.Northwestern semi-arid and arid zone	Nadi, tanka, khadin percolation, anicut, gully plugging, contour bunding	Adoption of improved design of nadi and tanka, sand-filled reservoir sub- surface barrier, flat batter tank.
7.Central semi-arid and arid zone	Pond, check bunding, percolation, anicut, gully plugging, contour bunding	Adoption of improved design of nadi and tanka, sand-filled reservoir sub- surface barrier, flat batter tank.
8.High rainfall, high runoff Chotanagpur Plateau	Tank, anicut/check dam, gully plugging, contour bunding	Improve design of tank for minimizing evaporation and seepage losses, control of sediment load and water pollution.
9.Assured rainfall, deep black soil of Malwa Plateau and Narmada basin	Ponds, check dams, sub-surface dams	Improvement of existing systems.
10. Variable rainfall South central Deccan plateau zone	Pond check dam, percolation tank, bandhara, gully plugging, sub-surface dam, contour bunding	Flat batter tank, selection of suitable site and improvement of existing system, better water management.
11. Chattisgarh plateau zone	Pond check dam, percolation tank, bandhara, gully plugging, sub-surface dam, contour bunding	Flat batter tank, selection of suitable site and improvement of existing system, better water management.
12.Southeastern brown/red soil zone	Ponds/tanks, percolation tanks, sub-surface dams	Flat batter tank, selection of suitable site and improvement of existing system, better water management.
13. Southern variable rainfall, mixed soil zone	Pond/tanks, check dam, percolation tank sub- surface dam gully plugging	
14. Southern bi-model rainfall zone	Ponds/tanks, percolation tank gully plugging contour bunding, check dams	Improvement of existing systems.
15.Eastern *Coromandel*	Pond/ tanks, check dam, percolation tank sub-surface dam gully plugging	Adoption of improved design of tank, selection of suitable site and improvement of existing system, better water management
16.Western Malabar	Pond/ tanks, check dam, percolation tank, contour bunding, bandhara, Kolhapur weirs, sub- surface dam	Improvement in existing systems, better water management, construction of structures at suitable sites.

Table2: Rainwater Harvesting Structures in Different Agro ClimaticZones of India

and the importance of rainwater harvesting and rain water to recharge aquifer and maintain soil moisture.

In Banglore city, the residents of 16-acre *Sena Vihar* Housing Co-operative society have implemented a successful rainwater harvesting system. The benefits are evident, as a tube well around Sena Vihar has shown an increase in water yield despite unfavorable monsoon in 2001.

For individual houses and housing societies a typical rainwater harvesting system can cost between Rs 1,500 and 85,000, depending upon the size of the premises and the technology involved. A representative cost for construction of rainwater harvesting unit for different rooftop areas is shown in Table-3. The Delhi Water Board and Central Ground Water Board (CGWB, 1998) offer free technical advice to install such systems.

Delhi receives an annual average rainfall of 625 mm over an area of 1500 sq. km, which gives it an estimated rainwater potential of about 900 billion liters of water annually. This is enough to meet the city's water requirement for nine months in a year, if it is not allowed to drain as runoff in the river Yamuna.

Rainwater can be conserved and harvested instead of allowing it to go waste as runoff during monsoon periods for future use in lean periods. Rooftop rainwater harvesting is a promising option in Delhi as rooftop area is worked out to be 138 sq. km, which would yield about 68 MCM of rainwater. It is estimated that if only institutional buildings are considered in the first phase for rainwater harvesting, about six MCM rainwater would be available for the recharge (Chakrabartoy et al, 2001).

The CGWB has also constructed four check dams in Jawahar Lal Nehru University campus and IIT, Delhi campus. The rainwater availability for these check dams varies from 0.3 MCM to 0.71 MCM. The construction of these check dams has increased the ground water levels from zero to two meters in the downstream side of the dams. A total of 49,000 m^3 of storage capacity has been created in these four dams and 1,25,000 m^3 of rainwater has been recharged to the aquifers.

The Channai city receives about 1200 mm of average annual rainfall. This rainfall, if conserved, can efficiently overcome the city's critical drinking water supply situation. The Channai Metro Water and Sewerage board is making serious efforts to disseminate rainwater-harvesting techniques to the citizens. The city corporation has also issued necessary circulation for implementing measures for the conservation of rain water while sanctioning the building plans. The implementation of Ground water Regulation Act and different rainwater harvesting measures undertaken by various organizations, the ground water level has increased from 6.6 m below ground level in 1987 to 4.55 m below ground level in 1998.

The Hyderabad Metro water Board, Municipal Corporation and private builders has constructed about 3000 structures during 1998 for artificial recharge. The state Government has also made it mandatory for all new constructions in urban areas to adopt rooftop rainwater harvesting and leaving sufficient open space for ground water recharge. It has been observed that rainwater harvesting and artificial recharge has improved the ground water levels in twin city of Hyderabad and Secunderabad.

Water Harvesting in Ethiopia:

The wide range of diversity in agro ecology enables Ethiopia to produce many kinds of crops and livestocks. However, the country also experiences the most difficult terrain for the development of infrastructures, e.g. roads, water supply etc. The annual rainfall ranges between 400 to 1300 mm, with the largest variation felt in Tigray and Hararge. The agriculture is rain fed with a potential of 3.5 million hectare. The major river basins with high runoff include Blue Nile (4850, Omo-Gibe (16%), Baro-Akobo (11%), Genalle-Dawa (5%) and Awash (4%). The total runoff is estimated as 110 Billion m^3 and only less than 5% is used in the country and the remaining leave the country as Transboundary Rivers, such as Blue Nile, Baro, Alobo, Wabi- Shebele, Tekeze etc. The importance of rainwater harvesting was not recognized until very recently, after the devastating drought and famine of 1980s. Thus in order to alleviate the problem of agricultural outputs and other water uses, sustainable and reliable development and proper use of water resources in Ethiopia becomes an imperative. For this, the Govt. has to promote the practices of efficient and appropriate watershed management to maximize water yields and its quality. Also it has to be ensured that watershed management practices constitute an integral part of the overall water resources management therefore, there is a great need for water harvesting in the country. The rainwater harvesting techniques mostly used in Ethiopia is as described below (Getachew, 2000):

Runoff Irrigation:

It is widely used in Hararge for the production of major crops in the area; sorghum and chat (Chat edulis) at the altitude betbeen 1700 to 2500 amsl where the crop productivity has significantly increased.

Flood Irrigation (or Spate Irrigation):

The flash flood, as it appears along the riverbanks, is diverted using temporary structures reach the individual farmlands located along the riverbanks and the diverted water is spread into the crop fields as supplementary irrigation. The flood depends upon the rainfall situation in the upland areas, stays in the riverbed generally not more than two hours. Two to three irrigation at the early and late parts of season will bring the crop full maturity and thus the crop yields are dramatically increased relative to the traditional practice where crops most often fail in Hararge.

Roof Area (square feet)	Rainfall Received (In liters)	Recommended Water Harvesting System	Cost (Rs)
Up to 550	30	Recharge pit/hand pump	1,500-5000
1000	60	Recharge pit/hand pump	1,500-5000
1,100 - 3,200	65-180	Recharge trench	5,000-10,000
3,250 - 4,300	185-250	Gravity head recharge well	50,000-80,000
16,100	900	Recharge shaft or dug well	60,000-85,000

Table-3: Recommended Water Harvesting System and Their Cost For Different Roof Top Areas and Amount of Rainfall (CGWB, 1998)

Water Harvesting Ponds:

These have been used in Ethiopia to harvest rain water for both human and livestock watering in most rural areas, particularly in arid and semi-arid areas where the rain fall is less than 600 mm. such ponds are simple to construct and it can be easily managed by the community. Approximately 15% to 20% of the people and over 80% of the livestock in the country uses water from either rivers/streams or ponds. These days the use and promotion of ponds even for livestock watering is increasingly becoming difficult and challenging due to the spread of deadly child hood malaria and for this reason most NGOs are unable to promote and support pond construction due to environmental constraints.

Roof Water Harvesting:

In Early times roof water harvesting practices were confined to urban areas only. However, its use in the rural areas are increasingly becoming important these days as more people in the rural areas have corrugated roof houses. This is particularly true in the case of Hararge area where such projects are being initiated.

Thus there is ample scope of water harvesting in Ethiopia. Institutions like Arba Minch Water Technology Institute (AWTI) should take an initiative in this direction by constructing recharge wells in the eastern side of its campus and study its effect on augmentation of ground water. This harvested water can be used for bathing, washing of clothes, gardening, toilet use etc. This water can also be used for drinking purpose, of course after purification. Thus the augmentation of groundwater can reduce the cost of pumping the groundwater.

Conclusions

Water harvesting technique includes a wide range of methods, which are based on the basic points, namely, source of water available, required storage duration and the intended use of the harvested water. Various techniques are in vogue to recharge the ground water reservoir reduce the dependence on groundwater. These techniques vary widely with variations in hydro geological framework. Artificial groundwater recharge will improve water availability, replenish the depleted ground water resources due to over exploitation, mitigate flood intensity, reduce the cost of tube well construction and water lifting due to shallow water table and enhance non- monsoon river flows. Conserving and harvesting rainwater in urban areas is very important as it provides ready and clean water for the cities. In first phase rainwater harvesting may be recommended for institutional buildings having bigger roof top areas. Local authorities may further improve the situation through framing the regulations making roof water harvesting mandatory in new constructions as well as to improve upon the existing buildings. The individuals can also take rainwater conservation and harvesting at their own residential buildings with technical support and financial assistance from the various financial Institutions. Some of the relevant points which need due considerations are the following:

- For selection of an appropriate set of rainwater conservation technologies, proper consideration of climate, soil, land, crop and intended use of rainwater should be taken for location of specific situations.
- The research on smaller and cheaper methods of harvesting and recharge of water should be increased and greater interaction among Governmental agencies and NGO's should be extended.
- The involvement of community to protect the environment must push artificial recharge in all parts of country. This practice should be undertaken not only to augment the ground water resources but also to improve the quality of ground water recharge.
- Harvesting of roof top rain water and injecting it under ground should become an obligatory water management practice.

There is urgent need to have proper coordination/ correlation in the activities of various central and state organizations in construction and maintenance of rainwater harvesting/artificial ground water recharge.

- Institutions like Arba Minch Water Technology Institute (AWTI) should take an initiative in this direction by conducting applied research on water harvesting and groundwater recharge and promote the outcome of the result for the common users..

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Pooled Esitmates of Low-Flow Quantiles in the Wabi-Shebelle River Basin

Adane Abebe, AWTI, P.O.Box 21, Arba Minch,

Abstract

River systems are most stressed in low flow periods and thus an understanding of drought conditions in time and space is fundamental to a wide range of water management problems. Development of models of probabilistic phenomena such as low flows is often hindered by short record lengths or total absence of any record. This paper presents low flow characteristics and related hydrological features of the Wabi shebele basin lying within the boundaries of Ethiopia. The study employes basin area, mean annual precipitation, elevation, hydrogeologic information and normalized digital vegetation index(NDVI) as variables for identification of hydrologically homogeneus regions. The analysis was performed using hierarchical clustering by Ward's method. Weibull, also known as extreme value type III for minimum, and power distribution are adopted for the low frequency analysis. The parameters of the distributions are estimated using LL-moments, which are modified variants of the L-moments based on the lower elements of the sample. The fitted probability distribution has a better agreement with the lower part of the data. LL-moments of various orders (m) are used to estimate the parameters of the fitted Weibull and Power distributions. Quantile estimates using LL-moments and L-moments are also compared at one station. It is noted that an increase of m increases the weight of the lower part of the data.

Introduction

Low flow estimates are vital for planning water supplies, water quality management, issuing and renewing waste disposal permits, hydropower, irrigation systems and for assessing the impact of prolonged drought on aquatic ecosystems. Nowadays extreme low flow events are more diligently analysed and given focus in the emerging field of ecohydrology. Estimation of low flow is also important for small-scale irrigation projects that contribute significantly to poverty alleviation by means of increased cereal production and generation of rural employment.

The study focuses on the Wabi shebele river basin in Ethiopia, which is one of the basins with water availability below the common index for water scarcity 1000-1700m^3/capita (Engelman & La Roy, 1993).

Stream flow records may not be available at places where low flow frequency analysis is required or if there is any, it's of short lengths. However, short years of stream flow record leads to unreliable estimates of parameters and low-flow quantiles. In effect one seeks to employ spatial information to make up for the paucity of temporal information.

Geographical proximity of two catchments is no guarantee that they are similar from the flood frequency point of view (Cunnane, 1989). An alternative to geographical proximity as a measure of affinity offered by some clustering algorithms is Euclidean distance in the n-dimensional feature space that is defined by the n characteristics that have been adopted for site description. The final test of the homogeneity of the regions is independent of the method of identifying the regions. Due to the complexity of factors that affect the generation of stream flows, there are different objective methods of regionalization. Index flood procedure is used here. Different authors identify hydrologically homogeneous regions based on either geographical considerations or flood data characteristics or a combination of the two.

A possible disadvantage to methods of classification based upon Euclidean distance, including Kohonen networks, is the absolute certainty of the allocation to a particular class so artificial neural network is advised (Hall and Minns, 1999). Since the number of sites considered in this study is few, almost every possibility of cluster aggregation is attempted.

There is no generally agreed upon methodology for estimating low flow quantiles and associated parameters in the country. Parameter estimation using L-moments gives estimates that are highly efficient, almost unbiased and not much influenced by outliers in the data (Hosking & Walis, 1997). However, extreme sample values are given little weight, thus the quantiles at the tails may not be efficiently estimated when L-moments are used (van Gelder, 2000). The trends shown by low flows are expected to be better captured by the use of LL-moments.

Study Area:

The Wabi Shebele river basin in Ethiopia lies between 4°45' N to 9°45'N latitude and 38°45'E to 45°30'E longitude, including the closed watershed of the Fafen and the Bio Ado. It springs from the Bale mountain ranges of the Galama and the Ahmar about 4000 m above mean sea level and drains into Indian ocean crossing Somalia. About 72% of the catchment (202 220 square kilometers) is lying in Ethiopia.

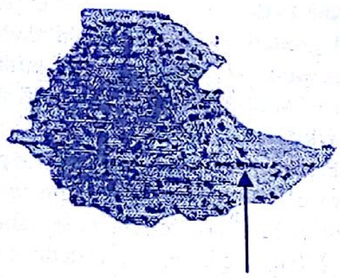

Fig.1 Wabi shebele river basin in Ethiopia

Wabi shebele river basin is one of the basins having high water scarcity in the country. It is among the largest in terms of basin area but its annual specific yield is very small (Table 1).

Basin	Wabi shebele	Genale Dawa	Awash	Abbay	Baro Akobo	Tekeze
Annual rainfall (mm)	425	528	557	1,224	1,419	838
Annual runoff ($x10^4m^3$)	3.4	5.88	4.60	52.6	11.81	7.63
Basinarea (square kilometer)	202,220	171,042	114,919	204,000	74,152	90,001
Annual runoff coefficient	0.04	0.07	0.07	0.21	0.11	0.10
Annual specific yield ($l/s/km^2$)	0.49	1.09	1.26	8.17	5 05	2.68
Water availability (m^3/ per capita)	588	3,601	493	3,608	6,328	1,768

Table 1. Estimated annual water yields of selected Ethiopian river basins (mainly WAPCOS data) (WAPCOS, 1990)

Hydrogeology: The study area is dominated by Mesozoic sedimentary formations, to some extent there are also volcanic rocks at the north west of the basin and isolated ridges and hills within the sedimentary basin. Metamorphic rocks outcrops in a small extent at the northern part of the study area. Alluvial deposits are also distributed linearly along the Wabi Shebele, Jerer, and Fafen rivers and fan deposits of seasonal floods and stream beds.

The volcanic rocks of Arsi-Bale basalt bordering the rift valley are highly fractured. Numerous springs outcrops along faults and fractures in this area and form substantial part of the base flow of Wabi Shebele river.

The water level monitoring for one hydrologic cycle on two wells at Gode showed that the water level is deep always lower than the Wabi shebele river bed and the phreatic water level is practically the same during the hydrologic cycle and no interaction with Wabi shebele river water indicating the permeability is very low. On the other hand at Kelafo there is interaction of the alluvial ground water with Wabi shebele river water. At Mustahil there is infiltration of Wabi Shebele floodwaters into the alluvial ground water.

Hydrometrological Data: the largest share of the wabishebele basin is located in Semi-arid to arid zones (about 102,220 square kilometers) but there are only three meteorological stations where as most of the meteorological stations are concentrated around the upper valley. As per MoWR the key rainfall stations in the basin with rainfall records of more than 30 years include:

Upper valley: Bekoji, Kulumsa, Meraro, Sagure, Kofele, Ticho, Adaba, Gasera, Ginir, Goba, Jara, Alemaya, Harer, Hirna, Girawa, Jara, Shashemene.

Middle valley: Meiso, Asbe Teferi, Dire Dawa, Awassa, Fedis, Jara, Gursum.

Lower Valley: Degeh Bur, Kebri Beyan, Gode , Gewane.

Statistical Tests: It is supposed that the flows used in this study are natural discharge records unaffected by major abstractions or sewage effluent discharge. Outliers were removed from all the data series. A non-parametric test of the lag-one serial correlation test was applied at a significance level of 10% for testing the independence of the data series.

Cluster Analysis: Statisticallly homogeneous regions, those regions likely to have similar low-flow producing characteristics in the basin were identified using multivariate statistical analysis . In the cluster analysis each gauging site is associated with one or more catchment characteristics. Then a measure of similarity between two subcatchments is measured by a scaled Euclidean distance between them in catchment characteristic space. A number of variables are considered in the cluster analysis. The procedure involved superimposing the location of each gauging station on the digital basin boundary map and identifying the mean area (A), the mean annual rainfall (MAP), mean elevation (Elev), hydrogeologic features (HyG) and NDVI (Normalized digital vegetation index),obtained from satellite images (EROS, 2002), for the analysis.

In this analysis hierarchical clustering using Ward's method is used.

This procedure attempts to identify relatively homogeneous groups of cases (or variables) based on selected characteristics, using an algorithm that starts with each case (or variable) in a separate cluster and combines clusters until only one is left.

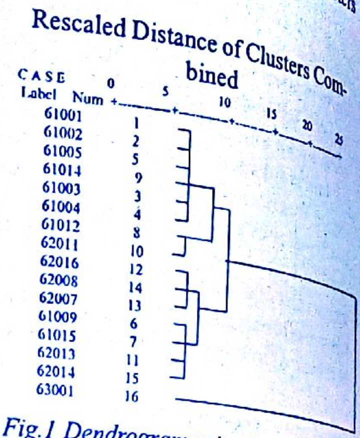

Fig.1 Dendrogram using Ward Method

In the dendrogram (fig.1) it can be noticed that if only two clusters are required all the subcatchments except one stand as one cluster and station no. 63001 (at Gode) stands out as a separate cluster. If three clusters are required the bigger cluster splits to two. Station no. 62011 (at Tebel) belongs hydrologically more to the category of Upper valley; Station No. 61009 (at Melka Wakena) and Station no. 61015 (Maribo at Kara Birole) belong to the middle valley category.

Discriminant Analysis: After homogeneous regions have been identified, a test was carried out to find out whether the proposed pool was reasonably homogeneous. This involved computing a statistic Cc, known as the coefficient of variation of the at-site LL-coeffcients of variation (see next section). A homogeneous region was expected to have a low value of Cc. The proposed pool was further sub-divided if the value of Cc was found to be more than 0.3. This value was considered a reasonable upper limit to consider regional homogeneity.

$$D_{ij} = \sqrt{\left(\frac{A_i - A_j}{stdev(A)}\right)^2 \times \left(\frac{MAP_i - MAP_j}{stdev(MAP)}\right)^2 \times \left(\frac{Elev_i - Elev_j}{stdev(Elev)}\right)^2 \times \left(\frac{HyG_i - HyG_j}{stdev(HyG)}\right)^2 \times \left(\frac{NDVI_i - NDVI_j}{stdev(NDVI)}\right)^2}$$

Excluding station no. 61006, which has large l_{L2}, pool A yielded Cc of 0.388 which is higher than the reasonable limit. In the absence of station no. 61009 pool B yielded Cc of 0.168. The null hypothesis that pool B is hydrologically homogeneous cannot be rejected. Thus station no. 61015 cannot be statistically justified to be out of pool A as it's indicated in the cluster analysis. However it is more likely that station no. 61009 belongs to another cluster.

Trial	Sub-catchment (Station No.)	Region	C.C
1	61001; 61002; 61003; 61004; 61005; 61006; 61009; 61015	Whole	0.694
2	61001; 61002; 61003; 61004; 61005; 61015; 61009;	Pool A	0.388
3	61001; 61002; 61003; 61004; 61005; 61015;	Pool B	0.168
4	61006; 61009; 61015	Pool C	0.26
5	61006; 61009;	Pool D	0.066

Table 2. Coeffcient of variation of l_{L2} for each cluster proposed.

LL-moments : Analogous to LH-moments applied for upper tail of the distribution, LL-moments give more weight to the smaller observations and place an emphasis on fitting the lower tail of the selected probability distribution. Quantiles have lower biases when estimated by LL-moments. LL-moments can be defined using samples of size r+m (m=1,2,...) and computing the expectations for the r smallest elements of the sample:

$$\lambda_{Lr}^{m} = r^{-1}\sum^{k}(-1)\binom{r-1}{k}E[x_{r-k/r+m}] \qquad r=1,2,...$$

where m=0 corresponds to the L-moments. An increase of m increases the weight of the lower part of the data. The first two LL-moments are:

$$\lambda_{L1}^{m} = E[X_{1/1+m}] \quad \lambda_{L2}^{m} = E[X_{2/2+m} - X_{1/2+m}]$$

Using equation (a) above, LL-moments can be expressed in terms of the distribution function F(x):

$$\lambda_{L1}^{m} = (1+m)\int_0^1 x(F)(1-F)^m dF$$

$$\lambda_{L2}^{m} = \frac{1}{2}\left[(1+m)(2+m)\int_0^1 x(F)(1-F)^m dF - (2+m)\int_0^1 x(F)(1-F)^{1+m} dF\right]$$

Expressions to estimate the LL-moments from a sample of size n arranged in ascending order can be derived following the approach of Wang (1996). Consider equation (b) for λ_{L1}^{m}. In a sample of size n, there are i – 1 values less than (or equal to) X_i and n – i values greater than (or equal to) x_i. For x_i to be the smallest of any combination of 1 + m values from the sample, the other m must come from the n – i larger values. There are $\binom{n-i}{m}$ such combinations. The total number of combinations is $\binom{n}{1+m}$

Therefore the estimate of λ_{L1}^{m} is :

$$\lambda_{L1}^{m} = \sum\binom{n-1}{m}x_i / \binom{n}{1+m}$$

Simalarly for x_i to be the second smallest of any combination of 2 + m values from the sample, m must come from the n – i larger values ($\binom{n-i}{m}$ combinations) and one element must come from i – 1 smaller values. For x_i to be the smallest of any combination of 2 + m values from the sample, 1 + m must come from the n – i larger values ($\binom{n-i}{1+m}$ such combinations). The total number of combinations is $\binom{n}{2+m}$ Therefore, λ_{L2}^{m} can be estimated as:

$$\lambda_{L2}^{m} = \sum\left[\binom{n-i}{m}\binom{i-1}{1} - \binom{n-i}{1+m}\right]x_i / 2\binom{n}{2+m}$$

Regionalization

Weibull distribution: Many literatures recommend Weibul distribution to analyse the frequency of low flows because it has a lower bound and also because of the appeal of the extreme value theory in statistics, in the context of annual minima.

The probability density function (pdf) and the distribution function of the Weibull distribution is presented in different ways and with different notations in the literature. In this paper the following form is used:

$$f(x) = \left(\frac{\theta_1}{\theta_2}\right)(x-\theta_3)^{\theta_1 - 1}\exp(-(x-\theta_3)^{\frac{\theta_1}{\theta_2}})$$

$$F(x) = 1 - \exp(-(x-\theta_3)^{\frac{\theta_1}{\theta_2}})$$

Where

q_1=shape parameter

q_2=scale parameter

q_3=lower bound (displacement) parameter

If the lower bound is equal to zero, i.e. if the probable minimum flow is zero or that there is the extreme possibility of the stream completely drying up, then the distribution takes the two parameter form. In fitting a three parameter distribution the following three types of failures occur:

(i) lower bound parameter is less than zero (q_3<0)

(ii) lower bound parameter is larger than the lowest observed discharge (q_3>Q_{min})

(iii) procedure fails to produce results

There are no failures in the two parameter procedures. Hence, unless clear evidence strongly suggest otherwise, for a particular set of data, it is always desirable to use two parameter procedures.

The inverse of the two parameter Weibull probability distribution function is

$$x(F) = \theta_2(-\ln(1-F(x))^{\frac{1}{\theta_1}} \quad x \geq 0$$

LL-moments can be computed using equation

$$\lambda_{L1}^{m} = (1+m)\int_0^1 \theta_2[-\ln(1-F)]^{\frac{1}{\theta_1}}(1-F)^m dF = \theta_2\Gamma\left(1+\frac{1}{\theta_1}\right)/(1+m)^{\frac{1}{\theta_1}}$$

$$\lambda_{L2}^{m} = \theta_2\Gamma\left(1+\frac{1}{\theta_1}\right)\left(\frac{2+m}{2}\right)\left[\frac{1}{(1+m)^{\frac{1}{\theta_1}}} - \frac{1}{(2+m)^{\frac{1}{\theta}}}\right]$$

Solving for the parameters K and a:

$$\theta_2 = (1+m)^{\frac{1}{\theta_1}}\lambda_{L1}^{m}/\Gamma\left(1+\frac{1}{\theta_1}\right) \quad \theta_1 = \ln\left(\frac{1+m}{2+m}\right)/\ln\left(1-\frac{2CV_L^{m}}{2+m}\right)$$

$CV_L^{m} = \lambda_{L2}^{m}/\lambda_{L1}^{m}$ where CV_L^{m} is the LL-moment coefficient of variation.

Power distribution: The power distribution has the upper bound X_0 and therefore it is a conditional distribution $F(x / X \leq x_0)$ (Onoz & Bayazit,2001).

Its inverse is given as:

$$x(F) = x_0 F^{\frac{1}{c}} \qquad 0 \leq x \leq x_0$$

Combining equation (27) with equation (9), one obtains:

$$\lambda_{L1}^{m} = (1+m)\, x_0\, \Gamma\left(1+\frac{1}{c}\right)\Gamma(1+m) / \Gamma\left(2+\frac{1}{c}+m\right)$$

$$\lambda_{L2}^{m} = (2+m)\, x_0 \left[(1+m)\Gamma\left(2+\frac{1}{c}\right)\Gamma(1+m) - \Gamma\left(1+\frac{1}{c}\right)\Gamma(2+m)\right] / 2\Gamma\left(3+\frac{1}{c}+m\right)$$

Solving for the parameters c and x_0, one obtains:

$$c = \left[\left(1+\frac{m}{2}\right)\frac{1}{CV_L^{m}} - 1\right] / (2+m) \qquad x_0 = \frac{(1+c)(1+2c)\ldots\{1+(1+m)c\}\,\lambda_{L1}^{m}}{(1+m)\, c^{1+m}}$$

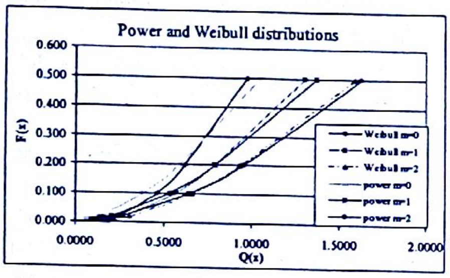

Fig 2 *Plots of probability versus low flow using Power and Weibull distributions.*

There is a drastic decline in the estimated quantiles using L-moments with increase in return period when the full data is considered

Conclusion

Quantile estimation of the fitted Weibull and power distributions differ when L-moments or LL-moments of various m values are used. Differences are larger when T increases. Estimates of quantiles for the lower 80% of the data using L-moments show minimum differences as that of the ones computed using LL-moments. Parameter estimation using LL moments gives more weight to the smaller observations in the sample.

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T (year)	Weibull (LL-moment)			Power (LL-moment)			Weibull, L-moments	
	m=0	m=1	m=2	m=0	m=1	m=2	lower 80%	Full data
2	0.995	0.980	0.996	1.363	1.210	1.332	1.232	0.927
5	0.850	0.828	0.849	1.132	1.019	1.145	1.099	0.309
10	0.766	0.740	0.764	0.984	0.895	1.021	1.019	0.150
50	0.609	0.578	0.605	0.711	0.662	0.782	0.863	0.030
100	0.552	0.521	0.548	0.618	0.582	0.697	0.804	0.015
150	0.522	0.490	0.518	0.569	0.539	0.652	0.772	0.010

Table 3. Low flow quantiles estimated by Weibull and power distributions using LL and L- moments of the lower 80% of the data.

Fishes as Bioindicators of Lake Water Pollution

Abayneh Ataro, AWTI, P.O.Box 21, Arbaminch

Abstract

Samples of two fish species (Tilapia *Oreochromis niloticus* and Catfish *Clarias gariepinus*) were collected from six sampling stations in Lakes Awassa and Ziway. The edible portion was separated and placed in a freeze-drying unit until constant mass was obtained. The calculated moisture content of the two fish species obtained from six sites in the two lakes varied from 79.3%-82.5%. Different digestion procedures were tested by varying types of reagents and temperature of digestion in an attempt to develop a protocol that consumes less reagent volume and requires short digestion time for mineralizing 2.0 g dried and powdered fish muscle. The optimal procedure required 7.0 hours and consumed 8.0 mL of 70% HNO_3, 2.0 mL of 98% H_2SO_4 and 10 mL of 35% H_2O_2 to completely digest 2.0 g of fish sample under reflux. The accuracy of the optimal procedure was checked by digesting a mixture of standard solutions or spiked fish samples and subsequently determining percent recovery. Recoveries varied from 98.5%-123% in a mixture of standard solutions and from 92.5%-120% in spiked fish samples. Trace metal concentrations in the two fish species were measured by flame atomic absorption spectrometer employing an external calibration graph. Concentrations of trace elements in the fishes ranged (μg element/g dry mass): Zn 23.04-30.92; Fe 19.25-59.75; Cu 1.03-2.78; Mn 1.54-4.46; Cd < 0.24; Pb < 1.66; Ni < 0.99; and Co < 0.71. The maximum levels of trace metals found in edible portion of fishes were far below the thresholds. Hence, without regard to bioavailability, *O. niloticus* and *C. gariepinus* may be considered safe for human consumption relative to the analyzed elements.

Keywords/Phrases: Bioindicators of lake pollution; *Clarias gariepinus*; Lakes; *Oreochromis niloticus*; Trace metals.

Introduction

Land degradation and growing trends in industrialization in Ethiopia have raised concerns about pollution of water bodies (in particular of lakes). However, lack of information hinders provision of comprehensive historical background of lake water pollution. The few scientific investigations carried out on Ethiopian lakes show the initiation of interest in the studies of lake water degradation. Talling and Talling (1965) measured concentrations of iron in Lakes Ziway, Langano, Abaya, Shala, Abijata and Methara. Baumann *et al.* (1975) recorded the concentrations of three heavy metals (copper, zinc and lead) among other elements, in Lakes Langano, Abijata, Shala and Chitu, and the study of Lake Abaya by Klein (1977) was primarily concerned with trace metals.

Recently the work by Telford (1998) indicated the presence of many trace metals in Lake Awassa. More recently Tamiru Alemayehu (2000) reported concentrations of some trace metals in Lake Langano, Edu Geyser, Oitu spring, Lake Shalla, Eastern Shalla spring, Wonji Bulbula spring, Gergedi spring and Awash River (at Wonji). Despite these findings in lake waters, hot springs and rivers, there has been paucity of literature on the trace metal accumulation by fish. This information is desirable because fish resources are important bioindicators of pollution.

Fishes in freshwater environments near urban and industrial locations are often subjected to pollutants due to run-off and in most cases deliberate discharges (Gbem *et al.*, 2001). Exposure of fish to water contaminated with trace metals can result in a significant accumulation of trace metals in their flesh (Jerzy, 1995; Farrell *et al.*, 2000). Several researchers have monitored the water quality by fish analysis, because higher and relatively stable concentrations would be obtained for fish samples compared with the water itself (Adeyeye, 1994; Yamazaki *et al.*, 1996; Camusso *et al.*, 1998). Thus, fishes have been proposed as bioindicators to monitor a variety of contaminants in the marine ecosystem (Astorga-Espana *et al.*, 1999).

The purpose of this study is therefore, to investigate some selected trace metals (Zn, Fe, Cu, Cd, Pb, Ni, Co and Mn) concentrations in edible parts of Tilapia *Oreochromis niloticus* and Catfish *Clarias gariepinus* of Lake Awassa and Lake Ziway, and to evaluate the quality of these fishes on the basis of their trace metals contents. *Oreochromis niloticus* and *Clarias gariepinus* are selected in this study since these species are commercially exploited in both lakes and commonly found in other lakes and rivers in Ethiopia. Results obtained, hopefully, will establish baseline data on trace metals in aquatic resources and will enable evaluation of future trends in environmental contamination in Ethiopia.

Materials and Methods

Study areas

Lake Awassa: This lake is believed to be volcano-tectonic in origin. Lake Awassa is located 6°33'-7°33'N latitude and 38°22'-39°29'E longitude (Demeke Admassu, 1989). It has an altitude of 1680 m. Lake Awassa has an area of 88 km², a maximum depth of 22 m and a mean depth of 11 m (Elias Dadebo, 2000). The Tikurwuha River at the northeastern shore is the only inlet (Demeke Admassu, 1989). The intensive cultivation of the surroundings of the lake and atmospheric deposition of particulate matter may cause pollution of the lake. Furthermore, Lake Awassa is likely to be affected by industrial sources because its in-flow (Tikurwuha) receives effluents from the Awassa textile factory and Tabor ceramic factory.

Lake Ziway: It lies within a broad

down faulted basin. The lake contains five main islands (Tulu Gudo, Gelila, Tedecha, Funduro and Debre Sina) of volcanic origin (Schroder, 1984). Lake Ziway is located 7°52'-8°8'N latitude and 38°40'-38°56'E longitude (Makin *et al.*, 1975). The altitude of Lake Ziway is 1636 m above sea level. It has an area of 440 km², a maximum depth of 8.9 m and a mean depth of 2.5 m (Tenalem Ayenew, 1998). Lake Ziway is fed by the two major rivers Meki and Katar, which drain from the Northwestern and Southeastern plateaus, respectively (Von Damm and Edmond, 1984). Lake Ziway is being used for irrigation purposes and much of the land around it is under continuous cultivation, which may cause contamination of fish. Like Lake Awassa, Lake Ziway is also prone to contamination from land degradation and consequent atmospheric deposition.

Sampling of fresh fish

Samples were collected from three stations in each of Lakes Awassa and Ziway in February 1 and 2, 2002, respectively. Minch, Tikurwuha and Deset served as sampling sites in Lake Awassa, whereas Shalo, Kofe and Koli in Lake Ziway (Figures 1 and 2). Two fish species, Catfish and Tilapia were caught with gill net from each sampling location of the Lakes. The fishes were dissected with plastic knife and stomach contents were purged. The fish samples were wrapped with plastic bags and placed in an icebox and transported to the Laboratory. Samples were then stored at −20°C until taken out for drying.

Sample preparation

The edible muscle of fish was separated with plastic knife and placed in a 100 mL volumetric flask. Wet mass was determined and the edible tissue was placed in a freeze-drying unit (FREEZE DRY-3, LABCONCO, KANSAS CITY, MISSOURI) for seven days until constant mass was obtained. The lyophilized fish was ground and homogenized in a blending device (Moulinex, France). The procedure developed by Van Loon (1985) was tested for the digestion of 2.0 g of powdered fish with a mixture of concentrated solutions of HNO_3 (SpectrosoL, BDH), 98% H_2SO_4 (AnalaR, BDH) and 35% H_2O_2 (Riedel-de Haen, Germany). Different modifications of this procedure obtained by varying types of reagents and temperature of digestion were subsequently tested.

Besides digesting the fish muscle completely, the procedure employed in this work consumed less reagent volume and required short digestion time. This procedure was carried out as follows: A 2.0-g aliquot of the dried and homogenized fish was added to a 100 mL round bottom flask. To the flask 4.0 mL of 70% HNO_3 was added followed by 2.0 mL of 98% H_2SO_4. When the reaction subsided, the flask fitted with water-cooled reflux condenser was placed in a Kjeldahl apparatus (Gallenkamp, Germany), heated to 100 ± 5°C and the contents were boiled for 30 minutes under reflux. The flask was removed from the Kjeldahl apparatus and allowed to cool for 5 minutes. The flask was placed in the Kjeldahl apparatus after adding another 4.0 mL HNO_3. The temperature was then increased to 190°C and the contents were heated at 190 ± 5°C for 2 hours, while the sample was boiling under reflux. The condenser was removed and the sample was heated near to dryness for 20 to 25 minutes at 190 ± 5°C. The flask was then removed and allowed to cool for 5 minutes. A 10.0 mL aliquot of hydrogen peroxide (35%) was added in 2.0 mL portions and the contents were heated at 190 ± 5°C while the sample was boiling under reflux until clear solution was obtained. The flask was removed from the Kjeldahl apparatus and the contents were cooled for 5 minutes. With a long glass dropper, the colorless solution in the digestion flask and the washings were carefully transferred to 25 mL volumetric flask and diluted to volume with distilled water.

Determination of trace metals

Standard stock solutions (BUCK SCIENTIFIC) that contained 1000 ppm of metals were systematically diluted to obtain series of working standards (0.1-3.6 mg metal/g). Three standard solutions were prepared for each metal. A blank solution and the standards were run in the atomic absorption spectrophotometer (BUCK SCIENTIFIC MODEL 210VGP) with air-acetylene flame and four point calibration curves were established. Sample solutions were each aspirated into the atomic absorption spectrophotometer (AAS) and direct readings of metal concentrations were recorded. Three replicate determinations were carried out on each sample.

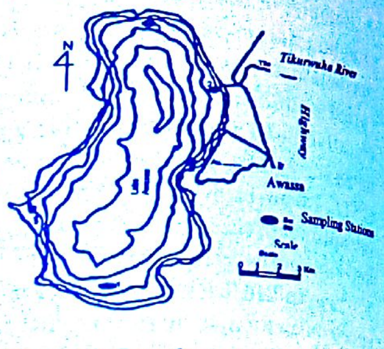

***Figure 1.** Sampling stations in Lake Awassa: 1) Minch; 2) Tikurwuha; 3) Deset.*

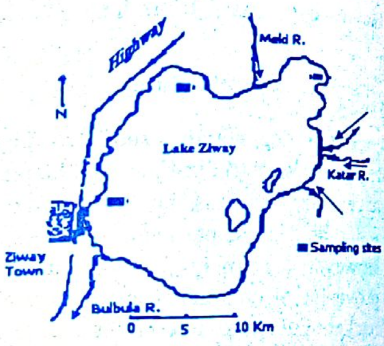

***Figure 2.** Sampling sites in Lake Ziway: 1) Shalo; 2) Kofe; 3) Koli.*

Recovery study

Two alternative techniques were used to evaluate the recovery of the digestion procedure. In the first case, a mixture of the standard solutions was digested in triplicate employing the optimized digestion procedure. Accordingly, aliquots (50 μL) of Fe, Zn, Co and Ni; 25 μL of Pb; and 10 μL of Cu, Cd and Mn were taken from the corresponding 1000-ppm stock standard solutions and transferred into a 100 mL round bottom digestion flasks. Digestion was done as described above for fish sample. The digests and the corresponding washings of the flask were carefully transferred into a 25 mL volumetric flask using a clean long glass dropper. The contents were diluted to volume and concentrations of the metals in the standards were determined with AAS using external calibration graphs as described above.

In the second case, a 2.0 g sample of the powdered fish was spiked with measured volumes of standard solutions of the metals: aliquots of Zn, Fe, Pb, Ni and Co (each 25 μL, 1000 ppm) and Cu, Cd, Mn (each 10 μL, 1000 ppm) were added to the digestion flask containing the powdered fish tissue. The optimized digestion procedure was applied. The resulting clear digests and washings were transferred into volumetric flask and diluted to 25 mL. Trace metals were determined with AAS using external calibration curve.

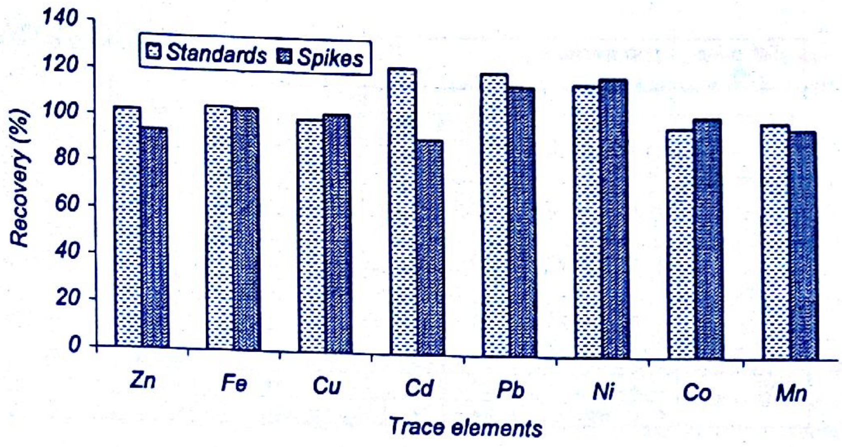

Figure 3. Recovery of trace metals in a mixture of standard solutions and spiked fish samples.

Results

Dry mass determination

In order to attain comparability between different fish species and samples, determination of dry mass of fish samples was necessary. Edible portions of each fish sample (*O. niloticus* or *C. gariepinus*) obtained from six sampling sites in Lakes Awassa and Ziway were placed separately in 100 mL thick-walled flasks and freeze-dried for seven days to constant mass. The percent loss in mass of fish was calculated as moisture content. The calculated percentage moisture content of the two fish species obtained from different spots in the two lakes varied from 79.3%-82.5%.

Efficiency of the optimized digestion procedure

Efficiency of the optimized digestion method was checked by mineralizing standard solutions of metals or spiked fish samples. The digests of standard solutions were diluted and trace elements were determined using AAS. Recoveries of metals in standard solutions analyzed gave values between 98.50% and 123.25%. Fish samples spiked with standard solutions of trace metals and digested following the optimal protocol yielded recoveries ranging from 92.5%-120% (Figure 3).

Concentrations of trace metals

The results on metals in fishes from Lake Awassa and Lake Ziway are compiled in Table 1. Zinc concentrations in fishes from two lakes varied from 23.04-30.92 μg/g dry masses. Iron ranged from 19.25-59.75 μg/g, with highest concentration being found in *Clarias gariepinus* from Koli station in Lake Ziway. Copper concentrations varied from 1.03-2.78 μg/g for the two species from both lakes. Manganese concentrations ranged from 1.54-4.46 μg/g, with the highest concentration being found in *Oreochromis niloticus* from Tikurwuha station in Lake Awassa.

The results obtained for cadmium, lead, nickel and cobalt for all samples were below the limits of detection, 0.24, 1.66, 0.99 and 0.71 μg/g dry mass, respectively.

Discussion

Water content of fishes

Use of dry masses rather than wet provides a more accurate measure of metal load since water content in biota varies with species, age, condition, etc. Moreover, comparisons between fishes can easily be made on dry mass basis. For this reason, water content was removed from the edible muscle of fishes by freeze-drying until constant mass was obtained. Such a determination resulted in the average water content of 81.06 ± 1.00% in the edible muscle. This transpires to a wet mass/dry mass ratio of 5.3 taking wet mass as 100% and dry mass as ~19%. Zauke *et al.* (1999) reported moisture content of 82% with wet mass/dry mass ratio of 5.6 for muscle, which is in good agreement with our data validating our method of moisture content determination. However, the moisture content of fish muscle reported by Windom *et al.* (1973) ranged from 65 to 78% for all samples analyzed. The observed difference between our data and that of Windom *et al.* (1973) could probably be attributed to difference in methods of determination. In our study, the water contents reveal absence of interspecies difference between fishes from the two lakes.

Digestion of fish samples

To transfer trace elements in fish tissues into aqueous solutions, appropriate digestion procedures are required. Such procedures permit the use of inorganic salts as calibration standards for the determination of trace elements in fishes. It is important that such procedures avoid analyte loss and be free from risk of contamination. Literature reports (Bock, 1979; Evans *et al.*, 1986) recommend different combinations of mineral acids with hydrogen peroxide to mineralize fish tissue in open vessels. However, many of such procedures used to digest fish tissue require long digestion times or large reagent volumes.

In this study, different digestion procedures were tested to mineralize dried and powdered fish samples. We wished to reduce the time taken, the volume of reagent consumed as well as to minimize contamination. At the beginning, the open-vessel digestion procedure developed by Van Loon (1985) was repeated to digest 2.0 g of dried fish sample. Such attempt gave clear solutions but the procedure consumed larger reagent volumes and required longer digestion time. As it consumed

Sampling site	Fish species	Concentration of metals (µg/g)							
		Zn	Fe	Cu	Cd	Pb	Ni	Co	Mn
Minch	*O. niloticus*	27.00 ± 2.16	32.38 ± 2.13	1.85 ± 0.21	< 0.24	< 1.66	< 0.99	< 0.71	2.56 ± 0.31
	C. gariepinus	26.04 ± 1.92	27.19 ± 0.19	1.63 ± 0.53	< 0.24	< 1.66	< 0.99	< 0.71	1.79 ± 0.11
Tikurwuha	*O. niloticus*	24.04 ± 1.88	31.81 ± 2.69	1.71 ± 0.06	< 0.24	< 1.66	< 0.99	< 0.71	4.46 ± 0.39
	C. gariepinus	23.75 ± 0.89	31.69 ± 4.19	1.52 ± 0.33	< 0.24	< 1.66	< 0.99	< 0.71	1.76 ± 0.11
Deset	*O. niloticus*	24.42 ± 1.91	22.94 ± 2.69	1.39 ±0.16	< 0.24	< 1.66	< 0.99	< 0.71	1.74 ± 0.08
	C. gariepinus	23.04 ± 1.93	27.13 ± 0.13	1.44 ± 0.09	< 0.24	< 1.66	< 0.99	< 0.71	1.54 ± 0.09
Shalo	*O. niloticus*	30.92 ± 0.65	19.25 ± 1.25	1.98 ± 0.04	< 0.24	< 1.66	< 0.99	< 0.71	1.66 ± 0.05
	C. gariepinus	25.21 ± 1.75	38.88 ± 0.75	2.78 ± 0.34	< 0.24	< 1.66	< 0.99	< 0.71	1.99 ± 0.16
Kofe	*O. niloticus*	28.04 ± 0.95	20.44 ± 1.44	1.34 ± 0.22	< 0.24	< 1.66	< 0.99	< 0.71	1.93 ± 0.13
	C. gariepinus	26.54 ± 1.45	30.00 ± 0.50	1.55 ± 0.28	< 0.24	< 1.66	< 0.99	< 0.71	1.76 ± 0.04
Koli	*O. niloticus*	26.29 ± 0.77	29.50 ± 7.63	1.03 ± 0.14	< 0.24	< 1.66	< 0.99	< 0.71	2.13 ± 0.19
	C. gariepinus	29.88 ± 1.74	59.75 ± 10.38	2.75 ± 0.53	< 0.24	< 1.66	< 0.99	< 0.71	2.49 ± 0.39

Table 1: *Trace metal concentrations (mean ± SD; µg metal/g dry mass) of selected fish species in Lakes Awassa and Ziway (n=3).*

larger volume of reagents and required longer digestion time modification of Van Loon's procedure was necessary. The modified procedure consumed lesser reagent volumes and required shorter digestion time than Van Loon's procedure (Van Loon, 1985). Possible explanation for this difference could presumably be attributed to the use of open systems without refluxing by Van Loon, which could lead to loss of solvents, by volatilization. Moreover, Van Loon's procedure could very likely be prone to contamination and losses of analytes due to volatilization. Refluxing has the advantage in decreasing blank values due to reduced reagent volumes and decreased contamination from the laboratory environment. Furthermore, increasing initial temperature of digestion coupled with refluxing considerably reduced the time required for digestion and the volume of reagents needed.

Validation of the optimized digestion procedure

The accuracy of the optimal digestion procedure was evaluated by analyzing digests of standard stock solutions and spiked fish samples. Good recoveries were obtained for zinc, iron, copper, cobalt and manganese, confirming the validity of the method developed. However, somewhat elevated recoveries were observed for cadmium, lead and nickel. Contaminants from reagents and vessels employed in the analysis may be responsible for these elevated recoveries. This was also evidenced by high blank concentrations for cadmium, lead and nickel. Similarly, trace metals were also recovered quantitatively from spiked fish samples. Recoveries from digests of standard solutions and spiked fish samples were in close agreement for Zn, Fe, Cu, Pb, Ni, Co and Mn (Figure 3), whereas, lower recovery of Cd was recorded in spiked fish samples. This may be attributed to the matrix effect of spiked fish digests.

Trace metals in fishes

The concentrations of eight trace metals (Zn, Fe, Cu, Cd, Pb, Ni, Co and Mn) in the digested and diluted solutions of fish tissues were determined with flame AAS employing external calibration method (Table 1). Elements Cd, Pb, Ni and Co were found below the detection limits in both fish species obtained from both lakes.

The t-test statistical method was employed to permit evaluation of possible interrelationships among the concentrations of metals in fishes. Applying t-test at 95 percent confidence level, the results revealed absence of significant difference in concentrations of the analyzed trace metals between *Oreochromis niloticus* and *Clarias gariepinus* in Lake Awassa. Similarly, no interspecies variability was observed in concentrations of all trace metals in Lake Ziway. Moreover, the differences in concentrations of trace metals among *Oreochromis niloticus* of both lakes were not significant. The variation of concentrations of trace metals among *Clarias gariepinus* of Lake Awassa and Lake Ziway was also insignificant. Absence of significant difference in the concentrations of trace elements in fishes might indicate absence of a distinctly pronounced influence from the environment in one of the lakes.

Lakes Awassa and Ziway belong to the same geochemical setting. Moreover, both lakes are prone to influences of anthropogenic origin, mainly related to agricultural activities and to atmospheric deposition of particulate matter. In addition, Lake Awassa receives industrial waste from the Awassa textile factory and the Tabor ceramic factory. Nevertheless, the lake seems to have a natural capacity to dilute the contaminants associated with the influent waste.

The results of this study have shown the accumulation of zinc, iron, copper and manganese in edible parts of *Oreochromis niloticus* and *Clarias gariepinus*. However, the results do not suggest the presence of any noticeable artificial contamination of fishes. This is evidenced by the low levels of cadmium and lead (below detection limit, Table 1) in fish muscles. Although a human impact within the catchments is not absent, those detected elements seem to be mainly geologically derived. Since thermal springs can be sources of heavy metals, the continuous input from such sources into fresh surface water bodies can change the overall chemical composition of the water. Furthermore, the lakes serve as major destination points for deep mineralized thermal water (Tamiru Alemayehu, 2000). With increasing rate of deforestation in the catchment areas, surface run off could contribute to the total stock of trace elements in the lakes.

While trace metal levels in analyzed fish species from Lakes Awassa and Ziway were not appreciable, despite anthropogenic pressure in the area (Zinabu Gebre Mariam and Elias Dadebo, 1989); the impacts on fishes of Lakes Awassa and Ziway will certainly be detectable in the near future. Since both lakes are in the neighborhood of fast growing cities, it is very likely that more domestic and industrial waste will find way directly into the lakes and elevate the levels of trace metals in fishes. The studies on trace metal accumulation in *Clarias gariepinus* exposed to sublethal levels of tannery effluent by Gbem *et al.* (2001) in Nigeria indicated the accumulation of metals to be concentration and time dependent. As a matter of fact, the fishes of Lakes Awassa and Ziway could presumably accumulate high metal concentrations with industrialization through time. Therefore, before irreversible changes occur, it is wise to show concern right from the start of industrialization.

Although there are interspecies differences in the uptake by and fate of elements in fish, no published data on species under study are available. Therefore, we found it plausible to compare muscle concentrations of metals determined in the present study with reported values of other species. Even though higher concentrations of zinc and iron than other metals in both species were obtained, these values are not exceptionally high when compared to reported values from different fish species. The concentration of iron reported by John *et al.* (1977) from *Brook silverside* species collected from Par Pond of South Carolina was 149.3 μg /g dry mass. Cohen *et al.* (2001) found 650 μg/g zinc and 440 μg/g copper in *Tagelus californianus* from Ballona Lagoon of California Coastal Wetland. These values are very much higher than the highest values obtained in our study for zinc (30.92 μg/g) and copper (2.78 μg/g).

Cohen *et al.* (2001) also reported 0.90 μg/g of cadmium, 6.8 μg/g of lead and 37 μg/g of nickel. Windom *et al.* (1973) detected cadmium as high as 1.6 μg/g from some species of North Atlantic Finfish. However, the concentrations of cadmium, lead and nickel are below detection limits in all samples we investigated.

Glover (1979) recorded concentrations of zinc (4.8 μg/g), copper (0.6 μg/g), cadmium (0.08 μg/g), lead (< 0.1 μg/g), nickel (< 0.2 μg/g), cobalt (< 0.3 μg/g) and manganese (0.6 μg/g) on wet mass basis from fishes in South-eastern Australian Waters. A definitive comparison among concentrations of trace elements in fishes from Lakes Awassa and Ziway may be made with literature values only when the geological setting, environmental and climatic conditions are known unambiguously. Without concern to this fact, the values obtained in the present study are found to lie within the same range to Glover's data (1979) on wet mass basis. However, cadmium has been found to be an exception. Astorga-Espana *et al.* (1999) determined 29.6 μg/g of Zn and 23.9 μg/g of Fe in fish from Canary Islands. These values are also within the same range of concentrations of the corresponding metals in fishes from Lakes Awassa and Ziway.

Comparison between trace metals concentrations in fishes and in lake waters

Table 2 shows the concentrations of trace metals in fishes of Lake Awassa and reported concentrations of metals in the lake water (Telford, 1998). As the concentration of metals in lake water increases the concentrations of the corresponding metals in fishes increase accordingly. This trend is demonstrated by our data and is consistent with theoretical predictions. Such observations also give additional support to the validity of our data.

The concentration of cobalt in fishes apparently looks higher than that in water. However, 0.71 μg Co/g of fish listed in the table above was the minimum concentration detectable by our method and does not suggest a higher concentration than that in water.

***Table 2:** Comparison of concentrations of trace metals in fish of Lake Awassa with reported concentration of lake water (Telford, 1998).*

Element	Concentration In Fish (μG/G)	Concentration In Lake Water (ug/L)
Zn	27.00	90.11
Fe	32.38	210
Cu	1.85	5.39
Cd	< 0.24	0.47
Pb	< 1.66	7.47
Ni	< 0.99	1.5
Co	< 0.71	0.07
Mn	4.46	24.54

To see the relationship between concentrations of metals in fishes and in lake waters, a plot was made using trace elements in the lake water as Y-axis and those in fish as X-axis. Such a plot (Figure 4) exhibits a strong correlation (r = 0.91) between concentration of trace elements in fishes and in the lake water, although the concentrations of trace metals in fishes are much higher than in the lake water. The concentrations of Cu, Mn, Zn and Fe in fishes increase with increasing concentration of these elements in the lake water. Thus, the investigated fishes seem to accumulate trace elements in their tissues and *Oreochromis niloticus* and *Clarias gariepinus* may be considered as important fish species for monitoring the level of trace metals.

Comparison of trace metals in fishes with the European dietary standards and guidelines

To evaluate whether metal levels found in fish samples from Lakes Awassa and Ziway are safe for human consumption, a comparison is made with reference values for fish muscles. The validity of such comparison may appear questionable. However, in the absence of national standards and guidelines, a comparison of this kind may provide preliminary idea about safety levels of our lake water fishes. Dietary standards and guidelines have been summarized by MAFF (1995). The guideline limits for cadmium, lead, copper and zinc are 0.2, 2.0, 20 and 50 mg/kg wet mass, respectively. The range of reference values proposed and issued in some European countries is rather narrow. In Russia (Zauke *et al.*, 1999), the maximum permissible value is 0.2 mg Cd/kg, 1.0mg Pb/kg, 10 mg Cu/kg and 40 mg Zn/kg (wet mass) whereas in Germany (Zauke *et al.*, 1999), 0.10 mg Cd kg^{-1} and 0.50 mg Pb kg^{-1} (wet mass) considered as critical values.

The maximum concentration of zinc found in fishes from Lakes Awassa and Ziway was 5.83 mg/kg wet mass. This value is about 7 times lower than the maximum permissible level (Zauke *et al.*, 1999). The maximum concentration of copper (0.52 mg/kg wet mass) detected in fishes from Lakes Awassa and Ziway was about 19 times lower than the critical value. The results for all fish samples

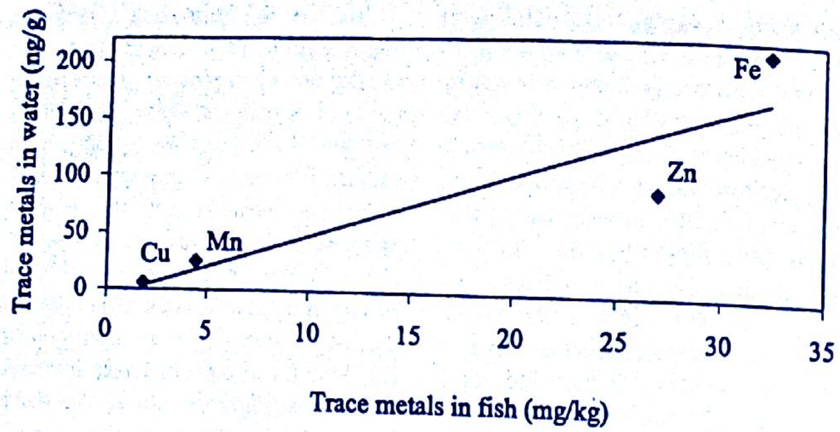

Figure 4. Relationship between trace metal concentrations in fishes and in the lake water of Awassa.

analyzed in this study revealed low concentrations of Cd and Pb (< 0.045 mg Cd/kg and < 0.31 mg Pb/kg wet mass) which are below the detection limits. Since the maximum levels of these trace metals found in edible portion of fishes are far below the thresholds, the analyzed fish species may be considered as safe for human consumption relative to the analyzed elements.

Conclusion & Recommendations

An efficient procedure for the digestion of edible tissue of fish has been developed and validated through recovery studies. Using the optimal digestion procedure, similar concentrations of trace metals in fishes (*Oreochromis niloticus* and *Clarias gariepinus*) from the two lakes were observed. Moreover, results revealed absence of any reliable interspecies differences in the content of trace metals in fish muscle tissue. Furthermore, *Oreochromis niloticus* and *Clarias gariepinus* tend to accumulate trace metals and thus, they may be considered as useful species for monitoring pollution of lakes by trace metals.

Although this data set is relatively small to draw authoritative conclusions about the status of the lakes, the survey has indicated the accumulation of trace metals (Zn, Fe, Cu and Mn) in fish muscle tissue and provided baseline data for comparison with possible future changes. However, compared to more industrialized regions, the concentrations of trace metals from fishes of Lakes Awassa and Ziway are low. The fish muscles in this study were also in safety baseline levels for human consumption relative to the analyzed elements.

Even though our findings do not indicate the contamination of fishes by trace metals from Lakes Awassa and Ziway, it is wise to take control measures right from the initial stage of industrialization. Control measures and management practices such as afforestation of the catchment area and proper treatment of industrial as well as domestic waste before discharging into the lakes are necessary to minimize pollution of the lakes. Otherwise, it is not too far that the impacts from industrial wastes together with other human activities in Lake Awassa will become detectable in fishes. Since much of the land around Lake Ziway is under continuous cultivation, which may cause contamination of fishes, proper care and management are necessary before these resources are endangered.

To assess metal accumulation, we examined only the fish muscle, which is the most important part to be used for human consumption. However, other tissues and organs such as liver, kidney, gills, gut, bones and scales may be equally important for evaluating accumulation of certain elements in fishes. Thus, our future studies will focus on the analysis of trace metals in different organs of fishes, sediments and water to establish correlation between different environmental compartments.

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Field Erosion and Model Verification

Agunwamba, J.C. Tanko, J.A**. & Ukpong, E.C**
AWTI,ETHIOPIA (Nigerian Technical Aid Corps Volunteer).

Abstract

Erosion study was undertaken at the old Government Residential Area in Port Harcourt, River State, Nigeria on a terrain of low vegetation density with an area of 68.00m². Soil analysis performed in the Geotechnical laboratory at UNN classified the soil as silty sandy soil with low infiltration capacity. The average specific gravity, cohesion and angle of internal friction were 2.28, 66.67KN/m² and 27.95° respectively. Data on soil loss and the amount and duration of rainfall were collected between September 1991 and May 1992. The run-off coefficient was found to be 0.3152. There was a good linear relationship between the rate of soil erosion and the rainfall intensity with a coefficient of correlation (r) and standard error (se) of 0.982 and 0.005 respectively. Verification of a laboratory and a field soil loss equation with laboratory and field data respectively revealed some disparity between measured and predicted values, especially in the laboratory model. The predictive capacity of the laboratory model, an exponential model proposed by Umeh and Ojiako was improved considerably when A (detachment capacity of flow) was expressed as a function of slope and soil density and the parameter (a) expressed in terms of velocity and slope. With A and a assumed constant as in Ume's and Ojiako's equations, the values of r and se are 0.227 and 0.327 respectively, whereas with A and a regarded as variables, the corresponding values were 0.978 and 0.072 respectively. Generally, Komura's model showed evidence of good predictive capacity when verified with field data. However, this was not obtained at low rainfall intensity (< 2 mm/hr) because of the assumption of constant momentum coefficient (b) which rather increases with decreasing rainfall intensity and the omission of interill detachment term which will usually be predominant for low flows.

Introduction

In a simplified form, hydraulic sheet erosion is firstly, the detachment of soil particles from the parent body by direct raindrop impact and/or runoff and shear. Secondly, it is the transport of the resulting sediment by raindrop splash and/or flowing runoff (Moulden and Long, 1974). The susceptibility of soil erosion is termed its erodibility and it has two components; interrill, which is soil' susceptibility to detachment transport by rain-drop impact and thin overland flow, and rill which reflects its vulnerability to erosion by channelized flowing water.

Accelerated soil erosion caused by human activities is very detrimental both in terms of reduced agricultural productivity and environmental impacts such as a non-point source pollution and siltation of reservoirs (Adewumi et al; 1997). Erosions poses a serious threat in different parts of Nigeria. The east central states of Abia, Anambra, Enugu and Imo with a total of over 2000 erosion sites constitute some of the worst erosion problems in the world (Concord 5 June, 1992). Other states like Cross River, Akwa Ibom, Edo Delta, and Benue are also affected.

Sheet erosion is a major cause of topsoil degradation affecting 98% of Nigeria's forest area. Up to about 10 to 15 million metric tons of soil loss annually was reported in Anambra, Imo and Abia States by 1982 (Anene, 1991). In many states of the country, erosion has resulted in several environmental hazards such as disruption of drains and roads (Eze-Uzoamaka, 1991); loss of agricultural productivity; siltation and washing away of chemical pollutants into water courses (Oyebande and Martin, 1986), and so on.

Gully had taken its toll in communities like Agulu, Ngwo Agu, Ohafia, Nanka, Uruala and other parts of the country (Eze-Uzoamaka, 1979). It was estimated that 3 to 5 million tons of sediments are retained annually in the Kainji reservoir (Oyebande and Martins, 1986).

Assessment of soil erodibility and prediction of erosion is, therefore important for sustained productive use of agricultural land and implementation of effective management and conservation policies (Eze-Uzoamaka, 1991). In recognition of the serious threat posed by erosion, the Federal Government of Nigeria spent N 1.1 billion on erosion control between 1985 and 1991 (Concord June 5, 1992). There is the need to study the effects of such factor as human activities, climate, soil type and lithology, and so on which initiate and promote erosion (Ofomata, 1985; Eze-Uzoamaka, 1979).

Despite the importance of erosion studies, only a few models exist for the computation of soil loss due to erosion. There are mainly two approaches in modeling. One is the empirical approach derived by using regression and correlation analysis to relate soil loss to environmental factors. This is useful for planning conservation strategies over a given area, but poor for extrapolation under varied conditions. The other is the conceptual approach capable of predicting spatial and temporal changes in erodibility, and is applicable to broader changes of climatic, topographic, crop and soil conditions

The so called Universal Soil Loss Equation (USLE) developed by the US Department is difficult to use because it requires the evaluation of several factors which vary significantly from place to place. Although Ume and Ojiako (1989) developed an exponential mathematical model for the rate of soil loss in gullies, it has not been tried out in practice. Eze-Uzoamaka (1991) pointed out that it did not incorporate the soil shear strength. An attempt was made to do this by Eze-Uzoamaka (1979) but it has not been developed to yield the rate of soil loss. The limitations of the laboratory model notwithstanding; it has not yet been verified using independent experimental data. Ogbonna (1990) compared measured and predicted values of erosion for gullies, using equation developed by Komura (1976). It predicted the soil losses well based on pilot-scale experiments. The experiments were, however, performed under controlled conditions, which may not exist in the field. None of the above models considered the rates of deposition, which will certainly influence the rate of soil movement under field conditions.

Process based erosion prediction models which separate erosion processes into rill and interril subprocesses and use different parameters and equations to quantify these subprocesses, have been proposed. An example is the USAD's Water Erosion Prediction Project (WEPP) equations (Nearing et al., 1989). In order to circumvent the problem of isolating and characterizing the subprocesses, Haung and Bradford (1993) interpreted the parameters of the WEPP equations as lumped processes in spatial scale. Yet the solutions of the equations are limited because they contain several unknowns which are difficult to determine. Besides, the validity of the rate process concept used to couple the difference between transport capacity and sediment rate and between flow detachment and deposition rate is yet to be proved (Haung and Bradford, 1993).

On account of the above limitations, the research objectives of this study are as follows:

1.To verify the Ume and Ojiako (1989) and Komura (1976) mathematical erosion models, and

2.To discuss the limitations of these models.

Mathematical Consideration

An exponential equation which demonstrates that the rate of soil loss varies with time, velocity of flow, distance in the direction of flow and mean particle size is given by Ume and Ojiaka (1989) as follows:

$$E = A \exp. a(ut - x_0) \qquad (1)$$

Where E is the soil loss; A, detachment capacity of flow; u, flow velocity; x_0, distance in the direction of flow, t, time, and a is a constant. An attempt was made in the calibration of the above equation but it was not actually verified. For erosion of silt and sand of uniform coefficient of 60 and median size 0.18mm, the average values of a and A were –0.02 and 0.791 respectively.

The model proposed by Komura (1976) for sheet erosion with rill is expressed as:

$$E = C_A C_E q^{*15/8} L^{3/8} S_0^{3/8} N/D \qquad (2)$$

In which E is the rate of soil loss (m^3/m^2 sec) and

$$q^* = 2.778 f I \times 10^{-7} \qquad (3)$$

Where, f is the runoff coefficient; I is the rainfall intensity (mm/hr); S_0 is the slope; L is the slope length (m); C_A is the bare-soil area ratio to total slope area; C_E is the erodibility coefficient; D is the sediment size (mm) and N is a whole number given at a temperature of 26°C as:

$$\frac{N}{D} = \frac{3000(1+2p)\, a_s v^{b/12} (K+0.012)^{1/2}}{(7b+6)(8g)^{b/3} \left(\frac{p_s-1}{p}\right)^{n} D^{n}} \left(\frac{2\beta}{s-1}\right)^{1/2} \qquad (4)$$

in which D is expressed in m; v = kinematics viscosity (1×10^6 m^2/s); p and p_s are the densities of water and sediment respectively, K= Darcy- Weisbach friction factor constant without rainfall; s = ratio of natural slope gradient to mean friction slope; g is acceleration due to gravity; b is momentum coefficient; a_s and b are constants, and p_1 = dimensionless parameter.

The sections that follow deal with the acquisition of data for verification of the above models as well as discussion on their limitations and, if possible, improvement.

Experimental Investigation

Laboratory Work:

Soil samples were collected from a site in old Government Residential Area ($68.00m^2$) in Port Harcourt, River State and analyzed in the Department of Civil Engineering soil laboratory, University of Nigeria, Nsukka.

All tests were performed according to the standard methods of BS 1377 (1975). The tests carried out include physical examination of soil to know its general nature, grain size analysis to quantitatively express the proportion by weight of various sizes of soil particles, Atterberg's limits for characterization and identification of the soil, compaction test, to find the maximum dry density, moisture content relationships, permeability which is related to how much water infiltrates into the soils, and shear strength which is related to the ability of the soil to be washed away. The results are shown in Table 1 based on the average of two samples.

Data used for verification of the exponential laboratory model were from an unpublished project work from the Department of Civil Engineering archives University of Nigeria, Nsukka. The experiments were conducted on a hydraulic channel of 6.6m x 0.39m x 0.37m with samples of silty fine sand collected around the Faculty of Engineering, University of Nigeria, Nsukka. The whole set up consisted of a discharge measuring unit and a sedimentation tank. Soil samples were rammed in three layers to a particular size of slope. After compaction and maintaining uniform slope with a vane shear instruments, in-situ density tests were conducted to estimate the soil dry density. A known quantity of water was allowed to flow over the soil for four flooding each of 15 minutes duration. After each case the collected soil particles were coagulated to facilitate sedimentation, dried in an oven and weighed to determine the amount of soil loss. At the end of the 60 minutes, the in-situ density was repeated to estimate the corresponding dry density under full saturation. The whole experiments were repeated for varying conditions of compaction, runoff and slope, in each case replacing the soil used with the same but fresh sample.

Field Work

The field experiment was conducted on a site of land in the old Government Residential Area in Port Harcourt, Rivers State. The site sloped down to the creek with a slope of 0.446. Vegetation includes palm, coconut and mango trees, and a few crops. The vegetative density (that is, the ratio of area covered with vegetation to total area) is estimated at 0 .300m.

Rainfall gauges, improvised using plastic containers, were set at 9 stations whose elevation was established from the creek low water level. The stations

Type of test	Details	Quantity	Remarks
Field Identification	Dilatancy test, feeling, physical examination		Organic soil with fine sand and little silt and clay
Sieve Analysis	Fine % Medium % Coarse % Silty/clay %	14.628 58.000 21.148 6.224	Silty fine
Attergerg Limits	Plastic Index Liquid Limit Blows) Shrinkage length	9.3 % 26.5% 7.478 % 0.005mm	From casagrande plasticity chart the soil is of low plastic. It contains clay and silt.
Shear Resistance	Angle of Internal friction (θ) Cohesion (c)	27.946^0 66.667KN/m^2	
Permeability		1.1×10^{-6}m/s	Soil has good drainage
Mean sediment Size Maximum dry Density Specific gravity	at OMC of 13.8 %	0.178mm 1840kg/m^3 2.28	

Table 1. Data from Laboratory Soil Analysis

were uniformly spread and marked from 1 to 9 in order to avoid confusing one station number for another, each rain gauge receiver was marked with a station number. All gauges have equal receiver diameter of approximately 28.253 cm as specified by the Standard of US Weather Bureau (Crane, 1985).

The average rainfall (p) for the site was simply estimated from

$$1/n\sum_{i=1}^{n} p_i$$

Where, n and p_i are respectively, the number of stations (ie 9) and the rainfall at station *i*. The arithmetic method was used since the gauges were uniformity spread and the area is far less than 500 km^2 (Ragbunath, 1979). A little channel was constructed parallel to the creek. At the down streamside of the channel, a big catchment's pit was dug to dissipate the kinetic energy of the flowing water and facilitate the sedimentation of the soil particles. A basin fitted into the pit collected the eroded sediments and runoff. After each rainfall event, the runoff was decanted into a measuring cylinder and the volume recorded while the sediments were sun dried for about 48 hours and then weighed. Despite all precaution taken, some runoff was lost through separate routes. However, the quantity was regarded as negligible compared with the quantity measured.

Results And Discussions

Soil Characteristics

Soil analysis indicates that the soil in the study area is silty sand with low plasticity and good drainage capacity. The mean sediment size is 0.178mm while the maximum dry density (at optimum moisture content of 13.8%) and the specific gravity are 1840g/m^3 and 2.28 respectively. The Atterberg's limits generally indicate that the soil is highly erodible. Although the triaxial test indicated the soil as cohesive; yet it is erodible (Wager, 1957).

Exponential Model

Although Ume and Ojiako (1989) mentioned that A and a are not constants, they failed to model the variations of A and a with some other variables such as slope and velocity. As a first step towards the determination of these variations, values of A and a as well as the coefficient of correlation were computed as shown in Table 2 only.

The above computation was followed by the determination of the coefficient of correlation of A and a each with the slope, velocity and soil density (Table 3).

Table 3 shows that a is highly dependent on u and S. On the other hand, A is dependent on p and S. Hence, equation (1) will not be appropriate under conditions where A and a are varying. In order to account better for these variations, and hence extend the application of equation (1), A and a should be expressed in terms of the appropriate significant factors mentioned above.

By performing multiple regression analysis the following equations were obtained:

$$A = 7.854 + 4.545\,S - 0.00435\,p \quad (5)$$

$$a = 0.287 + 0.273\,u + 0.411\,S \quad (6)$$

The coefficients of correlations for these equations are 0.812 and 0.930, respectively. These equations can be refined with the provision of more experimental data.

The predictive superiority of equations (5) and (6) together with equation (1) instead of equation (1) alone with A and a regarded as constants (average values) is illustrated in Figs. 1 and 2 by using a different set of data which was not used in determining the constants. Although the data are highly limited, it is obvious that the disparity between the measured and predicted values is reduced by making a and A dependent on u, s, and p.

The standard errors of using equation (1) with variable and constant a and A respectively are 0.072 and 0.372 while the corresponding coefficient of correlations are 0.978 and 0.277 respectively.

Verification of Komura Model

Komura (1976) evaluated the following constants $p_1 = 2$. $^2 = 3/2$, $a_s = 30$, s = 120, b = 1.1, K= 0.6. The other parameters were either determined in the field or they are known constants. From table 1, the specific gravity (p_s/p_1) and D are respectively, 2.28 and 0.178m. The kinematics viscosity (v) is 1 x 10^{-6}m^2/s at 26^{0}C (Webber, 1978). The slope (S_0) is 0.446, g = 9.81m/s^2 while the average L, is 15m. From the table presented by Komura (1976), C_E = 5 for sheet erosion with rills. Since the proportion of area with vegetation is 0.3, CA = 0.7. Regression of the relationship between runoff R and precipitation P (Table 3) gave

$$R = 0.3152\,p + 8.528 \times 10^{-3} \quad (7)$$

with a coefficient of correlation of 0.993 (Fig. 3).

Hence, the runoff coefficient (f) is selected as 0.3152 (see equation 7), which is close to the value for sandy soil (0.2-0.3) (See Raghunath, 1985). This value is reasonable since the area of study contained some sand as well as clay. There is also a high coefficient of

U (m/min)	Slope (S)	Density (p) kg/m^3	Length (X_0) m	α	A	Coefficient of correlation (r)
0.1539	0.1763	1840	1.72	-0.256	0.391	0.972
0.6335	0.1763	1840	1.72	-0.054	0.984	0.940
0.3258	0.1317	1840	1.72	-0.072	0.207	0934
0.1612	0.0875	1840	3.44	-0.078	0.147	0.999
1.1612	0.0875	1659	3.44	-0.200	1.100	0.977
0.1612	0.0875	1786	3.44	-0.279	0.677	0.993
0.3258	0.0875	1838	1.72	0.155	0.229	0.981
0.3258	0.1763	1610	1.72	-0.552	0.986	0.986
0.3258	0.1763	1621	1.72	-0.124	1.606	0.989
0.3258	0.1763	1837	1.72	-0186	0.801	0.984

Table 2: Computed values of A and a and the coefficient of correlation based on Equation (1)

Statistical Parameters	α			A		
	U	S	P	U	S	P
R	0.635	0.496	0.015	0.274	0.500	-0.864
Slope	0.336	0.870	1.12×10^{-5}	1.009	6.112	-0.005
Intercept	-2490	0.033	-0.172	0.477	-0.064	9.062
Standard Error	0.063	0.224	0.082	0.550	0.495	0.336

Table 3: Statistical correlation analysis of the variation of A and a with U, S and p.

Date	Average Rainfall Intensity (I) mm/hr	Runoff (L)	Lateral inflow Rate% $M^2 / M^2.s \times 10^{-7}$	Rate of soil Erosion kg/m^2.hr	
				Measured	Predicted
13/9/91	0.480	8.548	0.420	0.007	0.001
14/9/91	3.501	59.957	3.066	0.053	0.052
19/9/91	2.259	36.385	1.978	0.023	0.023
21/9/91	2.572	44.503	2.252	0.039	0.029
29/9/91	4.147	77.415	3.631	0.063	0.071
1/10/91	5.921	73.267	5.185	0.092	0.139
9/10/91	4.255	290.814	3.726	0.066	0.075
14/10/91	3.998	261.668	3.501	0.070	0.067
16/10/91	6.003	165.00	5.256	0.108	0.143
21/10/91	1.308	25.304	1.145	0.023	0.008
22/10/91	0.732	17.717	0.641	0.013	0.003
28/10/91	3.646	323.188	3.193	0.064	0.056
30/10/91	3.129	171.809	2.740	0.055	0.042
10/4/92	3.942	26.998	3.452	0.067	0.065
13/4/92	3.031	31.681	2.654	0.053	0.040
14/4/92	3.360	51.185	2.942	0.057	0.048
12/4/92	1.362	28.004	1.192	0.023	0.009
29/4/92	2.406	36.133	2.107	0.040	0.026
1/5/92	3.142	27.804	2.751	0.051	0.042
4/5/92	1.082	8.660	0.948	0.002	0.006
5/5/92	4.499	94.110	3.940	0.078	0.083
7/5/92	0.650	25.443	0.569	0.011	0.002
20/5/95	5.172	364.289	4.528	0.092	0.108
23/5/92	3.596	61.085	3.149	0.062	0.055
24/5/92	0.931	19.207	0.816	0.014	0.004
29/5/92	4.004	339.914	3.506	0.071	0.067

Table 4: Average rainfall intensity, runoff, lateral inflow rate and measured and predicted rate of soil erosion

correlation (0.9810) between the runoff and the weight of eroded soil (Fig 4). This implies that the weight of eroded soil increases generally with the amount of runoff.

The ratio of the average rainfall over the site to the rainfall duration gave the intensity (I).The lateral inflow rate, q was determine from equation (1).

Substitution of values of relevant parameters above in equation (3) gave N as 791. If N and other parameters are substituted in equation (2) and the unit of E converted from m^3/m^2 sec. to kg/m^{2}hr by multiplying by 1840 x 3600.

$$E = 0.0049526 (I)^{15/8} \qquad (8)$$

The rainfall intensity (I), lateral inflow rates, runoff and the computed rate of soil erosion are shown in Table 4.

Analysis of the field data obtained showed that an equation of the form $E = 0.01768(I) - 0.00391$ can be fitted to the relationship between the rate of soil erosion (E) and the intensity (I). The coefficient of correlation and standard error are 0.982 and 0.005 respectively. This model is preferred to $E = 0.0132 (I)^{1.160}$ which has the coefficient of correlation and standard error of 0.883 and 0.449 respectively.

Equation (2) does not account for the deposition process. However, generally it shows a good predictive capability since it is applied to the net sum of soil loss over the whole area of study and not to the individual processes of erosion and deposition occurring on each of the 9 stations. Regression of predicted (E_p) on measured (E_m) rate of soil erosion (Table 4) gave.

$$E_m = 0.670 E_p + 0.0164; \; r = 0.957; \; S_e = 0.012$$

It deviated from the 45° line (which represents perfect prediction) by 11.18° (see fig. 5)

Assumptions made in the derivation of equation (2) which are not very realistic and may have contributed to the deviation are many. The equation was derived for one dimension case, which ignores secondary, flows characteristic of several field cases. Similarly, the other assumptions like homogenous composition, slope surface, soil layer, non-cohesion, and constant infiltration are not easily satisfied.

Ogbonna (1990) obtained a better prediction when equation (2) was verified in a flume (3.9m x 23cm x 150m) built on a natural slope and exposed to a series of rainfalls of varying intensity. The reason is not far-fetched. The experiment was conducted under artificial conditions where cross flows were avoided, and runoff from house roof carefully channeled into the completely

Operation of Zuway Pilot Water Treatment Plant

Samson Tsewameskel, Ministry of Water Resources
P.O.Box: 3500, Addis Ababa

Abstract

A water supply project was finalized in Zuway town on March 2002 to provide domestic water to the inhabitants, public and private institutions of the town. The project was designed by TAHAL Consultants (Israeli Firm) and being supervised by Ministry of Water Resources (later the project office is transformed to Water Works Design & supervision Enterprise).

While the supervision works, it was learnt that the designed water treatment plant of this specific project might not capable of producing water quality to the level of World Health Organization (WHO) drinking water quality guidelines. Then, with the consultation and subsequent approval of Oromiya's Water, Mines & Energy Bureau (Owner of the project), a pilot plant was constructed and its operation was monitored for six months (two Cycles) to evaluate the effectiveness of the

1. Introduction

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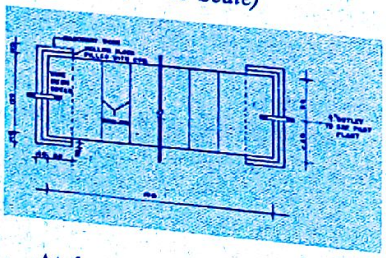
Figure 1: Plan of Horizontal Filter Pilot Plant (Not to Scale)



At the end of two cycles of operations of the pilot plant, it was verified that the treatment unit operations designed by TAHAL consultants could not produce drinking water to the requirements of WHO drinking water quality guidelines. The observations and the conclusion made on the operation of the pilot plant was presented to the consultants through the bureau and the latter accepted after scrutinizing the justifications behind the conclusion and having field observations on the operation of the pilot plant.

Consequently, the design of the treatment was changed completely and now a different water treatment plant, conventional water treatment type, is in operation. This paper discusses the operation of the pilot treatment plant and the lessons learned from the project from water quality and water treatment perspectives.

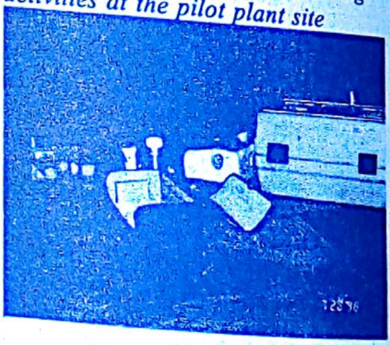
2. Raw Water Characteristics

The raw water quality, Bulbula River, is physically characterized by brown-yellowish color. Quantitatively, the color and turbidity are not very high for Ethiopian rivers standard; most of Ethiopian rivers turbidity and color do have relatively high values because of their course are associated indeed with rugged terrain. The maximum values for color and turbidity of the river during the operation are found be more than 550[1] Co Pt color unit and 200 NTU respectively.

The cause of color and turbidity of this particular river are not ordinary settable suspended materials; they are colloidal matters. The size of colloids lies between 0.01 to 1mm. They carry small negative electric charges, which in relation to their weight are large enough for the particles to repel each other and remain in suspension, or dispersed.

Regarding the chemical characteristics of the river at the intake site, the fluoride and manganese concentrations are beyond the limit set by World Health Organization (WHO) drinking water quality guidelines. Other analyzed chemical constituents are within the acceptable range.

Figure 2: Water Quality monitoring activities at the pilot plant site



Besides the dissolved oxygen of the raw water is very low and varies between 2.0 and 1.8 mg/l. The very low dissolved oxygen of the river at the intake site of the water supply project is not associated with organic pollutants discharges. It is because of the course of the river at this stage appeared stagnant and indeed very low velocity. This condition has created conducive environment for reproduction and subsequent decay of a variety of aquatic lives that consume huge amount of dissolved oxygen in the latter process.

3. Water Treatment Plant Design by TAHAL

The treatment process designed by TAHAL consists of the following unit operations: Cascade Aerator, Horizontal Flow Roughing Filter (HRF), Slow Sand Filter (SSF), pH correction facility by soda ash and Disinfection mechanisms by calcium hypochlorite. One can think that with such relatively low turbidity that varies between 84 to 200 NTU, it is possible to treat the water efficiently using SSF as main unit operation by employing suitable pre-treatment. However, due considerations should be given to identify the nature of turbidity causing materials and verify the water design treatment plant against the disguising physical characteristics of the raw water.

The consultants designed the HRF to produce suitable water less than 50 NTU, for proper operation of the SSF. The main treatment process in HRF is sedimentation; the filter acts multi-store sedimentation basin, thus providing a large surface area for the for the accumulations settelable solids. Because of their size (less than 1mm), the colloidal matters those are responsible for the turbidity and color of the raw water will not be removed by sedimentation. Thus the employment HRF on such cases will not serve what supposed to do. Consequently, it will practically be difficult to have SSF for effective treatment of the raw water.

In the design, pH correction unit operation using soda ash has been proposed. The objective this unit process is not clear, as there is no any kind of process or chemical application that necessitates to level up the lowered pH.

With the above-discussed disguising physical characteristics of the raw water and design of TAHAL consultants water treatment plant, ministry of water resources (project consultant during the construction phase) proposed to the client (water, mines and energy bureau of Oromiya) that to run pilot treatment plant operation to verify the effectiveness of the design. The latter accepted the proposal and the construction and subsequent operations of the pilot treatment plant were done according to the design.

3. Pilot Plant Operation

The main objective of running pilot treatment plant was to very that whether HRF can produce effluent for effective operation of the slow sand filter unit from Bulbula River. The pilot plant was working in such a way that the raw water pumped to elevated steel tank and allowed to flow through the HRF units and then SSF unit by gravity. The gravel and sand types and sizes of the pilot treatment plant were according to specifications made on the design.

The water quality parameters selected for monitoring the operation of the pilot treatment plant were influents and effluents of the HRF and SSF units against the raw water quality. Besides, the nitrate concentrations the influents and effluents were occasional measured to get indirect information on the operation of the pilot plant.

The pilot treatment plant operation was carried out in two cycles; the second cycle operation was conducted after some technical working conditions that had been assumed that affected the outputs of the first cycle operation.

3.1 First Cycle Pilot Water Treatment Plant operation

The following table shows the water quality monitoring during the operation of the pilot treatment plant for eighteen days. The monitoring was conducted using spectrophotometer, Hach DR 2000.

As can be seen from the table, the HRF unit of the pilot took twelve days to produce effluent suitable (turbidity less than 50 NTU) for slow sand filter. The maximum turbidity removal efficiency achieved by the plant was in the range of between 43 to 49 NTU. The continuous operation of the SSF with such range might adversely affect the SSF efficiency by shortening filter run. The color removal of the HRF is not appreciable; this is because the fact it is not good for removing colloidal particles.

Figure 3: Photo of the Pilot Water Treatment Plant during operation

The efficiency of the SSF is not as expected. Its poor efficiency at the start of operation can be explained by the following facts: crystalline quartz sand has negative charge and repelled the colloidal particles that are responsible for the turbidity and posses negative charge. However, during the ripening of the biological film positively charged impurities positively charged impurities may accumulate on the surface of the filter grains to such an extent that over super saturation occurs with subsequent

Date	Raw Water		HRF Effluent		SSF Effluent	
	Turbidity (NTU)	Apparent Color(Pt-Co)	Turbidity (NTU)	Apparent Color(Pt-Co)	Turbidity (NTU)	Apparent Color(Pt-Co)
26/03/98	83	467	80	390	80	435
26/03/98	138	550	118	550	181	550
26/03/98	136	550	115	550	99	501
27/03/98	119	550	115	550	76	423
27/03/98	130	550	105	534	71	384
27/03/98	118	550	97	510	71	395
28/03/98	122	548	91	500	72	405
28/03/98	100	493	92	473	67	351
28/03/98	101	550	89	430	38	203
04/04/98	100	530	56	300	34	175
05/04/98	102	503	50	275	31	154
06/04/98	99	539	43	267	25	127
06/04/98	102	550	49	261	32	209
07/04/98	95	539	43	225	27	145
07/04/98	95	503	44	223	34	173
08/04/98	105	550	43	225	32	209
08/04/98	99	539	47	272	36	203
09/04/98	101	541	39	217	30	180
09/04/98	105	550	35	292	32	141

Table 1: water quality monitoring results at the 1st cycle operation

charge reversal, rendering the grain to which attached positive charge. Adsorption on such grains is then able to remove negatively impurities including colloidal particles. The relative improvement of its efficiency at the later stage of the operation is related to the ripening of the biological layer (Schmutz deck) and subsequent charge reversal phenomenon.

The minimum turbidity and turbidity values in the operation are well above World Health Organization (WHO) drinking water guideline, which are 5 NTU and 15 Pt-Co color units respectively.

With time, the filtered quantity from SSF was decreasing continuously to the extent the supernatant water above the media was overflowing indicating the filter being clogged. In addition to the clogging, the effluent of the SSF had stated to impart unpleasant odor. The intensity (offensiveness) of the odor was increasing time and is associated to the prevalence of anaerobic condition on Schmutz deck, super maturation of the biological layer. This observation was confirmed by considerable reduction of nitrate of the final effluent compared with raw water. Table 2 depicts nitrate concentration monitoring during the operation.

As can be seen from table 2, there is inverse proportion relation between nitrate concentrations of the effluent and intensity of odor. The reason for this trend is that in the aerobic condition in the sand bed is maintained partly by oxygen from nitrate. This conclusion was agreed to observation of ammonia smell in the effluent. The observation is explained by the following chemical reaction:

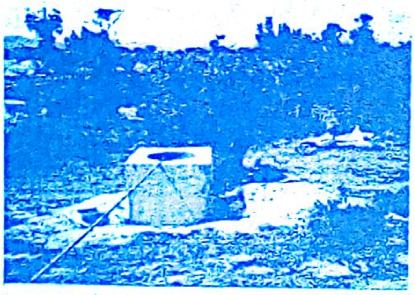
$$NO_3^- + 10H^+ + 8e^- \text{Û} NH_4^+ + 3H_2O$$

The effluent has also the odor of methane which can be explained the following chemical reaction:

$$CO_3^{--} + 10H^+ + 8e^- \text{Û} CH_4 + 3H_2O$$

After two weeks operation, the upper most part (about 10mm) of the sand filter bed was scrapped because of clogging. At the same time, the operation of the HRF operation was stopped to install sheet metal at the outlet of the HRF for purpose of aeration.

Figure 4: Slow Sand Filter Unit of the Pilot Treatment Plant



The following table shows that the pilot plant operation monitoring after scrapping the slow sand filter top layer and installing sheet metal at the out let of the HRF for the purpose of aeration.

As can be seen from table 3, the operation of the second run, the efficiency of the HRF was below what has been observed before scrapping. This is because the HRF has been stopped for one day to install the aerator unit, the deposited settled solids materials partly washed by incoming water. After few days of operation, it has started to maintain the same removal efficiency what has been exhibited before scrapping.

After two days operation, the HRF unit has started to impart unpleasant odor. The unpleasant odor has rotten egg in addition to ammonia and methane smell. The cause of the rotten egg is due to hydrogen sulfide formation as the result of the reduction sulfate as presented in the following reaction:

$$SO_4^{--} + 10H^+ + 8e^- \text{Û} H_2S + 4H_2O$$

As HRF efficiency improved with time, the performance of the SSF had improved as well appreciably. At later stage, the removal efficiency of the SSF had achieved the best performance with the lowest values for turbidity and color measurements were 21 NTU and 107 Pt-Co color unit respectively.

After two days (after scrapping) the SSF unit was imparting unpleasant odor and was increasing with time. On the fifth day of operation, the odor from imparted from the HRF was much stronger that of the slow sand filter.

3.2 Second Cycle Operation

Since both the HRF and SSF units had imparted unpleasant and noticeable smell during the 1st cycle operation, aeration mechanisms introduced in the 2nd cycle operation. Two aerators was introduced: the first one placed just before the HRF unit and it a sort of tray aerator with three stages of aeration facility, and the 2nd one was placed after the SSF unit. The main objective of the aerators was to raise the very low dissolved oxygen of the raw water, less than 2 mg/l.

Besides the filter material of the HRF, which was crashed gravel replaced by river gravel, and filter, which was sand from Langano area replaced by quartz sand from Negle Borena area, before conducting the 2nd cycle operation.

Table 2 : Nitrate concentration monitoring

Date	Raw Water		HRF Effluent		SSF Effluent	
	NO_3^- (Nmg/l)	Odor	NO_3^- (Nmg/l)	Odor	NO_3^- (Nmg/l)	Odor
08/04/99 (9:30 am)	10.20	Odorless	7.10		6.30	Noticeable smell
08/04/99 (2:30pm)	10.30	Odorless	6.20		6.10	Strong and bad smell
09/04/99	10.20	Odorless	5.70	Noticeable smell	5.30	Very and Strong bad smell
After Scrapping						
10/04/99	10.20	Odorless	12.60	No smell	8.1	No smell
11/04/99	10.30	Odorless	8.70	Noticeable smell	5.6	Noticeable smell
14/04/99	10.20	Odorless	6.80	Strong and bad smell	5.2	Strong and bad smell
15/04/99	10.20	Odorless	5.10	Very and Strong bad smell	5.5	Very and Strong bad smell

Date	Raw Water		HRF Effluent		SSF Effluent	
	Turbidity (NTU)	Apparent Color(Pt-Co)	Turbidity (NTU)	Apparent Color(Pt-Co)	Turbidity (NTU)	Apparent Color(Pt-Co)
10/04/98	91	510	68	380	54	276
11/04/98	108	550	60	311	42	216
12/04/98	96	540	60	308	45	217
13/04/98	109	550	52	279	37	202
14/04/98	111	550	49	264	29	169
14/04/98	114	550	49	264	29	169
15/04/98	96	523	42	226	22	116
15/04/98	95	509	49	246	26	146
16/04/98	99	517	45	234	21	107

Table 3: Pilot Plant Operation Monitoring (After Scrapping)

Figure 5: Aerator unit of the Pilot Treatment Plant

The main objective of the second cycle operation is that to verify the observations made on the first cycle by modifying the design and operation of the pilot plant. Accordingly, the following table shows the water quality monitoring for the second cycle operation.

After two weeks operation, the SSF was clogged and the HRF could produce suitable effluent for proper operation of the former on this period. The reason for rapid clogging of the SSF is related to the facts that the raw turbidity and color concentrations were relatively high because of the rainy season and nature of the filter media at the HRF.

The biological film (Schumtz deck) at the SSF was not well-matured comparing with first cycle operation because of relatively short filter run. The formation of the biological film confirmed by the prevalence of unpleasant smell at the effluent of SSF. The movements of big microorganisms (visible at naked eye) were observed at the top filter media when the SSF was being drained for scrapping.

The aeration units installed at the inlet of HRF at the inlet of SSF effluents increased their dissolved oxygen content to 4 to 5 mg/l respectively having the average dissolved oxygen amount 1.8 mg/l.

The gravel of the HRF used in the first used in 1st cycle of the pilot operation was crushed gravel and was able to remove some portion of the suspended after long period of time. However, the change of the gravel by river with reduced size could not exhibit the expected out come. The crushed gravel consisted of soluble particles (dust), which can be positively affected the sedimentation of suspended particles in the raw water.

The dissolved oxygen of the raw water is very low (average concentration 1.8 mg/l) because of relatively its rich organic constituents.

Consequently, the upper most part (about 10 mm) of the SSF was scrapped after confirming that the filter was being completely clogged. During the scrapping, the operation of the HRF unit was allowed to continue by passing the SSF. The following table shows the water quality monitoring of the pilot plant after scrapping of the SSF.

After six days operation, the slow sand filter again completely clogged. It also imparted strong and unpleasant odor. However, at this time the horizontal flow roughing filter could not produce suitable effluent to slow sand filter proper operation.

Table 4: water quality monitoring results at the 2nd cycle operation

Date	Raw Water		HRF Effluent		SSF Effluent	
	Turbidity (NTU)	Apparent Color(Pt-Co)	Turbidity (NTU)	Apparent Color(Pt-Co)	Turbidity (NTU)	Apparent Color(Pt-Co)
23/07/98	126	>550	114	>550	70	361
25/07/98	161	>550	128	>550	80	444
27/07/98	160	>550	131	>550	111	>550
28/07/98	163	>550	126	>550	95	507
28/07/98	162	>550	124	>550	86	453
29/07/98	158	>550	114	>550	95	496
29/07/98	167	>550	132	>550	91	479
30/07/98	143	>550	111	>550	81	419
30/07/98	142	>550	112	>550	82	423
31/07/98	165	>550	104	>550	61	321
01/08/98	154	>550	105	459	32	177
02/08/98	169	>550	113	451	31	164
03/08/98	159	>550	109	>550	53	278
04/08/98	167	>550	88	459	36	189
05/08/98	200	>550	87	451	28	158
05/08/98	183	>550	108	>550	53	278

4. Conclusion

The decision to run the pilot plant water treatment plant has achieved its objective, i.e., to confirm whether the HRF filter can produce color and turbidity concentrations of the raw water to the extent of producing suitable effluent to proper operation of the SSF. Besides, the pilot plant operation has enabled to understand the water characteristics of the raw water somewhat in detail manner. Accordingly, the following major conclusions were made:

· From the detail analysis of the two cycles of the water treatment plan operations, it was concluded that the main cause of turbidity and color of the raw water were colloidal matters. Colloidal particles are dispersed particles in solution with size of 1mm or less which cannot be removed by sedimentation. The HRF that acts multi-store sedimentation could not produce suitable effluent for proper operation of the SSF. This means that the construction of SSF as main unit operation at Zuway with HRF as pretreatment would create serious operational problems by increasing the frequency of scrapping.

Date	Raw Water		HRF Effluent		SSF Effluent	
	Turbidity (NTU)	Apparent Color(Pt-Co)	Turbidity (NTU)	Apparent Color(Pt-Co)	Turbidity (NTU)	Apparent Color(Pt-Co)
06/08/98	187	>550	100	>550	73	384
07/08/98	155	>550	93	488	57	308
08/08/98	169	>550	89	477	32	177
09/08/98	136	>550	72	379	47	240
10/08/98	173	>550	90	471	26	134
11/08/98	175	>550	89	477	26	134

Table 5: 2nd Pilot Plant Operation Monitoring (After Scrapping)

· Odor problem was observed during the operations of the water treatment plant because of the very low level of dissolved oxygen of the raw water. Therefore, it is mandatory to introduce appropriate aeration facility to improve the raw water quality.

· The need of pH correction unit operation is not necessary as there is no a possibility of either pH lowering or increasing in the operation of the pilot plant operation.

· Since the proposed treatment plant process designed by TAHAL consultants could not produce drinking water to the level of requirement set by design document of the project, it was recommended to replace the consultant design by conventional water treatment processes with appropriate type aeration facility just before Coagulation/Flocculation; chemical sedimentation (Coagulation/Flocculation), rapid sand filter and disinfection.

Actually, based on the conclusions and recommendations made in relation to these pilot water treatment plant operations the former design has been changed to conventional water treatment processes. The construction of the project has been completed and the treatment plant has become operational since March 2002.

Acknowledgments

The Water Mines & Energy Bureau of Oromiya deserves very great appreciation and respect for its strong commitments to the construction and supervision of the pilot treatment plant and subsequent instruction for the application of the recommendations based on the findings of the operation. The project team members of 8-Towns Water Supply Project were following the operation with great interest and enthusiasms. Particularly, the author highly acknowledges the direct inputs of Ato Tesfaye Zeleke and Ato Mulugetta Alico who were designer engineer of the 8-Towns project and resident engineer of Zuway Project respectively.

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(Footnotes)

[1] 550 C0 color Pt unit is the maximum detection limit for apparent color by Dr 2000 Spectrophotometer. No dilution was made because of the nature of color causing impurities.

Evaluation of Stable Channel Design Methods in Erodible Materials

Dr. Bayou Chane

Abstract

Prediction of changes in erodible channels transporting water is illustrated by evaluating four method of stable channel design selected from different approaches: regime method using Lacey's equations, tractive force method of Lane's with Simons and Albertson's extension to channels transporting sediment, minimum stream power method using Engelund and Hansen's equations of sediment transport and flow resistance and 'wfs' method of algebraic manipulation of equations for width, flow resistance and sediment transport. These design methods are evaluated, first, by comparing them among themselves, then, by using them to predict field data. No similarity of results was obtained by comparing them among themselves. Prediction of the field data was acceptable by the minimum stream power and the 'wfs' methods, but it was poor by the other two methods. The results altogether showed the uniqueness of the design methods.

Introduction

The approaches of stable channel design in erodible materials can be classified into four parts: regime channel approach, tractive force approach, extremal approach, and an approach using width, flow resistance, and sediment transport equations. Various extremal approaches are available to design a stable channel (Shiqiang et al, 1986). The minimum stream power approach appears more reasonable and it is considered here. The basic concepts underlying each approach are briefly presented in Secs. 1.1 - 1.4. A specific method is selected from each approach for evaluation. In Sec. 2.1, comparisons are made among the selected methods. In Sec. 2.2, the design methods are evaluated using the field data collected from the Amibara Irrigation canal in Ethiopia.

The Regime Channel Approach

Channels flowing in erodible materials are dynamic. The discharge, sediment load, sediment characteristics vary with space and time. Channel erosion and deposition accompanies these changes. If the variation even out in an annual cycle and the channel operates without much silting or scouring, the channel is said to be stable. Thomas Blench (1952) defines a regime type channel: (1) as a channel that has formed the major part of every cross section from material that has been transported or could be transported at some stage of flow; (2) as a channel whose mean measurable behavior during a certain time interval does not differ significantly from its mean behavior during comparable times before or after the given interval. Channels excavated in rigid materials and sections that prevent deposition are not of regime type. The regime approach of stable channel design is based on the observation of channels operating in regime condition.

Lindley (1919) stated that when an artificial channel is used to convey silty water, both its bed and banks scour or fill, changing its depth, gradient and width, until a state of balance is attained at which the channel is said to be in regime. These regime dimensions depend on the water discharge, quantity and nature of bed-and berm-silt, and rugosity of the silted section. This was an important step in the study of erodible channels.

Lacey (1930) analyzed data collected from regime channels in India, taking into account the effect of sediment size on the relationship for velocity, and developed a set of stable channel design equations which can be written in SI system of units as

$$P = 4.75\, Q^{1/2} \quad [1]$$

$$A = 2.28\, \frac{Q^{5/6}}{f_1^{1/3}} \quad [2]$$

$$R = 0.48\, \frac{Q^{1/3}}{f_1^{1/3}} \quad [3]$$

$$S = 0.00031\, \frac{f_1^{5/3}}{Q^{1/6}} \quad [4]$$

in which f_1 = silt factor $= 1.76\, d^{1/2}$ (= 1, for Kennedy's data); d = sediment size in mm; and P = wetted perimeter.

The regime approach of stable channel design using Lacey's equations has been successfully used in India. Some researchers do not recommend using the Lacey's regime equations to places other than India. However, many engineers in different countries use it in the absence of other alternatives. Therefore, it is useful to know the credibility of the Lacey's regime method as compared to other methods of design.

The Tractive Force Approach

The tractive force approach of stable channel design is based on the basic concept of initiation of motion of sediment particles on the channel boundary. When a channel is designed by this approach, the distribution of the tractive force along the sides and bottom of the channel should give forces at all points of the channel so that the channel is not eroded in large quantities. This criterion prevents the deposition of sediment.

For uniform steady channel flow

tractive force is equal to γALS and unit tractive force, $\tau_o = \gamma ALS/PL = \gamma RS$, where L = length of channel reach under consideration and P = wetted perimeter. For wide channels, $\tau_o = \gamma DS$.

Trapezoidal channels are commonly used in hydraulic engineering. The tractive force acting on these channels is not uniformly distributed along the wetted perimeter. A typical distribution of this force is shown in Fig. 1. The maximum tractive force on the bottom of the channel is approximately equal to ^{3}DS and on the sides it is approximately equal to 0.76^{3}DS. Based on the study of the distribution pattern of the tractive force, Lane (1955) has prepared curves, Fig. 2, for use in stable channel design. The maximum tractive forces given in Fig. 2 are average values over time.

The effect of side slope on the stability of sediment particles located on the channel sides is obtained from Eq. 5.

$$\frac{\tau_{sc}}{\tau_c} = k = \cos\beta \sqrt{1 - \left[\frac{\tan\beta}{\tan\alpha}\right]^2} \qquad [5]$$

in which ^{2} = inclination angle of channel wall,

± = angle of repose of channel material.

The tractive force approach for stable channel design requires the limiting tractive force of the channel material. Lane (1955) related tractive force with particle size, Eq. 6, from data on stable channels which had a wide range of particle sizes.

$$\tau_c = 0.754\, d_{75} \qquad [6]$$

in which d_{75} is particle size of the channel material in mm such that 75% (by weight) of the material is finer. The tractive force used to derive this relationship was obtained from the maximum sustained flow in the channel.

$$n = \frac{d_{75}^{1/6}}{21.1} \qquad [7]$$

Lane (1955) related hydraulic roughness to the particle size of the channel material; Eq. 7.

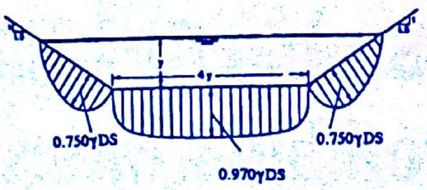

Fig.1 Distribution of tractive force in a trapezoidal channel section

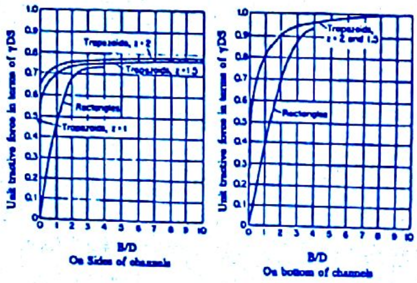

Fig.2 Maximum tractive force in a channel,lane(1955)

The independent variables in the tractive force design method are discharge, Q, size of bed material, d_{75}, side slope, and either depth of flow, D, or water surface slope, S. If the depth is given, slope and width can be determined; if the slope is given, depth and width can be determined. Taking Q, d_{75}, side slope, and S as unknown variables, the design procedure is as follows:

(1) The limiting tractive force, $Ä_c$, is computed using Eq. 6.

(2) The angle of repose, ^{2}, is obtained from observations relating ^{2} versus d.

(3) The tractive force ratio, K, is computed using Eq. 5.

(4) The limiting tractive force on the sides is computed by Eq. 5.

(5) Taking a trial value of B/D, values of $Ä_{max}$/(^{3}DS) are obtained for the channel bed and sides from Fig. 2. If these values are designated by C_H and C_s, respectively, then, $Ä_{maxH}$ = C_H^{3}DS and $Ä_{maxS}$ = C_S^{3}DS.

(6) Equating $Ä_{maxH}$ and $Ä_{maxS}$ obtained in step (5) to the respective values of limiting stresses obtained in steps (1) and (4), the longitudinal slope S for which the channel is safe from erosion is determined

(7) Manning's roughness coefficient is computed using Eq. 7.

(8) Finally, B, A, R, and Q are computed and the value of computed Q is compared with the given value of Q. If the two values are not equal, another B/D ratio is selected and steps (5) to (8) are repeated.The flow chart given in Fig. 3 shows the procedure of computation.

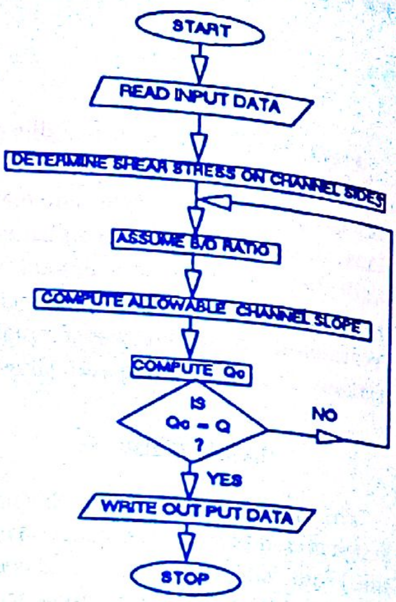

Fig.3 Flow chart for tractive force method of design

Simons and Albertson (1963) attempted to extend the tractive force concept of stable channel design to channels transporting sediment load (up to 500 ppm by weight) by plotting variation of tractive force with bed material size, type of channel and discharge, Fig. 4.

Assuming that the tractive force distribution around the wetted perimeter of a channel transporting sediment loaded water is similar to that transporting clear water, the former can be designed using the limiting tractive stress, Fig. 4, and following the procedure given earlier.

The tractive force method of stable channel design has been popular in the USA and Europe for channels in coarse non-cohesive materials carrying nearly clear water flow. Since this method has a good physical basis, it is compared with other methods of design by extending its application to sediment transporting channels, see Sec. 2.

The Minimum Stream Power Approach

Minimum stream power is a necessary and sufficient condition for equilibrium, (Chang, 1980). An alluvial channel tends to adjust its width, depth and

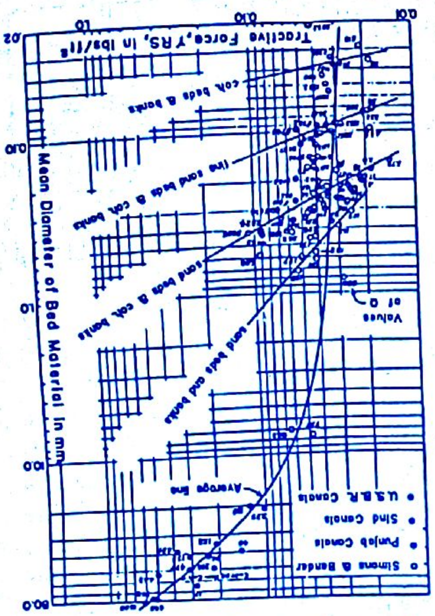

Fig.4 Variation of tractive force with bed material, d, type of channel, & discharge(simons & Albersto,1963)

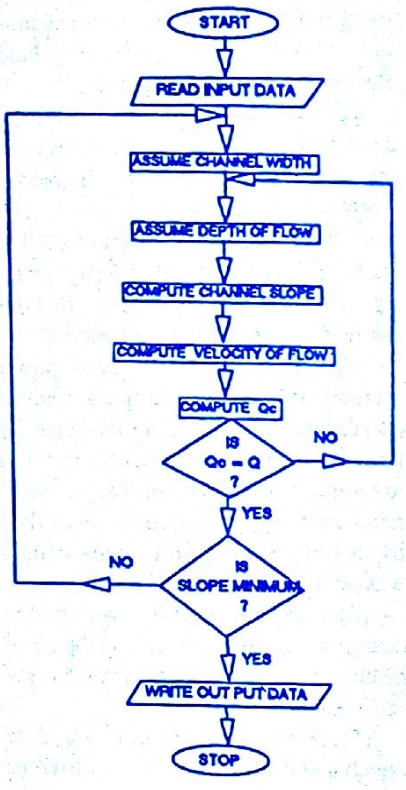

Fig.5 Flow chart for minmum stream power design method

slope to acquire minimum stream power. For a given discharge and sediment transport rate, the slope of a stable alluvial channel is unique and it corresponds to the minimum stream power. This condition is used as one of the three conditions required to determine the width, depth and slope of a stable channel by the minimum stream power approach. A sediment transport equation and a flow resistance equation provide the remaining two conditions.

For a given discharge, sediment transport rate, and sediment size; the slope, depth, and width of a channel can be computed by the following iterative procedure:

(1) Width and depth are assumed;

(2) Slope is computed using sediment transport equation;

(3) Mean velocity is computed using flow resistance equation;

(4) Discharge, Q = AU, and it is compared with given discharge; if computed discharge is different from given discharge, the depth is changed and steps (2), (3), and (4) are repeated.

(5) The slope is computed, and if it is not found to be the minimum value, the width is changed and steps (2) to (5) are repeated.

The flow chart given in Fig. 5 demonstrates the procedure of computation.The sediment transport equation, Eq. 8, and flow resistance equations, Eq. 9a and Eq. 9b, developed by Engelund and Hansen (1967) are used to design stable channels by the minimum stream power approach because they have sound physical basis, they are simple to use and they are found to give good simulation of data. The sediment transport equation gave reasonable estimates to the field data from the irrigation canal in Amibara. In addition, these equations have performed well in the appraisal of flow resistance and sediment transport equations using flume and field data.

The Engelund and Hansen sediment transport equation is

$$f\phi = 0.1\,\tau_*^{5/2} \qquad [8]$$

in which Æ [ϕ] = dimensionless sediment transport rate [$=q_s/\{(s_g-1)gd^3\}^{1/2}$]; q_s = sediment transport rate per unit width of channel; and f = friction factor.

The flow resistance equation for wide channels is

$$S = 7.368\left[g\,(s_g-1)^4\, d^2\, B_w^2\, D\,\frac{1}{Q^2}\,\frac{Q_s^2}{Q^2}\right]^{1/3} \qquad [9a]$$

For channels that are not very wide

$$S = 7.368\left[(s_g-1)^4\, gd^2\,\frac{P^4 R}{B_w^2}\,\frac{1}{Q^2}\,\frac{Q_s^2}{Q^2}\right]^{1/3} \qquad [9b]$$

'WFS' Approach

'WFS' is a designation given here to represent an approach of design that employs equations for Width, Flow resistance, and Sediment transport. Note that compared to the minimum stream power approach, the third criterion used in the 'WFS' approach is an equation relating width with pertinent variables (flow properties, other channel dimensions, slope, fluid properties, and sediment properties). However, the relationship of width with some of the variables is not well established.

Among a few of the relationships available for width, the equations by Lacey, Eq. 1 and by Simons et al (1963) indicate that at low rates of sediment transport width is primarily dependent on Q. Maddock and Leopold (1953) proposed Eq. 10 for natural streams transporting sediment.

$$B_w = 155.4\,\frac{D\,S^{1/2}\,Q^{0.555}}{n\,(C_s\,\omega_s)^{0.395}} \qquad [10]$$

in which Bw = width of water surface; D = mean depth of flow; n = roughness coefficient; Cs = sediment concentration, ppm by weight; $É_s$= mean fall velocity of sediment particles; and Q = dominant discharge.

Kondap (1977) disregarded sediment concentration in the analysis of stable channel data from various countries. He obtained Eq. 11 in terms of non-dimensional discharge and sediment parameter ($g^{1/2}d^{3/2}/v$) .

$$B_w = 0.212\,d\left[\frac{g^{1/2}\,d^{3/2}}{v}\right]^{0.231}\left[\frac{Q}{d^2\sqrt{g(s_g-1)d}}\right]^{0.548} \qquad [11]$$

Engelund and Hansen (1967) related width to discharge and sediment size, Eq. 12.

$$B_w = 0.78\,Q^{0.525}\,d^{-0.316} \qquad [12]$$

The equation is valid for dimensionless shear stress, $Ä_* = (DS)/\{(s_g-1)d\} > 0.15$.

The width equation needed in the 'WFS' approach of stable channel design is selected from the available four equations (Eqs. 1, 10, 11, and 12). In the selection process, first, a channel was designed by the regime method for a hypothetical data. Then, the width was calculated by each of the width equations. The sediment concentration required in Eq. 10 was calculated using the Engelund-Hansen sediment transport equation, Eq. 8.

The performances of the equations were examined using personal judgment. Then, they were employed to predict the observed widths of the Amibara canal. Tables 1 and 2, respectively, show the calculated widths using the observed values of variables for the Amibara canal data and using assumed values of a hypothetical data.

Maddock and Leopold give large values. Engelund and Hansen also give large values. Lacey and Kondap give comparable and more reasonable values. The best estimates for the field data are given Lacey. Thus, the Lacey equation of width, Eq.1, was selected to be used in the 'WFS' approach of stable channel design.

Comparisons between Methods of Stable Channel Design

Comparison Using Hypothetical Data

Discharges were taken at an increment of 5 m^3/s up to a maximum of 50 m^3/s and uniform non-cohesive sediment of size 0.150 mm is used in the design of channels so that the results will have relevance to the situation of the canal in Amibara. Approximate values of limiting stress $Ä_c$ corresponding to sediment sizes were obtained from studies by Simons and Albertson, Table 3. and an angle of repose of ± = 28 was used for the grain size under consideration (Simons and Albertson, 1963). A trapezoidal section of side slope 2H: 1V was used in all cases. Since this slope is smaller than the angle of repose of the channel material, the channel sides are expected to be stable.

Values of $Ä_{MAX}$ on the bottom and sides of trapezoidal channels are obtained from curves of B/D versus $Ä_{MAX}$/(³DS), Fig. 4. The values of the ratios of B/D and $Ä_{MAX}$/(³DS) for a channel with

d (mm)	0.100	0.150	0.200
τ_c (N/m^2)	1.45	1.53	1.58

Table 3: Limiting stress versus sediment size

side slopes of 2H:1V are extracted from Fig. 4 and presented in Table 4.

Design of channels by the regime method is simple and it is easily handled manually. The designs by the other methods are time consuming and the author has developed computer programs for the designs. The main features of these programs are shown in the flow charts given in Figs.3 and 5.

The following procedure was adopted in making the comparisons:

(1) The regime method was used to design a channel to convey a given discharge in a known material. The sediment transport capacity of the channel is estimated using the Engelund-Hansen transport equation, Eq. 8.

(2) The tractive force method was used to design a channel corresponding to the one designed by the regime method in the same bed material to convey the same water discharge. The slope and sediment transporting capacity required as input data by this method were obtained from Step 1.

(3) The minimum stream power method was used to design a channel corresponding to the one designed by the regime method in the same material to convey the same discharge. Sediment discharge required as input data by the minimum stream power method was obtained from Step 1.

(4) The 'WFS' method was used to design a channel to transport the same discharge and sediment load in the same bed material.

(5) The dimensions and slopes of the channels estimated by the different methods were compared with those estimated by the regime method. The regime method is picked arbitrarily to serve as a basis of comparison.

Results of channel bed widths B, flow depths D, bed slopes S and sediment concentrations Qs/Q, obtained by the different design methods plotted versus discharge are shown respectively in Figs. 6, 7, 8 and 9.

Table 1: Widths of the Amibara Canal estimated using Eqs. 1, 10, 11 and 12

Observed data of the Amibara Canal					B^*_{wc}/B^*_{wo}			
Q	S X 10^3	$C_s = Q_s/Q$	D	B^*_{wo}	Lac*	Mad*	Eng*	Kon*
m^3/s	—	ppm	m	m	m	m	m	m
4.45	1.5	152	0.93	10.3	1.0	4.98	3.05	0.87
6.19	2.0	663	1.13	11.4	1.04	4.38	3.27	0.95
3.13	1.0	80	0.90	10.9	0.77	2.65	2.40	0.67
0.89	0.8	83	0.63	10.3	0.44	0.40	1.31	0.36
1.23	0.8	30	0.48	10.2	0.52	0.95	1.57	0.43

* *Bwo = observed width of water surface; Bwc = calculated width of water surface; Lac = Lacey; Mad = maddock; Eng = Engelund and Hansen; Kon = Kondap*

Table 2: Widths of a hypothetical canal estimated using Eqs. 1, 10, 11 and 12 for d = 0.150 mm and T = 20 °C

Assumed data of a hypothetical canal				Bwc			
Q	S X 10^3	D	C_s	Lac	Mad	Eng	Kon
m^3/s	—	m	ppm	m	m	m	m
1	1.64	0.41	54	4.8	18.3	12.6	3.8
5	1.25	0.86	62	10.6	77.3	29.3	9.3
10	1.12	1.19	66	15.0	145.1	42.2	13.6
15	1.04	1.44	68	18.4	209.4	52.2	16.9
20	0.99	1.65	70	21.2	271.5	60.7	19.8
25	0.96	1.83	71	23.8	333.8	68.3	22.4
30	0.93	2.00	72	26.0	395.1	75.2	24.8
35	0.90	2.15	73	28.1	452.6	81.5	27.0
40	0.89	2.29	74	30.0	513.5	87.4	29.0
45	0.87	2.42	75	31.9	569.8	93.0	30.9
50	0.85	2.54	75	33.6	626.7	98.3	32.8

Table 4: Values of B/D versus $\frac{\tau Max}{\gamma DS}$

B/D	$\frac{\tau Max}{\gamma DS}$ bottom		B/D	$\frac{\tau Max}{\gamma DS}$ Bottom	sides
0.0	0.65	0.00	2.5	0.77	0.92
0.5	0.70	0.66	3.0	0.77	0.94
0.7	0.72	0.74	3.5	0.77	0.96
1.0	0.73	0.77	4.0	0.77	0.97
1.2	0.75	0.81	5.0	0.77	0.98
1.5	0.76	0.85	7.0	0.77	0.99
2.0	0.76	0.89	10.0	0.78	1.00

The following are observations made from the results obtained by the different design methods.

Tractive Force Method

The flow cross-sectional areas were smaller for lower discharges (below 20 m^3/s) and higher for larger discharges (greater than 20 m^3/s). The sediment transporting capacities were lower. Generally, the channels were much shallower and wider. Analysis of the tractive force theory helps to understand the peculiar nature of the results.

According to the tractive force theory, the maximum shear on the sides of channels is a function of flow depth and width. Lane's (1955) findings show that depending on the side slope, the unit tractive force on a channel side becomes more or less constant for width to depth ratios of about 3 and above for trapezoidal channels of side slopes of 2H:1V and 1.5H:1V, thus, the depths of flow remain almost constant in the specified range.

Consequently, for relatively higher discharges, the additional flow cross-section required must be supplied almost exclusively through width increment.

Minimum Stream Power Method

The flow cross-sectional areas obtained are comparable to those obtained by the regime method. The bed slopes are slightly higher for low discharges, but lower for high discharges. Still, their order of magnitude is generally higher.

Deeper and narrower channels are obtained for all ranges of discharges. The minimum stream power theory for prismatic channels is equivalent to minimizing the energy gradient; i.e., the channel slope. This process minimizes flow resistance or wetted perimeter. As a result the wetted perimeters of the channels designed by this method are much lower, particularly for the higher discharges and the channels are narrower.

'WFS' Method

The flow cross-sectional areas and the hydraulic radii obtained by this method are larger than those obtained by the regime method. Thus, the channels of the 'WFS' method have higher roughness than the channels of the re-

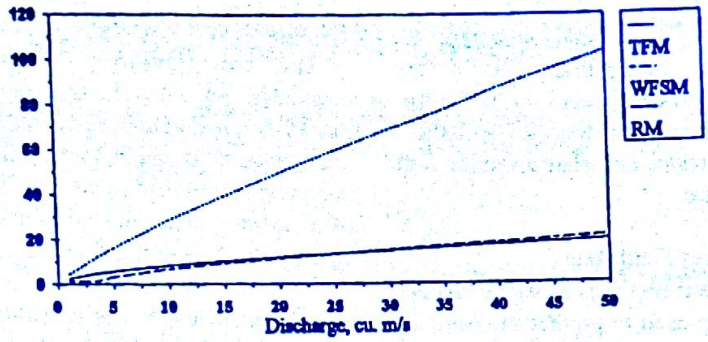

Fig.6 Bed width versus discharge for various methods

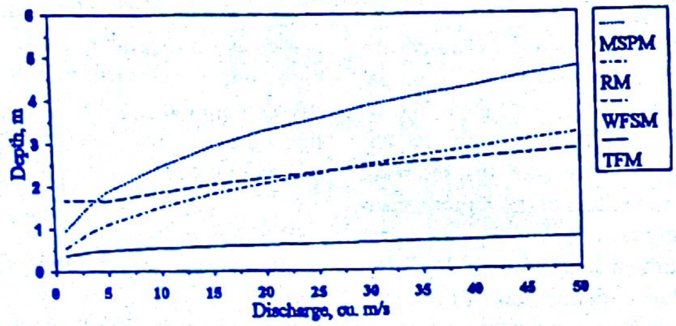

Fig.7 Depth versus discharge for various methods

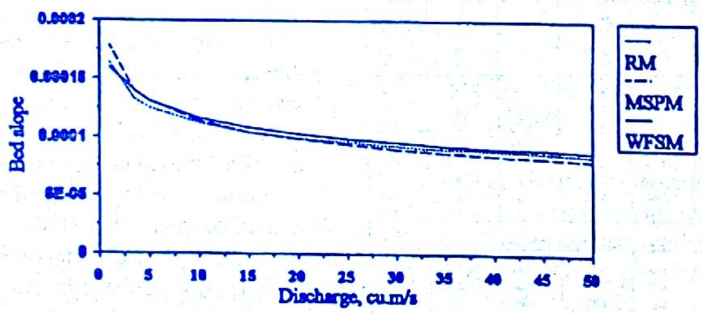

Fig.8 Bed slope versus discharge for various methods

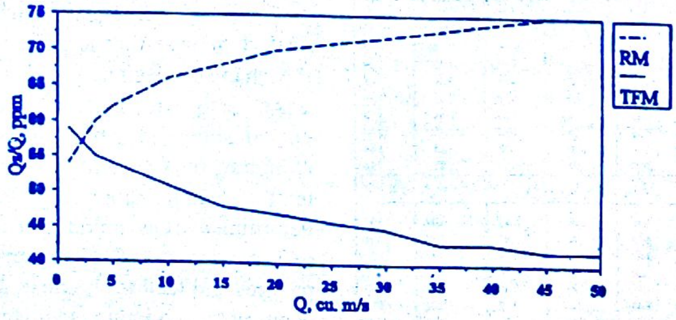

Fig.9 Q_s/Q versus Q for Various methods gime method. The bed slopes are of the same order of magnitude. The channels are narrower and deeper for low to medium discharges (up to 25 m³/s) and they are wider and shallower for high discharges.

Predictin of Field Data

The four methods of stable channel design are used to predict the Amibara canal data given in Table 1. The results obtained are shown in Table 5

Regime Method:

Channel dimensions obtained for the significant discharges were comparable to those of the field data, but the bed slopes were higher than the observed slopes. However, the sediment transport capacities of the regime channels were much lower than the measured sediment loads for all discharge ranges. Hence, deposition will occur in channels designed by this method. In fact, this phenomenon is observed in the Amibara main canal which was designed by the regime method. Hence, the method is not suitable for the case of the Amibara case.

Table 5: Simulated data

Source	Q	$(Q_s/Q)_r$	$(B_w)_r$	D_r	S_r
	m³/s	ppm	m	m	—
Regime Method					
AM1	4.45	0.31	0.92	1.17	0.45
AM2	6.19	0.07	0.98	1.14	0.32
AM3	3.13	0.56	0.73	1.03	0.72
AM4	0.89	0.49	0.42	0.73	1.10
AM5	1.23	1.47	0.52	0.77	1.05
SM1	12.60	0.17	1.37	0.93	1.17
SM2	1.56	0.22	1.60	0.81	0.68
CHAU1	27.52	0.28	1.00	1.42	1.40
Tractive Force Method					
AM1	4.45	0.91	1.90	0.40	1.00
AM2	6.19	0.28	3.24	0.28	1.00
AM3	3.13	1.09	0.91	0.62	1.00
AM4	0.89	0.51	0.41	1.21	1.00
AM5	1.23	1.37	0.66	1.58	1.00
SM1	12.60	0.13	1.87	0.50	1.00
SM2	1.56	0.32	3.54	0.30	1.00
CHAU1	27.52	0.10	3.06	0.39	1.00
Minimum Stream Power Method					
AM1	4.45	1.00	0.78	1.70	0.89
AM2	6.19	1.00	0.63	1.27	1.29
AM3	3.13	1.00	0.71	1.69	1.05
AM4	0.89	1.00	0.49	1.37	1.89
AM5	1.23	1.00	2.99	0.44	1.73
SM1	12.60	1.00	0.91	1.16	2.94
SM2	1.56	1.00	1.35	1.16	1.64
CHAU1	27.52	1.00	0.63	1.85	2.58
'WFS' Method					
AM1	4.45	1.00	0.92	1.24	0.92
AM2	6.19	1.00	1.01	0.65	1.49
AM3	3.13	1.00	0.70	1.82	1.05
AM4	0.89	1.00	0.38	2.46	—
AM5	1.23	1.00	0.50	2.58	—
SM1	12.60	1.00	1.39	0.61	3.33
SM2	1.56	1.00	1.60	0.84	1.70
CHAU1	27.52	1.00	1.02	0.89	2.98

Tractive Force Method:

For the significant discharges, channels are much wider and shallower than the actual ones. Sediment transport capacity is much lower than the observed values leading to possibilities of deposition. The method is not suitable for the case of the Amibara case.

Minimum Stream Power method:

Slightly deeper and narrower channels are obtained by using the minimum stream power method of design compared to the observed canal, but the slopes are comparable to the observed canal slopes. Sediment transport capacity, as input data, is the same as the actual loads. Hence, the field data were adequately simulated.

'WFS' Method:

Somewhat wider and shallower channels are obtained by using the 'WFS' method compared to the observed canal. The bed slopes are comparable to those in the Amibara canal, but they are somewhat higher for the other data. Sediment transporting capacities, as input data, are the same as the actual loads. Thus, the 'WFS' method simulates the field data reasonably well.

Discussion and Conclusion

The four methods of design of stable channels fall into two categories: Those that require sediment load as input data (the minimum stream power and 'WFS'' methods) and those that do not require sediment load as input data (the regime method and the tractive force method). The channel dimensions obtained by the methods in the first category account for sediment load as well as other flow characteristics and are, thus, expected to perform with reduced problems of sedimentation when operated at or near the design values. For the channels designed with the methods of design in the second category do not consider sediment load. The sediment transport capacity is computed after the channel dimensions have been determined. It is found that the channels have low sediment transport capacities and lead to sediment depositon even with moderate sediment loads. Therefore, the minimum stream power and 'WFS' design methods give relatively acceptable channel dimensions.

Also from economic considerations, the excessively wide and shallow channels obtained by the use of the tractive force method are not feasible because they require large area, more expensive maintenance, long channel crossings, and they provide low head that makes diversion of flow into branch channels difficult.

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Use Of Method of Maximum Likelihood for Flood Flow Estimation of Some Etiopian Rivers

Dr. Pande B.B.Lal,AWTI & Joseph Tanko Nigeria Aid Corps (TAC), at AWTI

Abstract

Use of EV1 distribution or Gumbel distribution is quite popular in literature for flood flow estimation. There are considerable number of ways in which the parameters of EV1 distribution can be estimated. The method of Maximum likelihood (MLH) appears to be the best. It is however time consuming as it requires many iteration to determine the value of concentration parameter a and characteristic largest value U. A computer program has been prepared from which the value a and U can be determined from the annual flood series at any site. A simplified version has also been suggested in this paper for the determination of a based on the first iteration, which cuts down the computation time and gives result fairly close to the results obtained from repeated number of iterations. Gumbel's formula thereafter, has been written in a simplified manner and the estimate of flood flows for various return periods for the method of MLH are compared with some other methods. Method of Sufficient estimation of parameters suggested by Kimball has also been verified for Ethiopian river data.

Introduction

Hall & Dracup (1970) define the flood as high stage of flow, which results in water entering, and covering lands otherwise used for economic purposes. Shen (1976) defines it as " relatively high flow " that may or may not over top the banks of the stream. The use of the word flood in this paper relates to a flow with a magnitude equal to its annual peak flow.

All rivers are subjected to a non zero probability that any particular level of flow will be equaled or exceeded. With each level of flow there is a frequency with which a flow of that quantity or greater will be experienced over a long time interval. The frequency can be used to define return period. Estimation of flood peaks for various return periods is very important for the design of hydraulic structures. The frequency methods using statistical distribution is based on the assumption that flood peak occurring every year is a random variable. Various other assumptions associated with the use of statistical methods are well known and hence need not be summarized. So also there is a large number of probability distribution functions being used for flood flow estimation, a reference can be made for these in Shen's publication (1976) or in other standard texts on the topic.

Estimation Of Parameters For Gumbel Distribution

The four parameters that defines Gumbel's distribution are the four moments:

(i) Mean $\gamma = 0.5772$ called Euler's constant
(ii) Variance $= \pi^2/6 = 1.6449$
(iii) Coefficient of skewness $= C_s = +1.1396$
(iv) Kurtosis $C_k = 5.4$

The discharge with a return period of T years can be estimated as

$$Q_T = U + (1/\alpha)[-\ln\ln(T/T-1)] \quad (1)$$

where, α is known as concentration parameters and U is the characteristic largest value or mode. Although, theoretically for EV1 distribution the use of [-lnln(T/T-1)]is the only correct way but for simplifications in the literature **[-lnln(T/T-1)]** has been replaced by **ln(T- 0.5)**. It is further suggested here for the design of hydraulic structures flood flow estimation is carried out for a minimum period of about 50 years, therefore **[-lnln(T/T-1)]** can be replaced by **ln(T)**. The variation between **[-lnln(T/T-1)]**, **ln(T-0.5)** and **ln(T)** is shown in table 1.

Hence, equation (1) can be rewritten in a simpler manner as:

$$Q_T = U + (1/\alpha)[\ln(T)] \quad \ldots(2)$$

The values of U & α can be estimated by various methods such as use of order statistics, method of moments, least square technique, method of probability weighted moments(PWM), power transformation method and method of maximum likelihood (MLH). In a M.Sc. thesis done by Mujdda al fattah (1979) under the guidance of senior author, the value of α & U determined for some rivers by various methods have been compared and are shown in table 2. This table indicates that the values of α and U determined by method of MLH are in the same range as estimated by other methods. Why should one use the method of MLH and the basic advantages of using MLH over other methods has been discussed later in this paper.

Method of Maximum likelihood (MLH)
The method of Maximum likelihood which leads to the determination of a unique value of α is based on the assertion that the value parameters is determined by making the probability of obtaining the observed out-come as high as possible.
The probability density function of EV1 can be written as

$$f(Q)\,dQ = \alpha e^{-\alpha(Q-U)} * e^{-e^{-\alpha(Q-U)}}\,dQ \quad \ldots\ldots(3)$$

TABLE 1. Variation Between [-lnln(T/T-1)], ln(T-0.5) and ln(T)

T	[-lnln(T/T-1)]	ln (T-0.5)	ln(T)	%variation between column 2 & clumn4
50	3.9019387	3.9019727	3.912020	0.25%
100	4.6001492	4.6001576	4.6051702	0.10%
200	5.2958121	5.2958142	5.2983174	0. 04%
500	6.2136073	6.2136076	6.2146081	0.016%
1000	6.9072551	6.9072552	6.9077553	0.007%
10000	9.2102904	9.2102904	9.2103404	0.0005%

TABLE 2: Estimated Values of α and U by some methods

Name of rivers	Parameters	Use of order statistics	Probability paper gumbel	Method of Moments	Sufficient estimate of parameters	MLH
River GREAT ER zab	α	$9.26 \bullet 10^{-4}$	$6.427 \bullet 10^{-4}$	$7.29 \bullet 10^{-4}$	$8.5 \bullet 10^{-4}$	$9.38 \bullet 10^{-4}$
	U	2010	2071	2126	2239	2213
River Tigris at Mosul	α	$6.55 \bullet 10^{-4}$	$6.65 \bullet 10^{-4}$	$7.38 \bullet 10^{-4}$	$7.38 \bullet 10^{-4}$	$7.67 \bullet 10^{-4}$
	U	3000	2947	2985	2985	3030
River Tigris at Fatha	α	$3.67 \bullet 10^{-4}$	$3.67 \bullet 10^{-4}$	$4.00 \bullet 10^{-4}$	$4.13 \bullet 10^{-4}$	$4.23 \bullet 10^{-4}$
	U	5262	5240	5282	5327	5302

Or, $f(Q)dQ = \alpha[Exp\{-\alpha(Q-U)\}]*Exp[-Exp\{-\alpha(Q-U)\}]\,dQ$

The probability density function of Q_1 occurring as an annual highest peak is

$$F(Q_1) = \alpha[Exp\{-\alpha(Q_1-U)\}]*Exp[-Exp\{-\alpha(Q_1-U)\}] \quad ....(4)$$

similarly the probability of Q_2 occurring as an annual highest peak is

$$f(Q_2) = \alpha[Exp\{-\alpha(Q_2-U)\}]*Exp[-Exp\{-\alpha(Q_2-U)\}] \quad ....(5)$$

Similarly the probability density function for any highest annual peak Q_i can be written as

$$F(Q_i) = \alpha[Exp\{-\alpha(Q_i-U)\}]*Exp[-Exp-\alpha(Q_i-U)\}] \quad ....(6)$$

By multiplication theorem for the joint occurrence of independent events it can be written as

$$f(Q_1, Q_2, Q_3, ... Q_N) = \prod f_i(Q_i)^N \quad ....(7)$$

or,

$$\prod_1^N f_i(Q_i) = \alpha^N [Exp\{-\Sigma_1^N \alpha(Q_i-U)\}]*Exp[-Exp\{-\Sigma_1 \alpha(Q_i-U)\}] \quad ....(8)$$

In order to maximize equation (8), we can maximize its logarithm

$$L = \ln\Pi_1 f_i(Q_i) = N\ln\alpha - \Sigma_1^N \alpha(Q_i-U) - \Sigma_1^N Exp\{-\alpha(Q_i-U)\} \quad ....(9)$$

Differentiating L, for maximizing, with respect to U and α we have

dL/ dU = 0 and dL/ dα =0 we have,

$$dL/d\alpha = N/\alpha - \Sigma_1^N (Q_i - U) + \Sigma_1^N (Q_i - U)\,Exp\{-\alpha(Q_i-U)\} = 0 \quad ....(10)$$

$$dL/dU = N\alpha - \alpha\Sigma_1^N Exp\{-\alpha(Q_i-U)\} = 0 \quad ....(11)$$

Solving equation (11) we get,

$$N\alpha - \alpha Exp(\alpha U)\Sigma_1^N Exp(-\alpha Q_i) = 0$$

or,

$$N = Exp(\alpha U)\Sigma_1^N Exp(-\alpha Q_i) \quad ....(12)$$

Combining equation(10) & equation (12)

$$dL/d\alpha = N/\alpha - NQ + NU + Exp(\alpha U)\Sigma_1^N Q_i\,Exp(-\alpha Q_i) - NU = 0$$

$$dL/d\alpha = N/\alpha - NQ + Exp(\alpha U)\Sigma_1^N Q_i\,Exp(-\alpha Q_i) = 0 \quad ....(13)$$

Substituting the value of N from equation (12) in equation (13) we get,

$$F(\alpha) = \Sigma_1 Q_i Exp(-\alpha Q_i) - (Q - 1/\alpha)\Sigma_1 Exp(-\alpha Q_i) = 0 \quad .....(14)$$

Equation (14) is a unique equation in terms of only one unknown variable α. However a closed form solution of equation (14) appears difficult. The same can be easily solved on computer by repeated iterations for different values of α till the equation for given variable Q_i reduces to zero. The neighborhood of a plausible solution can therefore be intuitively assessed first, thereafter a series of closer approximations to the true solution can be tried successively to bring $F(\alpha)$ to zero. A computer program in Fortran 4 with some features of Fortran 77 has been made with following algorithms.

A good start is made with $\alpha_1 = \pi/(\sqrt{6})\sigma$

(i) Read annual peak discharges Q_i from historical records for N years of different rivers as available.

(ii) Find $Q\,(Q_{AVG}) = \Sigma Q_i/N$ and $\sigma = \sqrt{(Q_i - Q)^2/N}$

(iii) Find $\alpha_1 = \pi/(\sqrt{6})\sigma$

(iv) Find the new Value $1/\alpha'_2 = \dfrac{\Sigma_1 Q_i Exp(-\alpha Q_i)}{\Sigma_1^N Exp(-\alpha Q_i)}$

(v) Find $\alpha_2 = 1/\alpha'_2$

(iv) Compare $(\alpha_2 - \alpha_1)$ if less than a small value say less than 10^{-4}, we can assume $\alpha = \alpha_2$

For different rivers , the program took different number of runs to give a stable value of α. These values are given in table 3 for various rivers. The program also yields the value of Q_{avg}, σ, and $\Sigma\exp(-\alpha Q_i)$. Value of U is then determined from eq(12) as:

$$U = (1/\alpha)\ln[N/\Sigma\exp(-\alpha Q_i)] \text{———}(15)$$

These values are also given in table(3). Having determined the values of U and α,t can be substituted in equation (2)

$$Q_T = U + (1/\alpha)[\ln(T)]$$

and combining it with eq (15) we get

$$Q_T = (1/\alpha)\ln[N\,T/\Sigma\exp(-\alpha Q_i)] \text{—}(16)$$

In the literature it is suggested that a value of 1.64 S can be added to bring it within 95% confidence limit. The value of S is given by:

$$S(1/\alpha\sqrt{N})[1 + (6/\pi^2)\{1 - \gamma - \ln\ln(T/(T-1))\}^2]^{0.5}$$

which can be further written in a simplified manner as

$$S = (1/\alpha\sqrt{N})[1 + 0.6085\{0.4228 + \ln(T)\}^2]^{0.5}$$

Table 3: Different values of α Q_{avg}, σ, $\Sigma \exp(-\alpha Q_i)$ and U

Nameo river	Q_{avg}	σ	starting α	1st trial α	Final α	$\Sigma\exp(-\alpha Q_i)$	U
River Andasa	187.40	84.80	0.0151	0.0126	0.0136	5.0024	147.13 18
River Gilgel Abay	394.85	102.67	0.0124	0.0146	0.0138	0.283	353.02
River koga	36.99	15.17	0.0845	0.0737	0.0779	3.621	29.83
River Ribb	157.61	43.07	0.0297	0.0230	0.0258	1.038	138.51
River gumer	328.89	74.113	0.0173	0.0181	0.0179	0.192	296.86

Thus the over all value of Q_T can be written as:

$$Q_T=(1/\alpha)\ln[NT/\Sigma\exp(-\alpha Q_i)]+1.64S \quad (17)$$

The value of Q_T estimated from equation (16) & equation (17) are given in table (4) for five-river system flowing in or flowing out of Lake Tanna in Ethiopia. A comparison is thereafter made with estimate made by conventional methods and power transformation method presented by senior author in the same symposium held in the year 2002.

Table 4: Estimated magnitude of flood flow for different return periods & its comparison : (a) River Andasa

Return Periods years	Q_T MLH	Q_T MLH + 1.64 S	Q_T Power Transformation	Q_T Gumbel
100	485.75	566.00	446.47	498.81
500	604.09	708.62	530.38	611.57
1000	655.05	770.13	565.12	663.45
5000	773.39	938.60	642.59	783.84
10000	824.36	974.63	674.86	835.68

(b) River Gilgel Abay

Return Periods years	Q_T MLH	Q_T MLH + 1.64 S	Q_T Power Transformation	Q_T Gumbel
100	686.84	765.92	790.72	762.25
500	803.46	906.48	966.82	908.33
1000	853.69	967.16	1043.78	971.13
5000	970.32	1107.96	1225.21	1116.88
10000	1020.00	1168.11	1304.62	1179.64

(C) River Koga

Return Periods years	Q_T MLH	Q_T MLH + 1.64 S	Q_T Power Transformation	Q_T Gumbel
100	88.95	89.25	81.79	91.29
500	109.61	110.00	95.94	112.90
1000	118.51	118.94	101.75	122.20
5000	139.71	139.69	114.67	143.70
10000	148.07	148.63	120.02	153.00

(d) River Ribb

Return Periods years	Q_T MLH	Q_T MLH + 1.64 S	Q_T Power Transformation	Q_T Gumbel
100	317.00	359.30	299.79	305.70
500	379.39	434.50	352.06	364.70
1000	406.25	466.91	374.24	390.10
5000	468.64	542.26	424.75	449.10
10000	495.50	574.72	446.20	474.40

(e) River Gumera

Return Periods years	Q_T MLH	Q_T MLH + 1.64 S	Q_T Power Transformation	Q_T Gumbel
100	551.19	612.15	567.07	593.56
500	641.10	740.53	648.56	699.01
1000	679.83	767.26	682.69	744.35
5000	69.74	875.85	759.57	849.56
10000	808.47	922.65	791.89	894.87

The comparison shows that the estimated values of flood magnitudes for different return periods are in the same range as other methods for parametric estimation of EV1 distribution. However, parameters estimated by method of MLH appear to be more accurate and elegant. The historical data has been used thrice viz estimation of Qavg, $\Sigma\exp(-\alpha Q_i)$and $\Sigma Q_i \exp(-\alpha Q_i)$. The method ensures the likelihood of maximum occurrence for parameters α and U. The fitting of EV1 distribution becomes more realistic and reliable.

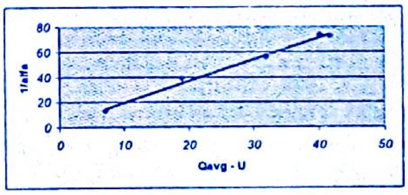
Sufficient Estimation of Parameters

Kmball suggests a method of estimation of parameters (Gumbel 58) which is called sufficient estimation for parameters according to him

$$U+\gamma/\alpha = Q_{avg} \quad \ldots\ldots\ldots\ldots(18)$$

This expression can be verified ab initio from our results by plotting Q_{avg} - U with $(1/\alpha)$ as shown in figure 1.

Slope of the above line has been worked out on Micro soft excel and is given as 0.576416432 which is very close to the value of γ (Euler's constant = **0.5772**). The correlation coefficient between the variables has been worked out as 0.995. The points plotted in the above figure are given in table (5)



Approximate method of MLH

An approximate method for MLH can be suggested at this stage in case the calculation need to be done with hand calculator at site or in other circumstances.

Table 5: Values of estimated parameter as plotted

Name or rivers	Qavg – U	1/α
River Andasa	40.27	73.53
River Gilgel Abay	41.83	72.46
αRiver Koga	7.16	12.84
River Ribb	19.10	38.76
River Gumer	32.03	55.87

Table 5a: Estimates of apprroximate value α for various rivers

Nameo river	starting α	1^{st} trial α	Approx α	Final α	γ/α	U=Qavg-γ/α
River Andasa	0.0151	0.0126	0.0134	0.0136	43.07	144.33
River Gilgel Abay	0.0124	0.0146	0.0138	0.0138	41.82	353.03
River koga	0.0845	0.0737	0.0773	0.0779	7.47	29.52
River Ribb	0.0298	0.0230	0.0252	0.0259	22.91	134.70
River gumer	0.0173	0.0181	0.0181	0.0179	32.43	296.46

Table5b: Estimate of flood flow for various return periods

$Q_T = U + 1/\alpha \ln T$

Return Period	River Andasa	River Gilgel Abay	River Koga	River Ribb	River Gumera
100	488.00	686.74	89.10	317.44	555.18
500	608.11	803.36	109.92	381.31	645.59
1000	659.83	853.59	118.88	408.82	684.53
5000	779.94	970.22	139.70	472.68	774.95
10000	831.67	1020.45	148.67	500.19	813.89

1.A study of table (3) indicates that an approximate method of α can be found close to the final value for design purpose as:

Approximate α = Value of α from 1^{st} trial + (1/3)(abs value (Starting α - 1^{st} trial α))

2. The value of U there after can be estimated from **U = Qavg - γ/α.**

These values along with the estimates of flood flows for various return period are given in table(5).

A comparison between the estimates by approximate method as given in the table 5b and actual detailed method of MLH as worked out in the 1^{st} column of table 4 (a) to (e) shows that difference if any is but minor. Therefore the use of the method can be recommended if the calculations are to be done on hand calculator.

Conclusion

1.The method of maximum likelihood can easily be applied to any set of river data by making a computer program.
2.The formula suggested by Kimball gets verified for the data of Ethiopian rivers.
3.In case of non-availability of a computer at site approximate method of analysisbased on estimation of α and U can be easily applied.

Acknowledgement

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Bed Material Characteristics and Bed Load Transport of Kulfo River: Measurements and Analysis

Nigussie Teklie, AWTI P.O.Box 21,Arbaminch

Abstract

Information on sediment movement and particle-size characteristics is needed in the design of hydraulic structures, such as dams, canals, and irrigation works. Where riverbed aggradation or degradation would bring adverse consequences, e.g., in the vicinity of bridge piers and other structures, the stability of the bed sediment might be assessed if the relation between flow and bed material grain size distribution (both surface and subsurface) were understood.

Channel surveys and bed material grain size analysis show that Kulfo is a steep-sloped gravel-bed river. The grain size of the material forming the bed, both surface and subsurface, is predominantly gravel. However, the surface is generally coarser than the subsurface; the fines being removed by winnowing. The two distributions are found to be approaching each other at the coarse end of the grain size distribution curve, which shows that the surface material is a truncated form of the subsurface with respect to the fines.

Bed load transport was measured by Helley-Smith sampler, and its rate and grain size distribution analyzed in the laboratory by oven drying and weighing. For the range of sampling period, i.e., April – October 2002 the bed load discharge at station 3 (near the foot bridge) was found to comprise about 42% of the total load, which shows bed load to be a significant proportion of the total load of this river. The analysis of measured bed load depicted that in general the bed load varies with water discharge and bed shear stress, the increase being faster for discharges greater than about $3m^3/s$. For the flow less than $3m^3/s$, the increase is very small and the data show very much scatter. The same trend is observed from the plot of median grain size of transported material vs. bed shear stress. Beyond the bed shear stress of about $9N/m^2$, the coarsening of the bed load material is seen to be significant.

Preliminary test was also conducted on few of the available bed load transport equations applicable for gravel-bed rivers to find out the ones that may be appropriate for Kulfo River. At this stage, it may not be possible to reach at a conclusion as to the selection of the equation that applies to this river. However, the current analyses demonstrate that some of the predictions are close to measured results and that with more data better results could be obtained.

Introduction

Man's activities on the flood plains and rivers are causing changes to various variables affecting sediment erosion, transportation, and deposition. Thus, there is a need for direct and indirect measurement of fluvial sediment movement and its characteristics. Sediment data are useful in coping with problems and goals related to water utilization. Information on sediment movement and particle-size characteristics is needed in the design of hydraulic structures, such as dams, canals, and irrigation works. Where riverbed aggradation or degradation would bring adverse consequences, e.g., in the vicinity of bridge piers and other structures, the stability of the bed sediment might be assessed if the relation between flow and bed material grain size distribution (both surface and subsurface) were understood. To properly sample bed material for interpretation, it is first necessary to establish what constitutes bed material and understand its relation to transported load, especially to bed load. Bed load is the sediment, which moves in close contact with the bed; the particles displacing themselves by sliding, rolling or jumping (or saltating). This type of transport is mainly concerned with the relatively coarser materials coming from the riverbed. Bed material, on the other hand, is the sediment mixture of which the bed is composed. Bed-material particles are likely to be moved at any moment or during some future flow conditions as suspended load or bed load depending on the grain size of the particles. Compared to sand bed rivers the amount of bed load transported by rivers with coarse-grained beds is relatively large. Generally, the amount of bed load transported by a large, deep (lowland) river is about 5 to 25% of the suspended load (Simons & Sentürk, 1992) while for mountain rivers it is 10 to 50% of the total load (Bathurst, et al, 1987). Although the amount of bed load may be small (esp. in low land rivers), as compared with the total sediment load, it is very important because it shapes the bed and influences the stability of channel, the grain roughness, and the form of bed roughness.

The focus of this paper is on the study reach selected in the middle course of Kulfo River near Arba Minch. The reach, with a length of 4570m, was surveyed from 10 to 22 January 2002 from which longitudinal profile, mean channel slope, and sediment sampling stations were determined (Figure 1). From this survey, the channel slope was found to vary between 0.7% and 1.4%, with an average value of 1% for the reach. According to Bathurst, et al (1987), channel slopes are steep if they are between 0.1% and 10%; so, Kulfo can be classified as a river with a steep slope.

In the subsequent sections, the methods employed in sampling and analysis of gravel-bed material and bed load will be discussed. Variations of bed load discharge and transported material grain size distributions with flow will be analyzed and finally comparison of measured bed load discharge with those computed using various bed load transport equations will be presented.

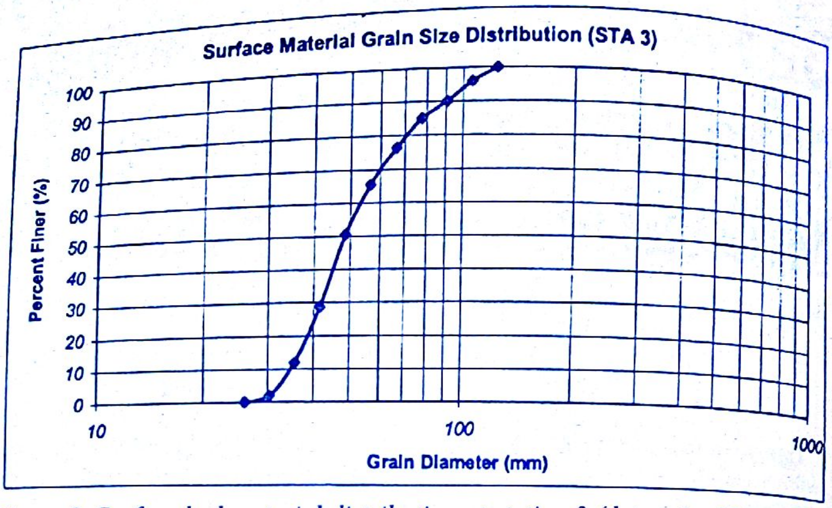

Figure 2. Surface bed material distribution at station 3 (determined by grid-by-number method).

Bed Material Sampling and Analysis

In sediment transport studies of a river, knowledge of the size, and size distribution of the bed material is important. Moreover, for riverbeds with coarse-grained sediments the major emphasis related to sampling and analysis is normally placed on the evaluation of characteristic sizes and size distributions of the surface and subsurface layers. The surface bed material is used for roughness calculation and estimation of the flow competence (Church, et al., 1987); some grain sizes (such as d_{90}) are even used to represent the roughness height. The sub-surface material, on the other hand, is of interest for sediment transport studies, stability considerations, and gravel resources appraisal. However, as the grain size range of gravel-bed (coarse material bed) rivers is very wide, it becomes difficult to maintain a single method of measurement. Hence, surface and sub-surface bed materials are sampled and analyzed separately using different sampling and analyses techniques. Bed material, both surface and sub-surface, was sampled from the five stations shown in figure 1, in February 2002.

Surface Bed Material

The most typical feature of gravel-bed riverbed is a surface cover that is relatively coarse in comparison with the bulk gravel/sand mixture beneath. This coarsening of surface material is the result of winnowing process, which removes the fines from the surface and leaves deposit of coarse material one grain deep (Church, et al., 1987). Winnowing results in the surface size distribution that is a truncated form of the underlying sediment size distribution.

The surface bed material was sampled by grid method of sampling demonstrated by Kellerlhals & Bray (1971) and Church, et al., (1987) at low flow when the channel was accessible. A grid of 0.5mX0.5m is established over the riverbed and those stones falling under each grid point are collected. According to Wolman, 1954 (Church, et al., 1987) at least 100 stones have to be collected at a sampling station in order to get a representative sample to determine the surface bed material grain size distribution. As a result, about 100 stones (and in most of the cases >100 stones) from each sampling station were collected and the grain size distribution determined based on frequency-by-number (or pebble-count) method.

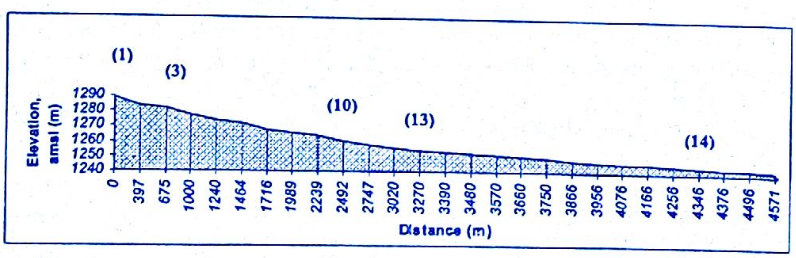

Figure 1. Longitudinal profile of the study reach, showing the five sampling stations. The station numbers are shown in the parenthesis.

The results of this analysis are shown in figure 2 for station 3, and characteristic diameters (d_{50} and d_{90}) for all stations are shown in table 1.

Sub-surface Bed Material

The sub-surface bed material is also sampled from those stations where surface sample was collected. In a similar manner, this sampling was carried at low flow from the abandoned riverbed. The sub-surface bed material is sampled after removing approximately one-grain thick coarse surface material. Herein the bulk sampling technique is employed and the material is removed by shoveling. The grain-size distribution of the bulk sub-surface material is analyzed using two procedures and later plotted together. The coarse fraction is analyzed by dry sieving in the laboratory and apportioning by weight (volume-by-weight), while sedimentation technique (or hydrometer analysis) is employed using Stoke´s law for the fine fraction (<0.075 mm).

Important parameters derived from subsurface bed materials that are required for sediment transport studies include the characteristic diameters (e.g., d_{16}, d_{35}, d_{50}, d_{84} and d_{90}), the specific gravity, etc. The characteristic diameters are obtained from the grain size distribution whereas the specific gravity is determined by displacement method in the laboratory. For the reach under study, the specific gravity was determined for all the stations, which gave an average value of 2.83. The grain size distribution curve for station 3 determined using the method described

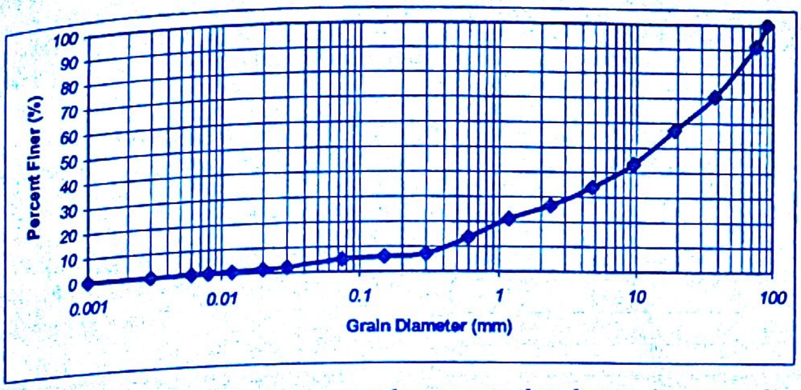

Figure 3a. Sub-surface bed material grain size distribution (at station 3)

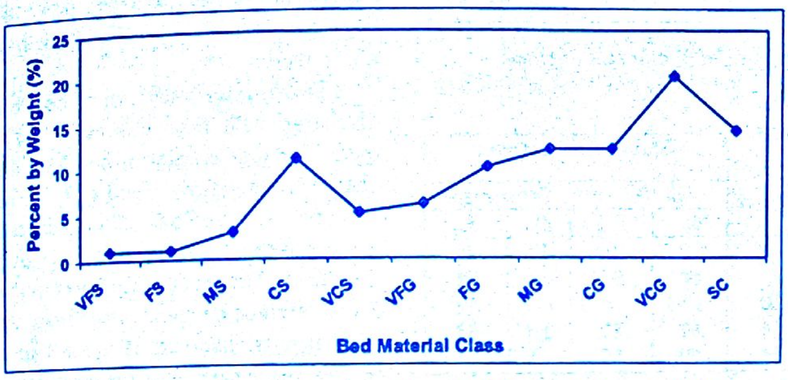

Figure 3b. Subsurface material composition of different bed material classes at station 3

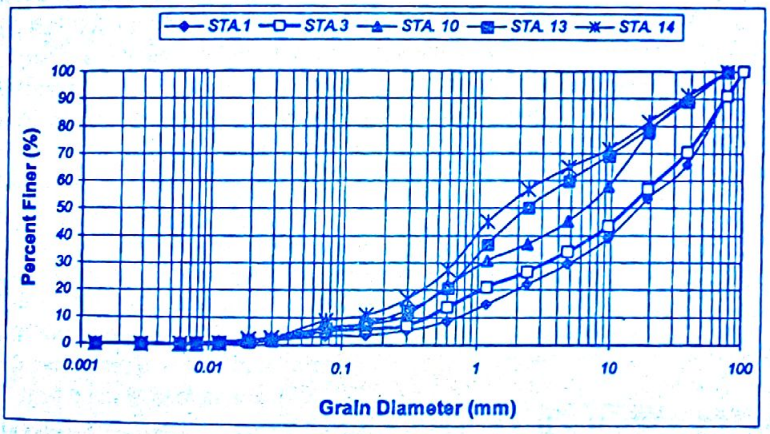

Figure 4. Grain-size distribution of the five stations (station 1, 3, 10, 13 and 14) drawn together.

above is shown in figure 3 and that of the five sampling stations plotted together is shown in figure 4 for comparison purposes. From the grain size distributions of the five stations studied, the sub-surface material is found to be predominantly gravel whose proportion in all cases is more than 50%. For station 3, for instance, 60% of the material is gravel while sand comprised of 22% and cobbles about 14% of the total. Further, very close examination of the substrate grain size distributions show that they are weakly bimodal and poorly sorted as depicted by the large values of the geometric standard deviations.

According to Church, et al (1987), if the surface and sub-surface are comparably sampled, one distribution can be transformed into the other by truncation. Therefore, as the same range should be considered to make comparison between samples, the sub-surface material is truncated from the finer end and the percentage of each class is recalculated. As can be seen from figure 5, truncated sub-surface size distribution closely resembles the overlying surface size distribution. The maximum sizes of the two distributions (surface and sub-surface) are approaching each other and hence $d_{95\ surface}/d_{95\ sub\text{-}surface}$ '‡1. Figure 5 shows the comparison of surface and sub-surface material after the sub-surface material is truncated together with the full sub-surface sample. From table 1 and the subsequent figures, it can be observed that the surface material is generally coarser than the sub-surface and both the surface and sub-surface materials get finer in the downstream direction (i.e., downstream fining due to selective transport).

Bed Load Sampling and Analysis

Measurement of sediment discharge is necessary to directly determine the amount of sediment load and establish or check analytical or empirical sediment transport equations. These measurements differ in principle based on the mode of transport, i.e. bed load or suspended load.

Bed load measurement is concerned with the coarse material carried by the flow, which is moving by rolling, sliding or saltating on or near the riverbed. This is accomplished by using samplers or other devices, including sediment traps, bed load samplers, or other techniques, such as tracer techniques or measurement of migration of bed forms. Direct measuring devices, such as samplers and sediment traps, collect the volume of the bed material in motion from which the total weight of sediment is determined after drying and weighing.

Direct measurement of bed load is difficult due to various reasons. Any device placed on or near the bed disturbs the flow and hence the rate of bed load movement. Moreover, the measured bed load, at a given point may not represent the entire channel cross section since the velocity and sediment movement close to the bed vary considerably with both time and space. The variability of the bed-load transport rate at one location, especially on a bed form, is so large (factor of 10 to 100) that

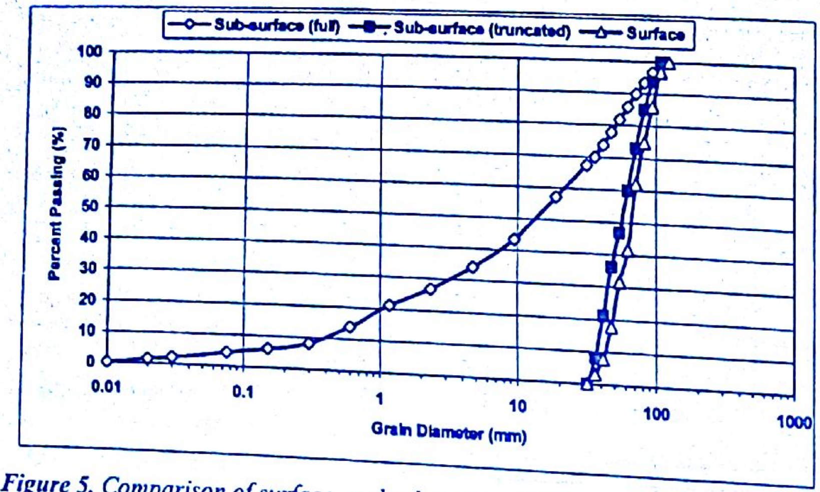

Figure 5. Comparison of surface, and sub-surface (full), and sub-surface (truncated) grain-size distributions for station 3.

the mean transport rate can only be determined accurately by taking a large number of samples (van Rijn, 1993). Ideally, the best measurement of bed load would occur when the entire bed load moving through a given width during a specific period was measured (Edwards and Glysson, 1998). This can closely be achieved only by pit or slot sampler. The usual practice in measurement of bed load is, however, to place the sampler at various verticals across the section on the riverbed for a specific period, weigh the solid material collected at each vertical and then calculate the mean bed load discharge for the whole cross-section.

In this study, bed load was measured with Helley-Smith sampler (pressure difference type), with square nozzle of size 152mm and expansion ratio of 3.22, following the procedure recommended by Edwards and Glysson, 1998. The Helley-Smith sampler traps bed load moving along the bed of the channel in a metal container with an attached catch bag. Herein, the width of the channel at the sampling cross section is divided into four equal parts using EWI (Equal-Width-Increment) method. This will result in three sampling vertical at ¼ W, ½ W and ¾ W, where W is the width of the channel at the sampling cross section. The sampling time varied from 1 to 5 minutes, depending the prevailing flow, shorter for higher flow and longer for low flow so that the sampler become only partially full as the efficiency of the sampler is reduced when filled more than about 40% (Edwards and Glysson, 1998).

Station	Grain Diameter (mm)			
	Surface		Sub-surface	
	d_{50}	D_{90}	d_{50}	d_{90}
1	70	100	17	75
3	66	96	14	72
10	65	94	6.5	37
13	62	87	2.4	38
14	60	90	1.8	35

Table 1. Surface and sub-surface material d_{90} and median sizes

The material collected from each vertical is separately bagged, oven-dried, and weighed to determine the bed load rate at each vertical and the grain size distribution of transported material. For Helley-Smith sampler of the above specification, the bed load rate at each measuring vertical is calculated from the following relation:

$$R_i = 9.474 \frac{M_i}{T_i}$$

Where R_i=bed load transport rate, as measured by bed load sampler at vertical i (kg/day/m),

M_i = mass of the sample collected at vertical i (g), and

T_i = time the sampler was on the river bed at vertical i (min.)

Then the total bed load rate at a section for each sampling occasion is determined by using the mid-section method (Herschy, 1995) of calculation. The grain size distribution analysis of transported material (i.e., bed load size) is also conducted for each of the sampling occasions using standard techniques to find out the variations of the bed load grain sizes with different flow strengths. A plot of bed material and bed load materials for different flows, given in figure 6, shows that the grain size of the bed material gets coarser with increasing flow as one may expect. However, the increase in size is less than that of the discharge. For instance, in figure 6, each discharge was selected to be about double the preceding one but the increase in the median size was less than double.

From figure 6, it is also clear that the bed load is finer than the bed material, which shows that at usual flows the largest materials present in the bed are not moved.

Likewise, the variation of bed load discharge with flow was also considered. The log-log plot of bed load discharge versus flow (Figure 7) shows that up to about a flow of 3 m^3/s the data is so scattered that no clear trend can be observed. However, for flows above 3m^3/s obvious increase in bed load with discharge is observed. It seems that up to this discharge only marginal transport is taking place. From the abrupt change that can be seen from this point onwards, it seems reasonable to assume the threshold condition for bed load movement to be around a discharge of about 3m^3/s for this river. . Variation of bed load discharge at station 3 with water discharge.

According to Bathurst, et al (1987) bed load for steep sloped mountain rivers varies between 10 and 50% of the total sediment load. For period of sediment measurement (April – October, 2002), the measured bed load of Kulfo River at station 3 is found to be about 42% of the total load. Even though this figure is a partial result, which does not cover all seasons of the year, it is an indication that a large amount of bed load is carried by this river.

Apart from the above observations, significant variability in bed load discharge was also seen. According to Hubbell (1987), the rate of bed load transport at a fixed location (point) usually varies markedly with time in a cyclic manner, even during steady flow conditions. When there are bed forms, such as dunes, the transport rate varies from near zero at the troughs to a maximum value at the crests. However, these cyclic variations have been observed even where there are no bed-forms (for

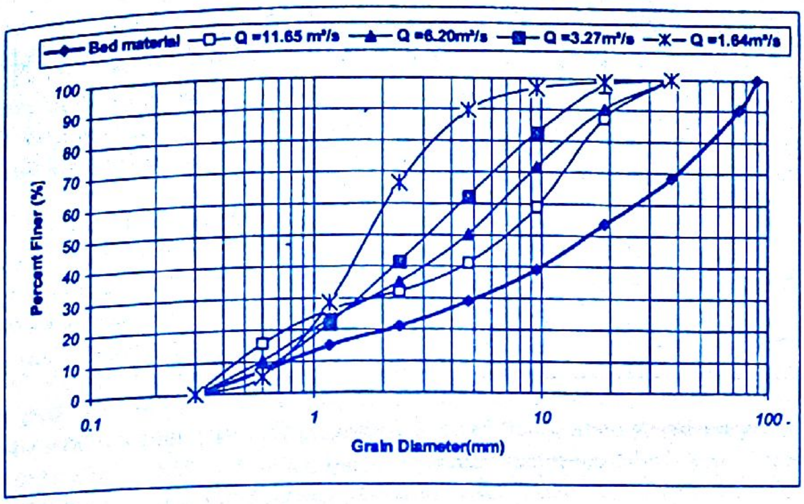

Figure 6. Comparison of bed material and bed load grain-size distributions (for various discharges)at station 3

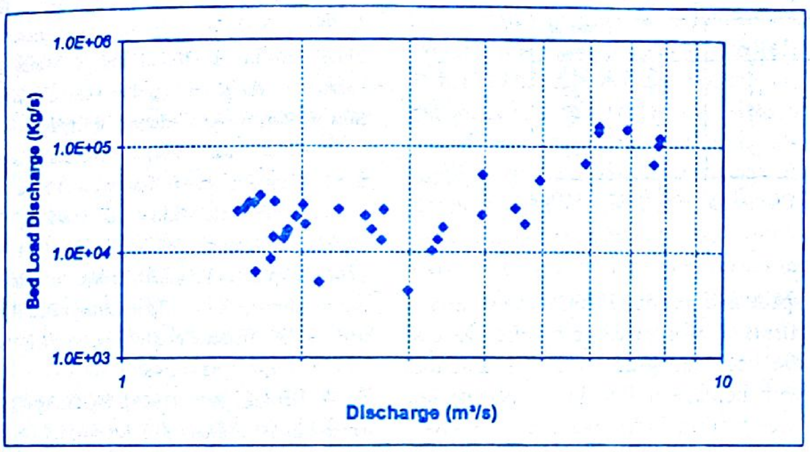

Figure 7. Variation of bed load discharge at station3 with water discharge

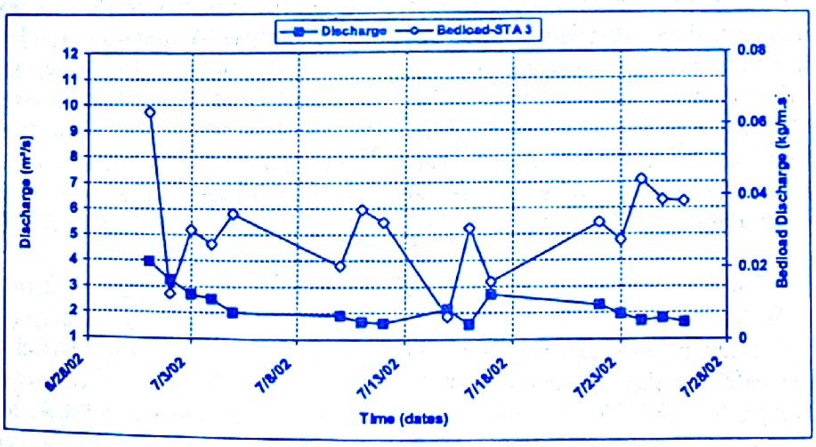

Figure 8. Bed load variation with gradually varying discharge over time (July 1-26, 2002)

instance, in coarse-bedded streams). For instance, observations made by Ehrenberger, 1931 (Hubbell, 1987) in Danube River at Vienna, where the median size of the bed material is 20 mm and maximum size of 70 mm, have shown similar variations.

Even though sufficient measurements were not made in Kulfo River to observe the spatial variations, quite significant variation with time for near constant water discharge was evident. For instance, for the sampling period between 1 and 26 July 2002, the water discharge varied from 0.73 to 1.79 times the mean. In the same period and at the same sampling station the variation of bed load discharge was from 0.2 to 2.07 times the mean showing the large variability of bed load with time (figure 8).

Preliminary Test of Bed Load Equations and Comparison with Measured Values

In the past, several formulas are developed with various assumptions and for different hydraulic conditions. Most of them are based on the assumption that sediment transport is at equilibrium, water discharge is steady, and the bed material is uniform. Further, they are developed for some specific range of flows, sediment size, and most of them are developed in laboratory flumes and are not tested with field data. When such equations are applied in natural rivers, their predictions usually vary very much from measured values and different formulas give very much different result for the same set of data.

Comparisons and tests of sediment transport formulas have been made by different researchers (van Rijn, 1984; Nakato, 1990; Yang, 1996; Habersack & Laronne, 2002, etc). These analysis show that generally there is no universal formula, which applies to all hydraulic conditions. Van Rijn (1984), for instance, after analyzing some laboratory experiments by different research workers under similar flow conditions, concluded that it seems hardly possible to predict the total load with an accuracy of less than a factor of 2.

Herein, preliminary tests and comparisons of few bed load transport formulas are made. Comparison between measured and computed sediment discharge is made using discrepancy ratio (r) as a criteria, where r is the ratio of predicted and measured sediment discharges. As this analysis is based on limited data, the conclusions drawn from these results are only preliminary.

Even though a number of formulas are available for bed load transport, those which apply to gravel-bed rivers with steep slopes are less in number. Among the existing formulas that apply for coarse-grained sediments, four of them are tested herein, i.e. equations of

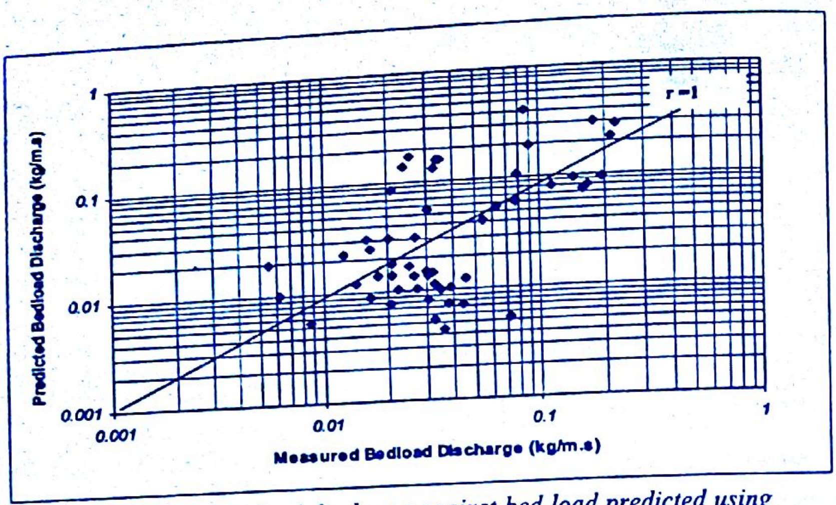

Figure 9. Measured bed load discharge against bed load predicted using Bagnold's equation. The line with r = 1 shows the perfect agreement between measured and predicted values

Method	Data within discrepancy ratio, r (%)			No. of data
	¼ < r < 4	1/3 < r < 3	½ < r < 2	
Ackers & White (1973)	59	38	24	34
Bagnold (1966)	81	67	54	52
Meyer-Peter & Müller (1948)	69	65	46	52
Schoklitsch (1934)	2	2	0	52
Schoklitsch (1950)	17	12	2	52

Table 2. Discrepancy ratio (predicted/measured) of bed load sediment discharge at station 3

Ackers & White (1973), Bagnold (1966), Schoklitsch (1934 & 1950), and Meyer-Peter & Müller (1948) (cited in Graf, 1984; Simons & Sentürk, 1992; Yang, 1996; van Rijn, 1993). The result of this analysis given in table 2 shows that Bagnold's equation has the best performance. Due to the space limitations, only one of the methods is given in graphical form (figure 9) to demonstrate the discrepancy between measured and computed bed load discharges.

Summary and Conclusion

Measurements of bed material, both surface and sub-surface, was made from which the characteristic diameters and specific gravity was determined. The comparison between the two distributions showed that surface material is the truncated form of subsurface material. Hence, the subsurface distribution closely resembles the overlying material when truncated from the fine end. Further, both distributions showed a decrease in sediment size in the downstream direction, which could be the result of selective transport.

Sediment measurements and analysis show that bed load varied both in space and in time. From these measurements, it was possible to observe that the bed load grain size is coarsening with increase in flow. This is because for wide grading in bed material, the different sizes come into motion gradually and at usual flows, the larger sizes are not moved.

The diagrams of predicted bed load discharge show better agreement at values well above the threshold of sediment motion. At low flows that are near initiation of sediment motion, a significant scatter can be observed. This shows the difficulties of measuring and calculating bed load discharge under the uncertain conditions of weak transport rates near initiation of sediment motion.

Finally, the preliminary comparison of measured and computed bed load discharges suggest that there are some equations with promising results. Therefore, their predictive ability may further be improve if they are modified and calibrated with the data of the river under consideration. However, still more equations have to be tested with additional data in order to select the equation which is applicable to this river.

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Relationships among Precipitation, Stream Flow, and Water Supply

***Dr. Taffa Tulu**, Ambo College of Agriculture, P.O. Box 19, Ambo, Ethiopia*

Abstract

Analyses of responses in stream flow are very important, since stream flow represents the integrated basin responses to the variations of several important climatic variables such as precipitation and temperature. Four representative watersheds of West Shewa in Ethiopia were considered for the analyses. Significant responses of stream flows to precipitation were detected. The storage-reliability-resilience and yield relationships were also investigated. The resilience indices (m) of those watersheds were computed. Those indices showed that year-to-year (carryover) storage is required in all of the four watersheds. The values of the mean annual inflows and the standard deviations were close to each other implying that the stream flow fluctuations have followed similar trends in all of the watersheds. The calculated N-year non-failure reliability (RN) gave very small values even for only two years.

Introduction

Most previous investigations of the relationship among climate, stream flow and water supply have combined general circulation models of atmosphere (GCM), rainfall-runoff models and a reservoir operations models to explore potential impact of climatic change on the behaviour of a particular water supply system. The literature on the impact of potential climatic change on hydrology and water supply systems is much too large to summarize here; comprehensive reviews may be found in Gleik (1989), Gleik (1990), Klemes (1990), Chang et al. (1992), Rind et al. (1992), Ballentine and Stakhive (1993), Leavesley (1994), and Loaiciga (1996).

In recent years there has been increased attention to the variable and changing nature of climate, and concern about associated shifts in water resource regimes. Modelling studies of the association between climate change and water resources have focused particularly on the relationships between stream flow, precipitation, and temperature. Stream flow provides a gross measure of the surface water regime in its most accessible form, and precipitation and temperature provide gross measures of the climate state. Stream flow is one of the surface signatures of precipitation. The behaviour of many complex water supplies is controlled primarily by year-to-year variations in hydrology and climate. Such systems, termed over-year systems, can be modelled using an annual time-scale, leading to remarkably simple modelling approaches, which exploit both at site and regional information about climate and stream flow. Vogel and Bolognese (1995), and Taffa Tulu (1991 and 1998) have documented that an annual time-scale will suffice for modelling both stream flow and water supply system behaviour for a system dominated by carry-over or over-year storage requirements. The main objectives of this paper are to (1) assess the stream flow response to precipitation; and (2) assess the storage reliability, resilience and yield relationships. Four representative watersheds in West Shewa, Ethiopia, were considered for the study.

Materials and Methods of the Investigation

The monthly stream flow data series were obtained from Water Resource Authority of Ethiopia for the years 1959 to 1996 at four sites located on Belo, Bite, Guder and Indris rivers in Western Shewa. The rainfall data was obtained from Ethiopian National Meteorological Services Agency for the stations Ginchi, Shenen, Ambo, Guder, and Gedo from which the areal rainfall was computed using the hypsometric curve. The hypsometric curve was used because of the large elevation differences in the watersheds.

Stream Flow Response to Precipitation

The responses of stream flows to precipitation were assessed using the correlation coefficients of their percentage changes. The percentage changes were computed from their sequential differences. The correlation coefficients between the percentage changes in annual mean precipitation and stream flows of Belo, Bite, Guder and Indris watersheds over several years were calculated. The values of the percentage changes in precipitation versus changes in stream flows were graphically represented to show the nature of the response (linear or non-linear).

Storage Reliability, Resilience and Yield Relationships

Vogel et al (1995) documented that the index, m, introduced by Hazen (1914) is useful for classifying the behaviour of water supply system. The index m is defined as:

$$m = \frac{(1-\alpha)\mu}{\delta} = \frac{1-\alpha}{C_v} = \frac{\mu - Y}{\delta} \qquad (1)$$

Where Y is the average annual demand, a is a fraction of the average annual demand to the mean annual inflow (m) to the reservoir (given as Y/m), d is the standard deviation of the annual inflows, and Cv is the coefficient of variation of the annual inflows (Cv = d/m). As long as the index is in the range 0<m<1, the system will be dominated by the year-to-year or carryover storage requirements. Similarly systems with m>1 will be dominated by within-year storage requirements. The N-year no-failure reliability, R_N, can be related to annual reliability, Ra, using (Vogel and Bolognese, 1995):

$$R_N = R_a[1 - r(1 - R_a^{-1})]^{-(N-1)} \quad (2)$$

Where r is an index of resilience which can be estimated using:

$$r = \phi[\frac{1}{\sqrt{1-\rho^2}}(m - \frac{\rho}{\phi(-m)\exp(\frac{m^2}{2})\sqrt{2\pi}})] \quad (3)$$

Where f denotes the cumulative normal density function; and r is lag-one serial correlation of the inflows. The index of resilience, r, is defined as the probability that the reservoir system will be able to provide the stated yield, Y, in a year following failure. Here a failure year is one in which the reservoir system is unable to deliver its pre-specified yield, Y. No failure reliability, R_N, is the probability that a given system will provide a constant yield, Y, without failure over an N-year period. Annual reliability, Ra, is the steady state probability, in a given year, that the reservoir system will deliver the stated yield. Therefore, the reservoir system fails to deliver its yield (1-Ra)% of the time. Using equations (1) – (3), the storage reliability and yield relationships were investigated for the considered watersheds.

The mean annual inflows and standard deviation of the annual inflows were calculated from the monthly discharges of Belo, Bite, Guder, and Indris for the year 1966 to 1998. The average annual demand was estimated from the inventory of number of animal and human population as well as water requirement for the irrigated area in the region. The index of water behaviour (m) was calculated for those watersheds using Eq.(1)

The index of resilience (r) was determined from the index of water behaviour (m), lag-one serial correlation of inflows (r), and the cumulative normal density (f). Using the SPSS under the command 'scale', there exists the possibility of carrying out reliability analysis. The reliability analysis made it possible to determine the annual reliability (Ra) of the Belo, Bite, Guder, and Indris watersheds. Using Eq. (2) he N-year non-failure reliability (RN) was calculated.

Results and Discussion

A year with the largest percentage of precipitation change does not necessarily indicate the wettest year and similarly the one with the least percentage of precipitation change does not necessarily indicate the driest year. In West Shewa, the largest percentage in precipitation change was observed in 1991 and the least in 1992 (Table 1). From the historical data series of the considered time series, 1994 was the wettest year and 1972 was the driest years in West Shewa. The largest and the least percentage changes in stream flows also correspond to those percentage changes in precipitation. Therefore, the percentage changes imply stream flow responses to precipitation; but not necessarily the wettest or driest year. The response of stream flow to precipitation increase appears to be non-linear. That is, for larger precipitation increases, the percentage increase in stream flow becomes larger than the percentage increase in precipitation (Table 1) This would imply that the basin responds differently, depending on the magnitude of the precipitation change and mean climate state. The basin stream flow amount sensitivity to precipitation depends on the amount of precipitation change. The larger the precipitation change, the greater the non-linear response of stream flow. The non-linear response of stream flow to precipitation occurs for virtually all very wet years. This is also true regardless of moisture conditions in the previous year. The implication is that the watershed becomes saturated fairly quickly during an individual very wet season to produce expanded areas of saturation and runoff. For drier years the stream flow response is more linear or weakly non-linear. Non-linear effects do become apparent during runs of dry years (droughts) in the historical record.

The variability can be measured by means of standard deviation (s) or variance (s^2). The standard deviations of the percentage changes in precipitation for Belo, Bite, Guder and Indris watersheds were computed to be 22.79, 22.40, 16.72 and 20.31, respectively. The degree of closeness or association between the percentage changes in precipitation and stream flows, and the strength of the relationship between them can be measured by the coefficient of determination (r^2) and the coefficient of correlation (r). The coefficient of correlation between the percentage changes of precipitation and stream flows of Belo, Bite, Guder, and Indris watersheds are 0.907, 0.781, 0.656 and 0.827, respectively.

Table 1: Percentage changes in precipitation and stream flows as computed from sequential differences of average monthly P and Q for West Shewa

Year	Belo		Bite		Guder		Indris	
	ΔP (%)	ΔQ (%)	ΔP (%)	ΔQ (%)	ΔP (%)	ΔQ (%)	ΔP (%)	ΔQ (%)
1966								
1967	-2.0	7.5	-3.6	-29.4	2.1	-5.3	-24.2	-13.3
1968	30.8	41.9	14.9	18.2	-3.2	-8.3	20.4	19.6
1969	-56.9	-77.8	-29.7	-8.3	-12.4	4.6	-11.1	-43.9
1970	19.5	10.9	17.7	-2.6	20.2	0.0	3.0	8.5
1971	-3.3	-1.8	-16.5	-10.0	-14.9	-3.2	12.4	-13.0
1972	10.6	24.1	5.4	29.5	29.0	59.4	0.0	32.8
1973	13.1	9.1	4.6	-35.5	-8.5	-88.5	4.7	-19.5
1974	-13.7	-20.0	-3.6	2.4	-3.9	-2.0	-2.5	-10.2
1975	-7.2	0.0	-9.3	-12.2	-7.5	-8.0	-25.3	-16.7
1976	5.6	14.6	13.8	23.9	8.1	35.2	5.8	19.0
1977	-11.9	-26.8	-38.3	-37.1	-26.6	-31.4	-28.6	-37.3
1978	-16.0	-1.9	16.1	14.6	4.0	-10.9	15.9	7.1
1979	10.1	-3.8	-8.5	14.6	-2.1	19.6	7.5	44.6
1980	2.0	5.5	16.7	-14.3	9.2	-14.6	-2.0	-47.2
1981	3.1	-9.6	-5.9	-2.5	3.4	-4.3	-3.0	-11.3
1982	-8.6	5.3	-8.9	14.6	-4.7	16.3	1.0	16.9
1983	-5.9	-22.2	5.1	-20.0	-10.0	-46.3	-5.9	-32.7
1984	20.6	30.3	14.0	9.5	-1.0	11.7	28.7	29.2
1985	-1.2	-30.4	-47.5	-73.7	1.0	-20.8	-32.5	-56.5
1986	2.3	21.7	-11.0	-16.7	6.1	9.4	26.5	47.2
1987	-14.3	-21.3	4.6	26.0	7.5	1.7	-2.7	-18.4
1988	9.4	8.8	8.0	-12.3	-5.8	5.3	-18.2	-17.8
1989	-12.6	5.8	-25.2	-31.3	-15.4	-20.4	-9.9	1.9
1990	-14.3	-28.6	-6.9	-16.7	-21.0	-18.5	-9.0	-1.9
1991	45.5	49.2	34.4	39.8	38.6	39.0	24.8	37.7
1992	-68.9	-75.0	-64.4	-59.3	-46.2	-61.7	-53.7	-81.8
1993	-5.8	5.4	30.7	39.4	-2.6	2.6	-34.1	-80.0
1994	-24.8	-28.3	-18.3	-19.3	-16.2	8.1	19.5	37.0
1995	20.6	19.1	20.6	19.1	20.6	19.1	20.6	19.1

Note: "P% = percentage change in precipitation = $100*(P_i - P_{i+1})/P_i$; and "Q% = percentage change in stream flow = $100*(Q_i - Q_{i+1})/Q_i$

The dispersion (spread, scatter or variation) of the points, obtained from the coordinates formed by percent change in precipitation versus the percent change in stream flow values, around the trend line show the extent to which the stream flow responds to the precipitation. The greater the spread from the trend line, the greater the variability of the response and the closer the points to the trend line, the less will be the variability. Considering the scatter diagram of percent change in precipitation versus percent change in stream flow for the selected watersheds of West Shewa (Figs. 1 to 4), the least dispersion was observed in the Belo watershed and the greatest dispersion in Guder watershed (Fig. 1).

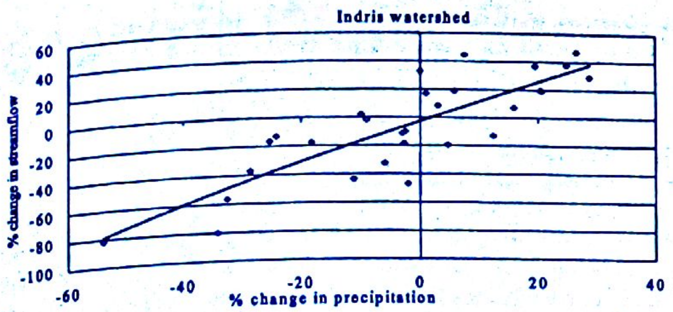

Fig. 1 Stream flow response to precipitation in Belo watershed

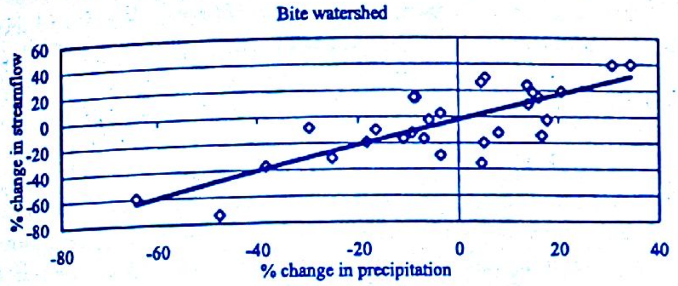

Fig. 2 Stream flow response to precipitation in Bite watershed

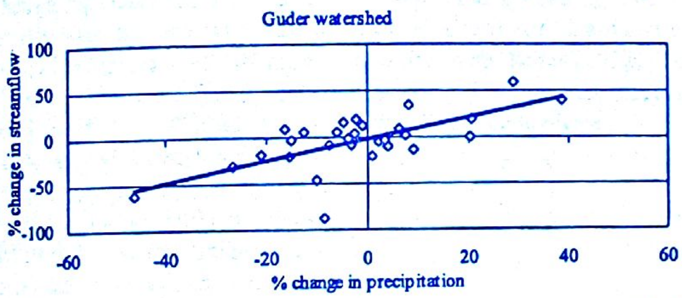

Fig. 3 Stream flow response to precipitation in Guder watershed

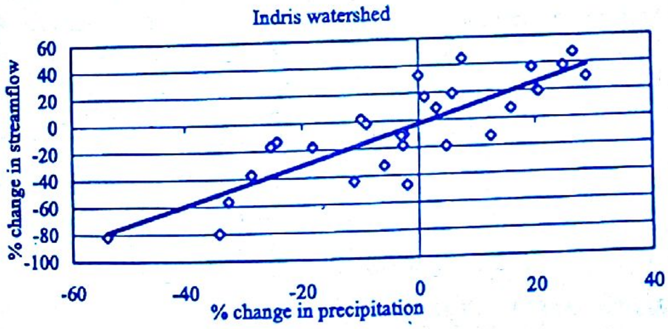

Fig. 4 Stream flow response to precipitation in Indris watershed

In all the watersheds, it was computed that 0<m<1 (Table 2) and therefore year-to-year (carryover) storage is required in all of the four watersheds. The values of the mean annual inflows and standard deviations are close to each other implying that the stream flow fluctuations have followed similar trend in all the watersheds. The value of the index of resilience (r) was high for the Guder River and least for the Bite River (Table 3). This implies that the probability that the reservoir will be able to provide a stated yield (Y) in a year following failure was highest in the Guder River and least in the Bite River. The annual reliability (Ra) was highest in Bite River followed by Guder River, and also the N-year non-failure reliability (R_N) is highest for Bite River followed by the Guder River (Table 4). Therefore, Ra is directly proportional to (R_N).

Table 2 Index of water behaviour for Belo, Bite, Guder, and Indris watersheds(1966 – 1998)

Watershed	μ (mm)	Y (mm)	δ (mm)	m
Belo	56	7	75	0.65
Bite	55	4	79	0.65
Guder	58	3	80	0.69
Indris	58	8	81	0.62

Note: m = Mean annual inflow; Average annual demand (Y); d = Standard deviation of annual inflow; and m = Index of water behaviour

Table 3 Resilience index, r

Watershed	m	ρ	ϕ	r
Belo	0.65	0.214	0.54	0.47
Bite	0.65	0.280	0.36	0.39
Guder	0.69	0.470	0.40	0.56
Indris	0.62	0.187	0.53	0.44

Note: m = index of water behaviour; r= lag-one serial correlation of inflows; ƒ = Cumulative normal density; r = index of resilience

Table 4. N-years non-failure reliability (R_N) of Belo, Bite, Guder, and Indris

Watershed	r	Ra	N-years non-failure reliability (R_N)				
			N=1	N=2	N=3	N=4	N=5
Belo	0.47	0.4045	0.40	0.24	0.14	0.08	0.05
Bite	0.39	0.6288	0.63	0.51	0.42	0.34	0.27
Guder	0.56	0.5015	0.50	0.32	0.21	0.13	0.09
Indris	0.44	0.4520	0.45	0.29	0.19	0.13	0.08

Note: Ra = annual reliability

Conclusion

Observational studies of annual mean stream flow response to precipitation indicate that stream flow amounts in the rivers are sensitive to precipitation in the considered watersheds. Stream flow responses to precipitation are more non-linear in wet years than in dry years. For dry years, the stream flow response to precipitation is more linear or weakly non-linear. The variability of stream flows is least in Belo River and highest in the Guder River. Carryover (year-to-year) storages are required in all the considered watersheds. The probability that a reservoir will be able to provide a stated yield (Y) in a year following failure is highest in Guder River and least in Bite River. The annual reliability (Ra) is directly proportional to the N-year non-failure reliability (R_N).

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Ecocentric Water Resource Management

Dr.Kandula V.N.Sarma, AWTI ,Arbaminch, Ethiopia

Abstract

Ganga, Sindu, Nile, Euphrates, Tigris and other river plains, supported early civilizations due to richness of the soil and plentiness of water (Wittogel 1956). Cultivation and trade were responsible for the beginning of the settled civilizations. Though man has adopted himself to the availability of water and other natural resources on land, efforts have equally been made to modify the water environment consistent with the available technology and management capability. Gradually people who did not raise food and cattle could be supported by those who did. Increase in this dependence of those who did not, on those who did, increased the dependence on regular and adequate supply of water in reserve for dry periods.

The technicians who built water supply and irrigations systems that helped farmers to grow more crops on available land became critical to the development of cities (Rogers and Feiss 1998). Water management gradually involved the utilization of the water that was scarce and that which had to be brought from distant places or greater depth or both.

Introduction

Ganga, Sindu,Nile, Euphrates, Tigris and other river plains , supported early civilizations due to richness of the soil and plentiness of water (Wittogel 1956). Cultivation and trade were responsible for the beginning of the settled civilizations. Though man has adopted himself to the availability of water and other natural resources on land, efforts have equally been made to modify the water environment consistent with the available technology and management capability. Gradually people who did not raise food and cattle could be supported by those who did. Increase in this dependence of those who did not, on those who did, increased the dependence on regular and adequate supply of water in reserve for dry periods.

The technicians who built water supply and irrigations systems that helped farmers to grow more crops on available land became critical to the development of cities (Rogers and Feiss 1998). Water management gradually involved the utilization of the water that was scarce and that which had to be brought from distant places or greater depth or both.

Water resource development

Leonardo da vinci described water as the 'driver of nature'. Civilizations flourished because of water and perished because of the lack of it. Water management consists of development and optimum utilization of this limited and precious resource.

From a technical point of view the main problem in water resource development arises out of the fact that the water is available only at certain times and certain locations and of certain quality, which are all different from the required. The problem is set in a dynamic frame of demands and stochastic frame of inputs.

The development problem is expressed in terms of a matrix transformation following Buras (1972). The input matrix S_i describes the properties of naturally occurring water.

$$Si = \begin{bmatrix} L_i \\ T_i \\ Q_i \end{bmatrix}$$

Where L_i is location vector, T_i the vector denoting quantitative availability in time and Q_i the quality vector.

The output matrix (required one) is given by S_o

$$S_0 = \begin{bmatrix} L_o \\ T_0 \\ Q_0 \end{bmatrix}$$

$$S_o = \theta\ S_i \qquad \text{———————(1)}$$

The transforming matrix q is, infact, the system that enables the development, utilization and control of the resource so that the objectives of the development project are achieved (Chaturvedi 1987)

Water Resource Management

The main question in water resource management is how to operate the system to achieve a given set of objectives?

The solution depends on the given set of objectives. There are usually conflicts among the several objectives. Some are sacrificed in preference to some others. The decision makers started relying on the universal acceptance of the paradigm that 'a few' can be sacrificed in the larger interest of many' (Sarma 2002 c).

The interests that are usually sacrificed are the interests of a few who are economically and politically weak. The interests served are those of highly vocal urban people and economically and politically strong industrialists.

Generally assured supplies of electricity for industries and irrigation water to the fields in the plains have become synonymous with development. To achieve this development, large reservoirs and elaborate water conveyance systems have been and are being created. The environmental and ecological disasters, which these grandiose schemes have produced, are coming to light recently. So people are becoming environment conscious.

Environmentalism

There are two types of environmentalisms that are being followed by the environmentalists today. They are

1.Technocentric Environmentalism

2. Ecocentric Environmentalism

Technocentric Environmentalism

Technocrats wish to subdue, conquer, tame and control nature. Through this they hope to achieve freedom from want, hunger and disease, for human beings and thereby improve the quality of life. But one should know that quality of life is a nebulous concept (Rogers and Feiss 1998). Taking for instance, the water requirement per capita per day, 140 lpcd is an accepted figure for domestic consumption in India and this figure is in the rage of 500-800 lpcd in developing countries. Pigmies of Africa have amply demonstrated that 2 lpcd is all that is required for sustenance of human life.

Man when he discovered fire around 0.45 million years ago, he has brought about a technological revolution. But he also started polluting atmosphere. When man started irrigating, fields of cultivation, a few thousand years ago, he increased agricultural production. But he also started making the land more saline and water logged. Industrial revolution of the 19th century resulted in a faster 'development ' and consequent faster depletion of resources and increased levels of pollution. As a consequence of this, the environmentally conscious technocrats of today coined a new slogan that any development should be sustainable at least for some generations to come. They are of the opinion that nature has to be modified for human benefit, through the use of technology and excesses which result in permanent damage to environment and ecosystems should be controlled through legislation and punitive action.

As water does not recognize political boundaries, international policing, according to them is necessary and possible.

In the case of water, the technocrats are hydraulic engineers and hydrologists. Their environmentalism is based on the philosophy that it is possible to find technological solutions to all environmental and ecological problems.

Ecocentric Environmentalism

Ecocentric environmentalism on the other hand is based on the philosophy that man has to live in harmony with nature and study it in its entirity and take advantage of its features. Nature has waste assimilation capacity. When man discovered fire and put it to limited use, the carbon dioxide could be advantageously absorbed by the plants. It is the burning of fossil fuels after industrial revolution, which caused the production of CO_2 and other air pollutants in excess of the local capacity of nature to assimilate them. Similarly domestic wastewaters produced by villages far apart in the earlier days could be taken care of by the water and soil environments.

Development of a region is possible through the flow of energy from other parts (Odum 1983). Odum has put dollar values on natural services provided by wetlands like fish and silt, Joules of energy for

Rainfall and river flow, oil yield and fuel, for opening of locks and gates and grams of sediment and coastal land loss. He has also put a value on the energy that is brought (not for mining and bringing the fuels like coal and oil- but in forming them) to develop and maintain a project. Then the B/C would much because would be very much smaller than one. Energy consumption by a population is a good index of its development. Twenty percent (20%) of world's population in developed countries use 80% of world's annual energy outputs leaving 20% of energy output to 80% of the worlds population. These high rates of resource utilization is causing problems like a global warming. Bullying developing nations to further cut their resource utilization for global safety is not going to be a solution. People willingly should reduce their wants and should realize that grand schemes do not always give grand results, which they are supposed to achieve.

Ecocentic environmentalism does not consider river water going to the seas is wasted, marshes as wastelands to be reclaimed by draining and floods as unwanted extremes to be controlled.

In case of water, the echocentic environmentalists argue, that one should look for simple hydraulic solutions that were in vogue and innovate them rather than hydrological solutions.

Before looking at some of the earlier hydraulic solutions and present day hydrological solutions, it is necessary to briefly discuss the development paradigm.

Development Paradigm

Development projects with benefit cost ratios (B/C) greater than one are considered commercially viable and projects with large ratios of the number of benefited people to the number of affected people are socially and morally justified. But development has different definition today.

Definition

Development is the improvement of life of people. It is not just the development of material resources like water. Quality of life depends on the assured availability in reasonable quantities and qualities of air, water, food, safety, entertainment and enlightenment in the order to all people in that area. If people are given money but no means to generate it, it is no eradication of poverty and hence no improvement in quality of life. Therefore money cannot be viewed as compensation for loosing means of livelihood. The key phrase is 'all people in that area'

As the water basins do not recognize political boundaries, the entire area may not fall in a single country or a single state of a country. Even if it does, different people living in that area usually depend on that water differently. Some may depend on it for fishing, some for navigation, some for farming, and some for power.

It is well known that all large water projects of development are located in an under-developed area, resulting in further hardship and loss of livelihood of the local people of that area and the fruits of development go to areas that are far away. This poses the question' for whose benefit and at whose cost is the development?' Rao (1990) an economist describes this as light and shadows of development. He says 'development is like a lighted candle. Candle throws light all round but some portion below it is always in shadow. It is easy and difficult to understand development. Easy because of its visibility and difficult because what shadows hide cannot easily be known'. We are more disturbed by a road accident, which we have witnessed than by the carpet-bombing in Afghanistan. Similarly many of us can empathise when we see read and understand the suffering of the urbanites. We read about the suffering of the poor high- landers some times. We may most of those times sympathise with them. But this suffering is alien to us to empathise and understand, hence our distorted vision of 'development'. The author of this paper wish to answer briefly the following questions through the analysis of a few development projects,

1. Do the projects achieve the intended objectives, always?
2. What are their side effects?

UNDP has developed two indices to quantify the development. They are development Index and Poverty Index. Sarma and Rao (2001) have discussed these indices in the context of Indian Scenario wherein, the gap between the rich industrialist in a metropolis and the poor tribal woman, who earns wages only for a few days in a year, is extremely wide. 75 % Indian population lives in villages which occupy 95 % geographical area generating 67 % of the revenue Therefore the numbers of average poverty, the average income, GDP and the average development index are misleading. The average income can go up while the majority can become poorer than what they were before the so-called development.

A river valley, sustaining millions of people, may produce virtually no' Gross National Product' in the sense that economists understand.

Examphes of unrealised objectives

Himalayan Dams

Two Himalayan dams 60 m high Ichari dam and 39m high Maneri dam, which were complited in 1970s, became silted to the crests of spillways within two years of operation and were put out of operation.

6.2 The Great Manmade River

Along the coast of North Africa, a narrow band of rain fed high lands is the only significant arable land between the coast and the southern margin of Sahara. It runs for a thousand kilometers. The population is sparse. Small farms supplied food for these people. These farms relied wholly on rainfall. Intermittent narrow wadis (drainage channels formed under earlier moisture conditions) and wells recharged by the precipitation from Mediterranean Sea, which is quite limited. Many aquifers are also contaminated with salt-water (saline wedge) intrusion.

In the later 20th century Libya experienced a ' 25 years population doubling rate' due to the growth of economy, which was mostly due to sale of petroleum. Even through Libya uses 80 % of its water for agriculture, it is not self sufficient in food sector. Gaddafi has isolated himself from all the big powers for various reasons and he wanted his country to become food independent, he undertook a project to bring ground water to the coast. It envisaged a pipe network of 3000 km. This project is to be completed in segments between 1991 and 2007 and ultimately deliver millions of cubic meters per year to irrigate hundreds of thousands of acres of land and provide stable potable source for both Libya's urban population and farms for the first time in decades.

But the cost of providing water will exceed the market value of any crop grown requiring permanently subsidizing agriculture. The residence time of the ground water in these aquifers in around 15000 years and they will get depleted in 75 years at this rate of pumping. It is perhaps likely that Egypt, Sudan, Chad and Tunisia, which are its neighboring countries, will be affected by this withdrawal leading to water disputes. So this project realises the object of self-sufficiency in food for a short period only if at all.

OMVS

Whenever planners attempt to manage river basins in a rational manner they seem to create irrationality. Organization pour la Mise en valeur de la vallee du fleuve Senegal set up by Mauritania, Mali and Senegal wanted to develop the Senegal river basin in a rational way.

It wishes to achieve the following objectives

1. To provide 800 G.Watt hours of cheap hydroelectric power annually to Dakar the capital of Senegal,
2. To provide enough water levels in the river, so that ocean going vessels could sail at any time of the year to the tiny river port of Kayes of Mali which is 900 km upstream,
3. To provide irrigation water to the cash crops of cotton, sugar along with rice to be grown in the farms of Mauritani and Senegal.

OMVS borrowed money heavily to complete the project by 1987. When the reservoir behind the dam began filling, it was suddenly realised that three countries became so poor with debt that turbines could not be brought; the water conveyance system for irrigation and navigation could not be built.

Mean while millions of people were deprived of their customary livelihood of flood-recession farming and fishing.

Examples of side effects

Irrigation

Water dissolves salt as it passes over rocks especially in the upper reaches of river catchments. Rivers deliver this salt to the sea in the normal process. But when the river waters are diverted to irrigate fields the salt ends up in soil.

Mesopotamia: 3800 years ago Mesopotamians noticed that black fields were becoming white due to irrigation

Soviet Union: Half the irrigated land in soviet Russia was taken out of production within 7 years of the first waters reaching the fields.

Mehenjadaro: Archaeologists believe that great city of Mahejadaro fell around 4000 years ago when water logging due to irrigation caused a buildup salts in the soil.

General: By 1985, 70% Of the fields in Uzbekistan, Kazakistan and Turkmenistan suffered seriously through salinisation due to over irrigation. Accumulation of salt is unavoidable in the long run, in the irrigated soils. But the question is how fast it is allowed to happen? The parallel one can draw is with the eutrophication of lakes. What normally takes place in about a few hundred to few thousands years is accelerated to take place in a couple of decades through the addition of nutrients by the agricultural and domestic wastewaters that are being discharged into them.

Drainage

Swamps are giant holding reservoirs for rivers natural flooding. They receive floodwaters and attenuate the peaks and discharge back the waters during the low river flows. In Europe drainage was far more important. Dutch were the pioneers in drainage in Europe. Windmills driving buckets drew water from trenches dug in mire . It has also become a practice to construct levees and drain the swamps.

Neworleans: The US Army corps blew up a levee which they built downstream of the city earlier and admitted their mistake of building it in the first place to drain the swamps.

Everglades National Park: Florida receives 125 to 150 cms of rainfall. Southern part of Florida is rather flat and is drained by Kissimmee River to lake Okeechobee. The out flow from the lake combined with the heavy rainfall and shallow water table supports a vast wetland with a well balanced complex ecological food chain that included brown – yellow algae, snails, frogs, alligators and even panthers. In this wetland is located Everglade National Park.

But as population and economy of Florida grew, digging deep canals and leading the water directly to the ocean drained the swamps. The decrease in run off to the lake and increase in nutrients, made the bay saltier. Blooms of nonnutrient algae occurred. Shrimp hatcheries disappeared. Ground water table is lowered and salt water is creeping gradually inland. Gradually once useful wells have to be abandoned.

Flood control

Man tried to control floods ever since he settled close to rivers, by building embankments. There is an episode in Sri Math Bhagavatham that Lord Krishna saved his people and tribe by raising a mountain (embankment). As per Hindu chronology, the present Kaliyuga started about 4000 years ago and Krishna belonged to the end of previous Dwapara Yuga. So this story pertains to the period, which is about 5000 years back. Krishna's elder brother was considered to be a great farmer. He is said to carry a plough, as a weapon.

The Sumerians of Mesapotamia, the kings of Umma and Gursu and the first records of Egyptian irrigation were all of this period.

At this period farmers began to plant seeds along the riverbanks, where the water flooded out of the main channel and deposited silt. The receding waters left enough moisture for the crops to grow in the coming months.

Floods also filled the swamps and depressions when they over flowed the banks of main channels. They helped to recharge the ground water and supplement river flows during lean periods. Fishing in the swamps and ponds provided livelihood for many thousands of people.

When large flood control structures were built all these advantages were lost.

Aswan Dam: For thousands of years the annual delivery of water and nutrients by Nile allowed Egyptians to plant one crop a year and live on the harvest until next flood. Naturally there was famine in drought years and damage due to floods in years of excessive rainfall. To overcome this difficulty. Aswan dam was built in the year 1971. On the positive side the floods are controlled, dependable yield of grain and cotton has rapidly increased and the power generation is more than what Egypt needs. On the negative side the dam traps nutrients along with alluvium thus requiring use of fertilizer and high capital. As a consequence of this, land changed hands from poor farmers to rich farmers. The second negative side is that on the d/s side of Aswan dam, the saline water introduced from the sea, when the fresh water pushing it back to the sea has reduced, into the Nile delta which is one of the most important agriculture areas of river Nile. Now the valley does not dry out between floods any more and the standing pools of water permit the spread of parasites and diseases.

Mekong Valley: The inhabitants of Mekong valley have made the best use of the rivers flood regime. It sustains 30 million people. A dam on that river may cause starvation and death to these people .The flood resource is being wasted and fertile silt and fish are unaccounted in B/c analysis.

Hydro Electric Power

The lure of cheap clean hydroelectric power is very strong. Even environmentalists prefer hydroelectric power to thermal and nuclear power. Most of the hydroelectric power generating dams occupies the best sites. But their life span is shorter than that of a coalmine, because of the rate at which they silt. Mahmood (1987) says that the high concentrations of sediment in river flows entering reservoirs are largely associated with climatic tectonic and geological factors and the sediment yields are largely unaffected by watershed management.

Sanmenxia Dam: This dam built in 1960 has to be dynamited twice and rebuilt.

The dams on Colorado: They trap 99.9% of sediment.

Lower Driper Dam: This dam is built for cheap hydropower. Instead of flooding the area, if hay had been planted in it and built it later to produce energy it would have produced more energy than the plant. Dredging today costs 20 times the price of building a reservoir of equivalent capacity. There goes cheapness!

Revenue Generation Through Cash crops

The British encouraged farmers to replace some of their traditional food crops such as millet with cash crops like wheat, cotton, sugar and indigo, and rice with tobacco, which were in strong demand *in their country*. India exported wheat to England in the famine year of 1876-77 for money and Ethiopia exported corn to produce beef in USA resulting in the starvation of its people late 1980's.

Cash crops are very water thirsty. The water that can irrigate 1ha of sugar cane, sustains

5 ha of rice or 10 ha of wheat or 30 hectares of millet.

Large dams, big reservoirs and long water- carrying -canal systems are all planned to help cultivate cash crops. Benefit-Cost ratios justifying the development projects include monies to be earned through the cash crops. The bumper crop of coffee seeds all over the world led to ethnic strife and great human suffering in countries like Brazil and Rwanda (Roger and Feiss 1998) and require constant supply of required water and nutrients. They also have to be protected by pesticides and insecticides. The suicides committed by cotton growers of Andhra pradesh (India) show how pesticides let them down.

7.6 Ground water and its conjunctive use

Of the $1.4x10^9$ $Km^3$of global water 97.3% is present in oceans and 2.1% in polar ice caps. Fresh surface and atmospheric waters together constitute about 0.01%. Ground water accounts for 0.59% (Sarma 2002 a, b).

As the surface water sources are becoming scarce people are turning into ground water. Ground water is a natural choice because it is available to the farmer when and the extent to which, it is required, without the governmental assistance.1970's are declared as the decade of ground water. Several studies were undertaken to study the conjunctive use of surface and ground water during that water. A study undertaken by Sridharan et.al (1980) on' Vedavath river basin' is one such. By 90's it has started becoming clear that ground water was being over exploited and there were many side effects

7.6.1 Israel

Every year Israel has been pumping 200 Mm^3more water than that had been going into the aquifer. In its natural state, the water table in the coastal aquifer is 3 to 5m above sea level, checking the salt-water intrusion. But now the water table is below the sea level causing salinity intrusion into the coastal

aquifer. Some damage due to salinity intrusion may be irreversible. The salty water may disintegrate the sand stone rocks of the aquifer causing the blocking of flows.

7.6.2 Libya: This case already been discussed in 6.2

3.3.3 Ogalla (USA)

The Ogalla aquifer of mid west USA is fast drying out, as the pumping is about 100 times that of recharge.

7.7River Training

Until a few decades back engineers believed that rivers can be trained to behave in a particular way. But gradually they realized that it is beyond the human power to control nature. It is worth reminding ourselves of what Francis Bacon said long ago. He said " We can not control nature without obeying it".

Mark Twain added" Ten thousand river commissions with all the power in world at their back can not train that lawless stream. They cannot say to it, 'Go here' ' Go there' and make it obey.

The desire to train a river stems from human frustration with the imposition of nature on economic progress and the increasing ability of the engineers to modify it to suit their requirement at a particular location though for a short time span. There are many examples of the long-term failures.

7.7.1 Rhine:

At the start of the nineteenth century Rhine used to take a tortuous path for most of its length. It used to branch off into two streams on the downstream side. These two branches used to shift their courses periodically. This came in the way of navigation. So upper Rhine was' trained', to flow in a single channel with shortest length to the sea. Because of this the velocities have increased by 30% resulting in scouring of the bed and banks. At Basel the bed fell by 7m. At Ruhi port it fell by 4m and the port head to be rebuilt. The water surface elevation also fell. As a consequence for several km on either side, forests or wells draied out. The river is still being meddled with.

7.7.2 Mississippi cutoff:

A cutoff was introduced in the river Mississippi to provide easy transport of logs. But this resulted in the river water taking gradually another short cut to the sea, instead of this intended, through Atchfalya, thus reducing the flow in the developed channel.

7.7.3 Ganga Bridge;

A bridge has been built on Ganga on a 'trained ' portion. But Ganga chose to wash it off and flow around it. Rogers of Harward University says ' No embankments on river training works in the world can control these forces (of floods) if they are taken head on'.

So the environmentalists say that the nature is defied rather than trained, bludgeoned rather than managed (Pearce, 1992)

7.8Large dams

There are about 3600 large dams with height greater than 15m and 100 super dams with height greater than 150m. 75% of the super dams have been built only during the last 50 years.

Dams have become a means to exploit a common resource by the powerful. Dams are damaging the states of natural equilibrium that results from, millions of years of evolution. They are exceeding the adaptation capacity of the environmental system.

The problems of siltation of reservoirs, submergence of valuable forest-land, salinity intrusion, trapping of the nutrients and water logging have already been discussed.

So herein the attention will be drawn to the problems of human displacement and water disputes.

7.8.1 Human displacement

World commission on large dams in its report (2001) has said that 40 % of the displaced people by construction of large dams were not still rehabilitated.

In India one-third of the tribal population is uprooted .The uprooted population (30-40 million) is approximately 3 to 4 % of Indias population. The sacrifiers have been all the time the tribals and benefits always went to people in plain and industries in cities. The development projects are usually

located in tribal areas but the tribals are not the recipients of the fruits. According to the ministry of Rural development, the tribals have been alienated from one million acres of land till November 1999. The percentage rehabilated is insignificant (Sarma 2000 c, e)

7.8.1.1 SCIP:

South Chad Irrigation Project takes water from the lake Chad and irrigates 670sqkm of empty scrub to grow rice, wheat and cotton. But the scrub was not really empty. 55000 families were growing drought -resistant crop there, which is particularly suited to that soil. They were evacuated. Now 3 decades after the development project the fields are permanently dry and largely barren.

7.8.1.2 Indian scenario (Sarma 2000 d, e)

Sardar Sarovar Project:

Narmada Valley Development authority (NVDA) is building the Sardar Sarovar project on the Narmada River. Narmada river Valley spreads over Madhya Pradesh, Maharastra and Gujarat. 43000 thousand families have been ousted by this project. The water dispute Tribunal (NWDT) tried to dispose of the problem by paying cash compensation. Narmada Bachao Andolan has emerged, as the votary well over a decade ago and as a consequence to its efforts, the subgroup of Narmada Control Authority recommended the compensation should include land. In October 2000 Supreme Court had given strict guidelines on resettlement and rehabilitation (Hindu, Feb 13,2002). In spite of that, nothing has been done and the state Governments wish to wash off their hands by awarding cash compensation.No:

The adivasis in the Satpura ranges who have been affected by the Sardar Sarovar project are in a precarious state. Between 1994 and 1996, the Maharastra Government had distributed between Rs 25000 to Rs 50000 to some of the ousters. Never had the Adivasis so much money they spent it or liquor.

Rihand dam

In 1996, 98 families were found fighting in Mithini and Khairi, their second displacement. When Rihand dam was built, these people opted for 10 acres of land in Mithini and Khairi for the 30 acres they owned in the villages submerged and shifted. Once again they were asked to vacate when NTPC wanted to construct 1500 acre-ash dyke at their new places of residence.

Legislation and Implementation:

The democratic government of India depends largely on the bureaucratic and legal system developed by the colonial rulers to suit their interest. The land acquisition act of 1894 is a typical one (Sarma & Nageswara Rao 2001). It says the government can acquire an individual's property for public good provided it compensates the loss to the individual. Not only what is public good is decided by the government but also the amount of compensation The law has been amended since then. The individual can contest the compensation amount he receives. The amendment helped only the rich who have a political clout and can afford to pay for legal battles against an all-powerful 'state'.

7.8.2 Fear of dam Breaks.

People living on the downstream of a dam always live in fear of the event of dam break. So they oppose the construction of the dam from the beginning.

7.8.2.1 Tehri dam. (Rama prasad 2002)

The Tehri dam is being built in the Himalayas across Bhagirathi, a tributary is Ganga. It is the first storage project in the Ganga Valley consisting of a 260.5m earth and rock fill dam. The dam is in a seismically active region and its structural failure due to earthquake could inflict considerable damage downstream. This is the main cause of the opposition of people living in that valley, though initially it was on the issue of displaced people.

7.8.2.2Canal from Danube:

The canal from Danube would carry 5000 cusecs of the river flow, through a 20 km journey to a dam at the village called Gabeikovo, where the water would drive turbines. The canal has, in some places, 17m high towering banks, within a few meters of many homes. In case of the failure of the bank, the wave front rushes with a celerity of $\sqrt{gh}$.

where h is the height above the ground.

7.8.3River Disputes

Waters of common rivers become increasingly responsible for political intrigue

7.8.3.1 Dams of Euphrates: Dams on Euphrates have led to tensions between, Syria,

Turkey and Iraq.

7.83.2 The Aswan Dam. (Pearce 1992)

Egypt had initially had an upper hand in controlling Nile waters through the construction of the Aswan Dam. Then it had to concede that Sudan also has a right over Nile waters. Less than a generation after Nasser had announced that Nile was now in Egypt's hands, Ghali admitted, that the national security, which is based on the waters of Nile, is in the hands of eight other African countries including Ethiopia. Today each country takes active interest in the politics of the other countries

Not only there are water disputes among neighboring countries but also between neighboring states in a country.

7.8.3.3 The Owens Valley Water War : (Rogers and Feiss 1998)

Los Angels has 9 million people but receives about 60 cms of rainfall each year from a small number of heavy storms. It is a desert basin. The adjacent San Fernando Valley is one of the richest agricultural regions of the world. The people and farms need water more than that is available locally. Los Angel's aqueduct system, hundred of kilometers of pipelines, siphons, reservoirs and channels bring water from surrounding area. The construction of the aqueduct pitted Los Angels against local farmers in Owens Valley. A bloodless 'Water War' was waged by the farmers of Owens Valley. At various times the portions of the aqueduct were blasted with dynamite. At one time a politician was kidnapped.

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7.8.3.4 Kaveri Water Dispute: (Sarma 2002 d, e)

Agricultural flourished in the fertile soil of Kaveri Delta from very ancient times. The river starts as Tala Kaveri in Western Ghats of Karnataka and joins the sea in Tamil Nadu. A dam was built across the river by the enlightened Wadayar of Karnataka a century ago. As per the agricultural needs of Karnataka water was stored in the reservoir and a certain minimum flow in river d/s of the dam was guaranteed to protect the riparian rights of the people in the lower regions. With the increase in command area due to the construction of the dam, the cultivation under irrigation increased in both or states. Usually there is enough water to meet the demands of both the states. However in drought years there is not enough water and both states claim a lion's share and quarrel. The fact is that if the dam was not built, so much land would not have been under irrigation.

7.8.4 Some concluding remarks on large dams

Rama Prasad (2002) in his analysis of opposition to projects of Western Ghats states. Although environmental grounds have been advanced by the agitating people, the real grounds appear to be the reluctance of displaced people to move and loose their agricultural property. To Ramaprasad this does not appear a good enough reason. It must be noted, the power produced from these projects benefit the industries at Banglore, which is 300km away and not the displaced people.

RamaPrasad admits that there is much to be desired in the implementation of rehabilitation scheme. He admits that availability of land for resettlement is becoming less and less and makes a suggestion as to what can be done. He says the resettlement should be in the command areas in the case of irrigation projects and jobs should be given in the case of power projects. If not the displaced people should get some royalty. All these things are nice if they are implementable in the right spirit. Where the beaurocracy is corrupt it is only wishful thinking,

Rehabilitation is defined by Oxford Dictionary as restoring to rights, privileges, reputation or proper condition Resettlement and Rehabilitation (R and R) schemes are not so far implemented sincerely and satisfactorily. Large dams remain today an experimental technology in part because few studies have ever attempted in assess their ultimate impact.

A Technology barely tested in the landscapes of Europe and North America was being unloaded on to foreign lands with very different and more vulnerable environments with a reckless disregard to the possible consequences. Dams were built to irrigate already highly productive farmland, to generate electricity where none was needed and to end seasonal floods on which millions of farmer and fishermen depended (Pearce 1992).

Why are the grand projects taken up?

Most of the countries and their leaders consider the grand projects as monuments like pyramids. They are proud to show the rest of the world, these modern temples, (a word coined by Nehru) as objects of their a achievement. Engineers see them as technological challenges to their abilities. Builders and corrupt politicians see them as sources of income.

Two examples will be given for this

8.1 Yangtze.

Three gorges plan has, 3 declared aims.

1.To protect some 10 million people from floods.

2.To generate hydro electricity for industry

3. To open up Chinese interior, above the gorges, by improved navigation

American engineers who visited the site in the early 1980s flew home unconvinced. They went on record saying that the project would not prevent flooding and land slides; earthquakes or military attack could breach the dam and kill millions. Chinese public opposed it. But the Chinese government arrested the public opponents of the dam in 1989. Scepticism was soon drowned by lure of big contacts. So within a couple of years USA's consortium of dam builders was bidding for the project. Canada spent 14 millions dollars of its money on feasibility report. Canadian environmentalist who read the report said it was expert prostitution (Pearce 1992).

8.2 Linking of Indian Rivers

Former minister of power and Irrigation of India KLRao who was also a civil engineer, first presented his plan to link the Ganga in the north and the Kavery in the south. The present government is planning to implement it. The scheme claims

1.To permanently solve the problem of drought by bringing in to cultivation through irrigation a further area which is equal to the present net grown area of about 150 million hectares.

2.To solve at least mitigate the annual floods in the rivers Ganga and Brahma putra

3.To add 3000 MW of hydropower.

The Nation Water Development Authority (NWDA) budgets it today at $112 billion at prices of 2002. But they know, it can go up to $ 200 billions (Alam, 2003). NWDA has to complete the project in 10 years though so far there is no detailed project report. It has conducted only some feasibility studies in the past 2 decades!

The first claim that Ganga, Brahmaputra and Godavari rivers are water surplus is raising serious doubts. Because it is planned to lift only 1500 cusecs out of 60000 cusecs of flood flows. How such a small portion of water at such a huge cost can solve the problem of drought and flood permanently, raises the doubts in the minds of the opponents.

The glacier Gangothri which feeds Ganga has receded by over 14 Km in the past century alone. Moreover, almost half of the Gangas waters at Patna originate in Nepal and Nepal has its own plans to develop its hydrological resources.

The riparian states through which these rivers pass have their own plans to use the surplus water for developing their backward regions. Already there are enough water disputes like the disputes of Karnataka state with Tamilnadu and Andhra pradesh states. The interstate water disputes will increase in numbers and recently (Dec 2002) Karnataka has almost disobeyed the order of Supreme Court giving an indication to the level to which water disputes can grow in future (Parsai 2003)

Linking these rivers and building storage reservoirs would eat into the natural habitats of wild life and reshape the ecology of the country with unknown consequences. The number of people who would be displaced can go up to the tens of millions.

Countries with a history of meddling with rivers are now investing billions of dollars, to restore them by blasting their dams and embankments. In the US alone more than 100 dams were removed between 1999 and 2002.

How will the Government of India going to raise the money needed to implement this grandiose scheme? It will be another 'OMVS' situation. India will be in great debt without really realizing any one of its dreams successfully.

Conclusions

There are several examples of how unexpected or ignored consequences of large hydrological projects have overwhelmed benefits. With most of the super dams only completed in the last four decades it is likely that the tally of impacts will grow.

In tropical Africa most large water projects do more harm than good, rewarding a few to the detriment of many and the long turn destruction of natural wealth. Irrigation projects in many arid regions grow fewer crops than the farms they replace while fisheries, flood plains and ground waters start disappearing.

From India to Turkey to Paraguay soldiers stand guard over dam construction sites and herd refugees to their new homes.

Stalin, Nehru, Nasser, Gadaffi, and the military commanders of South America were all proud of their large dams. The reasons for taking up large hydrological projects appeared to be other than technical. In economist Jargon more dams can only provide supply side solution to the demand side problem. There are plenty of demand side solutions. The half forgotten world of traditional water systems is full of them. We should know that we cannot command nature without obeying her. Small is not only beautiful but also viable.

A shift in paradigms of development ownership of water and benefit cost ratios is needed and emerging.

Dedication

The author wish to dedicate this paper to the great ancient Indian scientist Varaha Mihira who has authored Brihath Samhitha (Grand Compilation). In this he has given a good description of a gauge that was used to measure rainfall (rain gauge) and also some ground level indications to locate the water table below.

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Bio-Kinetic Application Of Tannery Waste Water

Dr.N.B. Prakash, AWTI, Arba Minch, Ethiopia

Abstract

The present study deals with the chemical and biological treatment of composite tan liquor. Effect of lime on chromium precipitation has been studied. Anaerobic digestion of chromium free composite liquor at varying BOD loadings was carried out. The maintenance of alkalinity and volatile acids for maximum BOD reduction was studied. The role of calcium carbonate in anaerobic digestion for biogas enhancement has been studied. Biokinetic constants were determined to study the metabolic performance of microorganisms in the reactor.

Keywords: Composite liquor, anaerobic digestion, Organic load, BOD reduction. Biokinetic constants.

Introduction

Environmental pollution has become a major concern in developing countries in the last few decades. Major sources of water pollution are the untreated or partially treated industrial effluents. Tanning industry is reputed globally as major industry, which contributes to water pollution [1]. The quality of discharged waters from tanneries is far from the desired level of acceptance into water-ways [2].

A tannery discharges from 21,500-21,950 liters a day, corresponding to 86-88 liters per kg of leather processed. Chromium is known to be highly toxic to the living aquatic organisms in the hexavalent state and somewhat less toxic in the trivalent form. The effluents from chrome tanning industry shall meet with the specific tolerance limits for chloride with 1000 mg/L, BOD (5 day at 20° C) with 30 mg/L, hexavalent chromium with 0.1 mg/L and pH between 5.5 and 9.0.

Arumugam has reported on the recovery of chromium from spent chrome tan liquor by chemical precipitation using lime [3]. Pathe. has studied the properties of chromium sludge from chrome tan liquor and related the sludge volume, sludge settling rate, and surface loading rate[4]. Archana Shukla and Shukla have studied the treatment of tannery and electroplating effluents using lime, NaOH and their mixture in the temperature range of 25 to 100° C[5]. Guruswamy conducted a study on a laboratory scale completely mixed continuous flow activated sludge system to treat settled chrome tannery wastewater and observed that the BOD and COD removal ranged from 84 to 96%[6]. Elangovan has conducted experiments on the activated sludge treatment of vegetable tanning waste admixture with 10,25 and 50% settled sanitary sewage and obtained BOD removal from 87 to 96%[7].

Experimental

A 5 liter bottle was used as the digester. The gas produced was collected in a calibrated aspirator bottle of 2-liter capacity. Tubes were connected to the digester to facilitate feeding of the waste and removal of the effluent. The digester was kept in a water bath at a constant temperature of 35°C. Cow dung was used as the seed material and fed into the digester to start with. After establishing necessary biota from cow dung sludge, the chromium free composite liquor is fed into the digester daily. The pH of the influent sample was adjusted to pH7 by adding alkali before feeding. After feeding the contents in the digester, the contents were given a thorough mixing by manual shaking. The BOD load was kept at 0.25 kg BOD/ m^3/ day in the beginning. After several displacements of the digester contents and after establishing stable conditions of digestion the loading rate was gradually increased. The samples of effluents drawn at different loading rates were analyzed for pH, alkalinity, volatile acids and BOD. Gas measurements were done once a day. The gas was burnt periodically to confirm the presence of methane, which formed a major portion of the gas. The gas collection apparatus consisted of a glass bottle of 500 ml capacity and another leveling bottle of 1-liter capacity of the water displaced from the gas bottle. The reaction was carried out in the airtight container. About 2 liter of the effluent was added to the digester and allowed to stand till gas evolution was noticed. The influent was added in terms of BOD load and the digestion was carried out until stabilized condition was achieved as represented by sludge growth and the effluent BOD remained constant.. Calculated amount of diammonium phosphate and urea were added to the feed solution to maintain the BOD: N: P ratio as 100: 2.5: 0.5.

Results and Discussion

The general characteristic properties of the composite tannery effluent are presented in table 1. The results indicate that the liquor is basic with pH 7.8. The chromium content has been found to be 120 mg / L and the BOD and COD of the effluent have been estimated to be 1360 and 2510 mg / L respectively. The results indicate that the effluent has to be treated for an effective removal of chromium before being subjected to biological treatment.

Table-1 General characteristics of composite Tan Liquor

Parameter	Value
PH	7.8
Alkalinity	1100
Total solids	22400
Total dissolved solids	20890
Total suspended solids	1510
Volatile suspended solids	810
Chlorides	7600
Sulphates	2840
BOD	1360
COD	2510
Chromium	120
Sulphide	90

All values except pH are expressed in mg/L.

Table-2 Effect of lime on chromium precipitation

Weight of lime added (in grams)	pH	Chromium in filtrate(mg/L)
4.0	9.6	3.64
4.5	9.9	2.89
5.0	10.3	2.66
5.5	10.9	2.00
6.0	11.4	1.64
6.5	11.6	0.90
7.0	11.9	0.40
7.3	12.0	0.54
7.8	12.3	0.66
8.5	12.4	0.68

Lime was used as the precipitating agent for chromium removal and the effect of lime on chrome precipitation is presented in table 2. It was observed that the chromium removal increased with increase in pH and the maximum chromium removal of 99.7% was observed at pH 11.9 with a lime dose of 7.0 g/lt. Further increase in lime has resulted in the decrease of chromium removal due to redissolution of the mixture under such experimental conditions. The results of the alkalinity variation with pH are presented in table 3. The data consists of varying BOD loading rate, changes in pH, alkalinity, volatile acids and percentage BOD reduction. It was observed that a maximum BOD reduction of 96.9% was obtained at the BOD loading rate of 0.80 kg BOD/m^3/ day and throughout different loading rates, the BOD reduction was more than 94%, which could be due to the proper maintenance of alkalinity and volatile acids in the digester.

In the beginning of the process, the pH of the effluent was 6.9. As the loading increased gradually the pH increased to 7.6 up to the optimum loading and dropped down slightly to 7.4. The increase in alkalinity was steady as the loading increased gradually. Side by side, there was a production of volatile acids but was not considerable. With the initial pH correction and with proper seeding of the waste, the process of digestion has taken place unhindered, without undue accumulation of intermediate products. There was no possibility for the formation of free volatile acids.

Due to initial pH correction, the alkalinity level in the waste was boosted up and this gradually increased at every increase in loading. This helped in maintaining adequate buffer capacity in the digester to neutralize the volatile acids. Much of the alkalinity build up in the digester may also be due to the release of ammonia from the nitrogenous organic matter in the waste undergoing digestion. The volatile acids may also react with the alkalinity formed and form an acid salt with release of carbon dioxide. The salt in turn reacts with acid and appears as part of the alkalinity.

The presence of traces of H_2S in the gas may be due to the reduction of sulphates present in the waste. Although the presence of higher sulphide concentration affect volatile acid production and methane fermentation during anaerobic digestion the presence of less amount of volatile acids in the experiment seemed to indicate that methane fermentation has in no way been affected. The volatile acid production was kept under control and this may be due to the high level of alkalinity maintained in the digester. Parameters measured during the study were the influent and effluent substrate concentrations (So and Se) in terms of BOD and COD, mixed liquor volatile suspended solids (MLVSS) etc. The mean cell residence time (θc) was varied by operating the reactor at varying food-to-microorganism ratios (F/M) and this was achieved by varying the MLSS concentration. Analyses have been done using standard methods.

The results of the anaerobic treatment of physico-chemically treated liquor are presented in table 4. It has been observed that with an influent load of 0.8 Kg BOD / m^3/ day, a maximum BOD removal of 96.9 was achieved in a detention time of 4. 1 days. Throughout the experiment, the mean cell residence time (θc) was varied from 5.6 to 7.8 day by operating the reactor at varying food-to-microorganism ratio (U) from 0.31 to 0.60 day^{-1} and by varying the mixed liquor volatile suspended solids (MLVSS) concentrations from 4160 to 2140 mg/L. It was found that the BOD removal efficiency decreased with decrease in mean cell residence time and with increase in food-to-microorganism ratio.

In the present study, the modified monad's equations were used to develop kinetic parameters.

$$\frac{1}{U} = \frac{Ks}{k} x \frac{1}{Se} + \frac{1}{k} \quad \ldots\ldots (1)$$

and

$$\frac{1}{\theta c} = YU - Kd \quad \ldots\ldots (2)$$

The reciprocal values of F/M ratios (1/U) were plotted against 1/Se and by using the method of least squares, the line of best fit was obtained. The slope of the line equals Ks/k, the intercept gives, 1/ k. The reciprocal values of the mean cell residence time (1/θc) were plotted against specific substrate utilization rate (U). The yield coefficient Y was determined from the slope of the straight-line and the endogenous decay constant, Kd was obtained from the intercept.

The biokinetic constants obtained in the present study is presented in table 5. It was observed that the substrate removal rate constant, k, was found to be high which might probably due to the high growth rate of methanogenic bacteria. The yield coefficient was also significant indicating a larger portion of degradable organic matter synthesized into new cells. The endogenous decay constant was calculated to be around 0.06-day^{1} which showed that a substantial decay of the cells has taken place by way of endogenous respiration.

Table-3 Alkalinity Variation with pH

BOD load (Kg BOD/m^3/day)	pH	Alkalinity (mg/L)	Volatile acids	BOD reduction (%)
0.25	6.9	340	40	94.6
0.30	7.0	410	60	95.0
0.35	7.2	560	76	95.2
0.40	7.4	950	110	95.4
0.50	7.4	980	144	96.0
0.60	7.6	1460	168	96.2
0.70	7.6	1880	190	96.80
0.80	7.6	1920	236	96.90

Kinetics of BOD Reactions

Studies on the kinetics of BOD reaction have established that they are most practical purposes first order in charac-

Table-4 Anaerobic digestion of Tan Liquor with varying organic load

Organic load Kg $BOD/m^3/day$	Final BOD (mg/l)	MLVSS (mg/l)	HRT (day)	θc (day^{-1})	U(day-1)	BOD removal efficiency (%)
0.4	63	2140	3.2	7.8	0.31	95.4
0.5	55	2380	3.6	7.2	0.38	96.0
0.6	52	3490	3.8	7.0	0.40	96.0
0.7	44	3570	3.9	6.2	0.44	96.8
0.8	43	4160	4.1	5.6	0.60	96.9

ter as the rate of the reaction is proportional to the amount of oxidizable organic matter remaining at anytime, as modified by the population of active organisms. Once the population of organisms has reached a level at which only minor variations occur, the reaction rate is controlled by the amount of food available to the organisms and may be expressed as follows.

$$\frac{-dC}{dt} \alpha C \quad or \quad \frac{-dC}{dt} = kC$$

Where, C represents the concentration of oxidizable organic matter at the start of the time t, and k is the rate constant for the reaction. This means that the rate of the reaction gradually decreases as the concentration C of food of organic matter decreases.

Since the BOD reaction is closely related to a first order type of reaction, a plot of the amount of organic matter remaining versus time yields a parabolic curve. In the present investigation, the anaerobic digestion of tannery effluent followed a first order kinetics since these are reactions that proceed at a rate directly proportional to the concentration of one reactant that is organic substrates. As the rate of the reaction depends on the concentration of the reactant and since the concentration of reactant changes with time, an arithmetic plot of the variation in the concentration of the reactant with time gives a parabolic curve, which confirms that the BOD reactions in the present study followed a first order reaction.

Role Of Calcium Carbonate In Anaerobic Digestion

The pH of the tannery effluent was adjusted to about 7.0 by adding calcium carbonate. The pH gradually increased with loading and at the maximum loading it was 7.3. The increase in alkalinity has resulted in reduction of excess volatile acids formed during the digestion process thereby maintaining adequate buffer capacity in the digester. The alkalinity built up in the digester may also be due to the release of ammonia from the nitrogenous organic matter in the waste undergoing digestion. There might have been the possibility that the volatile acids and alkalinity formed might react and form an acid salt with release of CO_2.The salt intern might have reacted with acid and appeared as part of the alkalinity.

Methane organisms are extremely sensitive to pH values. They are most reactive in the pH range from 6.6 to 7.2. In the present study, the influent pH was adjusted to 7.0 using calcium carbonate, which apart from raising the pH might also be useful for methane organisms as a source supply of CO_2 in producing additional quantities of methane. The reaction may be represented as follows:

$$CaCO_3 + 2H_2O \rightleftarrows Ca(OH)_2 + H_2CO_3$$
$$H_2CO_3 \longrightarrow H_2O + CO_2$$

This is a reversible reaction. Initially there was certain amount of $Ca(OH)_2$ produced which helped to neutralize the acidity in the raw waste. It was possible that during anaerobic digestion of the waste, the methane organisms might utilize the CO_2 gradually for forming methane since CO_2 is a hydrogen acceptor.

$$4H_2A + CO_2 \longrightarrow 4A + CH_4 + 2H_2O$$

Where A is any oxidized substrate.

The volume of the methane gas produced by the use of $CaCO_3$ and other alkalis during biological digestion has been compared. Compared to Na OH and $Ca(OH)_2$, 10 to 20% increase in volume of biogas production was possible by the addition of $CaCO_3$ in the system. With the gradual depletion of CO_2, the production of "$Ca(OH)_2$ increased to restore the balance . This cycle repeated till $CaCO_3$ were completely utilized. This helped in increasing the alkalinity level in the process

Conclusion

The results of the study lead to the following conclusions.

a) By proper maintenances of required alkalinity, the BOD reduction can be increased.

b) The maximum BOD reduction was obtained at an applied organic load of 0.80 kg BOD/m^3/ day.

c) The addition calcium carbonate for pH correction has helped in building up the alkalinity level and also increased the biogas evolution.

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Table-5Biokinetic constants

Influent BOD Kg BOD/m^3/ day	k (day^{-1})	Ks (day)	Kd (day)	Y	μ_m (day^{-1})
0.4	1.80	1620	0.064	0.76	1.368
0.5	1.66	1510	0.066	0.68	1.129
0.6	1.23	1380	0.080	0.66	0.811
0.7	1.46	1300	0.076	0.70	1.022
0.8	1.52	1440	0.068	0.66	1.003

An Assessment of the Agricultural Development Activities in Semi-Arid Areas of Ethiopia

Mamuye Belihu

Abstract

Ethiopians the majority are involved in rain fed agriculture but food deficit country for long time. Even in under normal climatic condition, the country experience s a short fall in food production to 25% of what people actually need. A major challenge confronting agriculture is the rapid increase in the size of the population and drought.

As part of the country, Semi-Arid areas agricultural development activities are back word and subsistence type of small holders farming. It shares most of the problems that the country faced. But climatic and environmental characteristics made the area more difficult to Rain fed agriculture. Crop failurity and even total loss is common due to moisture stress. This is also aggravated by backward agricultural practices and unsustainable resource utilization.

Zeway area has high potential for arable land and water resources to support the existing population, and has better infrastructure to promote irrigation agriculture. This paper assesses the rain fed and irrigation agriculture, and its performance with relation to the available natural resources. The total agricultural production should support the existing population efficiently. In this regard, based on the area population and production base year quantitative data, the food security status is analyzed.

Agricultural production and development of the area is highly constrained by various problems, and if this sector has remained and will also remain as backbone of the economy, especial attention should be given to improve production and productivity. This paper has also identified major agricultural problems and suggests possibilities to improve the performance of agricultural and sustainable resource utilization.

Introduction

Today more than 800 million of peoples who live in developing countries do not have enough food to meet their nutritional needs. Worse yet the number of such peoples is expected to grow at an alarming rate. Unabated and unbacked by an equal growth in food production There is a general agreement that there is no shortage of food in the world, but the distribution is un even. According to World Bank report in 1990 the calorie supply at the global level was war above demand, however more than 100mi. people affected by famine, the World Bank also estimates, by year 2020AD Africa alone will have experienced a shortage of 250 mi. of tones of food (MOA 1998)

Agriculture is the principal sector of the Ethiopian economy, which provides a lively hood to 85%if the population which generates about 52%if the GDP and 90% of exchange earning (MOA 1998). But it is still performing too much below the growing demand. A major challenge confronting agriculture is the rapid increase in the size of the population. Wide scale poverty among the farming population is another factor closely linked to agricultural performance. As part of the country, Semi-Arid Areas agricultural activities are subsistence type of smallholder farming. It shares most of the agricultural problems that country faced. Peasants are suffering due to food shortage because of high dependency of back ward agricultural practices. Even if this is so, the study area is highly endowed by agricultural resources such as land and water, which can economically support the existing population. Lack of proper utilization and management of resources is not only reducing the required amount of production but also affects the resource sustainability.

This paper assess the status of agricultural production, resource management and utilization, Analyse the food security condition based on the writers' assumption that the existing food production is below the optimum requirement and discuss the basic constraints and recommend possibilities to improve the performance of agriculture in the area.

This study include 2 woredas namely- Adamitulu and Dugda Bora in Eastern Shoa, Oromia region.

Geographical location - Southern Riftvally, lat. 7° 50' N and 8° 10' N long. 38° 30' & E 39°and the altitudinal range between 1580m – 1880m.

Climatically it is semi – arid area having annual rainfall 742mm, but its distributions too much variable. The mean annual temp is 20.7c, its mean max. temp. is 27.2c and 14.0c respectively. The soils are variable in morphology and many parts are influenced by recent sediments deposition. Soil fertility, structure and drainage are favourable for arable use.

These two Woredas are endowed with suitable ground and surface water irrigation resources. These available water resources would help to maximize agricultural production and to diversify the agriculture system in the area. The Meki and Bulbula Rivers and Lake Zeway can provide sufficient and quality water for irrigation development. The river systems and the Lake can provide about 1.12billion m^3/yr.

Assessment of the Agricultural Development Activities

Rain fed production

Crop production of the small scale farmers sector

Growing seasons

The great majority of farmers of the study area are engaged in rain fed agriculture and under take mixed farming system where both crops and live stocks are managed in an integrated, but backward and traditional ways. The study area has got a bimodal rainfall pattern where:

- The small rainy season (Belg rains) normally occurs between ends of February to the end of April.
- The big rainy season (Meher) normally occurs between end of June and early September.

Area cultivated and crops grown

Rain fed crop production is currently conducted on about 97,080 hectares of land (60,209 hectares in Dugda Bora Woreda, and 36,871 hectares in Adamitulu Jido Woreda based on data from Oromia region agricultural bureau, 1997). Out of the total cultivated area, Rainfed production conducted 98%.

Few decades ago, the study area was sparsely populated and that crop production activities have concentrated in limited areas. However, up on time and mainly as a function of population increase the cropped area have been remarkably increasing at the expense of continuous clearing of forest lands. Currently, out of the total land area of the two woredas, the proportion of cropped lands is about 31.7%. The cropped area and production estimates of the two woredas based on the 1997 production is indicated below.

Cropped area, proportion and production (1997 crop season).

Crops	Area coverage	Production (Qt)	Percent
Cereal	75087.3	293505	73.3
Pulse	13095.0	72246	13.5
Others	8897.2	63669	7.2
Total	97079.5	429,420	100

Source: Oromia Agricultural office

The long cycle stalk crops (Maize, Sorghum) are the most dominant crops covering 77.3% of the totally cultivate area where as the short cycle crops share about 22.7% of the annual cultivated lands.

Productivity and Production

As indicated above the annual total production volume of the two woredas is about 429,420 quintals out of which 47.0% and 53.0% is contributed from Adamitulu Jido and Dugda Bora Woredas respectively. Relatively in crop wise the largest production comes from Maize (25%); followed by Wheat (10.5%).

Generally, no significant improvements on the volume of the total production was reported during the subsequent cropping years, and according to information from Woreda Agricultural offices, a striking production shortfall and stagnation in the total volume of production has been seen during the last decades mainly as a result of shortage of rains.

The low-input, low-output production system of the farmers couldn't able to improve the yield (productivity) levels of cultivated crops. As indicated below crop yield levels are found very low and that the average productivity of cereals and pulses are only, about 3.9 Qt/ha, and 5.5 Qt/ha respectively. comparative analysis of the main crops of the study area with the national average of the country has been made and a substantial productivity shortfall can be analyzed.

Crop	National average (Qt/ ha)	Ziway area average (Qt/ ha)
Cereal	13.3	3.9
Pulse	6.7	5.5

Range of productivity of food grain and comparisons with the national average productivity (1997 crop season).

Agricultural in-put Utilization

The existing agricultural in-put utilization is not satisfactory when we compare its importance in productivity. Agricultural experts in the area based on the distribution through their offices shows an increasing demand for fertilizers, pesticides and improved seeds. The following table shows the input distributed to the small-scale farmers.

Agricultural inputs used by farmers in Ziway area Agricultural inputs(*average of 1996 & 1997).*

Agricultural inputs	Type	Quantity
Fertilizer	DAP	14894.0 Qt
	UREA	456.5 Qt
	Total	15350.5 Qt
Improved seed	Teff	225.0 Qt
	Wheat	924.8 Qt
	Maize	400.0 Qt
	Haricot Beans	7.0 Qt
	Total	1556.8 Qt
Pesticide	Powder	414.5 kg
	Liquid	499 Lt

Source: Oromia Bureau of physical planning department

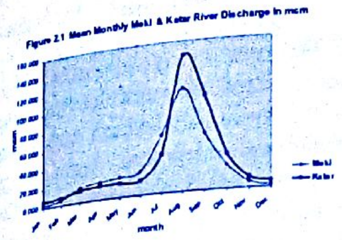
From these data, the average consumption is about 0.2 Qt/ha. Similarly, the improved seeds consumption as a factor of total land cultivated is 0.2 Qt/ha.

Irrigation potential & Production

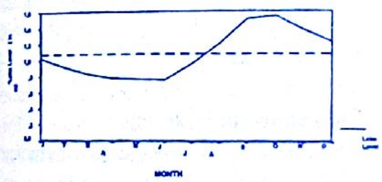
Meki River: Its source is from Gurage High lands (western escarpment) having many tributaries, of those tributaries Lebu, Akamoja and Weja are the main. The river before joining Zeway Lake it meanders about 15 km. Because of its low gradient, it is suitable for irrigation development with relatively lower cost. The mean annual discharge is 290.7 million m^3. The maximum monthly discharge in the last 20 years record is 139.62 million m^3/sec (August 1998).

Catar River: is the main contributor to lake Zeway, where its source is from Arsi Highlands. The annual Mean discharge is 412.48mi.m^3 the max. discharge reaches 508.224mi.m^3 the steepest gradient makes the river makes unsuitable for irrigation development, instead the prime importance is its contribution to the lake.

As shown in the lower figure, the discharge from the rivers is highly variable with seasons. Both rivers Meki and Catar, contribute on average 703.257 millionm^3 annually. Bulbula River is the out let from lake Ziway, which is determined by the lake level. Bulbula river discharge, just at the mouth of the river is 175 million m^3 annually. The river comes out from the lake and flows about 30 km and empties at Abyata, a terminal lake.



Ziway lake: is the largest water surface of an area 434 k m². It is the shallowest and having lowest salt content in the Riff valley lakes. The lake level (volume) determined by the catchments run off. It has catchments area of 1700 kmD². Ziway lake has high potential to different socio-economic activities in the area, mostly to fishery and irrigation agriculture development. Average & maximum depth is 2.5m. and 4m.respectively. The level shows more variation with in a year than annual variation and its mean monthly variation shown by the following graph.



Take lake level figures indicates heights above 1635 mts.

The major water surface, the Lake, has the following water balance:

MEKI FLOW + CATAR FLOW + RAIN ONLAKE=EVAPORATION + BULBULA FLOW + CHANGE IN STORAGE

The area has got an enormous irrigation resource as indicated above. The Ziway lake, Meki, Bulbula and Katar river are the sources of water. The farmers who are situated along the watercourses have traditionally experienced irrigation and the need of irrigation among the farmers has been substantially increasing mainly as a result of moisture stress during growing seasons. Currently the total area under irrigated production is estimated by the Woredas agricultural offices is about 1700 hectares, out of which 59% belongs to the state farms, 29% belongs to private investors and 12% belongs to small scale farmers. These almost entirely practice traditional irrigation systems with a gravity water conveyance or furrow system of application under this system, the farmers are used to conduct both dry season full irrigation practices and supplementary irrigation where the later is mainly experienced on rainfed crops which are exposed to late season moisture stress. On sloped areas utilization of irrigation pumps with diesel engines is gradually developing even though it requires more costs and intensive management.

The farmers intend to produce under irrigation crops which are suitable for irrigated water application (mostly row crops) and those which have relatively higher market prices. The common crops under irrigation area, fruits (mostly papayas), Vegetables (Onion, Tomatoes Cabbages etc..) long cycle cereals (mainly Maize, to supplement the rain fall).

Crop Production of the State Farm and the Private Commercial Investors

The Ziway Horticultural Development Enterprise is the only available state farm in the area. It was initially private Owned commercial farm before Derg regime, This was expropriated as a state farm in 1976 following the land reform..

The farm has total area of about 1000 hectares and is administered nationally under the Horticulture Development Corporation. It has been running totally under irrigation and used semi-mechanized production and processing systems. The farm has better capacity in production system and farming equipment's relative to other farms in the area. Currently, major crop grown in the farm are Beans, Tomato, Onion, Grape, Orange, Papaya ,Mango, Grape vine, Orange, Maize and flower because of market facilities specially to export, production of flower becomes declining, in this regard only Allium is currently growing Allium produce flower at the same time its root (Garlic) sale to local market.

With in the broad policy framework of the new economic policy of the FDRE (1991), a free economic development policy which puts an emphasis and support to the participation of private commercial investors in the agriculture sector has been adopted. The engagement of private commercial investors in agricultural development in the study area has emerged following this policy guidelines, and through the pace of private commercial investments in this sector is very low, the study area appears to be relatively attractive for commercial developments in view of the irrigation potential, proximity or location of the area, infrastructure and social facilities suitability and etc.

According to the data from the area investment office about six private investors have been engaged in irrigated production with an estimated area of about 300 hectares. The land acquired for investment is usually acquired in two forms.

I. Leasing of uncultivated lands from the Regional government based on the state policies, rules and regulations of investment.

II. Contractual renting of the accessible irrigable lands from the indigenous farmers based on mutual agreement.

A number of other small private investors, applying low capitals and holding land through rent from the farmers (averagely 2-3 ha) and utilize pump-irrigation systems. The tendency of renting land to small-scale investors appears to be developing from time to time, because:

- The farmers lack the required financial capacity to develop pump irrigation systems,
- The increasing menace of rainfall shortage and production shortfall unless it is supplemented with irrigation,
- Employment opportunity of the farmer on the rented land.

Irrigation method

Furrowing or basin irrigation covers about 80% and the rest by using border strip and sprinklers. In case of state farm Water is pumped to the main canal which is cement basement at length of 2277m and the rest are soil basements. Regarding water resource, it is poorly managed by the state farm and all other private irrigators.

The Food Security Conditions

Both chronic and transitory type of food insecurity commonly occurs in the study area. Chronic food insecurity occurs mainly due to unemployment and lack of other income generating schemes. Moreover, in view of the highly increasing population and the gradual reduction of the farm land holdings for sustained production of food crops at the required food security levels. On the other hand, transitory food insecurity became the major challenge mainly arising from drought. Drought has been occurring in the area in relatively high frequency since the big famine of the mid 1980's and the study area has been under a close relief assistance allover the past year.

Based on the current available data of the study area, the writer made the following quantitative analysis to reveal the food security condition of the area in terms of calories /head/day.

Quantitative Analysis of Food Security Status

Basic assumptions

The assumption is based on internationally accepted and computed by FAO and Ethiopian nutrition Institute (ENI). Conversion figures – source: Taken from MOA Report on the crop production... Vol. I and II 1998.

a. Population - crop production base year.

b. Conversion of food grain production to cereal equivalents.

- Gross food grain production = the estimate of annual harvest.
- Net production = Gross production – Post harvest loss (12%) -Seed requirement (5%) - Livestock feed requirement (0.5%).

c. Livestock and livestock products contribute about 12.5% of the daily caloric in take as a proportion to the local production.

Cereal conversion factor for cereal = 1
Pulse = 0.98

The minimum requirement of calorie/head/day = 2100C/H/D or 2.25Q/H/Yr

Food Security Quantitative Status

Food Security level of the Area

The universally accepted food security level or calories of 2100/Head / Day. Livestock contribution (12.5% of the food grain production) proportion taken from national survey by the crop production and protection Technology and Regulatory Department of MOA. level is 2100 calories /Head / Day. In other terms, for healthy life and efficient labor an individual shall have to consume food items (food grain or livestock products), which can generate the minimum energy.

In the study area, the grain and livestock productions can generate only 1185.3 calories/H/D that is a total production of 1.27Qt in CE, which can fulfill only 56.4% of the required food security (caloric) levels. The remaining deficit, which is about 914.7 C/H/D, shall be fulfilled from external sources (mostly from relief food aid assistance) to make survival of the population.

Generally, the most striking factors of the study area in the context of food security are:

. First, due to lack of other employment generating schemes and other means of income, the population does not have the financial means to express food needs on the market, even in good years.

. Second, agricultural production shows very poor performance, and up to now they did not have substantial support ensuring food security is a prerequisite to promote the overall economic development of area.

Food grain estimate converted to cereal equivalents

Food grain	Gross production (Qt)	Net production (Qt)	Production converted to Cereal equivalents
Cereal	293,505	242,141.6	242,141.6
Pulses	72,246	59,603.0	58,410.9
Total	365,751	301,744.6	300,552.5

Food Security balance in terms of caloric contribution is summarized as:

Total Population	265,114
Total available from local production (Crop + Livestock)	338,121.6
Requirement at 2100 C/H/D or 2.25Qt/H/Yr	596,506.5
Balance	258,384.9

Problems

The area has got substantial resource bases and suitable conditions for the overall agriculture and socio-economic development. Even though agriculture has remained and will also remain as a backbone of the economy of the area, the level of production and productivity is far below to meet the population consumption requirement

The average annual income level of this community is smaller than the incomes of the highlanders of the country. Further more, destitute life, malnutrition, illiteracy and health problems are serious and alarming.

A number of agricultural production and development factors constrain the community. In this study, the following key constraints have been identified and it is expected that any intervention activities or proposals targeted to alleviate the current devastative socio-economic and development status of the community shall put prior emphasis to alleviate these constraints.

Environmental Calamities

The area is particularly characterized as semi-arid that the serious scarcity and uneven distribution of rainfall coupled with high rate of evapotranspiration triggered moisture loss have been seriously impacting crop production. The rain of the area is erratic and not well distributed over the growing season even if the overall amount seems sufficient. Substantial amount of production shortfall (sometime even the total loss) is registered in most growing seasons.

The eruption of crop pests and diseases such as Army worms, Aphids, grasshoppers is highly favored under high temperatures and drought prone conditions. Furthermore, pests of both migratory and non-migratory natures such as quelea birds, stalk borers, cut worms, etc. inflict a tremendous degree of production loss. The experience and the level of utilization of pest / disease control regulations of both the Federal and Regional Governments', the eruption of migratory pests at economically threshold levels (for army worms and Quelea birds) can be controlled on free-pesticide-supply bases.

Back ward farming practices and low-level technology adoption

The land has been continuously cultivated for many decades and the pressure on the farmland is increasing. On due course, the inherent fertility status of soil gradually decreases due to the continuous take up of the soil nutrients by the crops without further measures to stabilize the fertility with replenishment of either natural or artificial fertilizers. On the other hand, tremendous amount of fertile topsoils are annually taken away through wind erosion, which is serious in the area. Assuming a crude fertilizer application of 1.5 Qt/ha, the total fertilized area of the cultivated land is estimated to be about 6968 hectares. As compared to the area cultivated is 7.6% compared to the 52% of area fertilized in the Oromia region, which is significantly lower.

The low and erratic rainfall of the area highly necessitates and places a premium on the utilization of high yielding, drought tolerant, and early maturing crop varieties. The farmers use the local land races, which are mostly low yielder and pest/disease susceptible. The improved seed adoption as a factor of total land cultivated is 0.02Qt/ha. It is about 52.69% in Oromia region. The low area coverage of improved seeds has two negative implications.

They are: -

1.The entire consumption is very lower and in adequate compared to the other parts of the region and about 92.3% of the cultivated land is using local land races.

2.The strategic input, fertilizer, is still not adequately supported by using high yielding improved seeds and that additional yield increments from synergetic and integrated effects of fertilizers and improved seeds is not exploited.

Constraints in irrigation and irrigation development

In view of the existing moisture stress, crop production wouldn't be sustainable with out some sort of irrigation supplement. Even though the irrigation water source of the study area is very, there are a number of loopholes constraining the development of irrigation at the required level, the important are:

- Salinity
- Pollution and gradual depletion of Lake Ziway The surrounding irrigation activity that abstracts a large volume of water to irrigate the extensive land, most activities are going on with out the knowledge of irrigation, so its efficiency is lower. There is no regulation to control the existing situation.
- Absence of appropriate water management practices

Eco-system and Environmental Degradation

A few decades before, the area is reported as constituting a well balanced eco-system and vegetation cover encompassing stable inhabitancy between the flora, fauna, and nature as a whole. However, due to a continuous interference of man, live stocks and lack of appropriate eco-system conservation and utilization practices, the ecological system has been tremendously eroding and the past biodiversity status has been alarmingly declining.

- The root causes of ecological degradation in the area are

·Land fragmentation

·The rapid population growth and pressure

· Pollution

· Over exploitation of resource

· Low public awareness

· Poor farming and husbandry practice

· Commercial land use activities and lack of clear land use policy.

Conclusion and Recommendation

Conclusion

The nature of agricultural development activities of the area since agriculture is the main stay of the population of the study area; meanwhile, based on interpolations of the population and production data (taking 1997 as a reference year) the current food security (caloric) status of the area was quantitatively analysed and the balance between food requirement and food currently available from the local production was analysed. The analysis clearly indicates that the study area is under a serous food in-security conditions and that the agricultural production is by far very low to satisfy the minimum food security requirement of the area. The various constraints which negatively affecting the increase of agricultural production and conditions which aggravating the food insecurity of the area are mainly the back ward farming practices and low level of technology adoption, less efforts in irrigation development and absence of appropriate water management practices, ecological degradation, and absence of clear policy in resource utilization. Even though the status of this sector in the area is far behind and constrained by various problems, the study area has been found endowed with promising resource bases and prospects not only to satisfy the consumption and the lively hood needs of the community, but also reasonable potentials to promote and strengthen the economy of the Oromia region and the nation as a whole. There fore, the following recommendations have been made on how to utilize the available resources and on how to promote agricultural development in the study area.

Recommendations

Agriculture will stay the backbone of the community of the study area not only for the current period, but also for many years to come. There fore, the over all strategy to improve the socio-economic condition of the area shall concentrate on agricultural development interventions. The over all agricultural development strategic approaches are visualized on the following main areas:

· Growth in the agriculture sector shall be visualized in the integrated context of crop production with live stock production. The integrated production of the two and the interdependence shall be the main strategic approach to raise the agricultural production,

· Increase agricultural production through utilization constraint based and area-specific production technologies and particularly those practices selected under a semi-arid environment.

· Substantial resource identification and optimising the utilization of the available resources (like irrigation) and implementation of farming practices which would avoid the entire dependence on nature (rainfall),

· Agricultural diversification and eco-system maintenance and conservation based agriculture and other income generation schemes development.

Based on these approaches agricultural development objectives should be focus:

• In the improvement of the productivity of small scale farmers and attaining a level of self-sufficiency from local production,

• Simultaneously, promotion of eco-system maintenance and conservation for sustained development and to minimize the gradual degradation of the environment.

• Promotion of long term and commercial private investments primarily targeted to increase employment, to link agriculture with industry, to maintain the natural resources etc.

Increasing the production and productivity of crops

. Introduction of dry-land cultural practices shall be extensively promoted in order to minimize the risk of crop loss due to moisture stress, which has been the key constraint of the study area

. Introduction and development of moisture conservation practices to effectively utilize the excess moisture of the wet seasons and to minimize the losses

. Increasing utilization of agricultural inputs and modern farming technologies suitable to the area.

. Implementing substantial research and extension system suitable to the area based on the actual farmers problems.

Development of irrigated production

Only about 31% of the available irrigation resources have been utilized in spite of the fact that moisture stress is the key production constraint in this area. Even though irrigation is in gradual verge of development over the past years (mostly by the state and private investors) the pace of irrigation development is still very slow and there is a general lack of tradition in irrigation practices in the peasant level development systems.

The repeated failures in production at time of inadequate rainfall, however, have repeatedly shown the weakness of the rain fed subsistence base in the area. Therefore, promotion of development of irrigation to increase crop productivity is a serious concern for immediate intervention. Irrigation supports shall be rendered, such as in:

- Conducting area-based irrigation research to identify viable irrigated-production technologies,

- Promoting extension education, market and credit supports introduction of inputs and technologies, etc... to maximize the level of productivity of irrigated production,

- Increasing the irrigation efficiency and establishment of water users associations,

- Application of appropriate salinity control measures

Eco-system maintenance and conservation – based resources development

The rate of deforestation and destabilizing of the eco-system has been rapidly increasing over the past years, if this wouldn't be controlled, the study area would undoubtedly be changed in to seriously dry land and be marginal for agricultural activities in the near future. Therefore, effective eco-system maintenance and resource conservation shall be done particularly focusing in the following measures.

- Ensure that rural development is based on the conservation and rational utilization of natural resource. Give special attention to a forestation and reforestation programs, water and soil conservation and appropriate water shad management and catchment development.

- Promotion of Agro-forestry development. This includes systematic management of land combining supportive or integrated production of forest trees, agricultural crops, live stocks, and wild life simultaneously or sequentially. Canopy of the selected tree species is to be managed in such a way that crop and animal production is enhanced with out impairing the system as a whole.

- Promotion of inter-sectoral linkages by making sure all government institutions involved in rural development have an integrated plan of action and close coordination in their programs and that any development endeavour shall be visualized with eco-system management context.

- Development of alternative energy sources (such as bio-gas) and other means of income to minimize the risk of deforestation and charcoal production.

- Initiation of closure system and protection of the interance of human and animals in to forest areas so as to stimulate natural regeneration of the deforested areas and to create suitable conditions for wild life inhabitancy.

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Desertification In Ethiopia*

Engida Mersha, Ethiopian Agricultural Research Organisation P.O.Box 2003; Addis Abeba, Ethiopia

Abstract

The rainfall in Ethiopia is highly variable both temporally and spatially and it is erratic in its nature. This affects the country's rainfed agriculture significantly. Most of the rural population depends on subsistence agriculture for its livelihood. Hence if there is a failure of rain in one season, the farmer is unable to satisfy his needs and pay his obligations. This indicates that the rural population in Ethiopia, which feeds all the population, is in the bottom line of poverty. He is leading a risky live. Moreover, due to climate change and other human induced factors, areas affected by desertification are increasing in Ethiopia. Hence, a study to identify parts of the country that are susceptible to the effects of desertification is undertaken. Areas susceptible to desertification prone areas of the country are identified based on the rainfall: PET ratio recommended by UNEP. Based on this methodology, five desertification zones that range from moist to hyper arid zones are identified. The semi arid, arid and hyper arid zones cover about 57% of the country and are located mostly over the eastern parts of the country. The dry sub humid and moist zones those are located mostly over the western half of the country and cover about 42% of the area. From the results of this study it is concluded that the areas covered by the dry semi arid, arid and hyper arid zones have increased by about 8% during the recent years. This is a good indication that desertification in Ethiopia is progressively extending. Appropriate measures should be taken to combat desertification in the country.

Introduction

Desertification is threatening the lives of millions of people that occupy about one third of the land surface. Mainly deforestation is one of the major causes that aggravated drought and desertification especially over the semi arid and arid areas. The implications of drought for agriculture specially in the semi arid to arid zones, can be drastic in terms of yield variability, crop failure, livestock loses and human sufferings. Desertification has been greater disruption of an ecological system. Therefore, an understanding of drought and desertification is essential in any efforts to avert the damaging effects of them.

In Ethiopian, drought and desertification occur over marginal areas of semi arid, arid and hyper arid zones. They are mostly caused by natural and anthropogenic interferences. The vegetation in these marginal areas is normally in ecological balance with the environment. However, when human activities are imposed to upset this balance, then either drought or desertification sets in. Human activities that contribute to the problem are increased demands for food and shelter due to population pressure. This is expressed in terms of increased cultivation, overgrazing and deforestation.

Agriculture supplies 51.8% of the gross product and 90% of the export earnings of the country as well as supplying significant proportion of the raw materials for the agro-industries and 85% of the population is engaged in agriculture (CSA, 1999). Improvements in the agriculture sector meant the generation of higher incomes, reduction of poverty, and promotion of higher standards of nutrition and health of the rural people. It would also mean to increase and diversity the production of raw materials for the industries and export and make agriculture the driving force for economic development of the country.

The dominant man induced causes of land degradation the drylands of Ethiopia are poor farming practices, population pressure, overgrazing, soil erosion, deforestation, salinity and alkalinity problems, and the use of livestock manure and crop residue for fuel as energy resource of the rural households/Cesen 1986, World Bank 1984/. More than twenty seven million people live in the dry sub-humid, semi-arid and arid areas, where the ratio of RR/PET is less than 0.65. The map on figure 1 and the data on Table 1 show the extent and the coverage of the areas in Ethiopia which are susceptible and prone to desertification processes as defined by the UN: "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and humid activities" (UN CCD 1994).

The main objectives of this paper are to define desertification, identify its causes and delineate areas prone to desertification.

Definitions of desertification

There are many definitions of a desert and this varies with the individual's interest. In general, a simple index of aridity, which is commonly used, is Budyko's radiational index D, also termed " dryness ratio" by Letau (1969) and is defined as:

$$D = R_n/LP$$

Where

R_n = mean annual net radiation at surface,
P = mean annual precipitation, and
L = latent heat of vaporization of water

Following Hare (1983), we define a desert as a region from which perennial life is excluded or, at best rendered sparse, mainly due to deficient precipitation. Deserts are found in areas where the dryness ratios are ten or more. Except at ground water or riverine oases, where other water may be available, man does not largely settle desert regions. Since these regions are already deserts, they are not subject to desertification.

There are also different approaches to the concept of desertification. FAO/UNEP adopted the definition of desertification as a process involving all forms of degradation (natural or man-induced processes distributing the equilibrium of soil, vegetation, air and water) of land, vulnerable to severe edaphic or climatic aridity, leading to the reduction or destruction of biological potential of the land, deterioration of the living stan-

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dard and intensification of desert-like conditions (WMO, 1985).

According to Soviet scientists Kharin and Petrov (1977) desertification is defined as " the complex of physiographic and anthropogenic and degradation of all forms of organic life which, in turn, leads to the reduction of the natural and economic potential of those areas".

Causes of desertification

Two major factors are certainly involved in desertification, namely the periodic stress of climate on the one hand, and man's use and occupation of the sensitive and vulnerable dry-land ecosystem. To these must be added the concept that desertification as a dynamic phenomenon may be capable of feeding on itself. Climatic fluctuations with changes in the temporal and spatial destitution of rainfall may result in the lengthening of aridity phases, higher temperatures and winds of greater intensity. Similarly, increasing human pressure on the ecosystems may result in the extension of the cultivated area beyond the borders where man-environment equilibrium can be maintained. Such human pressure normally includes the extension of irrigated areas, extensive use of the tree-biomass for firewood and over-grazing of livestock. In addition, several processes may operate simultaneously, feeding back into the system, intensifying the degradation of the quality of the resource base and the decline of biological productivity (feedback mechanisms). We can, therefore, distinguish between the two groups of desertification factors, natural and induced.

Anthropogenic causes

Deforestation

The natural forest keeps the atmospheric balance (regulates rainfall amount and distribution, keeps the soil from erosion, maintain the soil water reserve, cleans carbon dioxide from the air, keeps the wildlife safe). However, for the purpose of construction, settlement, fuel wood, farmland expansion etc. man is continuously cutting down trees without replacing them. As a result of this we cannot get the above advantages from the forest, instead the location will be exposed to the effects of drought.

Historical sources indicate that high forests might have covered about 35-40% of the total area of Ethiopia. If the savannah woodlands are included, 66% of the country is believed to have been covered with forests and woodlands. (EFAP, 1994). However, the country's forest and woodland resources have been declining both in size (deforestation) and quality (degradation). These resources are vanishing at an alarming rate, estimated at 150,000 to 200,000 hectare per year (EARO, 1999b). As a result it has been estimated that high forests covered 16% of the land area in early 1950s, 3.6% in the early 1980s and only 2.7% in 1989 (IUCN, 1990; EFAP, 1994). With the current annual lose of high forests; it has been projected that the area covered by high forests may be reduced to scatter minor stands of heavily disturbed forests in inaccessible parts of the country within a few decades.

The major reasons for deforestation are clearing of forests and wood lands for cultivating crops and cutting of trees and shrubs for various purposes, notably for fuel wood, charcoal, construction material etc. Deforestation had caused and continues to cause environmental degradation in the form of land degradation, water resource deterioration and lose of bio-diversity.

Method of cultivation, selection of cropping pattern and inappropriate land use.

Since Ethiopian farmers are still continuing implementing unscientific way of cultivation, wind and rain are eroding the topsoil. As a result of erosion, water couldn't percolate into the soil and instead it is wasted as runoff. Therefore, the soil cannot maintain the required amount of soil moisture. As a result of depletion of soil moisture and soil nutrients, the soil cannot sustain plant growth. The Ethiopian Highland reclamation study (Constable and Belshaw, 1989) had estimated that over half of the highlands (270,000 km²) are already significantly eroded, of which about 100 tons per hectare of soil is eroded every year primarily because of the erosive cropping practices followed while the annual soil loss due to erosion is estimated at 1.9 to 3.5 billion tons, when the medium to lowland regions are included the cost of land degradation on the nation is astronomic (EARO, 1999a).

A case study, in Gojam on the amount of nutrients lost from unprotected cultivated land by sediments and run-off indicated 830 kg to 2068 kg/hectare. The amount of N, P and organic matter loss in this site were 64 kg, 138 kg and 1179 kg per hectare/year respectively. In terms of mineral fertilisers applied the amount of N and P lost are equivalent to 21.7 kg urea and 300 kg DAP or if TSP is substituted for DAP, it will amount to 139 kg of urea and 300 kg TSP/hectare year. Multiplying this over all the cultivated land it is a cost Ethiopia cannot pay back (EARO, 1999a).

Tamire Hawando (1989) also indicated that the removal of crop residues of maize and sorghum removes the three major nutrients (N, P and K) in the range of 255 to 800 kg equivalents to urea or TSP per hectare per year.

Heterogeneity in climate and soil types highly influenced the land use type and the population densities in different localities. About 75% of the highlands which is 44% of the landmass is considered to be highland (>1500 m), is carrying about 88% of the human population and T‡ of the livestock population.

It is widely believed that land degradation is mainly caused by cultivation. According to Hans Hurni (1986) study, soil loss on cultivated land is estimated to be four to ten times higher than on grazing land, and 80% of the recorded annual soil loss occurs in the month of ploughing and in the first month after planting. The Ethiopian Highland Reclamation Study (Constable and Belshaw, 1989) study stressed that the condition of land prior to sowing during the short rainy season (*belg*) or during the first month of growth is important in averting soil erosion.

Livestock density, grazing patterns and overgrazing

Ethiopia has one of the largest livestock populations in Africa with 30 million cattle, 22 million sheep, 17 million goats, 7 million equines and 1 million camels (CSA. 1999). Between 70-80% of these livestock are found in the highlands (Alemneh Dejene, 1990). Livestock provides crucial support to cropping in terms of traction, manure and transportation. Hence, as the human population increases, the livestock also increases and results in an increase in grazing land. This condition created a competition between livestock and crop production for the same land. FAO (1986b) tried to study the nature of this competition and its effect. According to this study it is concluded that the presence of livestock in the 'culprit' in land degradation in the high lands of Ethiopia and that all other factors are secondary. Alemneh Dejene (1990) conducted a survey in Wello to understand whether there is a competition between livestock and crop and the extent to which this competition would affect the loss of vegetation cover. 80% of the respondents indicated that grazing occurred in different areas during the rainy and dry seasons. Planting of major crops in Ethiopia is carried out during the main rainy season (*kiremt*). 57% of the farmers grazed their cattle on slopes during this season. Moreover, it is during this season that farmers plough the relatively fertile valleys and plains in preparation for planting. 37% of the respondents used the valley; crops lands and plains for grazing that are batter suited for cultivation than slopes. Therefore, there are two implications from these findings regarding the direct contribution of livestock to soil erosion. First most of the livestock grazed on slopes during the rainy season, a period when most soil erosion occurs. Thus livestock grazing has a great impact on the loose vegetation cover and degradation of the slope at a time when there is severe erosion is taking place. Secondly, large numbers of livestock were grazing in the fertile valleys at a time when the land is too wet and the soil structure and organic matter can be damaged.

Overgrazing is indeed a major cause of drought and desertification. Rangelands account for almost 90% of desertified lands (Mabbutt, 1984) in general and 51% of the land mass of Ethiopia in particular (CSA,1999). Overgrazing results when livestock density becomes excessive and too many animals are grazed at the same area of rangeland, leading to degradation of vegetation and the compaction and erosion of the soil. Overgrazing affects the vegetation, the soil and even the health of animals themselves. It can lead to a decline in the annual production of rangeland vegetation and to a change in the species composition, with a drop in the proportion of palatable grass species, particularly perennials that are good at holding the soil together.

The uncontrolled browsing of trees and shrubs is another aspect of overgrazing and a patent cause of deforestation, leading to flooding and siltation in adjacent areas because rains are no longer geld back by the sponge effect of the trees and carry with them large loads of eroded soil. Overgrazing also leads to soil erosion. The degradation of sparse rangeland vegetation by overgrazing exposes the soil to erosion by wind and water.

Socio-economic and institutional factors

Population Pressure

There is in fact a rapid population growth in Ethiopia and this undoubtedly has direct consequences for the environment: growing demand for more land for crop production; for fuel wood; shortening of fallow cycles and contribution to over cultivation. Ethiopia has a total area of 1.24 million km^2 with a population is estimated at 3-4% growth rate and agriculture has always been the backbone of the country.

Using the 1994 census data, (CSA, 1998) population projects were reconstructed for the years 1995-2030. Table 1 indicates that the population growth rate in Ethiopia is staggering. Without a major fertility decline, Ethiopia will have to feed a population nearly double in the year 2030. These are frightening figures to consider since the land cannot support even the present population.

An important feature of Ethiopia's population is that a considerable amount of its population (about 45%) is under the age of 15 years (CSA, 1999). These figures signify a high dependency burden on the working population.

Because of high population growth, the size of individually owned plots is shrinking in the relatively fertile highland and medium altitudes. This diminution will lead to intensive cultivation, which will inevitably result in a loss of soil fertility. In the absence of modern techniques for enriching the soil, and with dung being increasingly converted into a source of fuel, the reduction in soil fertility is imminent. Thus diminishing land size will lead to reduced soil fertility and subsequently to a decline both the soils capacity to produce food and its resistance to drought condition.

Land redistribution, which in recent years has been the only means of formally acquiring access to land to accommodate new households, has led to severe fragmentation of plots, a reduction of crop fields and insecurity. Reduction of cropland per capita and insecurity lead to reduction in activities such as fallowing, planting trees and investing in conservation structures, while reduction in cropland per capita has caused cropping and grazing activities to be shifted to hillside and ecologically fragile areas. For example, UNECA (1996) found that shortage of farmland was cited by 90% of households interviewed in the Amhara region as the main constraint to fallowing.

Without adequate alternative sources of energy, population growth increases the demand for fuel wood, which in turn leads to the destruction of forests. It also contributes to the use of crop residues and dung for fuel rather than using them as sources of organic fertilizer to improve the already poor soils. UNECA (1996) revealed that about 94% of the households meet their principal energy demand through fuel wood and dung in the Amhara region. About 60% of the households did not use manure on their farmlands. When

Region	1995	2000	2010	2020	2030	Annual growth rate, %
Oromiya	19.2	22.4	29.6	37.8	46.2	2.52
Amhara	14.1	16.3	21.2	26.8	32.7	2.40
SNNP	10.6	12.5	16.6	21.1	25.6	2.51
Somali	3.2	3.7	4.80	6.0	7.3	2.30
Tigrai	3.2	3.7	4.8	6.1	7.4	2.39
Addis Abeba	2.2	2.5	3.30	4.2	5.1	2.45
Afar	1.1	1.2	150	·1.8	2.1	1.94
Benshangul	0.47	0.54	0.69	0.86	1.04	2.27
Dire Dawa	0.26	0.32	0.46	0.62	0.81	3.26
Gambella	0.18	0.21	0.27	0.34	0.42	2.32
Harari	0.13	0.16	0.22	0.30	0.38	2.95
Total	54.6	63.5	83.5	106.0	129.1	2.45

Table 1.Projected population of Ethiopia (in million) (CSA, 1998).

asked why, 73% of them said there was not enough to use as manure (UNECA 1996).

In general land resources in Ethiopia are under increasing pressure due to population growth that increases the use of land in economies dependant on agriculture; drought which have forced pastoralists to move away from drought prone areas and rely increasingly on crop cultivation, and farmers to increase the cultivated area in order to compensate for low yields and the excessive development of cash crops. Increased usage takes two main forms. First is the extension of the cultivated area. The second and even more widely reported form of increased land pressure is the shortening of fallow cycles. In traditional farming systems at least some land is cultivated in rotation when land was plenty. But due to population pressure the areas left as fallow are being cultivated now. These forms of extension of cultivation have encroached areas that once supplied fuel wood and resulted in villagers have to travel further to fetch fuel wood. More serious is the encroachment an the grazing land, thus putting more pressure on the remaining usually poorer range lands

Poverty

Poverty is very likely to contribute to land degradation for many reasons. When people lack access to alternative sources of livelihood, there is a tendency to exert more pressure on the few resources that are available to them. Bekele Shiferaw and Holden (1997) showed the intensified pressure on natural resources as a vicious cycle in which resource degradation and drought lead to reduced household assets, and reduced household assets in turn affect degradation in the Ethiopian highlands. Deforestation, and burning of dung and crop resides are increased by people's inability to afford, or lack of alternative fuel sources. Electricity and kerosene are expensive and in most cases not available. For cooking, most households prefer the three-stone open fire, which is believed to be only 10% efficient in overall thermal energy production and use. Improved stoves, such as the improved biomass fuel-saving injera stove, which is believed to be 45-82% more efficient than the three-stone open fire, are not used since they are expensive to construct and, generally, not affordable by rural households.

Income from the sale of farm produce is inadequate to meet essential family expenses such as taxes, school fees, and medicine, clothing and household items. Rarely is enough leftover for the purchase of seed, chemicals, let alone for large capital items such as oxen and water pumps. This unavailability of inputs is especially serious in the marginal areas where the productive capacity of the land is inherently low.

Problem of land ownership

Investment decisions on land are affected by tenure security (Place and Hazell 1993; Basley 1995: Gavain and Fafchamps 1996). Communal ownership is believed to lead to mismanagement, particularly, over-grazing and inefficient removal of wood for fuel (Hudson 1981). The ability to transfer land sales and leasing also allow land to be used by farmers who are able to earn the highest return from it, through mobility of scarce factors to production such as draft animals, farm implements, labour and management ability (Pender and Kerr 1999).

The systems of land tenure that have developed in the country have had varying and significant impacts on land management. From a historical perspective, it is the land. This has led to cultivation for short-term needs rather than long-term yield. Accordingly, no long-term investments are made that would maintain or boost yields, and this has resulted in ecological damage, which has become almost impossible to reverse.

In Ethiopia, before 1974, the relationship between land users and owners was based on a feudal system. The Emperor, who granted tenure subject to feudal obligations, owned Land. Tenure forms known as ***gult*** and ***rist*** were practised. Communal ownership of land was generally denoted by the term ***rist*** and an individual was entitled to ***rist*** rights in a commune if he or she could prove some blood relation to the founding patriarch of the commune. A person who held ***rist*** rights was called ***ristegna***. The usufruct rights conferred by ***rist*** were generally valid for a lifetime and extended over many generations (Dessalegn Rahmato 1984). However, since any "legitmate" member's claims were always honoured, frequent redistribution was necessary to accommodate all claims. Others challenged often rist rights on the grounds of closer ties to an ancestor.

As Hoben (1973) put it 'there were always more legitimate descendants of an ancestral first holder than there are (People) who hold fields in the land tract'. Therefore, the potential of being challenged was always there and so the incentive to improve ones ***rist*** holding was diminished.

The ***gult*** was not distinctively different from ***rist***, since it often applied to the same area of land. The difference between the two was in the nature of the tenure, as ***gult*** was linked with the legal and political status of the receiver in the grant of tenure. A ***gultegna*** was responsible for partial administration and justice at the local level in maintaining law and order and at the same time collecting taxes levied on land, which formed the greatest part of his income. ***Gultegnas*** could collect payment from ***ristegnas*** in the form of tributes, taxes or labour. Under the gult, as a rule, tax was 20% of the total crop production.

Upon overthrow of the monarch, the military government (also known as the Derg) in its land reform proclamation of March 1975, declared land as the collective property of the people, redistributed land to farmers, and abolished the system of tenancy and elite rule. Under this new system, all customary and other pre-existing land rights were abolished and land was declared public property. Large holdings that existed under the ***gult*** system and under control of the church were confiscated. The maximum holding allowed per household was set at 10 ha, but in practice was usually less than 3 ha due to scarcity of land and population pressure (ARBoA 1997).

Selling, buying, leasing and mortgaging land were legally forbidden. Hiring of labour was also forbidden to destabilize the feudal system. Local administration, know as the Peasant Association (PA, today's kebele administration) was created and charged with the responsibility of distributing and managing common resources, subject to equitable distribution and to accommodate new claimants. Redistribution of cultivated fields to meet the increasing demand by new households to further fragmentation of farmland holdings and limited farmers' incentive to invest in the land. The PA set common grazing and browsing areas. If a farmer wanted to make use of trees, the PA executive committee had to approve the cutting of trees, even if the trees were on the farmer's homestead. This restriction and others discouraged investment in private tree-planting activities. Later, however, special areas were set aside for community tree-planting activities (woodlots), with seedlings and labour compensation provided by the government and food-for-work assisted programmes. Natural resource conservation activities such as terracing, pond construction and tree planting were planned at the top and handed down for implementation through mass mobilization.

Today, based on the new 1995 constitution, land is the state's property and redistribution is the sole mechanism through which land transfer, to accommodate new claimants, is effected. The differences between the present and previous Derg land policy are that the present land policy allows rural households to hire labour to work on their fields, while land leasing, share-cropping and lending of land are again legal and widely practiced. However, buying, selling, and mortgaging land are still prohibited. For example the last land redistribution in the Amhara region was declared and undertaken in February 1997. In that reallocation, as in previous ones, landless and resource poor farmers gained access to farmland, and in some areas (e.g. in parts of North Shoa zone) new landowners were issued some form of documents, which stated the name, address, quality of land, and degree or nature of the land fertility. While some farmers felt this was a symbol of ownership, others did not think so and felt that it was only a form of proof to be utilized incase of disputes in the future, as most of the land redistributed had belonged to migrants (abandoned land) and previous *Derg* officials. When asked if their sense of ownership affected the manner in which they cultivated their land, they responded in the negative. They reasoned that the new landowners were poor and, thus, did not have the resources and ability to exploit the land and differently. Although they did not have the resources and ability to exploit the land any differently. Although they did not anticipate any future redistribution, some of the farmers felt that the document represented the completion of the process of 'ownership'. However, those without the document were not pushing for similar documents and had adopted a 'don't ask' perspective, since they felt an equal sense of ownership.

Therefore insecure Land tenure and small, fragmented farm size is the major problem in Ethiopia. Lack of land ownership or lease right has created reluctance among farmers to invest in long-term investments (e.g. soil and water conservation structures) and exploitation rather than conservation of resource base. Distribution and redistribution of cultivated land was done every three years up to 1998 in the Amhara Regional State (SAERP, 1988). As the land remains the government's property, individual farmers are always expecting redistribution of land sometimes in the future, indicating that the current holdings of each farmer may be given to another. Therefore, farmers are not taking care of the land they are currently ploughing.

Other soil and water conservation measures on croplands are lagging behind due to the problem of land insecurity for long-term utilisation of the land. For instance, construction of terraces, buds, check dams, ridges and other labour demanding permanent structures need at least a longer-term guarantee for farmer to use a particular plot of land.

Environmental problems

Degradation

Land degradation, defined, as a temporary or permanent decline in productive capacity of the land or its potential for environmental management has been a significant factor of low yield of crops and livestock in Ethiopia. Land degradation in Ethiopia is characterised by both soil erosion and loses of soil fertility, especially in the highlands it has been estimated to be moderately to seriously eroded (FAO, 1986a; EFAP, 1994). Of the remaining half, 50% had soils susceptible to erosion that required proper management. Erosion causes cropped areas to loose on an average 100 tons of soils per hectare annually, and the highlands to loose a total of 1.9 to 3.5 billion tons of soils as a result of erosion. The loss in soil fertility is due in part to the use of animal dung and crop residues as fuel to meet household energy requirements. The use of these items for energy represents a loss in crop production of 700,000 tons of grain. The impact of soil erosion on crop yields is estimated to be a reduction of between 1 and 2% per year. The biological degradation due to the decline in organic matter causes a further loss of 1%. At the same time about 20,000 to 30,000 hectare of crop land in the highlands is being abandoned annually since cropping can no longer be supported by the soils. It is projected that 2.4 to 3.8 million people will be affected by the year 2000, and that land degradation at the present rate could destroy the farm lands of 10 million highland farmers by 2010. One other aspect of land degradation is the deterioration of range lands that is directly related to the low quality of animals, inadequate feeding systems and the breakdown of traditional systems for management of cattle grazing (EFAP, 1994).

The constraint to sustainable agricultural growth is in fact the ongoing deterioration of the natural resource base and the environment. Increasing demand for land for farming crops have partly contributed to the clearing of forests. For example, in Ethiopia forest resources are currently being cleared at the rate of 150,000 to 200,000 hectare annually. The forest had been depleted to a mere 2.7% of the land area from about 16% in the early 1950s (FAO 1986b). Therefore, degradation of the natural vegetation is very extensive across Ethiopia. In pasture areas primarily overgrazing causes this. In the forest areas the cause is excessive cutting both for fuel wood and other purposes.

Therefore, high runoff and severe erosion has lead to the loss of topsoil in many parts of Ethiopia. According to EFAP (1994), it is estimated that about 1.900 million tones of the soil are lost annually from the highlands. As degradation continues, largely irreversible, crop yields decline and farmers move cultivation to new lands, more frequently to sloppy areas, which are not suitable for cultivation.

Most of the soils are also

characterised by sandy textured and low organic matter content. In addition, the rainfall is usually torrential with high intensity. This leads to soil crusting, which limits the infiltration capacity of the soil and aggravates the erosion problem. In severe cases, it can prevent seedlings from emerging through the soil surface.

Extensive areas of the country particularly the arid regions of the Afar and Somali are under continuous threat of desertification. This is mainly due to high human and livestock population pressure, which are leading to soil erosion and land degradation, resulting in land actually going out of production. Everywhere, where this is the case, land productivity is always declining, so the net effect is the equivalent of land being lost. This situation is widely spread in not only in Ethiopia but also in many African countries. For instance, FAO (1986c) indicated that where no measures has been taken to check soil erosion in Africa, there has been a long term net decrease in rainfed crop production of about 16.5%, and a decrease in crop productivity of 29.4%. Hurni (1986) reported that soils in the Tigrai region has lost about 30 to 50 % of their productive capacity compared with their original state, implying that a farmer today with the same input as a farmer 500 years ago would obtain only 50-70 % of the yield at the same time.

It is also worth to note that with increasing land degradation and aridity, the arable land will decline leading to reduced population carrying capacity of the land and there will also be a progressive increase in the population rate in poverty. The extent of soil degradation in Ethiopian highlands varies from region to region and from place to place within a region (Hurni, 1986). But the most seriously affected are the drier Ethiopian highlands, which are found in central, northern and eastern parts of the country. The drier highlands constitute a third of the Ethiopian highlands (EARO, 1999b).

In the northern highland areas of Ethiopia, it is estimated that about 20,000 to 30,000 ha of cropland are abandoned annually because cropping can no longer be supported on the highly degraded areas. In the northern highlands there has been continuous population pressure on arable land, and as a result, cultivation has moved to very steep slopes. It is claimed that four-fifth of the erosion in the highlands results from croplands, with the rest resulting from overgrazed lands, wastelands and newly deforested, but cultivated areas (Constable and Belshaw 1989). In these areas it is projected that 2.4 to 3.8 million people will be affected by the year 2000, and land degradation if it continues at the present rate could destroy the farm land of 10 million people by 2010. Therefore, it can be concluded that unless appropriate national and regional control measures of these resources are forthcoming, they will degenerate much more rapidly in the future to a point of no return because of the demand of the increasing population.

Soil water stress

Under rainfed farming conditions water is the major limiting factor for successful crop production. The rainfall over the most important rainfed crop growing areas of the country is generally limited in amount, of short duration, and highly variable between and within seasons. Consequently, crops are usually exposed to water stress early in the season, mid season or late season.

It is generally considered that semi-arid areas receiving between 500 mm and 800 mm of annual rainfall split into two seasons are suitable for growing crops. However, the average rainfall amounts can be misleading for the arid and semi-arid regions. The rainfall is highly erratic both within and between the seasons and often of high intensity storms are received within a short duration resulting in tremendous soil and fertility loss. This compounded with high temperatures and evaporation rates, and low moisture holding capacity of the soils often leads to crop and animal losses even in years of reasonably high rainfall.

Low Soil fertility

Soil fertility is a declining asset over most parts of the country. The reasons for decline vary widely in different locations. There is pressing need to increase crop production to meet the food demands for the ever increasing population in almost the entire country with particular emphasis in the drought prone areas. As a result most soils are intensively cultivated, deforested and overgrazed.

The soils are severely eroded with low fertility leading to reduced crop yields. The soils of the drought prone areas are particularly low in N and P. The organic matter content is very low generally less than 1%. Retention of crop residues is an important soil management strategy and their effects in reducing runoff losses and soil erosion are well documented. However, a major constraint to its applicability is the alternative uses of crop residues for feed, fuel and fencing and other purposes (EARO, 1999b).

The typical farmer in the country is caught up in a typical vicious circle as the soil is mined of nutrients and organic matter by removing the crop residues; surface runoff and soil and nutrient erosion are increased. These losses lead to degraded soil which is capable of only low crop yields for food, and provide little crop residues, leaving no option for retaining some in the farm land. Under these circumstances the seasonal production in the region is bound to decrease with time and indeed has. The important question is whether it is possible for a farmer to break this vicious circle? The practical options considering the technical and socio-economic limitations needed to address the soil fertility of smallholder farmers are discussed in the forthcoming section.

Desertification map of Ethiopia

Materials and methods

For the delineation of different levels of desertification of the country, mean annual rainfall (R) and mean annual potential evapo-transpiration (PET) data for 381 stations well distributed all over the country were used.

Most of the procedures for the classifications that are in wider use are annual indices e.g. Köopen, 1936; Thornthwaite, 1948; Thornthwaite and Mather, 1955; Budyko, 1956 amongst others, while the procedures based on the moist or dry period zonations are commonly used for the sub division of semi arid zones (Cocheme and Franquin, 1967; Brown and Cocheme, 1969; Raman and Murthy, 1971). As our interest here was mainly directed towards the identification of regions that are susceptible to desertification, the formula of the convention to Combat Drought and Desertification was adopted which is shown below:

$$Im = R: PET$$

where
Im- moisture index
R - mean annual rainfall (mm)
PET - mean annual potential evapotranspiration (mm)

The rainfall:PET ratio expresses the fraction of the PET met by rainfall. Since PET represents the maximum amount of the moisture, which could be evaporated from the soil surface and transpired by vegetation, The R/PET ratio gives an idea of humidity index. Table 2 gives classification guidelines used by UNEP to map dry climates (Hare and Ogallo, 1993).

The mean annual rainfall was computed from the daily rainfall data. First, annual totals were computed for individual years; then from a series of individual years the arithmetic mean was computed. This is termed as mean annual rainfall. The most widely used method to estimate PET is the Penman (1948) combination approach; it links evaporation rate to the net flux of radiant energy at the surface and to the effective ventilation of the surface by air motion over it. This approach as modified by Frere and Popov (1979). We adapted it for the estimation of PET over Ethiopia for this study.

Table2 Aridity zones by rainfall/PET ratio

Climate zone	R/PET	Description
Hyper Arid	<0.05	Human activity is limited around oasis
Arid	0.05 ≤R/PET<0.2	Pastoralism is possible but highly susceptible inter annual climate variability or ground water resources
Semi arid	0.20≤R/PET<0.50	Sustainable pastoralism. Agriculture susceptible to high degree of inter annual climate Variability
Dry sub humid	0.50≤R/PET<0.65	Wide range of rainfed agricultural activity is practiced
Moist	>0.65	Wet-land Agriculture, tropical forestry

Table 3. Area coverage of the moisture zones of Ethiopia.

Moisture Zone	Area coverage (km²)	Percentage of total
Hyper Arid	171,167	16
Arid	157,915	14
Semi arid	301,474	27
Dry sub humid	133,620	12
Moist	32,394	30
Water body	7,730	<1
Total	1,104,300	100

Results and discussion

The different levels of desertification zones of the country are shown in Figure 1. While drawing the map, annual rainfall and PET patterns and relief and its aspects were taken into consideration. The area coverage of each of the zones is given in Table 3.

As shown in Figure 1, five zones are identified in the country. These are the hyper arid, arid, semi arid, dry sub humid and moist zones. Generally, the dry sub humid and the moist zones are located in the western half of the country (with few exceptions e.g. the Sidammo, Bale, Arsi and Hararghie highlands). The semi arid and arid zones are generally located in the eastern half of the country. The hyper arid zone is located over north-eastern parts of Afar and south-eastern parts of the Somali regional states. A brief description of each of the moisture zones is given below.

a) Moist zone

The moist zones of the country covers about 30% of the total area of the country, which is about 332,394 sq. km. Most of the highlands of the country are included in this zone. The moist zone is found over parts of north Gonder, south Gonder, east and west Gojam, most parts of north and south Wello especially to the western side, most parts of north Shoa, the highlands of Arsi, Bale and Hararghie, most parts of west Shoa, western Oromiya and most parts of Southern Nations and Nationalities People's Regional State (SNNP), eastern half of Gambella and most parts of Benshangul Gumuz. The climate of the moist zone is generally favorable for perennial and highland cereal crops. Inset and Coffee are among the perennial crops grown in this zone.

b)Dry sub humid zone

The dry sub humid zone covers about 12% of the total area of the country (133,620 sq. Km). This zone is generally found bordering the moist zone. The dry sub humid zone includes small area in central Tigrai bordering north Gonder, northern part of north Gonder, few areas of north and south Wello and north Shoa, to the right and the left sides of the Rift valley, few areas of the highlands of east & west Hararghie, west Shoa, south eastern margin of Arsi, Bale and parts of Borena. Few ar-

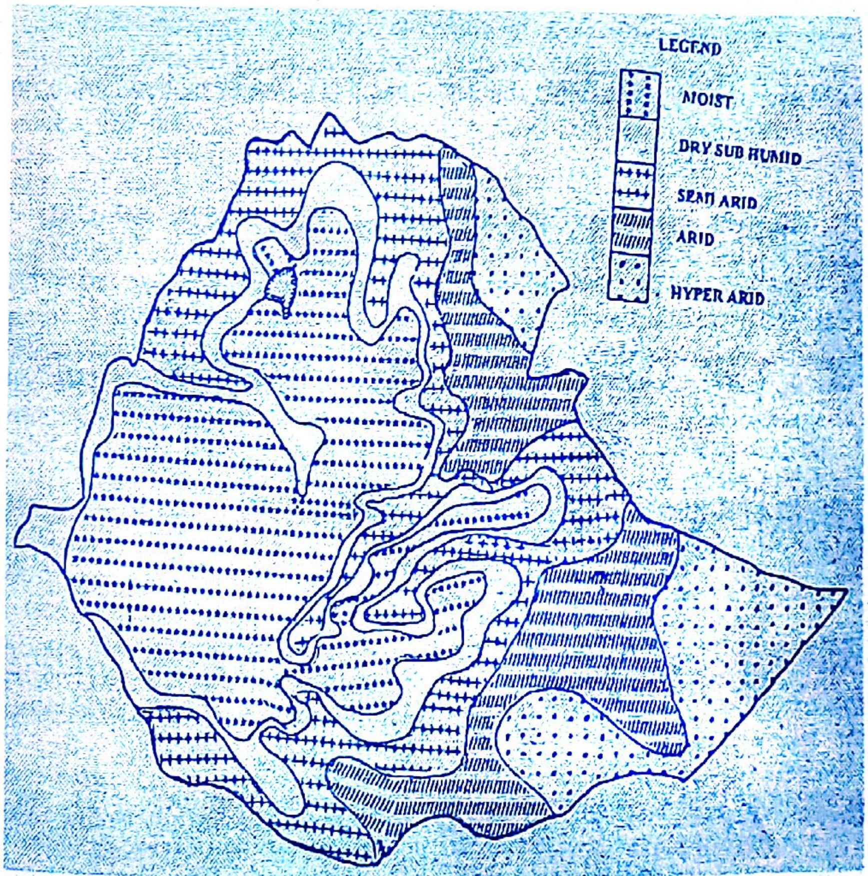

Figure 1. Desertification map of Ethiopia

eas of Sidamma, parts of north and south Omo, Gambella, few areas over southern Benshangul Gumuz and the Blue Nile gorge are included in this zone. Most of rainfed cereal crop production is carried out in this agro-ecological zone.

c)Semi-arid zone

The semi arid zone is found over the eastern half of the country and covers about 27% (301,474 sq. km.) of the area of the country. It is found over most parts of Tigrai, eastern margin of Amhara (parts of north and south Wello and north Shoa), parts of east and west Hararghie, most parts of Borena, northern parts of Somali, northern half of Benshangul Gumuz, the Rift Valley, south Omo, south eastern Arsi, parts of Bale and east Shoa. Most of maize and sorghum crops are grown in this zone.

d)Arid zone

The arid zone constitutes about 14 % of the area of the country (157,915 sq. km). This zone is found over parts of east Tigrai, western and southern parts of Afar, parts of west Hararghie, Borena and most parts of Somali including Shinile zone over northern Somali. This zone is generally favorable for pasture and rangeland. Rainfed agriculture in this zone is risky due to high inter-annual rainfall variability.

e)Hyper arid zone

The hyper arid zone covers about 16 % (or 171,167-sq. km.) and is spread over most parts of Afar and eastern and southern parts of Somali. This zone is found over marginal rainfall area with a high intra seasonal and inters annual variability. The annual PET is very high that the annual rainfall compensates only a small fraction of the evaporative demand. As a result the zone is barren, it has low vegetation index and with limited human activity.

V. Conclusions and Recommendations

Result of rainfall: PET study show that Ethiopia can be divided in to five moisture zones. These zones are moist, dry sub humid, semi arid, arid and hyper arid. The arid and the hyper arid zones are located in the north eastern and south eastern parts of the country, while the moist and dry sub humid zones are found in the western half of the country.

Though different classification methods for zoning are applied on study reported Engida Mersha (1992and 2000) are used, the areas covered by the dry semi arid, arid and hyper arid zones have increased by about 8% in the latter study. This is a good indication that desertification in Ethiopia is progressively increasing. Hence, appropriate measures should be taken to combat desertification in the country.

Combating and reversing the desertification process requires comprehensive and cost effective programme. Environment rehabilitation is better attained and sustained at lower cost if:

·It is fully integrated into mainstream agricultural and rural development programmes and activities starting right from the beginning.

·Bottom-up participatory planning, implementation and monitoring by the real stakeholders at grassroots are practiced.

· Conservation practices increase sustainable farm productivity levels and the incentives for rural households to construct and maintain effective conservation structures are well established with clear right of ownership structures.

·Appropriate technologies are adopted and integrated with local/traditional practices that are known to be effective in conservation of the land resources, increase food and fodder production, and are cost effective.

·Proper land use, farming practices, and appropriate technologies are planned and integrated at grassroots for each specific agro-ecological zone.

The impact from such integrated agricultural and rural development programmes will be much greater than that can be achieved by bunding and re-afforestation alone which are the core components of soil and water conservation programme presently implemented in Ethiopia.

The following actions are recommended:

·Conservation Based Sustainable Development (CBSD) Strategy appropriate for each agro-ecological zone with core components to sustain resources, increases yields, and conserve environment.

Appropriate technologies adopted and integrated with local practices t increase sustainable yield and rehabilitate the environment.

Increase productivity of the land resources and conserve the environment.

CBSD emphasizes increased vegetative cover on the land as the most important conservation component followed by bunds and terrace construction. Land cover has been found to be more important in controlling soil erosion under Ethiopian conditions than physical conservation measures.

·Land use policy and ownership right of land, physical constructions, trees and water wells/reservoirs with appropriate policy instruments should be established.

·Intensification of agricultural production with the integration of proven local practices and appropriate technologies should be pursued in dry sub-humid and semi-arid areas where population's density is high through use of small-scale irrigation and yield increasing farm production inputs.

·Release population pressure through family planning, creating off farm employment, other income generating activities, and also through voluntary and well-planned re-settlement programmes.

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Environmental Indicator Mapping Using Remotely Sensed Data and Indicator Based Approach A Case Study In the Desert of Tabernas, Spain And Its Application In the Ethiopian Context

Taye Alemayehu Oromia Water Resources Bureau P.O.Box 30664 Addis Ababa

Abstract

This research enabled to map, detect and quantify environmental changes in the Desert of Tabernas using multi temporal records of remotely sensed data and field survey. The hierarchical approach mapping technique has helped to identify five environments, 31 systems and 526 environmental units or morphdynamic units. This method helps to identify the smallest land use planning unit and is helpful in management of the natural resources.

The past and the on-going neotectonic activities are also among the main controlling factors of the surface activities and responsible agents for the formation of the badlands and affecting the overall environmental situation of the area.

In this research an overview of the geological and geomorphological processes are indicated, environmental units are presented with their distinct characteristics.

1 Introduction

Desertification has become prominent today both in science and in the public eye because of its impact on human life and as barometer for changing global climatic conditions (Reading, 1996). It is defined as land degradation in arid, semiarid and dry-sub humid areas resulting from various factors, including climatic variations and human activities (UNCED, 1994). According to various estimates, approximately one fourth (UNEP, 2000) to one-third (Walker, 1997) of the Earth's land surface is a desert. The livelihoods of over 1 billion people in more than 100 countries are also jeopardized by desertification (UNEP, 2000). Deserts are dry and fragile environments. The misuse of these lands is a serious and growing problem in many parts of the world. In case of our country, Ethiopia, desertification is manifested as repeated drought and numerous associated problems.

The study area, the desert of Tabernas, is located at about 37 km north of the city of Almeria in South-eastern Spain (Fig.1). With its mean annual precipitation of 218 millimetres, it is said to be the only true desert in the whole of Europe fulfilling the criteria of a desert. Many of the processes of desertification involve past and ongoing geological and geomorphological processes. The intrinsic geological and geomorphological nature of the Tabernas Desert is one of the main reasons for its characteristics of badlands (Recatalá *et al.*, 2000).

Despite its minimum rainfall record, which is the most important factor to categorise the area as desert, Tabernas area displays slightly different environmental features. It is not a type of sand or solely barren rock desert, which is commonly understood as a desert. It is a desert that displays different environments- mountain, piedmont, hilland, valley, and badland, each of them displaying different environmental features and responses. Its land cover ranges from a bare badland in the western part to irrigated olive and almond plantation fields in the fertile valleys, and forest cover in the mountain range. Due to its favourable location, closer to the Mediterranean coast, human beings have inhabited it since ancient times. Land degradation, salinity and other environmental problems are threatening the basin by accelerating desertification processes (ibid.).

Many studies have been conducted at various stages regarding the geological and environmental aspects of the basin. This research that focuses particularly on environmental mapping of the basin using an indicator based and remote sensing approach, is to help to identify all environmental units and associated desertification processes and their effects on the environmental quality of the area. According to the ELANEM project, environmental quality refers to the degree of naturalness and the capacity of natural resources to function as a source of materials, sink and support to human activities (Cenderero *et al.*, 2000).

The study area, the Desert of Tabernas, was chosen as one of the pilot study area by the on going European Union (EU) environmental research project, named 'Euro-Latin American Network for Environmental Assessment and Monitoring (ELANEM)'. This research is done as part of the project's research activities.□:

Methods

Data Acquisition and Data Quality

Acquiring data took longer than what was initially planned. All available materials at ITC were data that covered only part of the study area with hyperspectral maps. It was only at the end of September 2000 that all required data were purchased and, became fully available. The following are the input data that were used in both mapping and change detection processes.

Remotely sensed data:

- Black and white aerial photographs (AP) 1:20,000 taken in 1995 (Junta de Andalucia s. Cartografia, 1995);

- Digital topographic data 1:25,000 necessary for generating DTM (Junta de Andalucia s. Cartografia, 2000).

- Landsat TM images of the Landsat 5 and Landsat 7.

Ancillary data:

- Topographic maps: soft- and hard-copy of 1:10,000 (Instituto de Cartografia de Andalucia) and hard copy of 1:50,000 maps of 1997 (Servicio Geográfico del Ejércitol, 1997).

- 1:50,000 Geological map (Instituto Geologico y Minero de España, 1973)

- 1:100,000 Soil map (Ministerio de Agricultura, Pesca y Almentacion, 1987)

- Publications, reports and records on geology, geomorphology, soil, climate, hydrogeology, etc.

Except for the 1:100,000 soil map, all other maps and aerial photos are consistent with the 1:50,000 required minimum working scale.

Methods and Approaches Used

Environmental Indicator Selection

The overall procedure followed an indicator-based approach developed by Cenderero & Fischer, 1997. The use of the approach help to systematically assess and identify trends or Pressure - State- Response relationships. Prior to mapping a selected set of indicators was necessary to know what was/is happening in the environment, why it was/is happening, its significance and possible measures to take. The selection was based on a list of indicators already provided for assessing and monitoring desertification and its influence on environmental quality in Mediterranean arid environments and to be tested in the Desert of Tabernas, Almería, Spain (Recatála *et al*., 2000). The list of indicators was constructed considering their relation to the desired objective, ease of data collection and ease of use in mapping and decision–making. They also address some of the key issues of Agenda 21 (UNSCD, 1995), such as climate, agriculture, desertification, deforestation and land resources and other issues such as irrigation, and mining. The selected set of indicators that can serve for all sets of data was selected. They include landform, land use, land cover, climate, and materials from the natural resource category and hazards from the socio-economic element category of those indicators selected for assessing and monitoring desertification in the study area. The analysis of chosen indicators will be based on Pressure-State-Response framework adopted by OECD countries and the World Bank (ibid.). In this approach indicators are developed to assess the following: stress on the environment caused by human actions, the resulting conditions and the policy response to correct undesirable situations (COGEOENVIRONMENT Work Group, 1996).

Methods of Identification and Mapping of Environmental Units

The method involves the use of remotely sensed data and subsequent integration of the varying photos to map and detect changes apparently in the study area. Aerial photographs were used to have wider temporal coverage and due to their maximum interpretability, better resolution and minimum haze effect. Among the two spatial assessment units "environmental assessment units", which are regarded as 'administrative' and 'natural', only the later is emphasised in this study. These units are defined on the basis of physical features, both natural and human-determined (ELANEM, 2000). Regarding the 'administrative units' the study focuses mostly on the Tabernas administrative unit, although parts of Turillas, Tahal, Lucainena de las Torres, Nijar, Gergal, Roija, Godor, and Santa Fe de Mondujar administrative units are also included with various partial coverage.

The methodology used by Cenderero *et al*., (1990) for identification, description and hierarchical mapping of integrated environmental units, and other terrain classification and mapping systems developed by ITC (van Zuidam, 1991, Zinck, 1989) and by other scholars have been adapted in this study. According to the methodology developed by Cenderero *et al*., 1991 in the hierarchical mapping process the final result is a four-tier hierarchy. The first tier corresponds to major geological units, characterized by their lithostratigraphical and physiographical features. This hierarchy corresponds to morphogeneric environments of the Geoform classification system (Zinck, 1988). The second tier includes a series of "morphodynamic Environments" or Environments; that are defined on the basis of climatic, morphostructural and topographical features. This tier corresponds to the Group Four Category or to the Landscape Generic concept of the above mentioned classification system. The third tier in this work includes the sub-environments or systems defined on the basis of local geology and geomorphological features. In the Geoform Classification system this stage corresponds to the final category or to the Lithology/ facies generic category. The last tier that includes 'morphodynamic units' or the environmental units is defined on the basis of lithology, soil, geomorphology, land use, landcover and other active processes.

Mapping Procedures

Visual Interpretation & Field Survey

The procedure followed was to begin with aerial photo interpretation for the determination of the first three mapping hierarchies mentioned above and to develop a preliminary legend. The aerial photo interpretation was validated in the field and information on landcover, land use, and other relevant features were incorporated into these units on the basis of additional field observations and data derived from existing studies and reports. The overall mapping procedure is discussed below and the digital processing spatial data using the ILWIS geographic information system (GIS), is given in.

Aerial photographic interpretation was performed for preliminary identification and delineation of the geologic and physiographic units in the study area. Conventional stereoscopic and computer aided, on-screen, interpretations are the two visual aerial interpretation techniques employed side by side. After scanning at 8 bit 300dpi, the high resolution of the aerial photos (20m), and its quality has helped to extract much information by the zoom-in facility of on-screen visual interpretation. The other advantage of using aerial photographs was that they permitted a rapid analysis of large areas in terms of tone, texture, mottling, pattern, shadow, shape, etc. Furthermore, the delineation of the units was verified by consulting other sources of information such as remotely sensed data- Landsat TM, and hyper spectral images, and by making numerous field checks. In addition to the 3D view generated using a DEM, anagliph image of the study area was generated to help in the visual interpretation process.

Prior to the field survey, checklist covering most of the environmental characteristics that needed to be collected were prepared taking into account the different checklists prepared for similar purpose. Based on the resolution of the aerial photos and other source data, the minimum mappable unit was determined to be greater than 100 meters in length and width for both visual interpretation and the field survey work.

Orthorectification and Georeferenceing

Generation of orthophotos was found to be of primary importance as a basis for mapping. Orthophotos do not contain the scale, tilt, and relief distortions characterising normal photographs; they have one scale (even in varying terrains), and like photographs they show the terrain in actual detail (Lillesand & Kiefer, 2000). In addition to the possibility of direct interpretation, orthophotos help to directly measure distance, angles, and areas and can serve as an excellent base maps for compiling data to be input to a GIS or overlapping and editing data already incorporated in a GIS (ibid.).

The six strip aerial photographs used in this study have the following parameters: they were capture in January 1995 around noon with almost vertical camera projection centre and 151.92 mm principal distance. To start orthorectification the aerial photos were scanned with the resolution of 300dpi, 8bit in tiff format. After importing each scanned photo into the ILWIS GIS orthorectified using the 1:25,000 DEM. A 1:10,000 topomap, which was available both in hard and digital copy and a GPS reading from the field were, used to georeference the photos. Rough mapping accuracy or locational accuracy was made during the individual georeferencing of aerial photos after orthorectification by overlaying digitised roads and drainage maps.

Finally, after generation of a photo mosaic a root mean square error (RMSE) was calculated. Best-known locations on the 1:10,000 topographic map were selected randomly to be used as a reference. The overall calculated RMSE were found to be +/- 10.21 meter northing and easting and 4.14 meter of vector distance (Annex 9). This amount of error is insignificant or negligible when dealing with thematic map generation, because most thematic maps are mapped at 250mx250m resolution (Valenzuela, 1990). All necessary scanned topomaps and thematic maps were georeferenced and glued to be used as inputs in the process of mapping.

A colour separation operation was performed to allow the extraction of reflectance values, as if using colour filter when taking the pictures (ITC, 1997). This also allowed other map calculation operations that are not possible in an analogue picture domain. After colour separation all photos were resampled at 5m resolution using nearest neighbour function. This minimum pixel resolution was chosen based on the minimum size of mappable unit. This resolution was used only at the visual interpretation stage. At this resolution it was possible to see landcover and land use patterns and features at a convenient detailed level. The chosen resolution coincided with the requirement that says: to represent every entity present on a map, the cell size should be at least one half of the size of the minimum map unit, which in most natural resource maps is 2.5mm on a side (Valenzuela, 1990). Sub-photos that are covering the study area were created and glued afterwards. Finally, a photo mosaic of the study area was generated with a reasonable size of 16MB.

Digitising and Polygonization

The field survey and aerial photo interpretation (API) results were digitised on the photo mosaic using both the higher resolution, unresampled but orthorectified photos, which have a resolution of less than 2 meters, and the hard copies, as a reference. On-screen digitising of features on the photo mosaic has the disadvantage of requiring large memory and disk space and it is a slow and painstaking process. But it has provided the following major advantages:

(a) It assisted in tracing continuing features and helped to minimise the error that could arise in fitting polygon boundaries of individual photos, if the method of tracing-scanning-digitising-gluing of features of individual photos was followed. Overlapping photos of the mosaic help in increasing accuracy;

(b) It helped to extract features from orthorectified (with 25m resolution DEM) or geometrically corrected mosaic;

(c) Zoom-in option enabled to see the smallest possible features that are not clearly visible with naked eye or stereoscope, e.g. differentiating olive and almond plots;

(d) Possibility to edit and update at any stage of the work, and possibility of multiple use of segments for other mapping proposes, in this study they were used in the change detection phase.

After digitising the field observation and the API results on the photo mosaic, additional feature boundaries from soil and geological map were digitised by digital overlaying the respective maps on the photo mosaic. After checking, editing and updating the digitised map it was changed to polygon to have area representation of features. A total of 844 polygons, that have an area of more than one hectare, were generated to be used in the hierarchical mapping process mentioned in. Calculation of the histogram of the polygonised maps provided perimeter and area of each polygon. In the same manner the points and linear features were extracted from the topographic maps. In order to make any kind of map calculations and creating attribute maps from attribute tables, area features were represented as a raster data with a resolution of 20mx20m in a GIS after rasterisation.

Database generation

A database was generated with the GIS to be used in map classification. All the lithology, soil, landcover, and land use characteristics of the area were entered using already identified classes to facilitate data manipulation in GIS. A slope analysis map and an altitude range map were generated and the corresponding polygon values were transferred to the database. This database table was used to map the area in a hierarchy of four stages.

Classification

The information from field survey, API, and other complementary data such as soil and lithological information that were transferred to the GIS database were used in the hierarchical mapping to classify the area into different environmental categories. One of the required in put maps, the geomorphologic map, was made after extracting required information from the DEM. The DEM is sliced into different altitude classes that corresponded to various climatic and physiographic zones. A slope and aspect maps were also calculated from the DEM. The ITC terrain analysis and classification system (van Zuidam, 1983) was used to set boundaries of classes for the slope map. These classes were designed to suit the analysis of erosion and other land features on slope.

A total of five environments, 15 lithologic, 11 geomorhologic, 24 soil, 9 landcover, and 13 land use, classes were used to group the polygons to enter data into the database and hence to generate the corresponding maps. In addition to these most necessary factors, the database has also incorporated information on slope, altitude, and visual environmental quality. Finally, an environmental unit was identified following the criteria, by the similarities of characteristics in environment, lithology, soil, landcover and land use.

Legend and Visualization

Mapping Legends

Defining a hierarchy and formulating legend were tasks that started during the visual interpretation stage and were finally refined after the classification stage. Although top to bottom or from general to detail is the main method, bottom to top or from detail to general test has been done to check and validate the hierarchy. The overall hierarchy is done according to the following steps.

Morhostructural zones

The study area was first categorised in to two large morhostructural zones. The basement anticlinoriums, that form the elevated parts of the study area, were categorised in one group and the remaining area with Neogene sedimentary cover in another. These big zones represent two different climatic and ecological setting.

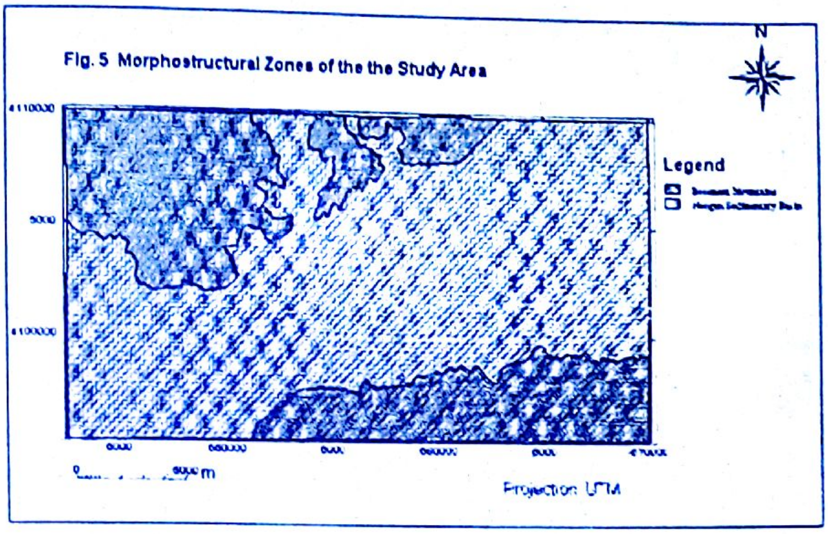


Figure 1 Morhostructural zones

Environments

Based on the classification system and criteria mentioned in Section 4.1.2, the morphostructural zones were sub divided in to five broad environments according to their morphodynamic nature. These environments, which were also identified by Fabbri and Recatalá-Boix, 2000, are Mountain, Piedmont, Hilland, Valley, and the Badlands.

a. Mountains

The high grounds of the southern extension of Sierra los de Filabres in the north and Sierra Alhamilla in the southern part of the study area that are mainly composed of Basement rocks, are grouped into the mountain environment. This environment is the largest of all, covering almost 30% of the study area with a total surface area of 119 km². It has an altitude ranging from 750 to 1317 m and dominantly, more than 30% slope. The slope in few places is as steep as 200%. It is covered dominantly by bush and grass. Few remnants of the original tree cover and pine tree plantation are limited to this zone. Apart from its use as a protected natural zone, for hunting, for the meteorological monitoring site, the TV tower and the economic benefit that can be derived from the tree plantations no significant land use is seen in this part of the study area. Due to their wide ecological, lithological, and physiographic differences Sierra Alhamilla Anticlinorium (Alpujarride Complex) and Seirra de los Filabres (Nevado-Filabride Complex), are treated as a higher sub-environments.

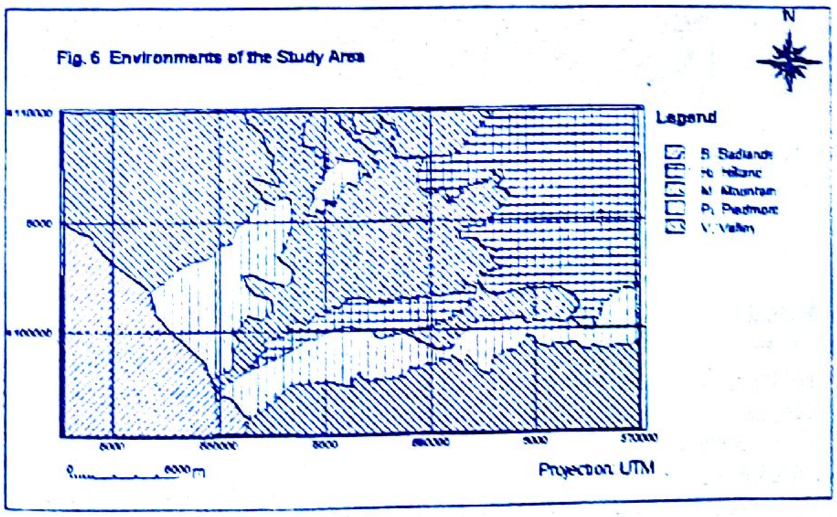


Figure 2 Environments of the Study area

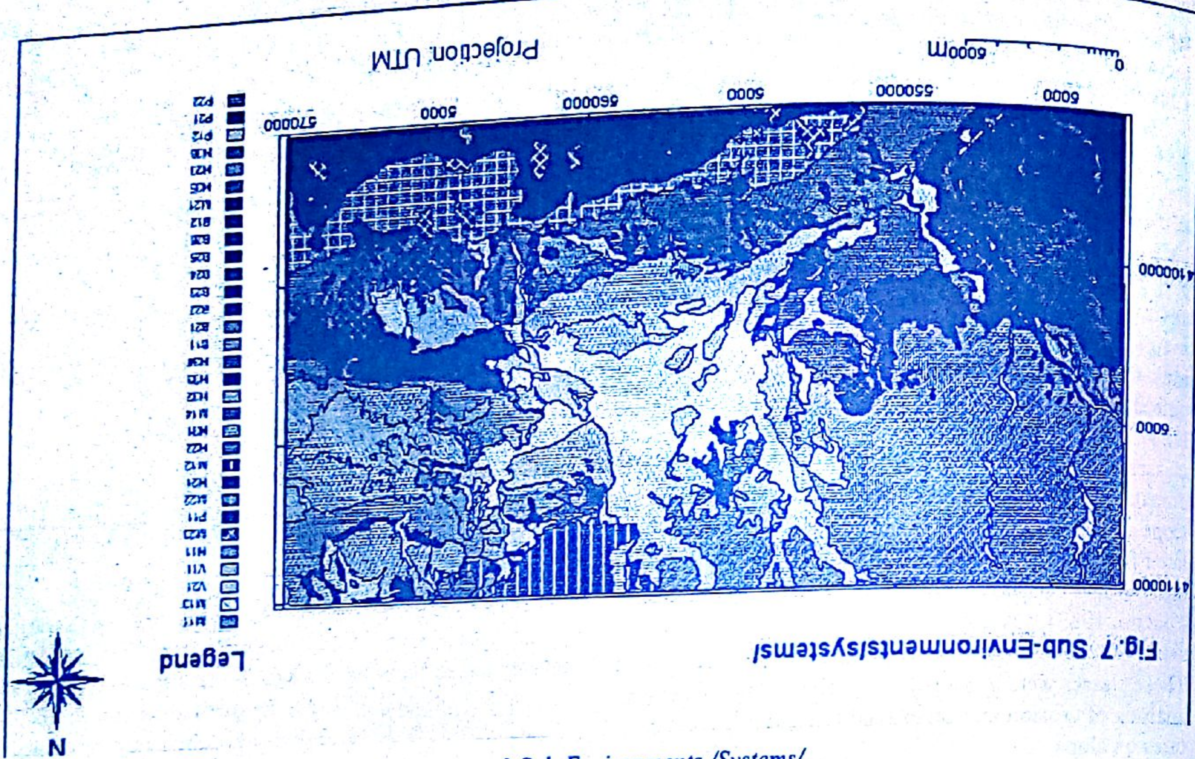


Figure 3 Sub-Environments /Systems/

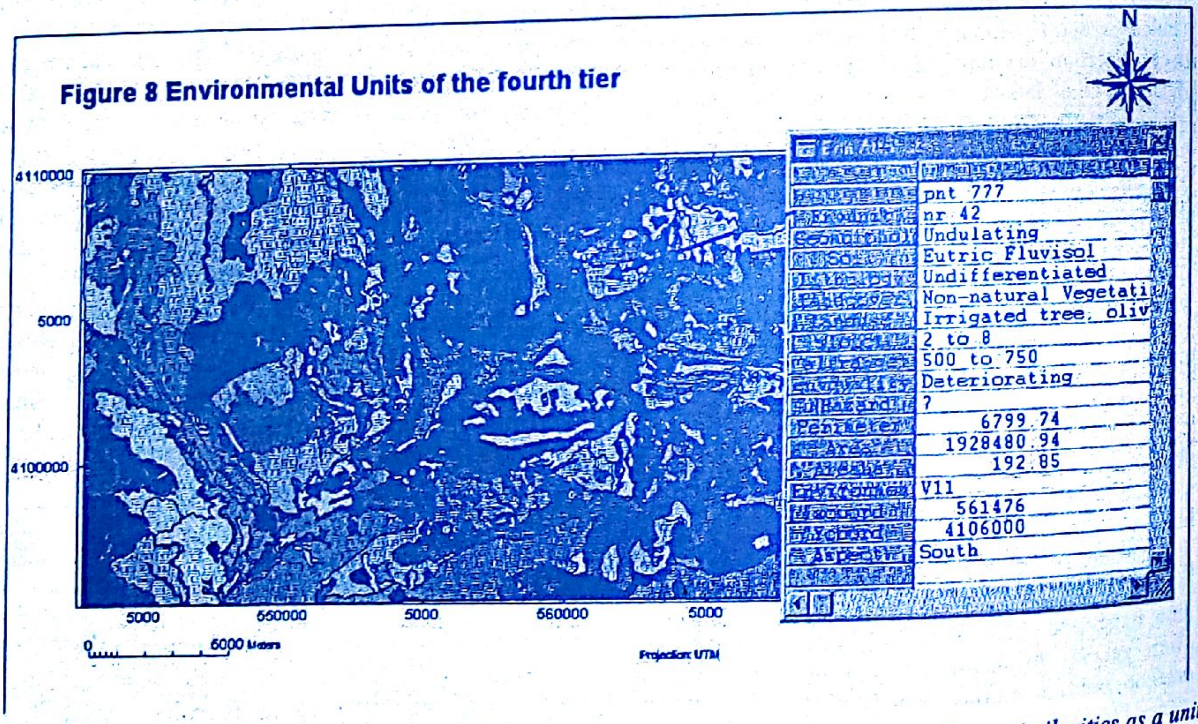


Figure 4 Environmental Units of the Fourth tier NB: Colors similarity do not neccessarly indicate similarities as a unit.

b. Piedmont

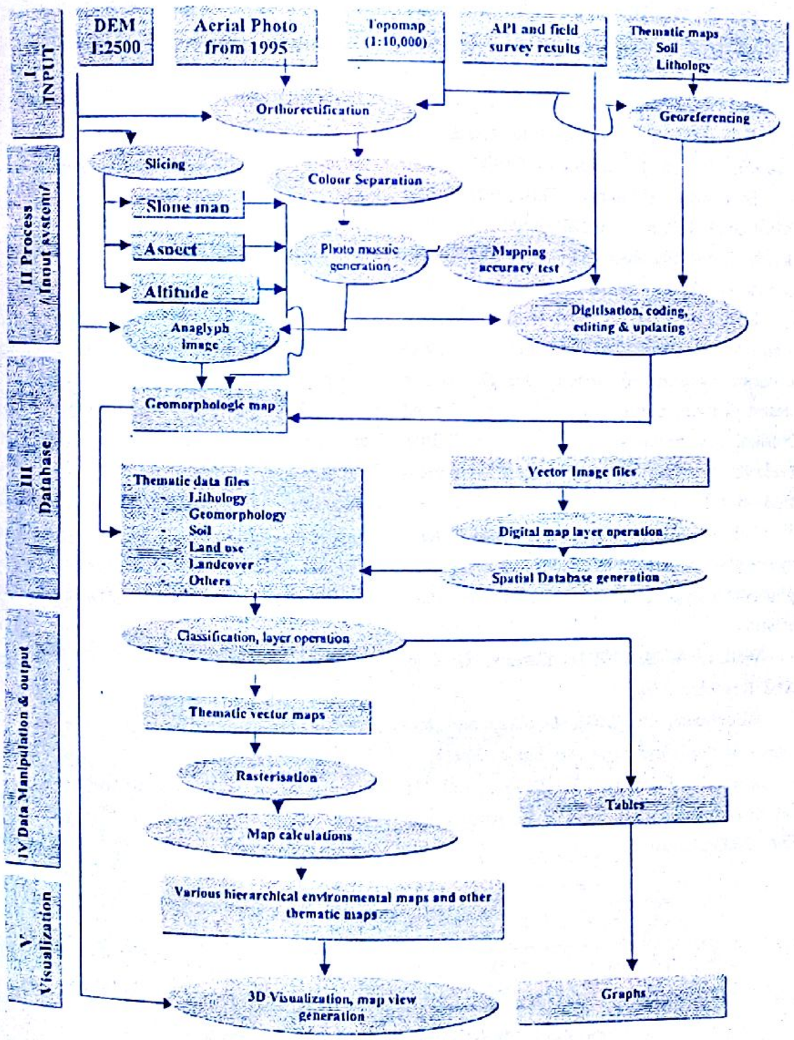
Areas next to the mountain that form gently undulating and are limited by escarpment to the lowland areas are classified as piedmonts (Zinc, 1989). About 80 sq.km or 20% of the study area is classified to this class. These areas are highly affected by tectonics and are also dissected by the incision of valleys. Most parts are slopping 8 to 16% and have an average altitudinal range of 500 to 750 m Most of the piedmonts are covered by Tortonian sediments and recent colluvial cover derived from the mountains. Because of the dryness of this zone and its less fertile and thin soil cover it is dominantly used for seasonal crop cultivation (Fig. 6).

c. Hilland

The hilland environment covers 13% or about 53 km² of the study area and it is mostly confined to the eastern and middle parts of the study area (Fig.

Morphostructural Units	Environments /Morphodynamic Environments/	Sub-Environments /Systems/	Number of Polygons	Number of Environmental units	Area (ha)
Basement Mountains	M1: Sierra Alhamilla Anticlinorium /Alpujarride Complex/	M11: PC-Pn	73	51	
		M12: P-TnA2	22	15	
		M13: Q	11	11	
		M14: Tbcc12	3	2	
	M2: Seirra d.L Filabres /Nevado-Filabride Complex/	M21: PC-D	10	9	
		M22: P-TaA	13	8	
		M23 TaA	14	10	
			146	106	13080.75 (32.46%)
Neogene Sedimentary Basin	H: Hilland	H11: Alluvial/Colluvial	11	8	
		H21: Tbcms12	22	14	
		H22: Tbcc12	15	8	
		H23: Tbcv12	12	9	
		H31: Tbc11	36	29	
		H32: T82-Q	36	20	
		H33: Tbc 11-12	28	20	
		H34: Tbc-b12-2	19	13	
		H35: Tbcms12	7	6	
		H36: TBcm-12	3	2	
			189	129	8041.75 (19.96%)
	B: Badlands	B11: Colluvial	7	7	
		B12: Alluvial	7	5	
		B21: Tbc11	6	4	
		B22: plio T12	2	2	
		B23: Tbc 11-12	11	5	
		B24: Tbcv12	3	5	
		B25: T82-Q	6	4	
		B26: TBcm-11	2	1	
			46	33	4914.75 (12.20%)
	P: Piedmont	P11: Colluvial	75	46	
		P12: Alluvial	23	20	
		P21: Tbc11	30	25	
		P22: Tbc 11-12	81	45	
			209	136	6250.00 (15.51%)
	V: Valley	V11: Colluvial	117	49	
		V12: Alluvial	137	73	
			254	122	8005.25 (19.87%)
	Grand Total		844	526	40292.50

Table 1 Hierarchical mapping units identified in the Desert of Tabernas



6). It is characterised by its repetition of hills, generally elongated, with uneven summit heights, separated by hydrographic network (Zinck, 1989). Hills have an average elevation ranging from 500 to 750 m and in most of the cases, have slops more than 30%. The northern hills are Tortonian sedimentary terrains with thin and non-fertile dry soil (Dante, 2000), and bush and grass cover (dominantly bush). The southern hills are dominantly formed by carbonate rocks and have developed into excellent grassland.

d.Badlands

The Badland environment is found in the south-western part of the study area. Although it is justified to be expanding, it is mapped as the smallest environment with a total area of about 45 km^2 or 11% of the total area (Fig. 6) Despite their similarities in many features with the adjacent environments, the Badlands were considered as a separate environment due to the extreme dryness, extreme dissection and other distinct features. Most of its features match with the criteria of badlands given by Campbell, 1986. The badlands have soft Neogene sedimentary covers, mainly composed of marls, clay sandstone and conglomerates. In its northern part gypsum forms the highest ground of this environment. The terrain has a very rugged and irregular lunar type landscape with regolith type soil, and sparse bushy cover. The badlands have little or no economic use.

e.Valleys

The areas classified as a valley are the next largest environments after the Mountains, covering a total area of 107 km^2 or about 27 % of the study area (Fig. 6). They constitute low-lying Quaternary sediment covered plains in the central part of the basin and wide intermontane valleys in the northern parts. They represent the recharge zone with better moisture content, thick and relatively fertile soil. The valleys are the economic backbone of the area on which many activities are going on. Most of these activities and the temporal changes that happened on this environment are discussed in the next chapter.

Sub-Environments /Systems

The above stated 'Morphodynamic Environments' or 'Environments' were divided in to 33 'Sub-Environments' or

'Morphodynamic Systems' defined on the basis of landform, bedrock, and surfacial deposits as explained earlier (Fig. 7).

'Morphodynamic units' or ' Environmental Units'

The last tier in the hierarchical mapping process are the 'morphodynamic units' or the 'Environmental units'. Using the thematic database that was allocated with each polygon, the above-mentioned 33 Environments were further sub-divided into 526 environmental units (Fig. 8 and 9). As can be seen from Table 1 and Figure 8 &9, the Piedmonts, the second smallest environment, consist of the highest number of environmental units but less polygons as compared with the valley. The large number of environmental units in the piedmonts is associated with the more diversified lithological and soil conditions. Despite the homogenous lithologic characteristics of the valleys, they are the second most divisible unit in the study area. This indicates the diversified use and cover type in the valleys to be more than any other environment. Similar to the piedmonts, the large number of environmental units in the Hilland environment is attributed more to the varying rock and soil characteristics than the land use and land cover patterns of these areas.

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Wastewater discharge in rural areas

Hartmut Eckstädt University of Rostock / Germany

1. Introduction

In rural areas it is necessary to use special rules for wastewater discharge systems. The treatment of wastewater helps to protect the lakes and rivers and to guaranteeing the hygienic standards. In each case the special hydrologic and climatic specifics and also the economic relationships has to be taken into account.

In Europe the water demand in this time is assumed to be from 90 to 150 litre per capita per day. Because of the water prices the consumption of water will decrease to about 100 to 120 litre per capita per day. In Europe there is an increasing use of rainwater (for washing and toilets).

In arid areas we have a compulsion to save and reuse water. In dependence of the region the water demand has to be assumed from about 50 to 100 litre per capita per day. This has directly consequences both on wastewater draw off and wastewater treatment.

2. Wastewater Draw Off

Firstly, the beginning of planning process has to be decided, which concept for the discharge of wastewater is the right one. The important discharge possibilities are shown in table 1.

In each case it must be proved, if central or decentral solutions should be used. This can only be decided after consideration of economial, ecological and technical conditions. It is also important to take the further expansion and developments into account. The total amount of wastewater can be computed as

$$Q = Q_{RW} + Q_{WW} + Q_{iW}$$

Where,

Q=total wastewater discharge in l/s
QRW=rainwater runoff in l/s
QiW=groundwater inflow in l/s

$$Q_{WW} = Q_{DW} + Q_{TW} + Q_{IW} + Q_{AW}$$

QWW=Wastewater flow in l/s
QDW=Domestic wastewater flow in l/s
QTW=Trade wastewater flow in l/s
QiW =Industrial wastewater flow in l/s
QAW=Agricultural wastewater flow in l/s

If the daily 24-hours average wastewater flow amount is QDWd, then the wastewater flow per hour QDWh can be computed as:

$$Q_{DWh} = \frac{1}{x} Q_{DWd}$$

The value x depends of the size of the town (x = 8 in rural areas with towns < 5 000 inhabitants, x = 16 in big towns with > 250 000 inhabitants).

For commercial, industrial and agricultural wastewater flow special considerations are necessary.

The rainwater flow values for the computation of sewers mostly will be assumed with

A=Area in ha, from which the rainwater comes to the sewers

$$Q_{RW} = A \cdot r \cdot \psi$$

R=Rainfall per second per area in l/s/ha (estimated from statistical computations, it is necessary to determine the duration and the frequency of the rain)

y=Coefficient of discharge (dep. of the rate of infiltration and slope of the area, y = 0,0 ... 1,0)

Wastewater treatment plants at the end of combined sewer systems will be designed for the double wastewater flow values. The rest has to be discharged over the storm-water overflow.

Parameter	Raw wastewater	Mechanically pre-treated wastewater average hydraulic detention period in h		
		0,5 – 1,0 h	1,0 – 1,5 h	> 1,5 h
BOD_5	60	50	45	40
COD	120	100	90	80
TSS	70	40	35	30
TKN	11	10	10	10
P_{tot}	2,5	1,3	2,3	2,3

BOD_5 Biological oxygen demand
COD Chemical oxygen demand
TSS Total suspended solid
TKN Total Kjehldal Nitrogen
P_{tot} Total Phosphorus

Tab. 2.Population equivalents from domestic wastewater (A 131, 1991).Values in g per inhabitant and day. This computation values will be remained in 85 % of all days.

Under arid conditions combined sewers very often are cheaper and advantageous. Special discharge systems (i.e. pressure and vacuum systems) need a big technical expense.

3.Wastewater pollution

The ingredients of domestic wastewater are faeces, urine, kitchen waster, washing powders and cleaning agents. They depend upon the eating habits and chemical ingredients of cleaning agents.

In Table 2 the population equivalents are given, which are used for the computation of wastewater treatment plants in Germany.

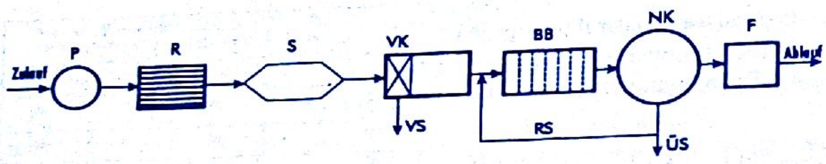
Using the values in Tab. 2 the pollutions of commercial, industrial and agricultural wastewater can be converted into population equivalents. But it is recommendable to estimate the real loads of pollution parameters. It is important to bear in mind, that there are also year and day changes and several temperatures.

	Wastewater	Rainwater (to be treated)	Rainwater (not to be treated)
Combined sewer system	Combined draw off to treatment plant		
Separated sewer system	Draw off to the treatment plant	Draw off to receiving water	
Modified combined sewer system	Combined draw off to treatment plant		Draw off to receiving water (infiltration flush irrigation)
Modified separated sewer system	Draw off to treatment plant	Draw off to receiving water	Draw off to receiving water (infiltration flush irrigation)

Table 1: Wastewater discharge systems

4. Construction of domestic wastewater treatment plants

4.1 Scheme of procedure



P	pumping station	mechanical treatment (1. step)
R	Grid	
S	Sand collector	
VK	Preliminary clarification tank	
VS	Sludge from pre-treatment	
BB	Activated sludge basin	biological treatment (2. step)
NK	Secondary sedimentation tank	
RS	Sludge return	
ÜS	Excess sludge	
F	Precipitation filter chemical, physical, biological treatment (3. step)	

Fg. 1: Scheme of wastewater treatment plant

4.2 Mechanical wastewater treatment

All solid materials which can disturb the treatment process must be removed out of the system first. To the mechanical step belong the following devices:

- Grid for the remove of solid waste
- Sand collector (elimination of sand particles until diameter from about 0,1 to 0,2 mm.)(Sometimes sand collectors are combined with grease remove devices.)
- Preliminary treatment basins (about 80 % of all suspended solids will be removed in 1,5 ... 2,0 h)
- Preliminary treatment basins in special cases are combined with phosphorus precipitation process, in this technology an exact dosage of precipitation materials is necessary

4.3 Biological wastewater treatment

In the biological step microorganism are used. In the activated sludge several kinds of bacterias can decompose specific chemical combination.

In activated sludge basin it is important to create optimal conditions for specific kinds of bacterias. The following combinations of procedures are possible:

- Degradation of carbon combinations (Docc)
- Docc with nitrification
- Docc with nitrification and sludge stabilisation
- Docc with nitrification and denitrification
- Docc with nitrification, denitrification and biological Phosphorus elimination

The <u>degradation of carbon combinations</u> occurs through oxidation. So called heterotrophic bacterias feed such materials. Optimal temperatures, oxygen supply and optimal substrat-bacteria-relationships support the degradation of carbon combinations.

The oxygen input mostly is made with pressurized air. In the mean time the wastewater will be mixed.

The nitrification (change of NH_4^+ to NO_2^- and NO_3^-) is made from autotrophic bacterias. Specialised microorganism realise the following processes:

Nitrosomonas:

$$2\,NH_4^+ + 3O_2 \rightarrow 2\,NO_2^- + 2\,H_2O + H^+$$

Nitrobacter:

$$2\,NH_2^- + O_2 \rightarrow 2\,NO_3$$

In relationship to degradation of carbon the nitrificants are working slowly. The specialised bacterias need a specific environment for good results.

Denitrification can be discribed with the exquation

$$5C + 4NO_3^- + 4H^+ \rightarrow 5CO_2 + 2N_2 + 2H_2O$$

Heterotrophic bacterias use oxygen from NO_3^- and NO_2^- if there is no free oxygen in the wastewater. For the denitrification the procedures of fig. 2 mostly are used.

The activated sludge process with final denitrification needs additions of carbon in the second step. Therefore this system is not used very often. The activated sludge process with preliminary denitrification avoids this disadvantage and is mostly used.

The elimination of phosphorus takes place in biological and chemical ways. Very often phosphorus is extracted through precipitation.

4.4 The third treatment step

Normally in the third step a final chemical treatment is realized. For instance phosphorus can be eliminated through addition of metal salts (FeCl3 and others). The developing precipitation sludge has to be eliminated in settling basins. For better hygienic conditions in Germany sometimes is used UV-irradiation.

4.5 Simulation of the wastewater treatment operation

Until now wastewater treatment plants are computed with so called "static" methods. It was not possible to describe the dynamic behaviour of treatment plants.

In the last years new models have been developed, with which also the dynamic simulations can be carried out. "Static" or "half-dynamic" simulations are possible with the programs such as DENIKA [HARTWIG, P. (1993)], University Hannover; IAWPRC-model (International Association of water pollution control); ARASIM (RTWH Aachen) and ASM2 [HENZE, M. et. al. (1994)] ETH Zürich.

A dynamic simulation of treatment plants can be realised with a program system SIMBA [ALEX, I. et. al. (1998)] from ifak in Magdeburg [TRÄNCKNER, J., (2002)].

5. Examples for small wastewater treatment plants

5.1 Methods

For small treatment plants up to 10 000 inhabitants the following types of plants have been well adapted.

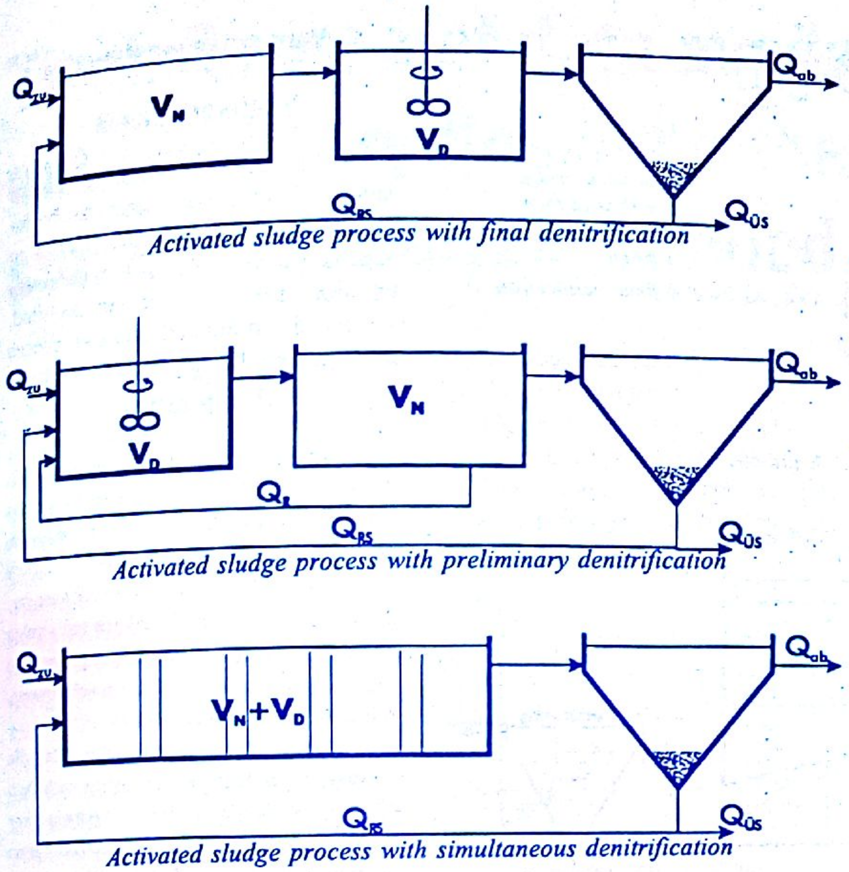


Fig.2 Several kinds of activated sludge processes

Natural methods

· Wastewater ponds (aerated and not aerated, sometimes with technical interconnected step)

· Plant treatment plants (horizontal and vertical flow)

Technical methods

· Mechanical and biological wastewater treatment plants (compact plants and in split up type)

To the mechanical step belong screens (for sizes > 5 000 Inh. also sand collectors and preliminary settling tanks are used).

The biological step can be realised with

- Activated sludge method (compact plants, oxidation ditches SBR-plants, membrane filter plants)
- Trickling filter
- Fixed bed plants
- Submerged contact aerators

5.2 Natural methods

__Wastewater ponds__

Bigger installations have often a mechanical pre-treatment in form of settling basins. This is for extraction of sludge. The volume of this basins is assumed to be > 0,5 m^3/ inhabitant. (Vmin > 300 m^3)

__Unaerated ponds__

They are used for sizes of < 1 000 inh. And have a big buffer possibility. The ponds surface should have about 10 m^2/inh. (without settling basin) or 8 m^3/inh. (with settling basin).

__Aerated ponds__

Used for sizes from 1 000 to 5 000 inhabitants. The surface loading is about 1,5 to 2,0 BOD5/(m^3 d). It is important to install a final clarifier.

__Technical interconnected steps__

If the capacity of the installation becomes to small, technical inter-connected steps will be constructed. Mostly trickling methods or submerged contact reactors are realised.

__Plant treatment plants__

The principle of plant treatment plants is the flow of pre-treated wastewater through sandy soil. On the soil swamp plants are growing up. The flow through the soil can be both in vertical and horizontal direction. The following values can be assumed for the computation:

__Horizontal working plants__

· Filter material: k_f > 10-3 to 10-4 m/s

· Specific filter bed area: 5...10m^2/inh.

· Depth: about 60 cm

· Organic load: 5 ... 8 g BOD5/(m^3 d)

· Hydraulic flow: 40 mm/d in case of dry weather

__Vertical working plants__

· Filter material: k_f > 10-3 to 10-5 m/s

· Specific filter bed area: 2 ... 4 m^2/inh.

· Depth: to about 2 m

· Organic load: 10...20 g BOD5/(m^3 d)

· Hydraulic flow: 30 ... 60 mm/d in case of dry weather

5.3 Technical methods

For the wastewater discharge from small villages, industry and commercial plants, technical equipments are very often necessary. If there is a connection to combined sewer systems, throttle devices can be used.

__Activated sludge plants__

The continuous working small activated sludge plants (look point 4.) must only eliminate carbon. They are used after the sludge stabilisation method, which can reduce the excess sludge.

A special kind of the activated sludge plants is the SBR-method (Sequenching Batch-Reactor-method). In SBR-method, several treatment steps are realised in chronological order (inlet, aeration, mixing, sedimentation, clear water discharge, excess sludge discharge).

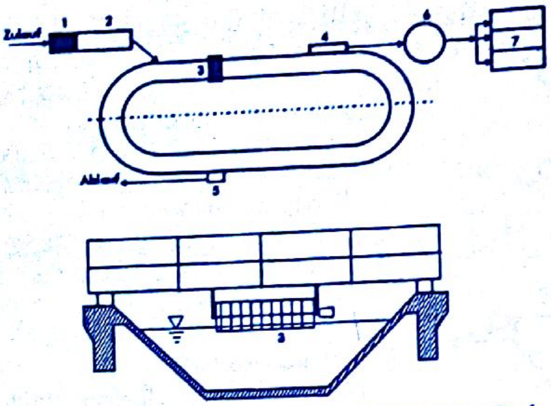
In oxidation ditches the treatment is made in a trapezium flume, which makes a circle flow possible. (Fig. 3)

These plants can serve normally up to 1 000 inhabitants without separating final clarification. The purified wastewater can be discharged over a laterally installed weir. In cases of biofilm methods, microorganism will grow on solid materials. So there are active layers, in which organic substances can be disintegrated. The following methods are used:

In trickling filter plants the wastewater will be irrigated over solid materials (Fig. 4).

In rotating disc plants the biofilm is on rotating discs. Through the moving discs the microorganism will come in contact with the wastewater and with air. The advantage is its low energy consumption.

Plants with submerged contact reactors are working with submerge materials (i.e. BioNed, Biopur, Biosub). It is on such material that the biofilm is developing. Below the materials aerators are installed for oxygen supply and flush. A sludge return is unusual in this method.



1 grid
2 sand collector
3 aeration bridge with cage rotor
4 sludge collector
5 outlet
6 final clarification

Fig 3 Oxidation ditch

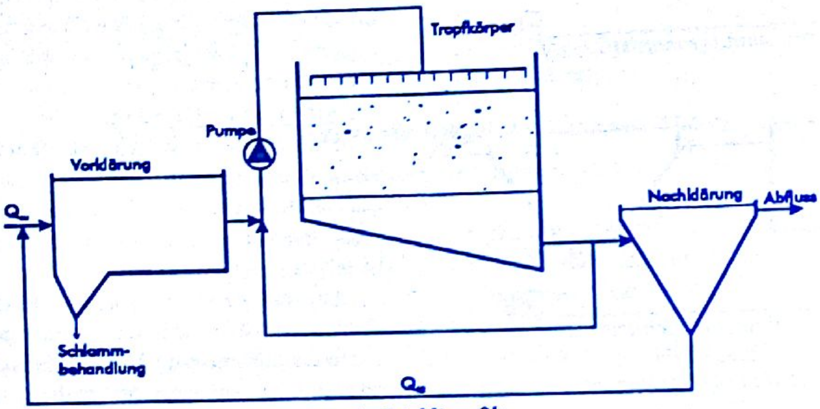


Fig. 4: Trickling filter

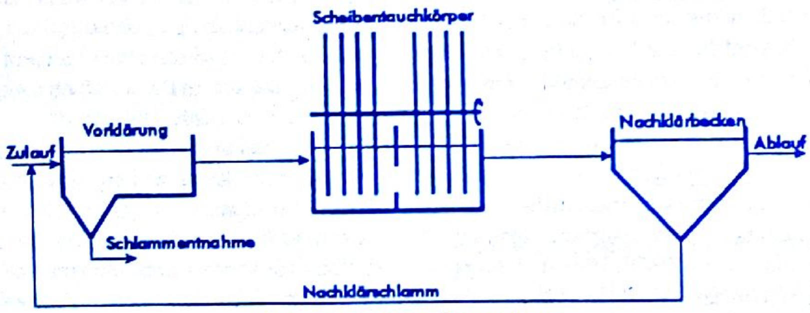


Fig. 5: Rotating disc reactor

Name	sign	Value	after DIN 4261	after A 122	
activated sludge plants					after A 126
sludge index	ISV	ml/g		100 or 150	75 – 200
content of dry solids	TS_{BB}	g/l		4,0 g/l	5 bis 3 g/l
sludge load	B_{TS}	kg BOD_5/kg TS · d	= 0,05	0,05	0,05
volume load	B_R	kg BOD_5/m^3 · d	= 0,2	0,2	0,25 – 0,15
oxygen load	O_B	kg/kg		= 3	3,0
content of oxygen	C_O	g/m^3		= 2	k.A.
Mixing energy	W_R	W/m^3		= 3	3 – 8
trickling filter					after A 135
volume load solids filling	B_R	kg BOD_5/m^3 · d	= 0,15 (material after DIN 19 557 Teil 1)	0,15 – 0,2	0,4 0,2 Nitrification
volume load plastic filling	B_R	kg BOD_5/m^3 · d		0,15 – 0,2 for $100 m^2/m^3$ 0,3 – 0,4 for $200 m^2/m^3$	0,4 for $100 m^2/m^3$ 0,8 for $200 m^2/m^3$
submerged bed reactors					after A 135
BOD_5-area load	B_A	g BOD_5/m^2	= 4,0 by minimum area of $45 m^2$	4,0 – 6,0	8,0 b. 2 cylinders 10 b. 3 cylinders

Tab. 3: Computation values for treatment biological steps in very small wastewater plants (DIN 4261), small wastewater plants (50 ... 500 inhabitants / A 122) and wastewater treatment plants below 500 to 5 000 inhabitants (A 126) after German orders [BARJENBRUCH, M. (1998)]

6. Very small wastewater treatment plants

For decentralized discharge systems very small wastewater plants can be installed for up to 50 inhabitants. If there is no possibility of using such plants, collectors for wastewater and faeces are required. The liquid part infiltrate into soil. Faeces can be collected in larger treatment plants.

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The influence of data availability and extraordinary floods on the result of statistical analysis of flood flow

Prof. Dr. Konrad Miegel University of Rostock / Germany

1. Introduction

The University of Rostock is found in the northeast of Germany. Rostock is located in Mecklenburg-Vorpommern (Picture 1), a state in the northeast of Germany. The focus of this paper is to undertake statistical analysis on time series of flood events in Sachsen, another state in the Middle East of Germany. For the analysis the regionalisation technique which was developed by Haupt (1999) will be used. Haupt (1999) has successfully applied the method for regionalization of peak discharges in Mecklenburg-Vorpommern. Such methods have been used in different regions and are useful for estimation of peak flows even for ungauged rivers.

For the analysis a multiple regression model of the following form has been adopted.

$$\ln Hq(T) = a + b_1 \cdot \ln A + b_2 \cdot \ln I + b_3 \cdot \ln LR + b_4 \cdot GF + b_5 \cdot e^{UD} + b_6 \cdot \ln \frac{P}{100}$$

where

a; b1 … b6 parameters of the model

Hq rate of peak flow (km2/s)

T recurrence period (years)

A basin area (km2)

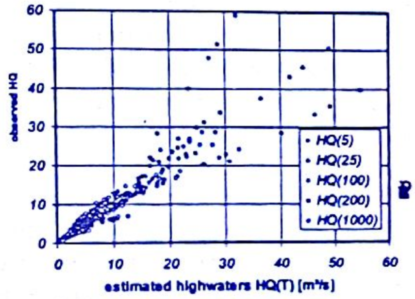
I mean slope

LR parameter of lake retention

GF shape parameter of the basin

UD parameter of soil permeability

P annual precipitation (mm/year)



Picture 2 Comparison calculated and observed peak discharges

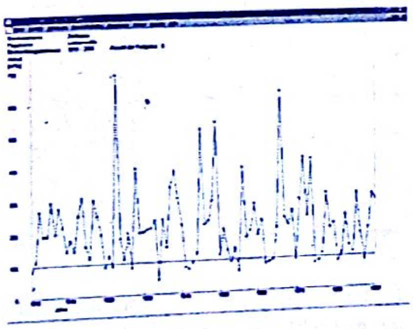
Picture 2 shows a comparison of model-estimated peak flows (regionalisation method) with floods of several recurrence periods. The floods were calculated using the distribution functions of all considered gauges. The results show considerable differences between peak flows of frequency analysis and model calculations. The mean difference of 18% is typical. Similar deviations were also observed in other regions.

Due to such differences the goal of many investigations is to further improve the estimation i.e., statistical methods as well as methods of regionalisation. But it is obvious that the availability of data and the limited duration of observation play a more significant role in the accuracy of frequency analysis than all other methodical details.

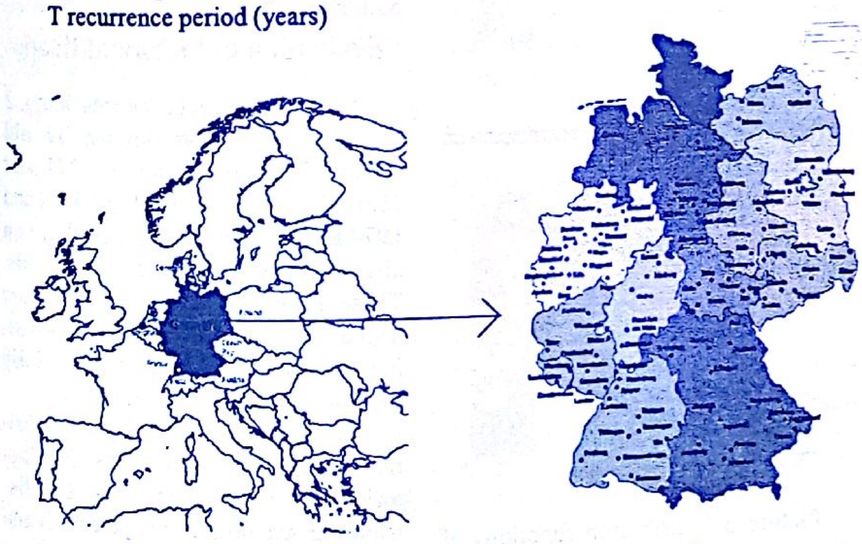
Therefore further investigations were initiated to analyse the importance of data availability on the results of frequency analysis using very long time series data. For this analysis the data of 4 gauge stations which are located in Sachsen in the middle east of Germany were selected. The stations are in operation for about 90 years and provide a continuous data. In Mecklenburg-Vorpommern such long observations of peak flows are not available.

2. Influence of data availability on statistical analysis

Picture 3 shows annual peak flows of the water level in Lichtenwalde. The basin area of this gauge is about 1575 km².



Picture 3 Maximum annual peak flows of the water level Lichtenwalde



Picture 1 Situation of Germany in Europe and states of Germany

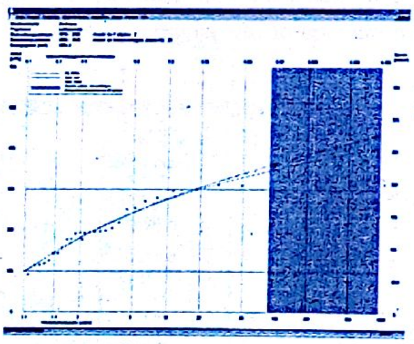
The four greatest peak flows represent extraordinary floods. These are the floods of the years 1932, 1954, 1958 and 1975. By testing with a = 0.1 to discover outliers these four peak flows are detected as outliers. To show the influence of data availability the complete time series was divided in to three periods of 30 years duration. Considering the three periods, the peak flows of 1932 and 1937 from the first period, 1975 from the third period and the peak flows of 1954 and 1958 of the second period were identified as outliers.

Picture 4 and 5 show the distribution functions of the periods 1910-1940 and 1941-1970 respectively (consider the different scales of ordinates).

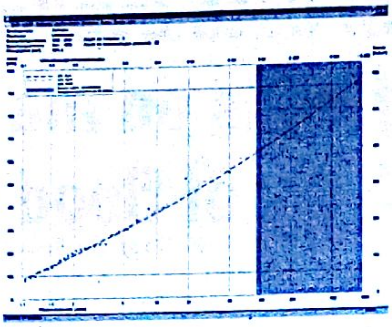
By analysing these periods separately different values of different peak discharges were estimated (see table below) i.e. the discharges of different recurrence periods T. The upper part of the table contains values that were obtained by testing extraordinary floods as outliers with strategy of discovery and the lower part without strategy of discovery. The table makes clear that not only peak flows of different periods are completely different, but also the peak flow obtained by adopting different strategies of testing outliers.

Statistical test of outliers, α = 0.1 outliers	1910 – 1940 1932 and 1937	1941 – 1970 no	1971 – 2000 1975
T = 20 a	304	450	377
T = 50 a	336	554	440
T = 100 a	357	636	484
Statistical test of outliers, α = 0.1	1910 - 1940	1941 - 1970	1971 - 2000
Outliers	1932	No	No
T = 20 a	332	450	454
T = 50 a	375	554	555
T = 100 a	404	636	630

Table: Maximum discharges of gauge Lichtenwalde (m3 s –1)

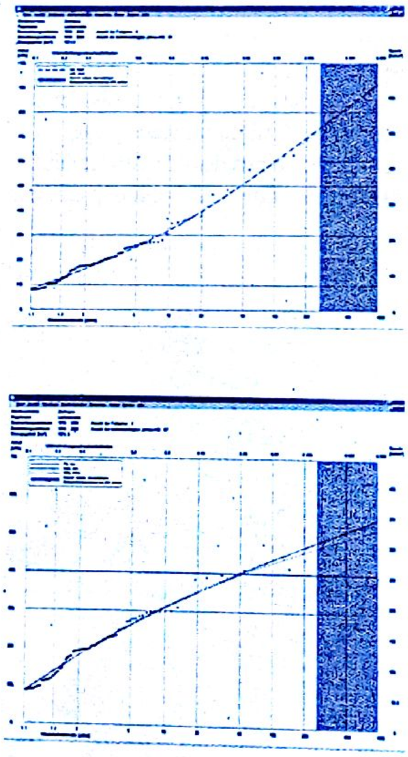


Picture 4 Distribution function of the gauge Lichtenwalde; period 1910 – 1940; outliers: HQ (1932) and HQ (1937) by testing with a level of significance a = 0.1



Picture 5 Distribution function of the gauge Lichtenwalde; period 1941 – 1970; no outliers by testing with a level of significance a = 0.1

The next two pictures show the complete series from 1910 to 2000. The first and the second figures are with and without outliers respectively. By different strategies of testing extraordinary floods, not only complete different peak discharges were found, but also different distribution functions seems to be the best for estimation of a given peak discharge. Furthermore the shapes of the best-fitted functions are different. The conclusion is that the evaluation of extraordinary floods is decisive for estimation of peak discharges and so it is necessary to evaluate such flood peaks very carefully.



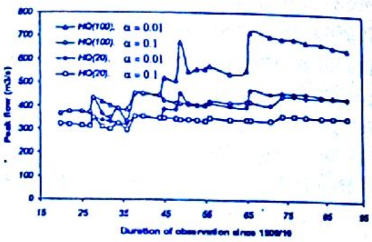
Picture 6 Distribution functions of the gauge Lichtenwalde with outliers, a = 0.01 (above) and without outliers a = 0.1 (below) (a = level of significance)

Importance of long observations

The picture 7 shows the importance of long duration of observation. Beginning with 20 years the duration was extended gradually.

Great fluctuations of peak discharges are the consequence of extended duration of observation. This is not only a matter of duration of observation itself. Rather it is a consequence of changed evaluation of extraordinary flood as outliers. The shorter the duration of observation the greater is the probability to identify an extraordinary flood as outliers. If there are several extraordinary values in longer time series, this probability is smaller.

Furthermore the peak discharges of long recurrence periods are increasing with each additional extraordinary flood that was observed. Especially, after several small peak discharges the peak flood become not only smaller, but also an extraordinary flood can appear to be an outlier again.



Picture 6 Peak discharge estimated by different strategies of testing outliers

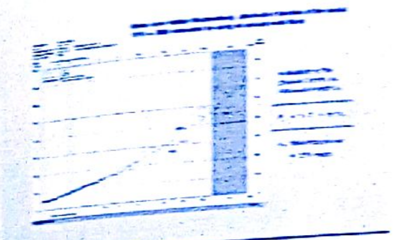
Evaluation of historical floods

At the water level in Wechselburg, 2 historical floods are known by old marks. These are events of 1771 and 1858. The flood events of 1932, 1954 and 1974 are so extraordinary that they can also be recognized as historical floods. These events are outliers if they are tested by strategy of discovery. By testing without strategy of discovery only the flood of 1954 is an outlier.

Picture 7 shows the plotting positions of all 5 historical events. The historical period is 370 years long. The distribution function in this picture is the function of the complete series from 1910 to 2000 using all annual peak flows.

The normal plotting positions of the events from 1932, 1954 and 1974 are located on the left side of the distribution function. The picture illustrates that the estimated function is realistic refer to the position of the historical flood events.

If the distribution function is estimated without the flood of 1954 its relation to the historical floods is worse. If it is estimated without all outliers the function is total unrealistic refer to the position of the historical floods. The conclusion is that the strategy to detect extraordinary floods as outliers with the strategy of discovery is clear wrong and unsuitable. The removal of such values is a grave lost of information about extraordinary floods.



Picture 7 Plotting position of historical peak flows at the gauging station Wechselburg

Nevertheless the evaluation of historical floods is a very difficult task. This was revealed by the flood 2002 in the Elbe-Basin, which was the greatest flood since 1845. The Elbe is one of the most important rivers in Germany. The small rivers, which were discussed in this paper, are tributaries of the Elbe. The following problems are connected with the evaluation of the flood 2002 in the Elbe-basin and its sub basins:

- maximum water levels were at some gauges higher than the highest measurable level,
- the stage-discharge-relations (rating equations) were uncertain at the level of maximum flow,
- gauges were destroyed,
- changes of cross sectional areas at gauging stations during the flood,
- relations between water level and discharge lost their validity totally,
- the estimation of peak flows is possible by hydrological models only.

The uncertainties of peak discharges show also the example of the Rote Weißeritz, a tributary of the Elbe. Its mean discharge runs to 1.5 $m^3 s^{-1}$ (basin area 105 km^2). The flood flow of the recurrence period T = 1000 years amounted to 147 $m^3 s^{-1}$ up to 2002. The peak flow of the flood 2002 was estimated at 230 $m^3 s^{-1}$. Considering the flood of T = 1000 years as threshold value, this value was exceeded during the flood of 2002 for about 16 hours. The runoff coefficient amounts to about 90%. Considering this values it becomes clear that the discharge of 147 $m^3 s^{-1}$ cannot be the realistic value of the recurrence period T = 1000 year. Further investigations are necessary to estimate peak flows which are more reliable.

Because of the in above mentioned problems, an extraordinary flood is general difficult to evaluate. Especially evaluation of historical floods, which were happened in the last centuries are difficult to evaluate.

Summary

The estimation of peak flows for dimensioning with recurrence periods > 200 years is very problematical.

The observation of extraordinary floods leads often to a changed evaluation of such floods.

There is a need of improved methods for estimation of peak flows with recurrence periods > 200 year.

A long duration of observation is very important to estimate dimensioning discharges with sufficient accuracy. Often 30 years duration are mentioned as minimum. Nevertheless dimensioning discharges are uncertain and longer durations are necessary.

Extraordinary floods should not be evaluated by tests of outliers with the strategy of discovery (great levels of significance a).