water

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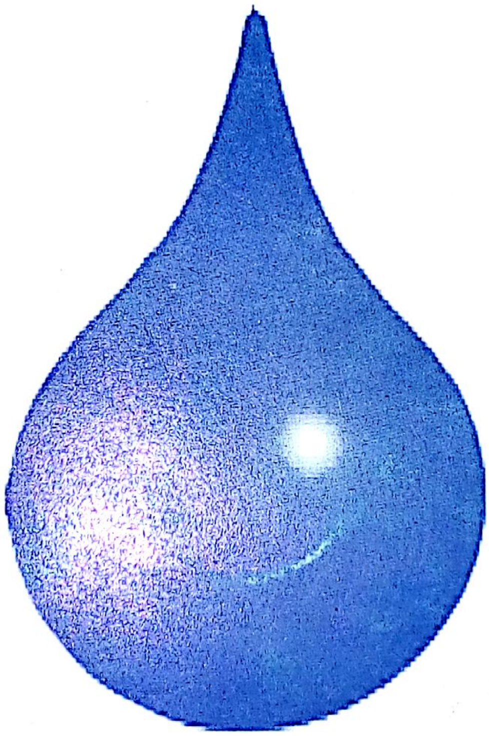
# Special Issue



## Proceeding of the 9th Symposium on Sustainable Water Resources Development

**Arba Minch University**

**Arba Minch**

**12 - 13 October 2005**

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## water

Is a biannual published by the Arba Minch University. Basically the journal entertains and / or supposed to entertain different approaches to the major issues and problems in the water sector. It is a forum which gives a great deal of access to various professional views and outlooks to be reflected and discussed. It also makes possible for the rich experience and wisdom of outstanding personalities in water engineering to reach and be utilized by those concerned. Most of all, **water** encourages and gives much more opportunity to young engineers to introduce their works and eventually to cultivate the tradition of using a journal.

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

## editorial board



## guide to authors

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

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

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

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

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

References in the text should have the following form:

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

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

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-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.

**Electronic Format**

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

## editorial office


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## subscriptions

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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 Readers,*
*Water is a finite resource that needs to be utilized and developed in an efficient and environmentally sound manner. The limited nature of fresh water on one hand and increasing need for water as the result of population growth on the other hand call for sustainability considerations during utilization of water.*

*Arba Minch University has been organizing annual symposia since 1996 on "Sustainable Water Resources Development". The ideas has been to create a forum for water and related professionals, practitioners in the water sector, actors from GOs and NGOs to come together and present new results or ideas from the research or practice. The proceedings of reviewed and presented papers have been published and distributed to different institutions, organizations and professionals in the country and abroad.*

*This proceeding (volume 9) contains papers that were presented in the 9th cycle of the symposium which was held on December 12-13, 2005. There are 21 papers focusing on broad categories of Soil and Water conservation, Hydrology and Water resources, Hydraulics, Hydropower and reservoir, Water supply and environment.*
*We believe that the proceeding with the results and issues discussed in the papers is a valuable reference resource for professionals operating in the water and water related sectors. Hence the copies are made available to the users free of charge.*

*The editorial board thanks all contributors and the GTZ (German Technical Cooperation) for sponsoring the symposium and publication of the proceeding.*

*Dr. Mekonen Ayana*
*Editor-in-Chief*

## Welcoming Address For the 9th Symposium on " Sustainable Water Resources Development," December 12-13/ 2005 Arbaminch

Distinguished guests
Ladies and Gentlemen:

*Dr. Mekonen Ayana*
*Resarche & Publication Co-ordinator*

It is a pleasure and honor for me to welcome each and every one of you on behalf of the organizing committee and on my own behalf to the Arba Minch University, Symposium on Sustainable Water resources Development.

Ladies and Gentlemen:

Water is needed in all aspects of life. Throughout history, secure access to water has been essential to socioeconomic development and the stability of cultures and civilization.

For some of us who have access to water, water may be considered as infinite resources that can be obtained inexpensively. Utilization of water under such sets of thinking impacts negatively on quality and quantity of available water resources. For those who have no access and should walk kilometers each day to find the water they need and carry it home, water is a precious resource that needs to be valued.

Indeed, the finite nature of fresh water resources on one hand and rapid increase in population growth on the other hand makes water a critical natural resource that needs to be examined in the context of population growth. As population increases, the average amount of fresh water per capital available declines. This causes water stress and outright scarcity and results in conflicts.

The technological capacities of human beings to capture and store fresh water have increased throughout the history. However, we have to realize that no technology can significantly expand the basic resource.

The continuous depletion and degradation of water resources combined with grater demand for more water are factors that make the sustainability issue very important. Only water resources systems that are managed to satisfy the changing demands placed on them, now and in the future, without degradation, can be called sustainable. Development can be evaluated as sustainable if "it meets the needs of the present without compromising the ability of future generation to meet their own needs."
This is the problem facing our generation, living in and contributing to an environment which is seriously affected by soil erosion and sedimentation, declining soil fertility, deforestation and desertification, population pressure and subsequently destructed ecosystem etc.
The fact that we are now not able to feed ourselves can be the driving force that may initiates us to aggressively utilize the resources available to bring about food self sufficiency and food security. Our challenge today is therefore, to establish our priorities more adequately and implement available technologies that should improve our efforts to use the resources more efficiently to bring about socioeconomic development by averting critical consequences due to waste, mismanagement and overuse of the resources.

*Dear participants,*

*Arba Minch University is organizing symposium on sustainable water resources development consistently for the last consecutive 8 years. The sole objective of these symposia is to provide to professionals in the water and related natural resources and environmental sectors from all over the country and abroad, a platform in which they can communicate, present research papers and new products, discuss ideas, share experiences and exchange information on specific topics related to sustainable water resources development.*
*The Research and Publication Office has been publishing the proceedings of the symposia and distributing them to different Universities, Research Institutions, and Organizations. About 4000 copies of proceedings from the past eight symposia have been published and distributed.*

*This symposium is the 9th in series. There were about 38 papers submitted to the organizing committee out of which 24 papers are selected and ready to be presented here. The papers can be broadly categorized under*

| | |
|---|---|
| *Soil and Water conservation* | *3 papers* |
| *Hydrology and Water resources* | *7 papers* |
| *Hydraulics, Hydropower and reservoir* | *5 papers* |
| *Water supply and environment* | *4 papers* |
| *Irrigation and Drainage* | *5 papers* |

*Once again, on behalf of organizing committee I would like to thank all researches in general who have responded to our call by submitting their paper on time and those who have personally appeared to present their papers in particular.*

*I also would like to express by sincerely thanks to GTZ for sponsoring the symposium.*

*Now, may I request Dr. Nigatu Chaffo, the acting president of the university to give his opening speech and thereby formally open the 9th symposium on sustainable water resources development.*

*I thank you all for your attention and wish you a fruitful symposium and a comfortable stay for our guests in Arba Minch.*

*Thank you*

**Opening Address For the 9th Symposium on**

**" Sustainable Water Resources Development,"**

**December 12-13/ 2005**

**Arbaminch**

**Dr. Engineer Nigatu Chaffo**

*Distinguished Guests*
*Dear participants*
*Ladies and gentlemen*

*On behalf of Arba Mich University and my own behalf, I am feeling delighted to have this opportunity to make an opening speech and welcome you to the 9th cycle symposium on Sustainable Water Resources Development.*

*At this juncture, I would like to pay tribute to the organizing committee who made their best efforts for the materialization of this symposium. And, I would also like to extend my sincere appreciation to the contributors and participants for your interest to attend this vital and timely symposium.*

*Ethiopia is well known for its huge amount of water resources potential. However, the spatial and temporal variations in its distribution as well as the limited human, financial and technological capacities are the main bottlenecks that are hindering the effective utilization of water. As the result, the contribution of water resource to the socioeconomic development of the country is indeed very low.*

*The Water Technology Institute of Arba Minch University is significantly contributing to the human resources development in the water sector. On top of this, the university is organizing the symposia on Sustainable Water Resources Development since 1996 without interruption. The symposium is meant to reflect the concern and contribution of the Arba Minch University for sustainable development and management of natural resources in general and water resources in particular.*

*The University is very much delighted and honoured to host this event and express its willingness and commitment to work in collaboration with all actors to address and ensure the sustainability of development activities in the water and related fields.*

*It is my strong belief that this symposium provides an essential forum in which a multitude issues on water resources are analyzed, discussed and share among professionals.*

*Ladies and gentlemen,*
*I have been informed that many papers addressing the issue of sustainable water resources development have been selected and ready for presentation.*
*I sincerely hope that the two days symposium will provide good opportunity to all of you to share ideas, experiences, discuss on research papers to be presented and identify possible solutions to research and development oriented activities.*

*I wish all the participants a successful and pleasant stay in Arba Minch.*

*Finally, I would like to thank GTZ for sponsoring this symposium.*

*With these brief remarks, I now declare that the 9th Symposium on Sustainable Water Resources Development is officially opened.*

*Thank you.*

# Farmers Perception of Soil Erosion and Adoption of Introduced Soil and Water Conservation Measures in the Dengelie Catchment, The Gamo Gofa High Lands, Ethiopia

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*P.O.Box 21, Arbaminch, Ethiopia*

## Abstract

**This paper surveys the level of farmers perception of soil erosion and the factors militating against farmers adopting SWC measures on farm lands based on a survey of 105 sampled house holds in Dengelie catchment, Gamo Gofa Zone,SNNPR.Tothis,structured questionnaires, field observation and informal and focus group discussion were employed to generate the data. The results indicate that, farmers perceived and ranked soil erosion as the first top problem in the Dengelie Catchment.As to the potential constraints affecting farmers adoption of introduced SWC measures on their farm land, farmers small land holding size was ranked first, followed by inappropriateness of the conservation structures during ploughing.Shortage of labor, subsistence farming, the problem of termites, lack of adequate technical assistance and advice and farmers lack of awareness of the problem of soil erosion were ranked from third to seventh respectively. the perception item ranked at the seventh level i.e lack of awareness of the problem of soil erosion has indicated and served as an indirect measure of the level of farmers perception soil erosion as a problem. There fore, Identifying farmers' level of perception of soil erosion and the constraints influencing their adoption of introduced SWC measures is vital for the formulation of erosion control measures and strategies according to management choices.**

**KEY WORDS: Erosion; perception; Adoption, Soil and Water conservation, Ethiopia**

## Introduction

In Ethiopia, under conditions of peasant subsistence agriculture in both the densely populated highlands and sparsely settled lowland areas, survival is solely linked to the exploitation of the land-based resources (Azene, 1997).However, these resources are exploited beyond their capacity to regenerate it self (Daniel, 1988).This has resulted in decline of productivity and consequently the low level of agricultural production in general and the current food insecurity in particular (Wolde Amlak, 2002).

Soil erosion by water takes the lead among the dozens of problems the Ethiopian rural sector is facing. The problem is more serious in most of the highland areas of the country above1500 m.a.m.s.l (Azene, 1997). According to the Ethiopian Highland Reclamation study (ECA/ FAO, 1986), about half of the highland areas (about 27 million ha) is seriously eroded. Other estimates also show that about 1900 million tones of soil are being eroded annually on the high lands, which is equivalent to 35 tones/ ha in a year. This supports the study of Ayanou (1996) that, almost 75 percent of the Ethiopian high lands need conservation measure of one sort or another, if they are to support sustained cultivation.

Although massive soil and water conservation measures have been going on over the years by various agencies, the outcome of the conservation practices has failed to bring higher productivity on sustainable basis and improve the economic status of the farmers

These tremendous efforts were not able to attain the objectives anticipated (Yohannes, 2000). Numbers of interrelated factors definitely have their respective shares. The conservation strategies have disregarded the local level biophysical factors and socio- economic requirements of the farmers. The farmers themselves have, in the past simply not been consulted about their knowledge and understanding of the processes of erosion. Both traditional technologies and social organizations have usually been ignored and solutions have been imposed from above (Herweg, 1992).

Similarly, Belay (1998) pointes out that the conservation measures in the country failed to be accepted by the users of the land, because the conservation measures were introduced prior to intensive understanding of the existing realities of the local environment. The existing realities such as the farmers perception of the basic problems of soil erosion, the socio- economic priorities and their effects on farmers' adoption of the introduced SWC measures have not been taken as a major factor in designing and implementing the conservation strategies.

The main objective of this paper was to assess the level of farmers' perception of soil erosion and factors affecting the adoption of the introduced structural conservation measures in the Dengelie catchment. The specific objectives were to: (1) examine the level /rank of farmers perception of soil erosion as a problem (2) identify the causes and consequences of soil erosion according to farmers perception, and ( 3) investigate the farmers level of perception regarding the potential factors militating farmers adoption of the introduced SWC measures in the Dengelie catchment.

## Data And Methods

The relevant data for this study were collected through structured questionnaires, field observation and group discussion. Firstly, 105 farmers were randomly selected from three locally identified 'Gotes' Dereba, Digo Chelbe and Wontona, and were interviewed between April and May 2003 using the structured questionnaires comprising of both close and open ended questions. The close ended questions have a Likert – type scale where items were designed to assess farmers' perceptions regarding soil erosion, and potential constraints in decision of the farmers in adopting the introduced SWC measures in Dengelie catchment. Respondents were also encouraged to give supplementary points on each item. Secondly discussions were held with different groups of people, 3-5 farmers selected from each village, and key informants. Farmers were allowed to comment on various issues focusing on the items designed to rank and determine their perception of soil erosion and the potential constraints of farmers' adoption of the introduced soil and water conservation measures. In addition to the formally structured questionnaire survey, informal discussions were also held with some farmers to generate additional information on the issues covered by the structured questionnaire.Direct observation was also conducted to crosscheck observable issues. Lastly, the data generated by the structured questionnaire was analyzed using frequencies and descriptive procedures of the SPSS release 10(Bryman and Cramer 2001).The qualitative data generated by informal discussions with different groups of the local people were used to substantiate the quantitative results from the structured questionnaire.

## Study Area: The Dengele Catchment

Dengelie catchment lies at 6$^0$ 36' N to 6$^0$ 48' N latitude and 37°36' to 37$^0$ 40' E longitude. In administrative terms, it is located in Boreda woreda (district), Gamo Gofa zone, Southern Nations, Nationalities and people regional state (Figure 1). The catchment is located at about 487 Kms South west of Addis Ababa, and 14 Kms NNW of Zefeni town, the center of the woreda in the Gamo high lands and forms part of the south western highlands of Ethiopia. Having an area of 360 ha (3.60 Km$^2$) 1128 people, 553 males and 575 females that constitute 49% and 51% respectively inhabit the catchment. Based on the projection made by taking into account the national growth rate of 2.9% per year, the total population of the study area was estimated at 1501 in 2004. According to CSA, the average family size in 1994 was between 5 and 6 persons. However, the survey of 105 sample house holds indicated that the total number of family members ranged from 3 to 10 with an average family size of 7 persons per household.

In terms of topography, the catchment is characterized by diverse conditions. Elevation ranges from 1720 m to 2280 m a.m.s.l, and slopes range from nearly flat(< 2 percent ) to steep (> 25 percent ) (Yechale,2003).According to the simplified traditional agroclimatic classification system, which considers only average temperature and altitudinal range, the catchment lies within the Woine Dega ( sub humid ) Zone and the climatic condition is generally sub humid. As measured at Gununo research station ( 6 $^0$ 6' and 37 $^0$39' E, and an elevation of between 1980 and 2100m),the mean annual temperature is 19.5 $^0{}_c$ with a range from 18.3°c in July and August to 21.3$^0{}_c$ in March, and mean annual rain fall is 1330 mm . More than 50 percent of the total rain falls in the four months of June to September (locally known as Kiremt season).The dry months are November to February / Locally Known as bega season ),when less than 13 percent of the annual total rainfall occurs. The farming system is a typical mixed crop – livestock system that is carried out on a subsistence scale. Land and Livestock are the main sources of livelihood of the farmers. Livestock provide the draught power and household member the labor that is needed for the farming operation. It is dominated by rain fed crops cultivated by traditional production techniques, traditional oxen plow and manually operated hand tools. As the land use estimates made by the woreda agricultural office shows both annual and perennial crops are grown which totally account for more than half of the total area of the catchment (Table 1).

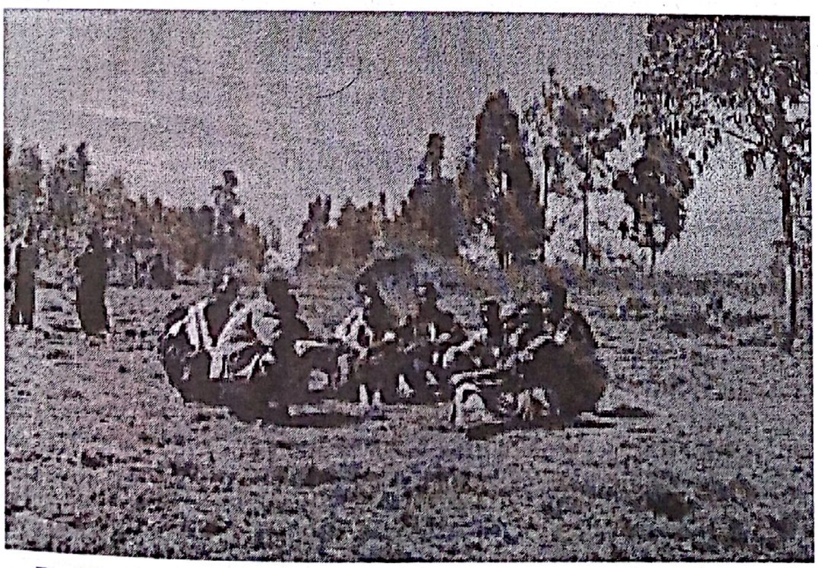

*Fig 1.Discussion with different groups of people in the Dengelie catchment*

*Table 1. Area under major land use categories*

| Land use | Total area(ha) | Percent of total area |
|---|---|---|
| cultivated land | 203.16 | 56.43 |
| -annual crops | 193.8 | 53.83 |
| -perennial crops | 9.36 | 2.6 |
| Forest cover | 7.12 | 1.98 |
| Grazing land | 30.20 | 8.39 |
| Currently un cultivable | 59.76 | 16.6 |
| Currently un productive | 34.20 | 9.5 |
| Others(including home stead) | 25.56 | 7.1 |
| Total area | 360.0 | 100 |

(Source, Woreda Agricultural Office, 2003)

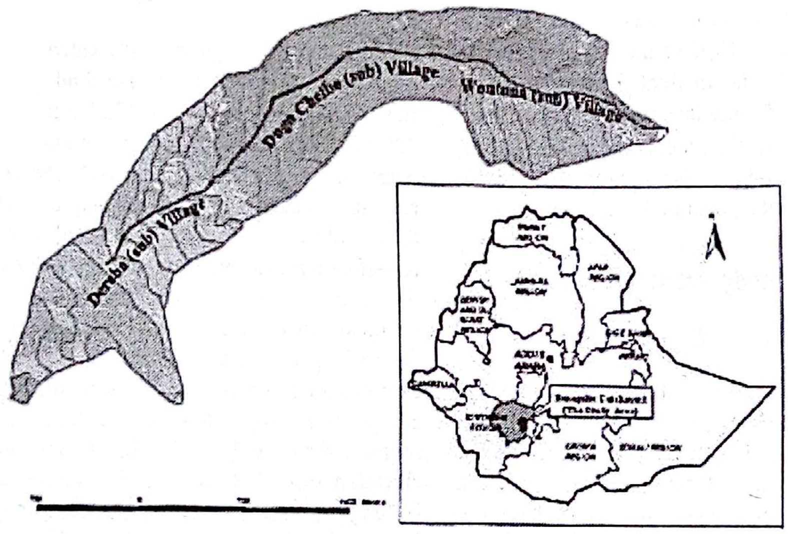

*Fig 2 Location map of the study area*

From Table - 1 The land use of the study area is dominated by primary land use types like agriculture and grazing.

## Results and Discussion

### Farmers Perception of Soil Erosion

The relevance of conservation measures to a farming system depends in part, on how farmers and other perceive erosion problem and its consequences (Morgan, 1995).In Dengelie catchment, as indicated in table 2, soil erosion was perceived by many of the respondents as the major problem adversely affecting the productivity of the farming system. And thus, it was ranked first, followed by food shortage, perhaps, it was perceived as resulted from soil erosion.

*Table 2, Means and Standard Deviations by Rank Regarding the Severity of Selected Items in affecting the productivity of the farming system (According to Farmers Perception).*

| Item | Mean[a] | Std.Deviation | Rank |
|---|---|---|---|
| Soil erosion | 2.8095 | .52064 | 1 |
| Food shortage | 2.7619 | .58051 | 2 |
| Landholding size and fragmentation | 2.7143 | .61573. | 3 |
| Price of Fertilizer | 2.6857 | .64023 | 4 |
| Oxen | 2.6762 | .64294 | 5 |
| Shortage of Fuel wood and construction | 2.6571 | .66258 | 6 |
| Road problem | 2.6000 | .68781 | 7 |
| Lack of Farm implements | 2.6000 | .68781 | 8 |
| Lack of credit | 2.6000 | .70165 | 9 |
| Land tenure and ownership | 2.0381 | .83117 | 10 |

*(Source Field survey, 2003) N =10 [a]scale 3=highly severe 2=severe 1=least severe*

Though, it was perceived and ranked as the first major problem, there were differences among farmers in understanding the level of erosion. The finding under table 2 has shown that more than 70 % of the respondents perceived soil erosion as a very sever and sever problem affecting their croplands. About 15.2% of the respondents under stood soil erosion as minor problem while 7.6% reported no problem of soil erosion and about 6% of c them were not certain about the problem of soil erosion.

Similarly, the survey or discussions have revealed that many farmers in the study area have awareness about the principal causes and consequences of soil erosion. About 51% of the respondents pointed out deforestation as the major cause of soil erosion followed by over cultivation 27.6 %, whereas high rainfall, topography/ slope, and over-population were rated by 9.5, 7.6 and 4.8 percent of respondents respectively (Table 4). It is only few respondents' recognize population pressure as one of the causes of soil erosion. This may be because many farmers in the catchment do not consider having large family size as a problem. How ever it was learnt that in the study area there is high population pressure that has given rise to the fragmentation of farmers land holding size into small uneconomic parcel size.

Regarding the consequences of soil erosion, more than half of the interviewees further pointed out that, the depth of the soil have decreased, and the top soil covering the plough has changed from time to time. They also emphasized that the fertility of their plots has declined, reflected on the lowering of the quantity of crop production from year to year.

Although farmers' awareness of the uses of artificial fertilizers to soil fertility is very high, they have shown their reluctancy to take a loan to buy fertilizer because they fear that the variable situation could worsen their livelihood if they had to repay a loan in addition to struggling to survive in the after math of a poor crop. Farmers further explained that since the price for grain is low,particularily during the

*Table 3. Farmer's perception of level of soil erosion on their plots*

| Level of soil Erosion | No. of respondents | Percentage |
|---|---|---|
| Very sever | 42 | 40 |
| Severe | 33 | 31.4 |
| Minor | 16 | 15.2 |
| No problem | 8 | 7.6 |
| Not certain | 6 | 5.7 |
| Total | 105 | 100 |

(Source, Field Survey, 2003/2004)

*Table 4. The main causes of erosion (according to farmers)*

| Causes of Erosion | No. of Respondents | % |
|---|---|---|
| Deforestation | 53 | 50.5 |
| Over cultivation | 29 | 27.6 |
| high rain fall/intensity | 10 | 9.5 |
| Topography | 8 | 7.6 |
| Population growth | 5 | 4.8 |
| Total | 105 | 100.00 |

*(Source field survey, 2003)*

harvesting time, the up side benefits from investment/application of fertilizer are more than off set by the down side risks of losing the investment as *a* result of unforeseen hazards such as drought, erosion, and others. Land tenure and owner ship was perceived significantly less than other problems. It was also learnt from discussions held with farmers, land tenure and owner ship is not under stood as a major problem by many farmers as compared to other items. Although most of the respondents felt secured under the existing land tenure system, there were few farmers who rented land, particularly the new house holds regard insecure tenure as a constraint, and making them reluctant to manage the land, which in turn affected their production.

Finally, the findings under table 2, and the responses from the discussions could be an indicator validating the farmers' previous ranking of soil erosion as the major problem in the study area. Probably, this has enabled them to develop their own techniques of soil and water conservation measures that are agronomic and structural origin. These practices have been used to control soil erosion and maintain and improve the fertility status of the soil. As checked during the field survey, among the indigenous practices of soil conservation, crop rotation mixed cropping and traditional stone terraces were commonly observed in many areas of the catchment. And, a good number of discussants repeatedly chose traditional coping mechanisms particularly the agronomic methods as the most effective and the cheapest management practice. And thus, many farmers reported that the indigenous conservation measures are their preferences as opposed to the introduced ones.

*Adoption of Introduced Structural Conservation Measures*

In Dengelie catchment, although various structural soil and water conservation measures were introduced in 1999 on Food for Work (FFW), and large sum of money was spent in the form of grain every year by the government, their effectiveness was not appreciated by many farmers. And, it appeared that the introduced soil and water conservation measures were not widely practiced on individual farms. Rather, the implementation was often regarded by the local people merely as a way to obtain food for survival. As the limited information from informal interview has indicated that majority of the farmers in the Dengelie catchment participated in the soil and water conservation against their will. There fore, as compared to the proportion of farmers who perceived soil erosion as the basic problem; it is not unwise to say that the introduced SWC measures are not taken as the major farming activity by farmers of the study area.

The result from the interview has shown that, adoption rate and performance of promoted technologies has been very low. A number of potential constraints to farmers' adoption of modern SWC measures were ranked by farmers on the level of their impacts / influences. As can be seen from table 5, lack of awareness of the problems of soil erosion was understood and perceived by farmers at the seventh level. It was not emphasized and ranked at the higher level showing that farmers understood it as a less potential constraint in influencing the farmers' adoption of SWC measures at the farm level. Thus, it is less important to provide explanation to the disinterest shown by most of the farmers to wards the adoption of introduced SWC activities. On the other hand, Small land holding size and inappropriateness of conservation structures during cultivation were leveled as the first and second major potential deters of adoption in their respective ranks. According to the accounts of local farmers, almost all farmers in the Dengelie catchment held a small size of cultivable land, and they feared that large proportion of their plots would be taken by the conservation structures as the bunds and terraces would occupy large area leading to further reduction in the size of cultivable plot.

As learnt from discussions with the Development agents and farmers, due

*Table 5.Mean and Standard Deviations by Rank regarding the impact level of selected*

| Factors/Items | Rank of mean | N | Mean | St.Dev |
|---|---|---|---|---|
| Small land holding size | 1 | 102 | 4.0686 | 1.2285 |
| Inappropriateness of conservation structures during cultivation | 2 | 105 | 3.9905 | 1.1477 |
| Shortage of labor | 3 | 105 | 3.8667 | 1.2095 |
| Subsistence farming/lack of resources | 4 | 105 | 3.7810 | 1.2324 |
| The problem of termites/herbs | 5 | 105 | 3.7714 | 1.3746 |
| Inefficient and inadequate advice | 6 | 104 | 3.7692 | 1.3527 |
| Lack of awareness of the problem of soil erosion | 7 | 105 | 3.0571 | 1.4860 |
| Total | | 731 | 3.7565 | 1.3255 |

*(Source: field survey, 2003/04) "Scale 5=very high potential constraint 4=High potential constraint 3=average potential 2=low potential 1=very low potential*

to the small land holding size the households were unable to produce enough grain to meet the requirement of their family consumption. And, nearly all farm produce as well as any non-farm income obtained was devoted to food. The households do not have enough income to support and sustain a reasonable standard of living. There is no surplus for investment and input purchase. Cost is often beyond the reach of many farmers of the study area. More over, they do not have access to appropriate tools and farm power.

It is true that most of the SWC measures are labor intensive, which required large human labor. Contrary to the large family size in the study area, farmers have reported the problem of labor shortage particularly during the cropping seasons. As under stood from focus group discussion with the farmers, shortage of labor was not only associated with the physical presence, but also lack of decision. Many of the young people in the area have not shown willingness to invest their labor in agricultural activities, like soil conservation or soil fertility management process as a result of their involvement in school and off farm activities such as petty trade and weaving. Since the farm sizes are small, they prefer to work off the farm. The wives and husband, as well as small children are the only ones managing the small farms.

Farmers also questioned as to what would be the benefit if a conservation measure, that required intensive labor force is practiced on this small land size. Soil and water conservation measures, particularly the physical structures, require a huge amount of labor with long term economic returns. The absence of immediate economic returns from conservation activities has certainly affected farmers' conservation decision. And, as a result, many farmers were reluctant to construct the conservation structures on their farms. In rare cases they ploughed the bunds before stabilized consequently exposing their plots to erosion. Farmers also argue that due to the shorter distances between bunds, it is in convenient to cross wise plough, particularly with oxen driven ploughs. Thus, many farmers have not shown any interest to maintain the conservation structures. That is why farmers might have ranked it as the second important constraint in adopting the introduced SWC practices on their plots.

During the field survey it was observed that although a considerable length of bunds has been constructed, only few of the constructed bunds seemed to have effectively contributed to soil stability in many areas in the catchment. They were not well maintained and efficiently constructed. This might be due to a number of factors. As pointed out by the Development Agent, the exact lay of the land, the quality of the soil, the degree of erosion hazard and other accompanying attributes where not assessed before construction.Similarily he added that, the development agents are not well trained to give adequate and efficient advisory service to the farmers.Woresning this condition, there were only two development agents serving for more than four catchments including the study area. They also stressed that the pivotal role of farmers in the sustainability of structures was exempted by the concerned officers and the planning was undertaken by the woreda agricultural officers without the consent of farmers at all stages.

The other issue the farmers reported was the fear of the habitation of termites in the conservation structures and the growing of herbs on the structures. During discussions, this problem was also under stood as a cause for some of the farmers to reject the conservation structures.Consequently, these short comings were causes for the lack of farmers' adoption of introduced SWC structures in general and maintenance of structures in particular.

## Conclusion

It is generally accepted that, the success of any soil conservation practice depends on the farmers' acceptance, which depends on the suitability

*Fig 3, Soil bund failed to meet their purposes. the Dengelie catchment* of the newly introduced conservation schemes to the agroecoloogical condition and its effectiveness in tackling the problem. It is also important to understand the needs perceived by the farmers and knowledge of their socio economic conditions. As the first finding of this paper has shown, many farmers in the Dengelie catchment have their own perceptions about the problem of soil erosion, its causes and effects. As the farmers perception level has shown, among the different attributes listed soil erosion was ranked as the first major problem. Although, soil erosion was perceived as a major problem, there were sort of differences in understanding its level. But, more than 70 percent of the respondents perceive soil erosion as a more severe and severe problem in affecting their productivity. As to the causes, about 50.5 percent of the respondents pointed out deforestation followed by over cultivation (27.6%), where as high rain fall, topography/slope and over population were identified as the causes of erosion by 9.5, 7.6 and 4.8 percent of respondents respectively. Similarly, they were also aware of the consequences of erosion at different levels and thus above 75 percent of the respondents believe that reduction in the productivity of plots is due to erosion. Pertaining to the potential constraints influencing farmers' adoption of introduced conservation measures, farmers ranked out the different items according to their perception. And thus, among the different constraints, small land holding size and inappropriateness of conservation structures during cultivation were ranked as the first and second potential constraints influencing farmers' adoption of introduced SWC measures at the farm level. Lack of awareness of the problem of soil erosion was ranked at the seventh level in influencing farmers' conservation decision.

There fore, it is important to identify the existing realities such as the socio- economic priorities and perception of the basic problems of soil erosion and their cumulative adverse effects on farmers' adoption of the introduced SWC measures in the designing and implementation of the new/introduced SWC measures. The problems should be clearly identified in such a way that, farmers in the Dengelie catchment would practice in true sense to reduce soil erosion and manage their plots.

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# Selection of Best Fit Parent Distribution for Estimation of Quantiles in Hydrological Homogeneous Regions(The Case of Blue Nile River Basin)

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**Abstract**

**Blue Nile River Basin has been delineated into five homogeneous regions based on statistical parameters of the site data. (A.Sine, Semu.A, Sileshi B., 2004). Such method of identification is useful in determining the best fit parent distribution for the purpose of flood frequency analysis which involves statistical manipulation that has been used during the regionalization of homogeneous regions.**

**For the identified homogeneous regions four different best fitted distribution types and robust parameter estimation methods were selected to fit the standardized flow data for various return period. Generalized logistic type of distribution is found to be the best fitting distribution for region one and region four. Whereas, log Pearson III for region two, log normal for region three, and generalized extreme value for region five are selected for fitting flood quantiles. For all distributions type probability weighted moment parameter estimation method is more efficient except for log Pearson III, in which method of ordinary moment is preferred. Based on this, regional flood frequency curves are developed for all regions using standardized flow data for the purpose of estimating flood quantiles in the ungauged catchments of the basin.**

## 1. Introduction

### 1.1. Background

Flood frequency analysis provides vital information for design and economic appraisal of a variety of engineering and water resources planning and development projects. Frequency analysis of flood is a very active area of investigation in statistical hydrology. Various distributions, methods of estimation of parameters, problems related to regionalization and other related topics are being investigated. The analysis involves estimation of a flood magnitude corresponding to a required return period or probability of exceedance.

The primary objective of frequency analysis is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions (Chow et al., 1988). Data observed over an extended period of time in a river system are analyzed in frequency analysis. The data are assumed to be independent and identically distributed. The flood data are considered to be stochastic and may even be assumed to be space and time independent. Further, it is assumed that the flood have not been affected by natural or man-made changes in the hydrological regime in the system. (Rao, 2000)

The use of regional information to estimate flood magnitudes at sites with little or no observed data has become increasingly important because many projects which require design flood information are located in areas where observed flood data are either missing or inadequate.

### 1.2. Description of Study Area

The Blue Nile (Abbay) River Basin is located in the western part of Ethiopia, between

70 45' and 120 45'N, and 340 05' and 39045'E as shown in Fig 1. The study area covers about 192,953 square kilometer with total perimeter of 2440 km. It accounts for almost 17.1% of Ethiopia's land area and about 50% of its total average annual runoff.

The climate of Abbay basin is dominated by an altitude ranging from 590 meters to more than 4000 meters. The influence of this factor determines the rich variety of local climates ranging from hot to desert-like climate along the Sudan boarder, to temperate on the high plateau, and cold on the mountain peaks. The annual rainfall varies between about 800mm to 2,220 mm with a mean of about 1420mm. (Master Plan of BNRB – Main Report)

## 2. Methodology and Procedure

### 2.1. Methodology and procedure

The best method used for selection of best fit distribution is identification of hydrological homogeneous regions. Regionalization based on statistical parameters is principally suitable to identify a single common parent distribution for a single region which also involves statistical analysis. Index flood method, which comprises the observed flow data at the region were pooled to provide a more precise estimate of standardized statistical parameters, is used in the selection procedure. Generally the study involves the following procedures:

- Collection of hydrological and meteorological data, topographical map and digitized and regionalized map of the basin.
- Checking of data for consistency

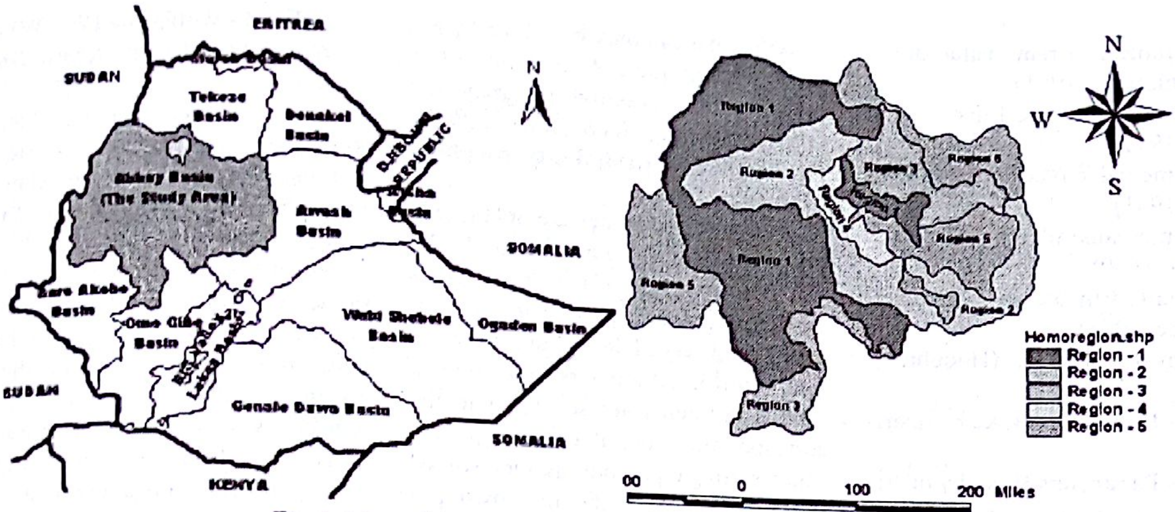



*Fig 1. Map of the Ethiopian's River Basins with the study basin*

and independence

➢ Computation of statistical parameters of selected stations within the basin

➢ Selection of the best fit distribution model using LMRD (L-Moment Ratio Diagram)

➢ Development of regional flood frequency curve for all homogeneous region

➢ Verification of measured flow data with the theoretical data which is derived from the regional curve

### 2.2. Source and Availability of Data

Time series data and topographical map of the area is used for this study. From time series data, peak series flow data is the most important one for fitting the historical data with the various distribution models. From 78 hydrological gauging stations in average of 25 years of flow data were collected from the Ministry of Water Resource. The digitized maps of the basin and map of the delineated homogeneous regions (A.Sine, 2004 page ...) map were also used to find the average statistical parameter of the stations in fitting the model.

### 2.3. Literature Review

Many flood frequency distributions have been suggested for modeling flood flows, but none has been accepted universally. Cunnane (1989) has listed the commonly used type of statistical distributions in FFA. Choice of distribution for AM series has received wide spread attention. The choice of distribution is influenced by many factors, such as methods of discrimination between distributions, methods of estimation parameters, the availability of data, etc. Generally, there is no general global agreement as to a preferable technique of model choice and no single one distribution accepted universally. For example,

➢ Log Pearson type III distribution was recommended by U.S. Water Resource council (1967) for USA

➢ General Extreme Value (GEV) distribution was recommended by the Natural Environmental Research council. (NERC, 1975) for U.K. and Ireland.

➢ Pearson type III was selected by the institute of Engineers in Australia etc.

In general the chosen distribution should be (Cunnane, 1989) widely accepted, Simple and convenient to apply, Consistent, flexible or robust (low sensibility to outliers, theoretically well based (established) and Documented in the Guide (WMO) or else where.

The importance of homogeneity for flood frequency analysis has been demonstrated by Hosking et al (1985), Wiltshire (1986). Homogeneity implies that regions having similar flood generating mechanisms which can be identified from statistical parameters of historical data. A more specific definition of a homogeneous region is that region which consists of sites having the same standardized frequency distributional form and parameters. Such a region must be geographically continuous and it forms a basic unit for carrying out regional frequency analysis.

In regional flood frequency analysis (RFFA), the established curve of flood variate versus return period can be used for estimating flood quantiles at any site within the region. For ungauged sites, RFFA involves the analysis of flood records of all gauged sites in the region, summarizing each record by few representative statistical values calculated from it and then finding a relation ship among these statistic values and measurable catchment characteristics. This will help to express the ungauged flood variate in terms of the gauged flood variate (Cunnane, 1985a).

## 3. Selection of Parameter Estimation & Distribution Models

### 3.1. Distribution Models

For fitting flood series, many distribution models are available: (Cunnane, 1989)

i- Normal and Related distributions (Hazen, 1914)

- Normal distribution
- Log normal two parameters distribution
- Log normal three parameters distribution

ii- The Gamma family

- Exponential distribution
- Two parameter Gamma distribution (Moran, 1957)
- Pearson III distribution (Foster, 1924)
- Log Pearson III distribution (USWRC, 1967)

iii- Extreme Value distribution

- Generalized extreme value distribution (Jenkinson, 1955)

- Extreme value type I distribution (Gumbel, 1941)

- Extreme value type II distribution (Gumbel, 1941)

- Extreme value type I distribution (Jenkinson, 1969)

- Weibull distribution ( Wuand Good Ridge, 1976)

iv- Wake-by distributions (Houghton, 1978 a)

- Five – Parameters Wake by distribution

- Four – Parameters Wake by distribution

- Generalized Pareto distribution.

v- Logistic distribution

- Log logistic distribution (Ahmad et. al. 1988)

- Generalized logistic distribution (Ahmad, 1988)

### 3.2. Parameter estimation methods

Numerous parameter estimation procedures have been proposed and studied in order to investigate their performance for various distributions (GUO, 1990). These include

**I. Method of Moments (MOM)**

It is one of the most commonly used methods of estimating parameters of a probability distribution. The estimates of the parameters of a probability distribution function are obtained by equating the moments of the sample with the moments of the probability distribution function. It provides simple calculations, but higher order moment estimates are biased (Wallis, et. al. 1974). Parameter estimation by MOM is known to be biased and inefficient especially with three parameter distributions.

**II. Method of Maximum Likelihood (MLM)**

Estimation by the Maximum Likelihood (ML) method involves the choice of parameter estimates that produce a maximum probability of occurrence of the observations. The parameter estimates that maximize the likelihood function are computed by partial differentiation with respect to each parameters and setting these partial derivatives equal to zero and finally solve the resulting set of equations simultaneously. The equations are usually complex that can only be solved by numerical techniques. As a result of this difficulty, the solution set may not properly found. (Roa & Hamed, 2000)

**III. Method of probability weighted Moments (PWM).**

Parameter estimates are obtained in this method, as in the case of MOM, by equating moments of the distributions with the corresponding sample moments of observed data. For a distribution with k parameters, the first k sample moments are set equal to the corresponding population moments. The resulting equations are then solved simultaneously for the unknown parameters. Parameter estimation by PWM, which is relatively new, is as easy to apply as ordinary moments (MOM), is usually unbiased and is almost as efficient as ML. Indeed in small samples PWM may be as efficient as ML. With a suitable choice of distribution PWM estimation also contributes to robustness and is attractive from that point of view. Another attraction of the PWM method is that it can be easily used in regional estimation schemes. (Roa & Hamed, 2000)

### 3.3. Selection of Parameter Estimation Methods

The selection of a distribution for flood frequency analysis goes hand in hand with the selection of the method of parameter estimation. Parameters estimated by any of the above methods are subjected to sampling errors. While a method may be efficient for one distribution it is not necessarily efficient for other distributions.

There fore, to select the most robust flood estimation procedure

- Descriptive ability tests and
- Predictive ability tests have to be applied.

## 4. Analysis and Result

### 4.1. Test for Independence and Stationarity

It is usually assumed that all the peak magnitudes in the AM series are mutually independent in the statistical sense. This assumption is usually justified. For preliminary statistical analysis, the available flow data from 78 stations were checked for the existence of dependence and persistence property with annual maximum series using

a) Wald - Wolfowitz (W - W) test

b) Lag-one serial correlation coefficient test.

Out of the analyzed data, 7 stations were found to be dependent using W-W test and 7 stations were correlated using serial correlation test: out of which 5 stations were common to both tests.

For the dependent or correlated stations, the data were corrected using double mass curve analysis with the neighboring stations. For the corrected flow data the above tests were repeated which shows that three stations (113014, 113017 and 116005) remain persistent and dependent. As a result these stations were rejected from further analysis.

Flood frequency analysis is one of the investigations of extreme events. In any time series data, outliers may or may not exist. These outliers may come due to personal error during recording and inadequacy of measuring device or really due to very extreme condition of natural phenomenon that is important information for flood frequency analysis. There fore, unless the source of the outliers clearly identified, it is difficult to remove outliers completely from analysis. Outliers can be excluded from the estimation procedure only if it is certain that AM flood can be adequately modeled by a single known distributional form. (Cunnane, 1989)

As a result outliers test was not done in this study. However, to avoid the effect of outliers an efficient method of parameter estimation like PWM was used. Even if retained in analysis, outliers have only a small effect if an efficient method of parameter estimation (ML or PWM) is used. (Cunnane, 1989)

### 4.2. Distribution Models

The distribution models that have been used in this study were recommended by WMO for AM flow data series. (Cunnane, 1989)

These are:- Normal distribution (N), Two parameter Lognormal distribution (LN2), Three parameter Lognormal distribution (LN 3), Exponential distribution (EXP), Two parameter Gamma distribution (Gam 2), Pearson III distribution (P-III), Log Pearson III distribution (LP-III), Generalized Extreme value distribution (GEV), Ex-

*Table-1*

| | | |
|---|---|---|
| Normal distribution (N) | $F(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(x-\mu)^2}$ | $-\infty < x < \infty$ <br> $\mu$ and $\sigma$ are parameters |
| Two parameter Lognormal distribution (LN2) | $F(x) = \frac{1}{\sqrt{2\pi}\, ax} \exp\left\{-\frac{1}{2}\left(\frac{\log x - b}{a}\right)^2\right\}$ | $0 < x$ |
| Three parameter Lognormal distribution (LN3) | $F(x) = \frac{1}{\sqrt{2\pi}\, a(x-m)} \exp\left\{-\frac{1}{2}\left(\frac{\log(x-m) - b}{a}\right)^2\right\}$ | $m < x$ |
| Exponential distribution (EXP) | $F(x) = \frac{1}{a} \exp\left(-\frac{x-m}{a}\right)$ | $m < x$ <br> (i.e. P-III with $b = 1$) |
| Two parameter Gamma distribution (Gam2) | $F(x) = \frac{(x/a)^{b-1}}{\lvert a \rvert \Gamma(b)} \exp\left(-\frac{x}{a}\right)$ | $0 \leq x$ if $a > 0$ <br> $x \leq 0$ if $a < 0$ <br> (i.e. P-III with $m = 0$) |
| Pearson-III distribution (P-III) | $F(x) = \frac{\left(\frac{x-m}{a}\right)^{b-1}}{\lvert a \rvert \Gamma(b)} \exp\left\{-\frac{x-m}{a}\right\}$ | $m \leq x$ if $a > 0$ <br> $x \leq m$ if $a < 0$ |
| Log Pearson-III distribution (LP-III) | $F(x) = \frac{\left(\frac{z-c}{a}\right)^{b-1}}{x \lvert a \rvert \Gamma(b)} \exp\left\{-\frac{z-c}{a}\right\}$ <br> If x P-III and $z = \log x$ | $c < z < \infty$ <br> $e^c < x < \infty$ $a > 0$ <br> $-\infty < z < c$ <br> $0 < x < e^c$ $a < 0$ |
| Generalized Extreme Value distribution (GEV) | $F(x) = \exp\left\{-\left[1 - k\left(\frac{x-u}{\alpha}\right)\right]^{1/k}\right\}$ | $\alpha > 0$ <br> $u + \frac{\alpha}{k} \leq x \leq \infty$ if $k < 0$ <br> $-\infty < x$ ? $u + \frac{\alpha}{k}$ if $k > 0$ |
| Extreme value Type I distribution (EV1) | $F(x) = \exp\left\{-e^{-\left(\frac{x-u}{\alpha}\right)}\right\}$ | $-\infty < x < \infty$ <br> $\alpha > 0$ |
| Five parameters Wake by distribution (WAK 5) | $x = m + \alpha\,[1-(1-F)^b] - c[1-(1-F)^d$ <br> where $F = F(x)$ | Note <br> It is analytically defined only in inverse form |
| Four parameters Wake by Dist. (WAK4) | $x = \frac{\alpha}{\beta}\left[1-(1-F)^{\beta}\right] - \frac{\gamma}{\delta}\left[1-(1-F)^{-\delta}\right]$ | |
| Generalized Pareto distribution (GPar) | $x = \varepsilon + \frac{\alpha}{k}\left[1-(1-F)^k\right]$ <br> $F = F(x) = 1 - \left[1 - \frac{k}{\alpha}(x-\varepsilon)\right]^{1/k}$ | |
| Log-Logistic distribution (LLg) | $F(x) = \left\{1 + \left[\left(\frac{x-a}{b}\right)\right]^{-1/c}\right\}^{-1}$ | $x > a, c > 0, b > 0$ |
| Generalized logistic distribution (GLg) | $F(x) = \left\{1 + \left[1 - \gamma\left(\frac{x-\alpha}{\beta}\right)\right]^{1/\gamma}\right\}^{-1}, \gamma \neq 0$ <br> $= \left\{1 + \exp\left[-\frac{x-\alpha}{\beta}\right]\right\}^{-1}, \gamma = 0$ | $\gamma < 0$, $\alpha + \frac{\beta}{\gamma}$ ? $x < \infty$ <br> $\gamma > 0$, $-\infty < x < \alpha + \frac{\beta}{\gamma}$ <br> $-\infty < x < \infty$ |

treme value Type I distribution (EV1), Five parameters Wake by distribution (WAK 5), Four parameters Wake by distribution (WAK 4), Generalized Pareto distribution (GPar), Log Logistic distribution (LLg) and Generalized Logistic distribution (GLg). The mathematical expressions for the distributions are shown on the table 1.

### 4.3. Use of L – Moment Ratio Diagrams

L–Moment ratio diagrams, $LC_s$ ($t_3$) versus $LC_k$ ($t_4$), were used to identify appropriate distribution to fit measured flow series of a particular station. For a given region, the sample L – moment ratios, $t_3$ and $t_4$, for each station as well as their regional average were plotted on the L – moment ratio diagram. The best parent distribution is the one that the average value of the point ($t_3$, $t_4$) of all stations within the region gets close to it.

As mentioned before, it was shown by Hosking (1990) that conventional moment ratio diagram, $C_s$ and $C_k$ values, from several samples drawn for different distributions lie close to a single line on the graph and overlap each other offering little hope of identifying the population distribution. In contrast, the sample L – moment ratios plot as fairly well separated groups and permit better discrimination between the distributions. Thus, the identification of a parent distribution could be achieved much more easily by using L-moment ratio diagrams than conventional $MRD_S$, especially for skewed distribution.

*Table 2: Selected candidate distributions for the homogeneous regions in BNRB*

| Region | Average regional L-moments $(t, t_3, t_4)$ | Selected candidate distribution |
|---|---|---|
| Region one | ( 0.15 , 0.08 , 0.16 ) | G.Logistic / Log-normal |
| Region two | ( 0.26 , 0.24 , 0.15 ) | Gamma / P – III/ LP – III |
| Region three | ( 0.38 , 0.30 , 0.19 ) | Log-normal |
| Region four | ( 0.37 , 0.41 , 0.33 ) | G.Logistic / GEV |
| Region five | ( 0.56 , 0.63 , 0.49 ) | G.Logistic / GEV |

### 4.4. Result of Identifying the Underlying Distribution

The obtained $LMRD_S$ for all regions of each station and regional average are shown in figure 2. Accordingly, the most possible underlying candidate distributions are summarized on the table 2.

### 4.5 Parameter Estimation Methods

After a distribution or a number of distributions are selected to fit the data, their parameters were estimated with different methods. The three parameter estimation methods used for evaluation are:

Method of moment (MOM)

Method of maximum likelihood (ML) and

Method of probability weighted moments (PWM)

For the candidate distributions, as chosen above, thirteen Distribution / Method of Estimation (Denoted as D/E) procedures were used in this research. These are:

GLg /MOM, GLg / PWM, LN / MOM, LN / ML, LN / PWM, Gam2 / MOM, Gam2 / ML, Gam2 / PWM, P III / MOM, P III / PWM, LP III / MOM, LP III / PWM, GEV / MOM, GEV / PWM.

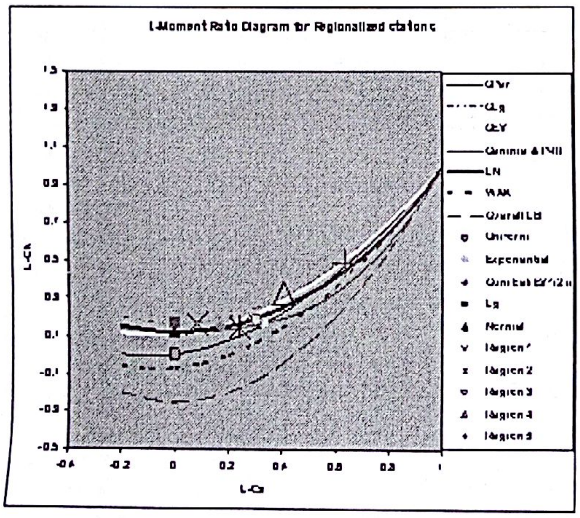
*Table 3: Candidate distributions with adopted methods of Parameter estimation*

| Candidate Distributions | Method of estimation | | |
|---|---|---|---|
| | MOM | ML | PWM |
| GLg | X | - | X |
| LN | X | X | X |
| Gam2 | X | X | X |
| P III | X | - | X |
| LP III | X | - | X |
| GEV | X | - | X |

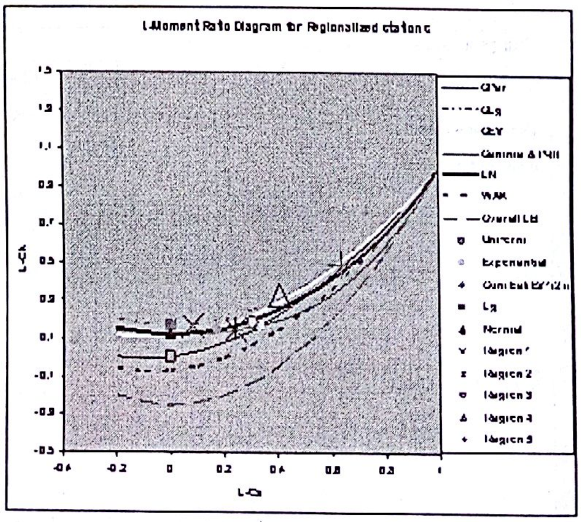
For Generalized Logistic, General Extreme Value, Pearson III and Log – Pearson III distributions, ML parameter estimation method are not selected because during the computation of the parameters the solution set did not diverge to real number. Of course this is a typical problem of ML method as mentioned in chapter three.

### 4. 6. Quantile Estimation and Confidence Intervals

After the parameters of a distribution are estimated, quantile estimates ($Q_T$) which correspond to different re-



*For all stations*



*For regional averages*

turn periods may be computed. The return period is related to the probability of non – exceedance (F) by the relation.

$$F = 1 - \frac{1}{T} \quad \text{......................... (4.1)}$$

Where $F = F(Q_T)$ is the probability of having a flood of magnitude $Q_T$ or smaller. The problem thus reduces to evaluating $Q_T$ or smaller. The problem thus reduces to evaluating $Q_T$ for a given value of F. Chow (1964) proposed a general form for calculating $Q_T$ as

$$Q_T = U_1' + K_T \sqrt{\mu_2} \quad \text{..... (4.2)}$$

Where, $K_T$ = frequency factor which is a function of return period and parameters of the distribution

$U'$, $\mu_2$ = Moments of the distribution which can be calculated by using the estimated parameters.

It is clear that a point estimate of a certain quantile corresponding to a return period may be of no real significance unless there is an indication of the accuracy of the estimate. Standard error of estimate $S_T$ which is defined as (Cunnane, 1989)

$$S_T = \sqrt{E\left(\hat{Q}_T - E\left(\hat{Q}_T\right)\right)^2} \quad \text{... (4.3)}$$

The standard error of estimate accounts for the error due to small samples, but not the error due to the choice of in appropriate distribution. The standard error of estimate depends in general on the method of parameter estimation.

Consequently each method gives a difference standard error of estimate. The most efficient method is that which gives the smallest standard error of estimate.

## 4.7. Selection of the Most Robust Flood Estimation Procedure

Descriptive ability and predictive ability tests have to be applied for evaluating the above 13 D/E procedures and come up with the most robust flood frequency model for each region.

### Descriptive Ability Test

One of the recent techniques, which are introduced under descriptive ability test, is goodness of fit measure. For the already identified regions, goodness – of – fit measure (Z) helps to test whether a given distribution fits the data acceptably or not.

For a chosen distribution, the goodness of fit measure $Z^{dist}$ is defined as:

$$Z^{dist} = \frac{\tau^{dist}_4 - \bar{t}_4 + \beta_4}{\sigma_4} \quad \text{.................................(4.4)}$$

Where, $\tau^{dist}_4$ = L-Kurtosis is value of the distribution (according to Hosking 1990))

$\bar{t}_4$ = The average L–Kurtosis value computed from the available stations data within the region.

$\sigma_4$ = Standard deviation of $\bar{t}_4$ which is obtained by repeated simulation of a homogeneous region with the distribution under test and sites having flood record lengths the same as those of the observed.

$\beta_4 = bias\ of\ \bar{t}_4$

The steps involved in a goodness of fit test are:

1. Consider a distribution
2. Fit each distribution to the group average L–moments $\bar{t}$ and $\bar{t}_3$. Denote the L – Kurtosis of the fitted distribution by $\tau^{dist}_4$

Where
$$\bar{t} = \frac{\sum_{i=1}^{N} n_i t^{(i)}}{\sum_{i=1}^{N} n_i} \quad \text{................ (4.5)}$$

$$\bar{t}_r = \frac{\sum_{i=1}^{N} n_i t_r^{(i)}}{\sum_{i=1}^{N} n_i}, \quad r = 3, 4, \ldots \quad \text{...................... (4.6)}$$

$t(i)$ = L – Moment ratio at site i

$$t^{(i)} = \frac{L_2}{L_1}$$

$L_2$ and L1 are as defined in chapter 4.

N = number of sites in a region

$n_i$ = record length at site i

3. Fit the considered distribution to the group average L – moments
4. Simulate a large number $N_{siml}$ (500) of regions from the fitted distribution. For the $m^{th}$ simulated region calculate the regional average L–skew ness $\bar{t}^{(m)}_3$ and L – Kutrosis $\bar{t}^{(m)}_4$.

1. Calculate the bias and standard deviation of $\bar{t}_4$ Using

$$\beta_4 = \frac{\sum_{m=1}^{N_{simul}} \left(\bar{t}^{(m)}_4 - \bar{t}_4\right)}{N_{siml}} \quad and \quad \text{..................... (4.7)}$$

$$\sigma_4 = \left[ (N_{siml} - 1)^{-1} \left( \sum_{m=1}^{N_{siml}} \left(\bar{t}^{m}_4 - \bar{t}_4\right)^2 - N_{siml}\ \beta^2_4 \right) \right]^{0.5} \quad (4.8)$$

A small value of $Z_{dist}$ implies that the considered distribution can be accepted as the true underlying frequency distribution for the region. According to Hosking and Wallis (1993) if

$\left| Z^{dist} \right| \leq 1.64$, The distribution is acceptable.

### Predictive Ability Test

Predictive ability tests investigate how well a distribution and its associated method of parameter estimation can estimate the Q – T relation ship or the frequency of future events when the population distribution is not identical to that of the proposed distribution.

The indicators which are used to test the predictive ability property of a distribution – method of parameter estimation (D/E) procedure are:

$$\text{Bias}(\%) = \frac{\sum \left| \hat{Q}_T - Q_T \right|}{Q_T} \times 100 \quad \ldots(4.9)$$

$$\text{Standard error (Se) (\%)} = \frac{\left[ \sum (\hat{Q}_T - \sum(\hat{Q}_T))^2 \right]^{0.5}}{Q_T} \times 100 \quad \ldots\ldots(4.10)$$

$$\text{rmse}(\%) = \frac{\left[ \sum (\hat{Q}_T - Q_T)^2 \right]^{0.5}}{Q_T} \times 100 \quad (4.11)$$

Where, $Q_T$ = Population value of standardized flood.

$\hat{Q}_T$ = Estimated value of standardized flood Quintile

The selected D/E procedures are used and sample sizes of 10, 30 and 50 are generated for unit mean and the computed weighted average values of Cv and Cs of each region in selecting a robust D/E procedure.

For a given parent distribution, sample size and return period, the simulation procedure comprises the following.

a) From regional statistics, estimate the parameters and then calculate the true flood quantile.

b) Generate a sample size of n from an assumed parent distribution

c) Fit each of D/E procedures to the synthetic data and estimate quantiles

d) Repeat steps a and b 1000 times to arrive at 1000 quantile estimates of

e) Estimate sampling distribution of values obtained in step C.

*Table 4. Selected of distributions for the regions in BNRB using Goodness of fit measure*

| Region | Candidate distributions | Goodness of fit Measure ($Z^{dist}$) | Remark |
|---|---|---|---|
| One | LN<br>GLg | 0.01<br>0.002 | Desirable |
| Two | Gamma<br>P-III / LP-III | 0.059<br>0.059 | |
| Three | LN | 0.0002 | |
| Four | GLg<br>GEV | 0.001<br>0.003 | Desirable |
| Five | GLg<br>GEV | 0.0032<br>0.0030 | Desirable |

*Table 5. Selected D/E procedures for the regions in BNRB by Comparison of measured quantiles with the simulated one*

| Region | Selected Procedure | |
|---|---|---|
| | Distribution type | Parameter estimation method |
| One | GLg | One |
| Two | LP-III | Two |
| Three | LN | Three |
| Four | GLg | Four |
| Five | GEV | PWM |

f) Apply the respective formula for each test (bias, se, rmse) to get their values for the considered D/E procedure, return period (T) and sample size (n).

The procedures giving the least estimator values are thus considered in the selection of the most robust flood estimation procedure for a given region.

However, due to time constraint and difficulty of writing programs which generate the synthetic data for different distributions, in place of predictive ability test, the following tests were used for selection of D/E procedure in addition

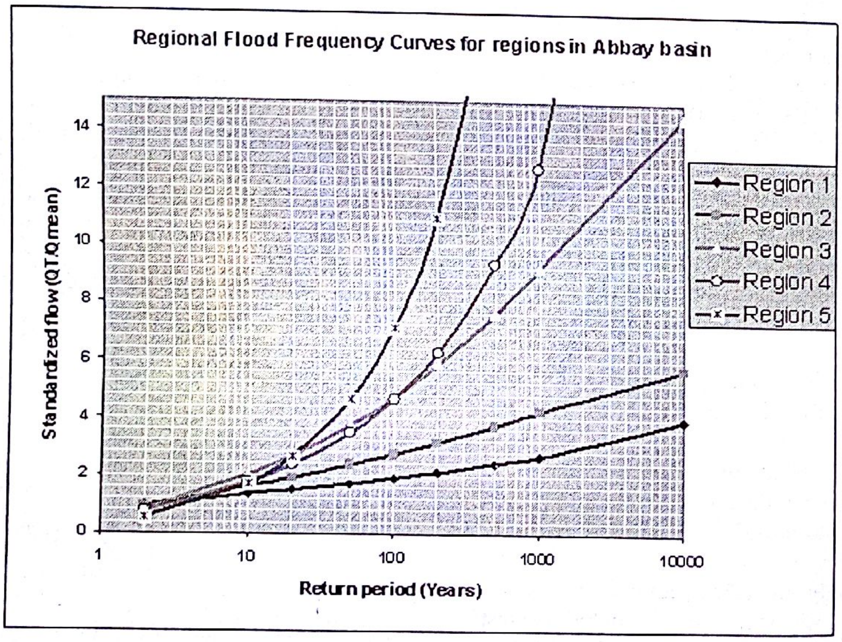



*Figure 3*

| Region | | One | | | | |
|---|---|---|---|---|---|---|
| D/E | | GLg/ MOM | GLg/ PWM | LN/ MOM | LN/ ML | LN/ PWM |
| Return period | 2 | 0.305 | 0.216 | 0.258 | 0.814 | 1.063 |
| | 10 | 0.325 | 0.277 | 0.460 | 0.937 | 1.088 |
| | 20 | 0.399 | 0.340 | 0.593 | 1.059 | 1.115 |
| | 50 | 0.531 | 0.478 | 0.784 | 1.881 | 1.144 |
| | 100 | 0.890 | 0.630 | 0.940 | 1.903 | 1.173 |
| | 200 | 1.256 | 0.831 | 1.103 | 2.126 | 1.205 |
| | 500 | 2.152 | 1.187 | 1.331 | 2.948 | 1.938 |
| | 1000 | 4.442 | 1.541 | 1.518 | 3.070 | 2.273 |
| | 10000 | 7.231 | 3.500 | 2.013 | 4.592 | 4.310 |

| Region | | Three | | |
|---|---|---|---|---|
| D/E | | LN/ MOM | LN/ ML | LN/ PWM |
| Return period | 2 | 0.143 | 0.107 | |
| | 10 | 0.490 | 0.333 | |
| | 20 | 0.747 | 0.493 | |
| | 50 | 1.145 | 0.774 | |
| | 100 | 1.496 | 1.047 | |
| | 200 | 1.894 | 1.385 | |
| | 500 | 2.502 | 1.945 | |
| | 1000 | 3.031 | 2.472 | |
| | 10000 | 5.303 | 5.066 | |

| Region | | Two | | | | | | |
|---|---|---|---|---|---|---|---|---|
| D/E | | Gam2/ MOM | Gam2/ ML | Gam2/ PWM | PIII/ MOM | PIII/ PWM | LPIII/ MOM | LPIII/ PWM |
| Return period | 2 | 0.093 | 0.109 | 0.166 | 0.057 | 0.055 | 0.028 | 0.053 |
| | 10 | 0.499 | 0.534 | 0.559 | 0.280 | 0.271 | 0.125 | 0.969 |
| | 20 | 0.659 | 0.690 | 0.705 | 0.436 | 0.434 | 0.213 | 1.299 |
| | 50 | 0.860 | 0.882 | 0.885 | 0.676 | 0.681 | 0.380 | 1.700 |
| | 100 | 1.011 | 1.024 | 1.019 | 0.885 | 0.893 | 0.566 | 2.001 |
| | 200 | 1.159 | 1.160 | 1.148 | 1.110 | 1.119 | 0.808 | 2.289 |
| | 500 | 1.352 | 1.336 | 1.316 | 1.432 | 1.438 | 1.263 | 3.662 |
| | 1000 | 1.501 | 1.471 | 1.445 | 1.701 | 1.703 | 1.761 | 3.931 |
| | 10000 | 1.866 | 1.795 | 1.756 | 2.423 | 2.406 | 3.858 | 4.636 |

| Region | | Four | | | |
|---|---|---|---|---|---|
| D/E | | GLg/ MOM | GLg/ PWM | GEV/ MOM | GEV/ PWM |
| Return period | 2 | 0.224 | 0.042 | 0.135 | 0.042 |
| | 10 | 0.491 | 0.117 | 0.401 | 0.121 |
| | 20 | 0.535 | 0.170 | 0.525 | 0.177 |
| | 50 | 0.622 | 0.279 | 0.706 | 0.289 |
| | 100 | 0.724 | 0.404 | 0.860 | 0.418 |
| | 200 | 0.881 | 0.588 | 1.033 | 0.604 |
| | 500 | 0.990 | 0.967 | 1.295 | 0.982 |
| | 1000 | 1.874 | 1.411 | 1.522 | 1.421 |
| | 10000 | 5.619 | 5.022 | 4.523 | 5.947 |

| Region | | Five | | | |
|---|---|---|---|---|---|
| D/E | | GLg/ MOM | GLg/ PWM | GEV/ MOM | GEV/ PWM |
| Return period | 2 | 0.224 | 0.024 | 0.110 | 0.022 |
| | 10 | 0.491 | 0.088 | 0.404 | 0.082 |
| | 20 | 0.535 | 0.132 | 0.533 | 0.124 |
| | 50 | 0.622 | 0.224 | 0.716 | 0.210 |
| | 100 | 0.724 | 0.335 | 0.869 | 0.316 |
| | 200 | 0.881 | 0.506 | 1.037 | 0.480 |
| | 500 | 0.990 | 0.885 | 1.292 | 0.854 |
| | 1000 | 1.874 | 1.368 | 1.514 | 1.338 |
| | 10000 | 5.619 | 5.838 | 4.525 | 5.175 |

*Table 6: SEE of the candidate distributions for different return periods*

| Region | One | Two | Three | Four | Five |
|---|---|---|---|---|---|
| D/E | GLg/PWM | LP-III/MOM | LN/MLM | GLg/PWM | GEV/PWM |

*Table 7: Selected D/E procedures for BNRB regions based on SEE*

| Region | Distribution | Method of estimation |
|---|---|---|
| Region 1 | G. Logistic | PWM |
| Region 2 | Log Pearson III | MOM |
| Region 3 | Log Normal | PWM |
| Region 4 | G. Logistic | PWM |
| Region 5 | G. Extreme Value | PWM |

*Table 4.6: Recommended D/E procedures for BNRB regions*

to description ability test.

Comparison of simulated quantiles using different D/E procedure with the actual flood quantiles.

Selection of the most efficient method that gives the smallest standard error of estimate (Cunnane, 1989)

### 4.8. Result for Selection of Parameter Estimation Method

I) Goodness of fit Measure

The results are obtained for goodness of fit on table 4.

(II) Comparison of simulated quantiles with measured flow

In this case, the simulated quantiles of each region using the candidate distributions with the selected D/E procedure has been compared with the actual flow of each station within that region. This method was used in identifying the most robust procedure to determine the flood frequency curve of the stations. Accordingly, the results were drawn out in table 5.

III) Smallest standard error of estimate (SEE)

The standard errors of the candidate distribution for different return period were computed to select the best D / E procedure which have smaller value. The result is shown in the table 6.SEE

Based on the the table 6 SEE result, the distributions have been selected for the regions in BNRB in table 7.

### 4.9. Derivation of Regional Frequency Curve for the Homogeneous Regions

According to the results obtained above, the following distributions were found to be the best procedure for describing the AM flood series and for predicting acceptable flood estimates for the five regions.

Finally for each region, the regional flood frequency curves were developed for standardized flood variate of different return periods as shown in Figure 3.

## 5.Conclusion and Recommendation

### 5.1.Conclusion

The L – Moment ratio diagram provides a practical method to identify the underlying distribution for a given region. The use of the L – Moment ratio diagram is very convenient in that one can compare the fit of several distributions using are superior to conventional moment ratios because the former are functions of probability weighted moments and less biased than ordinary moments.

Different tests were applied to select the most robust parameter estimation method. From the result, PWM were found to be the vigorous method for estimation of parameter for all regions except region 2 by MOM method. For all regions, five regional frequency curves were determined with the standardized flow series, which is important to estimate the quantiles of ungauged regions within that region after estimating the mean flood from catchment characteristics by developing regression model.

### 5.2. Recommendation

PWM parameter estimation method is found to be the most efficient method for majority of distributions used in Blue Nile River Basin. In region two, some of the observed flow data are out of the confidence interval limits for higher return period. This shows that the parameter estimation method, MOM, is not efficient in the presence of outliers.

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# Tomato Yield Response to Watering Depth and Interval

*Tilahun Hordofa, Schimeles A., Moltot Z., Lijalem Z., Melkassa ARC*


## Abstract

**Field experiments were carried out at the experimental farm of Werer Agricultural Research Center during 1996/97, 1998/99 and 2001/02 cool cropping season on alluvial soil (sandy-clay-loam to silty-clay loam) of Middle Awash Valley to establish irrigation scheduling for an optimum yield and water use efficiency tomato crop. The experiment consisted five levels of irrigation intervals (5, 7, 10, 12 and 14 days) as main plot and five levels of watering depths (50, 60, 75, 100 and 125 mm) as sub plot. The 25 treatments were laid out in a split-plot design in four replications. The response of tomato yield to irrigation depth and interval was significant only for irrigation interval. The highest yield of 462.5 q/ha was obtained for irrigation scheduled at ten days interval that has shown practically no much yield differences with five days interval. The irrigation applied at ten days interval with 50 mm depth of water resulted in higher water use efficiency (4.9 g/lt) and this was not significantly different than irrigation applied at 10 and 14 days interval with 60 and 100 mm depth of water, respectively. The average seasonal crop water requirement of tomato (592.15 mm) was estimated using Penman-Monthieth. With irrigation regime of ten days interval at 50 and 60 mm depth of water application and 14 days interval at 100 mm depth of water, the seasonal net irrigation requirements could range between 926.8 and 1176.8 mm. These irrigation regimes seem to be optimum for sustained production of tomato under the climatic condition of Middle Awash Valley.**


## Introduction

Tomato is one of the most important high value crops of Ethiopia. In the Awash valley, it is raised by small farmers and large-scale plantation for marketing and processing, respectively. In the Middle Awash valley, although cotton is the main sole crop grown by state farms, tomato is also an important vegetable crop cultivated by private farmers. The region has got excellent potential for large-scale farming. However, productivity of the farming communities largely depends on efficient use of water and proper irrigation scheduling techniques.

The importance of proper irrigation practices for optimum crop production needs no emphasis. Water should be applied to the crop in the correct amount at the proper time to obtain optimum yield. Both under and over irrigation practices would affect crop yield. Improper irrigation management practices not only waste water resources but also decrease the crop yield.

Optimal production of tomato could be achieved with proper irrigation scheduling in which the amount and interval of irrigation is determined. Climate is the major variables that govern the timing and amount of irrigation. Therefore, it is very important to develop irrigation scheduling under the prevailing climatic condition. Numerous studies have been reported in the past on the development and techniques of irrigation scheduling under different climate and management practices (Jensen et al., 1970; Singh, 1987; Wanjura et al., 1990; Fapohunda, 1992; Singh and Mohan, 1994; Imtiyaz et al. 1995; Mgadla et al., 1995; Imtiyaz et al., 1996; Steele et al., 1997).

A tomato plant is deep rooted and requires deeply wetted soil. Moisture deficits adversely affect growth and yield. Small and frequent irrigations also assure good germination and early development.

The objective of this study was to determine optimum irrigation interval and watering depth for an optimum yield and water use efficiency of tomato crop.

## Materials and Methods

Field experiment was conducted for three years to determine watering depth and interval for tomato at Werer Agricultural Research Center. The soil of the study area is brown alluvial soil having sandy-clay-loam to silty-clay loam texture. Soil physical and chemical properties show that they have no apparent constraints to crop production. Basic infiltration rate ranged from 10 to 15 mm $hr^{-1}$ whilst Ece and pH are in the range of 1.1 to 1.4 dS $m^{-1}$ and 8.0 to 8.2, respectively. The climate of the area is characterized as hot and dry during main cropping season of May to July and mild cool during second cropping season of September to February.

Tomato variety marglobe was seeded during 1996/97, 1998/99 and 2001/02 cool cropping season in mid August on nursery and transplanted to field plots of 4 by 4 m size. Transplanting time adopted in the area was mid September. The seedlings were transplanted on ridges of 80 cm at a spacing of 40 cm between plants.

The treatments consisting five levels of irrigation intervals, viz., 5, 7, 10, 12 and 14 days as main plot and five levels of watering depths, viz., 50, 60, 75, 100 and 125 mm as sub plot, were arranged in 4 replicates in split-plot design.

Four common irrigations of 50 mm were given to each treatment at five days interval before commencing the differential irrigation to insure plant establishment.

Quantities of irrigation water to be applied to each treatment-plot were predetermined and Parshal flume device was used for supplying the predetermined amount of irrigation water. All cultural practices other than treatment variables were the standard practices recommended for the area. Plot to plot yield data was collected for final analysis.

## Results and Discussion

Yield result of tomato from three years combined analysis is given in Table 1. The response of tomato yield to irrigation depth and interval was significant only for irrigation interval. The amount and interaction were found to be statistically not significant. Yields obtained at the different levels of irrigation interval and depth during the study period of 1996/7, 1998/9 and 2001/02 are given in Table 2 and 3. Except during 2001/02 irrigation interval has shown significant yield differences while watering depth has shown significant yield differences only during 1996/7.

The three years combined analysis has shown highly significant ($P<0.01$) yield difference for the different intervals of irrigation. Five, seven and ten days intervals were superior to 12 and 14 days intervals. The maximum yield of 462.5 q/ha was obtained at ten days interval that has shown practically no much yield differences with five days interval. A twelve days irrigation interval has given the lowest yield of 365.1 q/ha.

Yield of tomato has shown no significant difference for the different levels of amount. While the mean yield of tomato for the experiment was 430.1 q/ha, maximum and minimum yield of 452.6 and 386.5 q/ha was obtained at 100 and 75 mm of irrigation water application, respectively.

The yield difference obtained for the different levels of irrigation interval and amount interaction was not significant. However irrigation application at 12 days interval with an amount of 60, 75 and 100 mm and 14 days interval with an amount of 75 mm seem to be inferior particularly to five days interval with an amount of 50 mm. The five, seven and ten days irrigation interval in combination with all amounts seem to yield better compared to that of 12 days interval combined with all amounts and 14 days interval combined with amounts of 50 and 100 mm. The highest yield of 539.9 q/ha was obtained for an irrigation interval of five days and 50 mm of water application. Irrigation given at seven and ten days interval with an amount of 100 and 125 mm, respectively, gave better and comparable to the highest yield.

In 1996/7, 50, 100 and 125 mm of irrigation were superior to 75 mm of irrigation and 5, 7 and 10 days irrigation interval are superior to 12 and 14 days irrigation interval. Irrigation application of 50 mm at 5 days interval gave the highest yield whilst 100 mm at 5 and 7 days interval and 60 mm at 10 days interval gave better yield than any other treatments.

In 1998/9, 7 days interval was superior to 12 and 14 days interval while 5 and 10 days interval were superior to 12 days interval. Irrigation application of 60mm at 5 days interval gave the highest yield whilst 75mm at 5 days interval and 50, 60 and 100mm at 7 days interval gave better yield than any other treatments

During 2001/02, 14 days interval gave the highest mean yield and 50 mm of irrigation application gave the highest mean yield. The highest tomato yield was obtained from an irrigation application of 60 mm at 5 days interval.

Water use efficiency (WUE) has been computed as the ratio between the yield obtained per hectare and the water applied. WUE has been obtained from three years combined yield data. The number of irrigations, the total amount of water applied after transplanting and water use efficiency is given in Table 4. The amount of water applied for the season ranged from 450 mm to 3125 mm. The rainfall during the same season varied from 47 to 110 mm. Water use efficiency has been calculated for the treatments having yields above grand mean yield. The highest water use efficiency of 4.9 g/lt. has been obtained for irrigation applied at ten days interval with 50 mm depth of water which was not significantly different than irrigation applied at ten and 14 days interval with 60 and 100 mm depth of water, respectively. Irrigation applied at five and seven days interval with the amounts of 50 and 60 mm of water, respectively, were also seem to be better in terms of both yield and water use efficiency. Irrigation applied at 5 days interval with 100 mm of water gave the lowest water use efficiency of 1.7 g/lt.

Irrigation application of 50 and 60 mm depth of water at 5 days interval gave consistently better yield in the three years study. Nevertheless, irrigation application of 50 and 60 mm depth of watering at 10 days interval can be considered best optimum irrigation regime when considering yield and water use efficiency.

The crop water requirement of tomato calculated using Penman-Monthieth method was 592.15 mm. With irrigation regime of ten days interval at 50 and 60 mm depth of water application and 14 days interval at 100 mm depth of water, the seasonal net irrigation requirements could range between 926.8 and 1176.8 mm. These irrigation regimes seem to be optimum for sustainable production of tomato under the climatic condition of Middle Awash Valley. The number of irrigation at 10 and 14 days irrigation interval were 13 and 9, respectively.

## Conclusion and recommendation

In this study, irrigation interval did not differ significantly in one out of three year's seasons whilst depth of

*Table 1. Effect of irrigation interval and depth of water application on yield of tomato (q/ha)*

| Amount (mm) | Interval ( Days) | | | | | Mean (Amount) |
|---|---|---|---|---|---|---|
| | 5 | 7 | 10 | 12 | 14 | |
| 50 | 539.9 | 423.9 | 453.2 | 396.2 | 396.1 | 441.9 |
| 60 | 459.8 | 478.0 | 494.3 | 357.7 | 419.6 | 441.9 |
| 75 | 421.2 | 408.3 | 429.7 | 319.5 | 353.9 | 386.5 |
| 100 | 466.1 | 529.3 | 432.9 | 368.8 | 465.7 | 452.6 |
| 125 | 424.2 | 451.8 | 502.4 | 383.1 | 376.1 | 427.5 |
| Mean (Interval) | 462.2 | 458.3 | 462.5 | 365.1 | 402.3 | 430.1 |

| LSD | Interval | Amount | Interaction |
|---|---|---|---|
| 5 % - (q/ha) | 41.2 | NS | NS |
| 1 % -(q/ha) | 55.3 | NS | NS |
| S. E.-(q/ha) | 14.4 | 16.7 | 37.4 |
| C.V.- ( % ) | 25.9 | 30.2 | |

watering did not differ significantly in two out of three seasons. The interaction between interval and depth of watering were not significantly different in all three seasons. Optimum combinations of irrigation regimes were irrigation applied at 10 days interval with 50 or 60 mm depth of watering. Second best optimum combination of irrigation regime was irrigation applied at 14 days interval with 100 mm depth of water.

*Table 2. Effect of irrigation amount on tomato yield*

| Amount (mm) | Amount- mean tomato yield (q/ha) | | |
|---|---|---|---|
| | 1996/7 | 1998/9 | 2001/02 |
| 50 | 754.5 AB | 159.4 A | 411.7 A |
| 60 | 751.0 AB | 184.3 A | 390.3 A |
| 75 | 622.9 B | 172.8 A | 363.8 A |
| 100 | 835..0 A | 161.1 A | 361.5 A |
| 125 | 769.5 A | 167.7 A | 345.4 A |

*Numbers carrying the same letter are not significantly different at 5 % level.*

*Table 3. Effect of irrigation interval on tomato yield*

| Interval (Days) | Interval - mean tomato yield (q/ha) | | |
|---|---|---|---|
| | 1996/7 | 1998/9 | 2001/02 |
| 5 | 851.3 A | 177.8 A | 357.6 A |
| 7 | 825.1 A | 195.8 A | 354.0 A |
| 10 | 821.8 A | 182.0 A | 383.7 A |
| 12 | 586.9 B | 132.1 B | 376.2 A |
| 14 | 647.9 B | 157.6 AB | 401.3 A |

*Numbers carrying the same letter are not significantly different at 5 % level.*

*Table 4. Effect of irrigation interval and depth of water application on water use efficiency*

| Interval (Days) | Amount (mm) | Number of irrigation | Total irrigation (mm)* | Yield (q/ha) | Water use efficiency (g/lt)** |
|---|---|---|---|---|---|
| 5 | 50 | 25 | 1526.8 | 539.9 | 3.5 |
| | 60 | 25 | 1776.8 | 459.8 | 2.6 |
| | 75 | 25 | 2151.8 | 421.2 | |
| | 100 | 25 | 2776.8 | 466.1 | 1.7 |
| | 125 | 25 | 3401.8 | 424.2 | |
| 7 | 50 | 18 | 1176.8 | 423.9 | |
| | 60 | 18 | 1356.8 | 478.0 | 3.5 |
| | 75 | 18 | 1626.8 | 408.3 | |
| | 100 | 18 | 2076.8 | 529.3 | 2.5 |
| | 125 | 18 | 2526.8 | 451.8 | 1.8 |
| 10 | 50 | 13 | 926.8 | 453.2 | 4.9 |
| | 60 | 13 | 1056.8 | 494.3 | 4.7 |
| | 75 | 13 | 1251.8 | 429.7 | |
| | 100 | 13 | 1576.8 | 432.9 | 2.7 |
| | 125 | 13 | 1901.8 | 502.4 | 2.6 |
| 12 | 50 | 11 | 826.8 | 396.2 | |
| | 60 | 11 | 936.8 | 357.7 | |
| | 75 | 11 | 1101.8 | 319.5 | |
| | 100 | 11 | 1376.8 | 368.8 | |
| | 125 | 11 | 1651.8 | 383.1 | |
| 14 | 50 | 9 | 726.8 | 396.1 | |
| | 60 | 9 | 816.8 | 419.6 | |
| | 75 | 9 | 951.8 | 353.9 | |
| | 100 | 9 | 1176.8 | 465.7 | 4.0 |
| | 125 | 9 | 1401.8 | 376.1 | |

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# Mapping of Subsurface Features Related to Groundwater Occurrences (Geophysical Case Studies from Somali and Tigrai Regions)

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**Abstract**

**This paper deals with the results of resistivity surveys in Raya Valley (northern Ethiopia) and Horakelifo (eastern Ethiopia) conducted for groundwater explorations. The surveys carried out in Raya Valley have delineated up to six geoelectric layers. The upper three thin layers, with 5-7 meters cumulative thickness and 139-155 W-m resistivities, are attributed to dry sand, silt and sandy clay responses. The third and fourth layers, with thickness variation of 10-90 meters and resistivities of 12-38 W-m, are interpreted as effects of a saturated coarse sand/sandy-gravel bed and classified as the promising one for groundwater storage. The substratum, represented by fractured and weathered basalt, shows resistivities higher (47-105 W-m) than the overlying saturated layer.Based on resistivity survey data at Horafelifo up to eight geoelectric layers are differentiated. Among these the layer with 40-100 meters thickness and 19-48 at places up to 72 W-m, resistivity variations is interpreted to be the response of a coarse sand/sandy gravel bed and delineated as the most favorable for groundwater occurrence. This unit is underlain by a resistive (276-680 W-m) limestone bed (with a thickness of 40-100 meters), which fulfils the quality of an impermeable horizon and creating suitable environment for pore fluid accumulation by the upper sandy gravel bed. Another conductive layer (27-56 W-m) resting on the basement is mapped in the depth range of 350-800 meters. But due to its great depth of occurrence, exploitation of groundwater, which may be stored in this unit, will be expensive. Boreholes information received later confirmed the occurrence of groundwater in both areas in the suggested depth ranges. Particularly, comparisons of borehole data (acquired in the vicinity of Alamata town) with resistivity survey results from Raya Valley that conducted during the fieldwork revealed good similarities.**

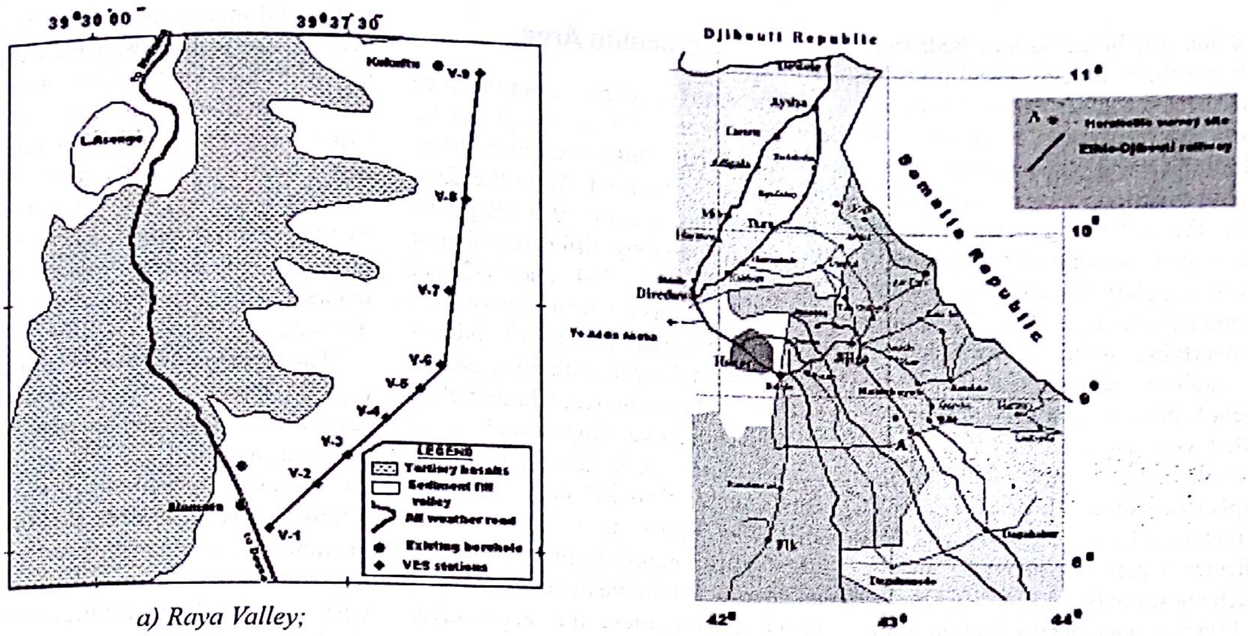
## Introduction

The entire rural community of Ethiopia gets drinking water from hand-dug wells and nearby ponds, streams and/or rivers. But cities like Addis Ababa, Mekele, Bahar Dar, Nazareth, Awassa, Dire Dawa, Dessie, Harar, Jijiga and many others are heavily dependent upon groundwater to meet their municipal and industrial water supply needs. Fortunately, groundwater resources and distributions are always related to certain favorable lithologies and/or structures, such as basins, local depressions as well as voids and openings in rocks (faults, fracture patterns, joints, beddings and contacts) that act as places for water storage or channels of circulations. Of course, due to salinity and other quality problems, water occurred in the subsurface may not always be suitable for domestic, irrigational or industrial purposes.

In any case to satisfy the community's water demand utilization of appropriate exploration techniques enabling delineation of suitable geological features, where groundwater occurs remains to be the primary objective of hydrogeology. Experiences gained so far witness that geophysical methods play a decisive role in identifying locations of such features, define their size and infer the groundwater qualities (salinity). The advantages of probing several thousands of meters into the earth at a least expense without affecting the ground so that the environmental remains safe also makes geophysical techniques the preferred and appropriate tool for groundwater exploration in different geological situations.

Therefore, among the geophysical techniques, the electrical resistivity method was implemented in two separate sites, Raya Valley and Horakelifo, situated in northern and eastern Ethiopia respectively. In Raya Valley the electrical sounding (VES) was carried out following the route between Alamata and Mohoni townships (39°30' - 39°50'E longitude and 12°17' - 12° 50'N latitude). Meanwhile, the Horakelifo site is situated in Jijiga Zone (Somali Region) about 32 km southeast of Kebrebeyah town with nearly 8 km offset from the Jijiga-Degahabour road. The coordinates bounding the survey site are 295440E–295597 E and 974937N-975242 N.

The Raya valley and Horakelifo survey sites are found at an altitude of about 1330 and 1400-1700 meters above sea level respectively. Thus, both areas have fairly flat topography and mostly covered by sand and silt. As the sediment cover in both cases is thick, there is no any better means of acquiring subsurface information that assist the groundwater exploration endeavors other than the geophysical methods. Conducting drilling without considering subsurface data could bring about negative consequences as it bears high degree of risk in terms of exploration cost. From the point of these views, resistivity surveys were conducted with ultimate targets of understanding the




a) Raya Valley;

b) Horakelifo.

*Figure 1. Location map of the survey areas*

subsurface geology and locate suitable test bore holes sites verifying whether water is available or not in a reasonable depth range and also infer its usefulness for drinking purposes.

## Objectives

With the above general considerations, the resistivity surveys in Raya Valley and Horakelifo sites were undertaken to meet the following specific objectives:

- Determine thicknesses and resistivities of the sedimentary units comprising the geologic sections and delineate those possibly related to groundwater.
- Map structurally disturbed zones, which may serve as conduits for groundwater to flow into or out of the aquifers;

Based on results of resistivity data analyses, locating suitable sites for test borehole and estimating the degree of salinity of the anticipated subsurface fluid were also parts of the survey objectives.

## Survey Methodology

In both areas the Schlumberger configuration was used. In Raya valley a 20 km long profile was surveyed with VES stations separations from 1500 to 5000 meters. The maximum spread of the depth probes was AB/2=500 meters. Meanwhile, VES stations at Horakelifo were located at 200-250 meters gap. Measurements were conducted along two, nearly perpendicularly aligned, short profiles using a maximum spacing of AB/2=1500 meters. The equipment system consisted of a 3KW Time/Frequency Domain transmitter and IPR-10A Time Domain IP/Resistivity receiver. To minimize resistivity variations that may arise due to anisotropic characters of the subsurface units, the alignment of electrodes' spreads along each profile was maintained as similar as possible.

Results revealed different kinds of VES curves that indicated variations of layers numbers and their physical characteristics. Interpretation of VES curves was initially done by curve-matching techniques using two- and three- layers master curves. Initial model parameters (depth/thickness and resistivities) obtained by such methods were then improved through iterative processes of curve generation and fitting using computer-assisted programs. Finally, the results are displayed as geoelectric sections, from which probable targets of groundwater occurrences can be differentiated.

## Results And Discussions

### Raya Valley

The electrical resistivity survey was carried out to delineate probable zones of saturation (aquifers) within the sedimentary column, determine their extensions and also delineate structurally weak zones, which may serve as conduits for groundwater to flow into or out of the aquifers. The total length of the profile was 23 km and along it VES points were located at an interval varying from 2 to 3.5 km. The maximum spread of the current electrodes was AB/2=500 meters.

Based on resistivity contrasts and significance of layers for groundwater storage, the whole section is classified into three distinct groups of geoelectric layers. The first group includes the upper thin layers with resistivities of 139-155 W-m and total thickness 5-7 meters. Due to slight variations of compositions, grain sizes and moisture contents of the sand, silt and sandy clay horizons, such minor fluctuations of resistivities could be observed. The second group comprises the intermediate two layers whose total thickness varies from 10 meters around Huda-Hula Ridge (V-6 and V-7) to 90 meters around Alamata (V-2). This group is characterized by comparatively low resistivities (12 - 38 W-m). Lithologically, these low responses are attributed to saturated coarse sand - sandy-gravel beds. The third group represents the bottom layer, which is characterized by values ranging between 47 and 105 W-m. It interpreted to be due to a relatively hard formation, which is slightly fractured and weathered basaltic bedrock.

From the hydrogeological point of view, the layers classified in the second group and interpreted as coarse sand and sandy gravel responses are the favorable ones for water storage. Meanwhile, the underlying resistive formation (slightly weathered basaltic rock) serves as an impermeable bed preventing the percolation of pore fluids from the overlying aquifer. These geophysical results were later compared with borehole data. Accordingly, at borehole drilled very close to the V-1 (at the borehole drilled for the Alamata water supply) the water table lies at a depth of 96 meters, whereas the resistivity data indicates a depth of about 85 meters, which shows only a ±3 % difference.

Figure 3. Geoelectric section of the Were Abaye survey site (Raya Valley).

It must be noted that at V-3 the resistivity values are low (4-9 W-m) compared to those at the neighboring stations. At a depth of 100 meters, which is the top of the hard impermeable bed, the resistivity values are in the range of 18-28 W-m only. These low responses indicate the conductive nature of the subsurface. During the field study various hand-dug wells were observed around V-3 and in this particular locality due to its green nature serves as a grazing land. Besides, domestic animals were seen eating not only the grass, but sometimes the soil too.These facts are indications of shallow groundwater, which may be saline to some extent. Hence the significance difference of resistivity values observed at V-3 for all layer the subsurface through which slightly saline water moves upward.

## Horakelifo Area

The sounding curves from this area are of different types, but a systematic interchanging of high and low resistivity values is observed. As to the data, the subsurface features at VES points V-1 and V-2 slightly differ from that of V-3 and V-4. At V-1 and V-2 six geoelectric layers are identified overlying the substratum. But at V-3 and V-4 one additional layer, with apparent resistivity values relatively higher than the immediate overlying or underlying units (figure 2a), is delineated in the depth range of 60-120 meters. Generally, the upper thin layers, with resistivities ranging from 17 to 58 W-m, have a cumulative thickness of 2-14 meters. Among these, the second layer is relatively conductive (17 W-m) and 3-4 meters thickness at stations V-3 and V-5. This low response may be due to slightly increased moisture content. A relatively thin layer of 0.2-2.3 meters thickness and 24-409 W-m resistivity is identified in the depth range of 3-3.5 meters. During the course of field survey hand-dug wells, with depth of about 2.6-3.o meters were observed, from which the local people are seen fetching water for domestic purposes and also animal drinking. Therefore, it is possible to conclude that water is associated with the second low resistivity bed, whereas the third resistive layer acts as an impermeable bed and taps the shallow water exploited by the local community.

The fourth layer shows resistivities ranging from 1 to 15 W-m and its thickness varyies from 13 meters (at station V-2) to 50 meters (at stations V-1 and V-4). These responses, which are detected throughout the line, are attributed to a stratum of sandy clay composition with considerable moisture content. Underlying it, but only at stations V-3 and V-4, a layer with high resistivity and thickness ranges (115 to 180 W-m and 50-80 meters respectively) is mapped. This response is attributed to dry sand.

The layer underlying the above-discussed ones is characterized by resistivities 19-48 W-m, at places up to 72 W-m, and thickness range of 100-245 meters. Its minimum thickness is inferred around station V-1 and the maximum at V-3. This low resistivity is interpreted due to saturated coarse sand with gravel and hence suggested to be the favorable horizon for water storage. From the anomalies' amplitude the fluid pores do not seem to be saline and thus suitable for human and animal life. A strong resistive layer, with values ranging from 276 to 680 W-m and thickness varying from nearly 40 meters at station V-1 to 100 meters around station V-2 is delineated below the saturated coarse sand/sandy gravel bed. This enhanced response is interpreted to be due to a limestone bed.

This resistive bed fulfils the condition of a stable acquiclude that prevents further percolation of pore fluids from the overlying sandy gravel bed. At station V-1 the top of this resistive bed occurs at a depth range 150-190 meters, whereas at station V-2 it lies at a depth of about 360 meters. However, the bottom of this resistive layer and the occurrence of other layers identified at

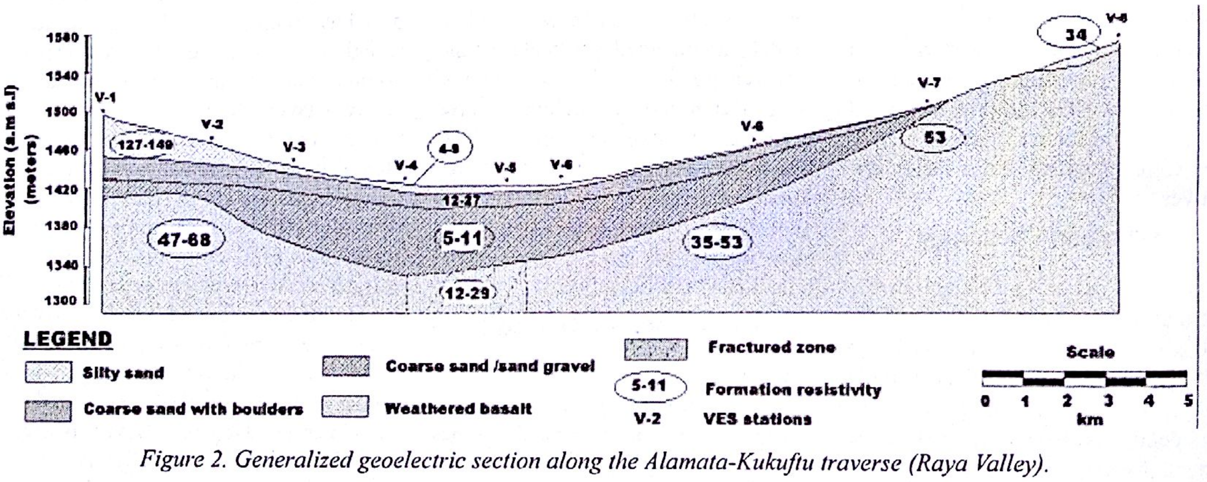



*Figure 2. Generalized geoelectric section along the Alamata-Kukuftu traverse (Raya Valley).*

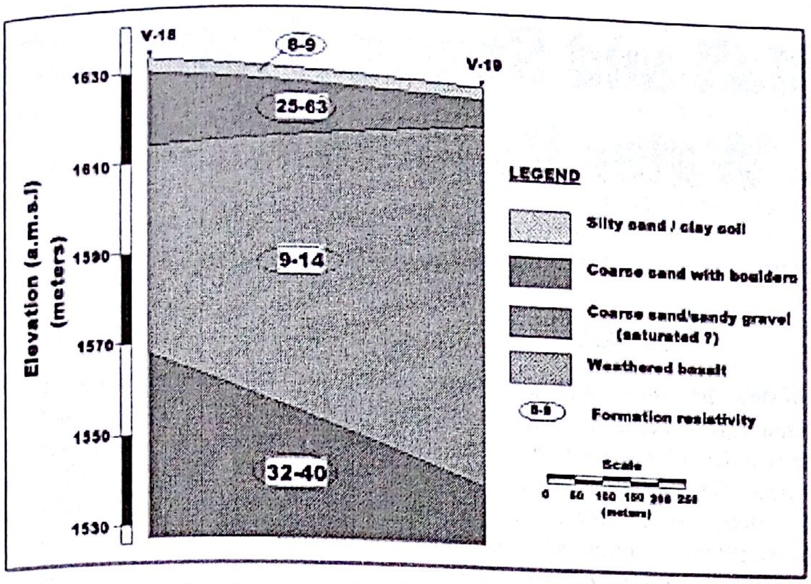



*Figure 3. Geoelectric section of the Were Abaye survey site (Raya Valley).*

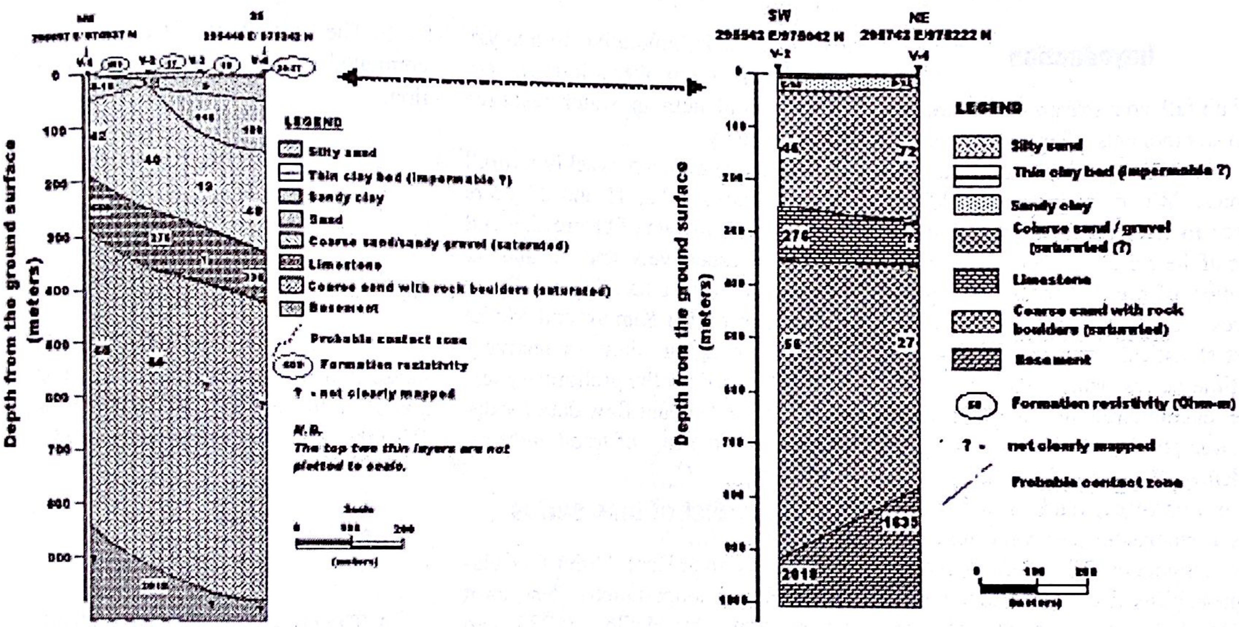



*Figure 2. Representative geoelectric sections along two survey lines of the Horakelifo site.*

stations V-1, V-2 and V-5 is not confirmed by this data. But a general picture about the geologic section of the area is acquired from stations V-2 and V-5. At stations, where the lower saturated bed and the basement are not mapped, it may be necessary to try to map using a wider electrodes' spread with more powerful equipment.

From the depth ranges of 300-400 meters up to 800-1000 meters a layer with a resistivity range of 28-98 W-m and thickness of ~500-550 meters is mapped. This relatively low resistive formation is interpreted to be a response of coarse sand with rock fragments. At stations V-2 and V-5 the depth to the bottom of this layer is estimated to be about 900-930 and 780-820 meters respectively (figure 2a). It is inferred that this low resistive and thick bed is the second aquifer, whose groundwater potential may be controlled by the regional trend of the underlying high resistive (1635 and 2018 èÙ W-m) formation interpreted as a basement response (figure 2b). The resistivity responses indicate the moderately massive nature of the basement top and hence allow the overlying coarse sand bed to accumulate sufficient fluid in free spaces. However, even if groundwater would be discovered associated with this bed, the great depth of occurrence will make the exploitation very expensive and hence does not attracts much.

## Conclusions

Survey results from both areas delineated target with groundwater potentials. In all cases such targets are characterized by moderately low apparent resistivity value (<30-40W-m) are attributed to layers of coarse sand/sandy gravel compositions. The depth groundwater of occurrences extends to 100-120 meters at Raya valley, 70 to 230 meters at Horakelifo. The amplitudes of resistivity anomalies suggest that the salinity of the groundwater it low, and therefore suitably used for drinking and other purposes. However, at Raya Valley around V-4 and V-5 the salinity may be relatively enhanced due to where the fractured character of the bottom layer which could bring saline solution from depth. Besides, at Horakelifo another probable aquifer zone sandwiched from top by limestone from bottom by the basement. But its depth doesn't make the exploration, and more than this the exploitation, very expensive.

# Preliminary Rainfall and Stream Flow Analysis prior to Water Resource planning study

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## Abstarct

Preliminary analysis of rainfall and stream flow time series is of paramount importance prior to water resource planning study. Sperman Rank Order Correlation (SROC) and the nonparametric run test were used to test the trend and randomness of rainfall and stream flow data series, which could be used to study the status of rainfall and stream flow, which would contribute for the recurrent drought situation in Ethiopia. The result indicated that the active weekly rainfall at Addis Ababa, the monthly rainfall at DeberZeit and Melkassa and the total flow of Awash river at Melka Kunure and Melka Hombole is trend free, showing that the data could be directly used for any stochastic modeling process with no effort to remove the trend. Most of the historical rainfall and stream flow time series tested under this study were random which confirmed the recurrent erratic pattern of hydrological time series of the study area.


Key words: Rainfall, Stream flow, Ethiopia, Trend, randomness test

## Introduction

Rainfall and stream flows are the main components of hydrologic cycle and are the major input of water resources. Water is indispensable resource to life and development in all parts of the world. The amount and distribution of rainfall holds the key for success of Agricultural production. Most statistical analyses of hydrological time series data at the usual time scale encountered in water resources planning studies are based on a set of fundamental assumptions i.e., the series is trend-free, random and constitutes a stochastic process whose random component follows the appropriate probability distribution function.

The study was carried out at the upper basin of Awash River in Ethiopia comprising the section of the catchments from the headwaters to Koka reservoir (Fig.1). The altitude ranges from 3000 m to 1800 m above sea level. Having the bi-modal (short rain during March and April and main rainy season June to September) nature of the rainfall pattern, the mean annual rainfall over the downstream catchments is 850 mm and the headwater of the Awash River is 1216 mm. However, the erratic distribution of this rainfall in the absence of water harvesting and supplementary irrigation schemes exposes the area to severe drought. Since rainfall distribution and river flows vary greatly through time and space, it is imperative to analyze the rainfall pattern over a long period, which would help in water resource planning study.

Twenty years active weekly rainfall data of Addis Ababa, 41 and 23 years monthly rainfall data of Debre Zeit and Melkassa respectively and 33 and 31 years stream flow data of Awash River recorded at Melka Kunure and Melka Hombole gauging sites respectively have been used for the preliminary test of rainfall and stream flow data for detecting the existence of trend and randomness.

## Trend Test of time series

The Sperman Rank Order Correlation (SROC) nonparametric test, as it was presented by McGhee (1985) and performed by Adeloye and Montaseri (2002) was used to investigate the existence and long term trend of the rainfall and stream flow data. The stepwise procedure is as follows.

The data series Yi, i= 1, 2, 3, n, are observed in time i:

1. Ranks (Ryi) were assigned to Yi, such that the largest Yi had Ryi = 1 and the least Yi had a rank = n. In a data series where there are ties in the Yi, a rank equal to the mean of the ranks that would have been used had there been no ties, was assigned to each of the ties.

2. The difference (di = Ryi – i), was computed.

3. The coefficient of trend, $r_s$, was computed using the following equation.

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)}$$

Where, n is the sample size.

The student's t distribution with n-2 degrees of freedom was taken as a test statistics to test the null hypothesis (Ho) that the time series has no trend.

$$t = r_s \sqrt{\frac{n-2}{1-r_s^2}}$$

4. The critical values of the t-distribution for the chosen significance level, ± = 5 % significance level, and n-2 degrees of freedom was obtained from the standard table.

5. The critical region of the test statistic was, Reject Ho if $t > t_{0.025\,n-2}$ or $t < -t_{0.025,\,n-2}$ for a two tailed test.

## Rainfall

The historical rainfall data of Addis Ababa, Debre Zeit and Melkassa were evaluated for their trend freeness with t-test hypothesis in which the null hypothesis (Ho) is that the time series has no trend. It means that reject Ho, if the calculated value $t_c > t_{0.025,\,n-2}$ or $t_c < -t_{0.025,\,n-2}$ or otherwise, at n-2 degrees of freedom and 5 % level of significance for two tail test. The tabulated values are ,

$\pm t_{0.025,18} = \pm 2.1($

$\pm t_{0.025,39} = \pm 2.0231$ and

$\pm t_{0.025,21} = \pm 2.080$ at 18, 39 and 21 degrees of freedom for rainfall of Addis Ababa, Debre Zeit and Melkassa respectively. As shown in Table 1 and 2 , the results indicated that all the positive values of calculated 't' is less than the corresponding critical tabulated 't' values of 2.101, 2.0231 and 2.080 and all the negative calculated 't' values are greater than that of tabulated values of -2.101, -2.0231 and –2.080 for the observed rainfall data of Addis Ababa, Debre Zeit and Melkassa respectively. This indicates that the null hypotheses is not rejected and the observed historical rainfall time series of the corresponding sites is trend free implying that "there is no statistical evidence of a long-term trend" in all the rainfall records.

## Stream flow

The calculated ' t' values for trend test of Awash River flow at Melka Kunture and Melka Hombole gauging sites are shown in Table 3 and 4 respectively. The critical tabulated values of 't' for the respective gauging sites are $\pm t_{0.025,31} = \pm 2.0399$ and $\pm t_{0.025,29} = \pm 2.045$. The null hypothesis (Ho) is that the time series has no trend, meaning that reject Ho, if the calculated value $t_c > t_{0.025,\, n-2}$ or $t_c < -t_{0.025,\, n-2}$ or otherwise, at n-2 degrees of freedom and 5 % level of significance for two tail test. The calculated ' t' values for total and mean flow of Awash River at Melka Kunutre and total and mean flows at Melka Hombole gauging stations respectively are compared with the critical tabulated 't' values. The results indicated that all the positive calculated 't' values of observed historical data of total and mean flow of Awash

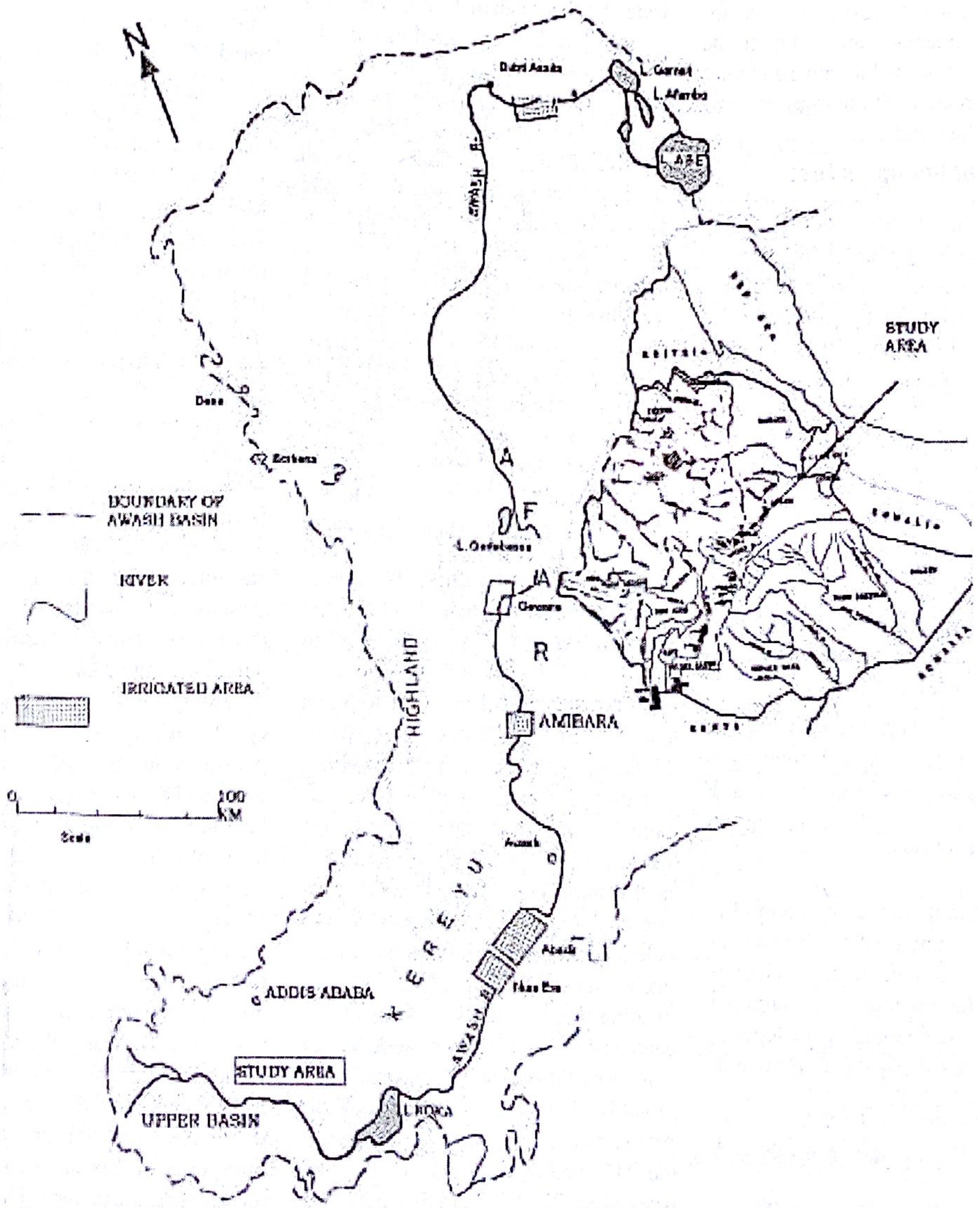


*Figure -1*

River recorded at Melka Kuntre and Melka Hombole gauging stations are less than 2.0399 and 2.045 and the negative calculated 't' values are greater than -2.0399 and –2.045 respectively. This shows that the null hypothesis is not rejected implying that the observed historical river flow data is trend free and "there is no statistical evidence of a lông-term trend" in all the stream flow events.

Adeloye and Montaseri (2002) testified that a stream flow data with the presence of trend would complicate any subsequent analysis, which could be difficult for stochastic modeling of the time series. Therefore, it could be concluded that the historical rainfall and stream flow time series, which were tested for their trend freeness under this study, could be directly used for any stochastic modeling process with no further effort to remove the trend.

## Randomness test

The nonparametric run test was used to test the data series for randomness as it was described by McGhee (1985), Agarwal (1988) and adapted by Adeloye and Montaseri (2002). The objective is to test whether the data series $Y_i$, i = 1, 2, 3, …n, is random based on the runs of the data with respect to the median of the observation. The stepwise procedure is as follows.

1. The median of monthly and weekly observations of rainfall data was determined. This was done by sorting the sample in an ascending order of magnitude such that $Y_1 \leq Y_2 \leq \cdots \leq Y_n$. Then for an integer k, such that n = 2k (even) or n = 2k + 1 (odd), the sample median denoted by was estimated as follows:

2. The data item, which exceeds the median, was named as letter S as a success case and the data item, which does not exceed the median, was examined as a failure case denoted by the letter F. Cases that are exactly equal to the median were excluded.

$$\hat{Y}_{05} = \begin{cases} Y_{k+1} & for\ n = 2k + 1 \\ 0.5(Y_k + Y_{k+1}) & for\ n = 2k \end{cases}$$

3. The number of success and failure were counted and denoted by $n_1$ and $n_2$ respectively.

4. The total number of runs were counted from the data set and denoted by R.

5. The test statistic was computed using the following equation.

$$Z = \frac{R - \left[\dfrac{2n_1n_2}{n_1+n_2} + 1\right]}{\sqrt{\dfrac{2n_1n_2\left(2n_1n_2 - n_1 - n_2\right)}{\left(n_1+n_2\right)^2\left(n_1+n_2-1\right)}}}$$

6. The null hypothesis (Ho) i.e. the sequence of Ss and Fs is random was rejected for the standard distribution $Z < -Z_{0.025}$ or $Z > Z_{0.025}$ at 5% significant levels.

## Rainfall

The historical rainfall time series was evaluated for their randomness with 'Z' hypothesis test statistic for weekly rainfall of Addis Ababa, monthly rainfall of Debre Zeit and Melkassa. The null hypothesis (Ho) taken for the test was that the time series is random. It means that reject Ho, if the calculated 'Z' values i.e. $Z_c > Z_{0.025}$ or $Zc < -Z_{0.025}$ or otherwise. The calculated standard normal variate (Z) value was tested at 5 % significance level for two-tailed test with that of the tabulated value i.e. $\pm Z_{0.025} = \pm 1.96$. Table 1 and 2 indicated that the Z value 2.297 during week 11 is greater than tabulated 'Z' value of 1.96 and 'Z' value of -2.297 in week 30 is less than –1.96 in the case of Addis Ababa rainfall and –2.1847 is less than –1.96 in October rainfall of Melkassa. This shows that the null hypothesis is rejected implying that the rainfall time series during these two weeks and in the month of October is not random. While during the other periods, all the positive calculated 'Z' values is less than 1.96 and the negative calculated values of 'Z' is less than –1.96 indicating that the null hypothesis is accepted implying that "there is statistical evidence of randomness" in weekly and monthly rainfall data series of Addis Ababa, Debre Zeit and Melkassa except the 11th week (March12-18) and 30th week (July 23-29) of Addis Ababa and October rainfall of Melkassa in which there is no statistical evidence of randomness in the data.

## Stream flow

The historical river flow time series of Awash River at Melka Kunture and Melka Hombole gauging sites were tested for their randomness taking the null hypothesis (Ho) as of the stream flow time series is random. It means that reject Ho, if the calculated 'Z' values i.e. $Z_c > Z_{0.025}$ or $Zc < -Z_{0.025}$ or otherwise. The calculated standard normal variate (Z) value was tested at 5 % significance level for two-tailed test with that of the tabulated value i.e. $\pm Z_{0.025} = \pm 1.96$.

As shown in Table 3 and 4, the result indicated that all the positive calculated 'Z' values are less than the tabulated 'Z' value of 1.96 and all the negative calculated 'Z' values are greater than tabulated 'Z' value of -1.96 except February mean monthly discharge at Melka Kunture where, 'Z' value is -2.156 and total flow and mean monthly discharge of January at Melka Hombole where, 'Z values are -3.345 which are less than –1.96. This shows that the null hypotheses is accepted implying that "there is statistical evidence of randomness" in all the observed stream flow data of Awash River recorded at Melka Kunture and Melka Hombole gauging sites except mean discharge in February at Melka Kunure and total flow and mean discharge in January at Melka Hombole in which there is no statistical evidence of randomness in the data.

Salas, (1993) and Locks et al., (1981) justifies that the outcome of non-randomness implies that there is persistence in the series, which could be modeled using one of the many available time series models such as the autoregressive or the Auto Regressive Moving Average (ARMA) model. On the other hand, Chow, (1964) testified that the observed values in a purely random time series imply that the series fluctuates erratically about some mean value. From this it could be concluded that the outcome of the randomness of the historical rainfall and stream flow time series of this study confirmed the recurrent erratic pattern of hydrological time series of the study area.

*Table1. Trend and Randomness test for weekly rainfall data of Addis Ababa*

| Week No. | t values | Z values | Result | Week No. | t values | Z values | Result |
|---|---|---|---|---|---|---|---|
| 09 | 0.7449 | -0.460 | trend-free & random | 25 | 0.6420 | 1.378 | trend-free & random |
| 10 | -0.4394 | -0.460 | trend-free & random | 26 | -0.6718 | 0.460 | trend-free & random |
| 11 | 0.6867 | 2.297 | trend-free, not random | 27 | -0.8864 | 0.919 | trend-free & random |
| 12 | 0.5255 | -1.378 | trend-free & random | 28 | -1.0814 | 0.460 | trend-free & random |
| 13 | 2.0757 | 0.000 | trend-free & random | 29 | -0.8796 | 0.919 | trend-free & random |
| 14 | 0.9616 | -0.919 | trend-free & random | 30 | 0.3973 | -2.297 | trend-free, not random |
| 15 | 0.8983 | 0.000 | trend-free & random | 31 | 1.2144 | -1.378 | trend-free & random |
| 16 | -0.9513 | 0.000 | trend-free & random | 32 | -1.3306 | 1.378 | trend-free & random |
| 17 | -0.5533 | -1.378 | trend-free & random | 33 | -0.1085 | 0.000 | trend-free & random |
| 18 | -0.3908 | 0.919 | trend-free & random | 34 | 0.2236 | -1.378 | trend-free & random |
| 19 | -0.5255 | -0.460 | trend-free & random | 35 | 0.0255 | -0.460 | trend-free & random |
| 20 | 1.136 | 0.000 | trend-free & random | 36 | 0.7800 | 0.919 | trend-free & random |
| 21 | 0.5288 | 0.000 | trend-free & random | 37 | 1.0048 | 0.919 | trend-free & random |
| 22 | -1.0169 | 0.000 | trend-free & random | 38 | 0.1213 | -0.460 | trend-free & random |
| 23 | -0.1468 | -0.460 | trend-free & random | 39 | 0.6453 | -1.838 | trend-free & random |
| 24 | -1.0797 | -0.919 | trend-free & random | 40 | 0.4702 | -0.919 | trend-free & random |

*Table 2. Trend and Randomness test for monthly rainfall of Debre Zeit and Melkassa*

| Month | Debre Zeit | | | Melkassa | | |
|---|---|---|---|---|---|---|
| | t | Z | Result | t | Z | Result |
| January | -0.6000 | | Trend-free | 0.47 | 0.4369 | Trend-free and random |
| February | 0.2930 | 1.6018 | Trend-free and random | 0.89 | 1.310 | Trend-free and random |
| March | -0.3618 | 1.9220 | Trend-free and random | -0.26 | 0.8739 | Trend-free and random |
| April | 0.5305 | -1.2815 | Trend-free and random | 0.04 | 1.7477 | Trend-free and random |
| May | -1.6200 | -0.3204 | Trend-free and random | 1.44 | 0.8739 | Trend-free and random |
| June | -1.6578 | -1.2815 | Trend-free and random | -0.55 | 0.4369 | Trend-free and random |
| July | -1.0721 | -0.9611 | Trend-free and random | -1.65 | 0.0000 | Trend-free and random |
| August | 1.1947 | -0.6407 | Trend-free and random | -1.04 | 0.4369 | Trend-free and random |
| September | 0.9754 | 0.0000 | Trend-free and random | 0.15 | 1.7477 | Trend-free and random |
| October | -0.8598 | -0.6407 | Trend-free and random | -0.04 | -2.1847 | Trend-free but not random |
| November | 0.6807 | | Trend-free | 0.59 | | Trend free |
| December | 1.9688 | | Trend free | 0.88 | -0.4369 | Trend-free and random |

*Table 3. Trend and randomness test for total and mean flow of Awash River at Melka kunture*

| Month | Total flow (MCM) | | | Mean monthly discharge (cmecs) | | |
|---|---|---|---|---|---|---|
| | t | Z | Result | t | Z | Result |
| January | 0.164 | -0.359 | Trend-free and random | 0.164 | -0.359 | Trend-free and random |
| February | 1.553 | -1.438 | Trend-free and random | 1.593 | -2.156 | Trend-free not random |
| March | 0.162 | 0.359 | Trend-free and random | 0.172 | 0.359 | Trend-free and random |
| April | 0.652 | 0.359 | Trend-free and random | 0.652 | 0.359 | Trend-free and random |
| May | -0.099 | 0.359 | Trend-free and random | -0.179 | 0.359 | Trend-free and random |
| June | -0.473 | -0.719 | Trend-free and random | -0.656 | -1.078 | Trend-free and random |
| July | 1.915 | 0.359 | Trend-free and random | 1.915 | 0.359 | Trend-free and random |
| August | 0.924 | 1.438 | Trend-free and random | 0.924 | 1.438 | Trend-free and random |
| September | 0.791 | 0.719 | Trend-free and random | 0.424 | 0.000 | Trend-free and random |
| October | 1.825 | 0.000 | Trend-free and random | 1.825 | 0.000 | Trend-free and random |
| November | 1.316 | -1.078 | Trend-free and random | 1.316 | -1.078 | Trend-free and random |
| December | 1.763 | -1.078 | Trend-free and random | 1.762 | -1.078 | Trend-free and random |

*Table 4. Trend and randomness test for total and mean flow of Awash River at Melka Hombole*

| Month | Total flow (MCM) | | | Mean monthly discharge (cmecs) | | |
|---|---|---|---|---|---|---|
| | t | Z | Result | t | Z | Result |
| January | 1.141 | -3.345 | Trend-free not random | 1.141 | -3.345 | Trend-free not random |
| February | 0.549 | -1.486 | Trend-free and random | 0.588 | -0.743 | Trend-free and random |
| March | 1.023 | 0.743 | Trend-free and random | 1.023 | 0.743 | Trend-free and random |
| April | 0.139 | 1.486 | Trend-free and random | 0.139 | 1.486 | Trend-free and random |
| May | 0.596 | 0.372 | Trend-free and random | 0.596 | 0.372 | Trend-free and random |
| June | -0.858 | -1.115 | Trend-free and random | -0.858 | -1.115 | Trend-free and random |
| July | 1.111 | 1.486 | Trend-free and random | 1.111 | 1.486 | Trend-free and random |
| August | 0.022 | 0.743 | Trend-free and random | 0.022 | 0.743 | Trend-free and random |
| September | 0.554 | 0.000 | Trend-free and random | 0.561 | 0.000 | Trend-free and random |
| October | -0.705 | 0.000 | Trend-free and random | -0.705 | 0.000 | Trend-free and random |
| November | -0.523 | -1.858 | Trend-free and random | -0.495 | -1.858 | Trend-free and random |
| December | 0.156 | -1.858 | Trend-free and random | 0.156 | -1.858 | Trend-free and random |

## Conclusion

The historical rainfall of Addis Ababa, Debre Zeit and Melkassa and Awash River flow at Melka Kunture and Melka Hombole gauging sites were evaluated for their trend freeness with t-test hypothesis and are trend free. It could be concluded that the historical rainfall and stream flow time series could be directly used for any stochastic modeling process with no further effort to remove the trend. Moreover, the time series resulted in purely random implying that the series fluctuates erratically about some mean value. From this it could be concluded that the outcome of the randomness of the historical rainfall and stream flow time series of this study confirmed the recurrent erratic pattern of hydrological time series of the study area in Ethiopia.

## Recommendation:

1. The historical rainfall time series of Addis Ababa, Debre Zeit and Melkassa and Awash River flow at Melka Kunture and Melka Hombole gauging sites are trend free so as it is easy for developing stochastic modeling of the time series in the agricultural development planning process.

2. The randomness of the historical rainfall and stream flow time series of this study confirmed the recurrent erratic pattern of hydrological time series of the study areas which could be taken into consideration by the policy makers for agricultural development planning and enhancing possible interventions to alleviate poverty and food insecurity in the nation.

## Notations:

*The following notations are used in this paper*

*SROC* = *Sperman Rank Order Correlation*
*EARO* = *Ethiopian Agricultural Research Organization*
*Ho* = *Null hypothesis*
$\hat{Y}_{0.5}$ = *Sample median*
*S* = *Success*
*F* = *Failure*
*R* = *Runs*
$n_1$ = *number of success*
$n_2$ = *number of failure*
*Z* = *Standard normal variate*
*ARMA* = *Auto Regressive Moving Average*

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# Evaluation of Selected Hydropower Potential Sites (A Case Study of Abbay River Basin, Ethiopia)

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**Abstract**

**The undulated topographic feature and the ample runoff water from streams of Ethiopia permits to exploit a huge amount of hydropower energy. Through it is believed that the country endowed with huge amount of hydropower potential, and also various studies have been conducted on the sector along with other water resource development, most of the studies are not satisfactory. There is a discrepancy on various documents and reports on the magnitude of the available hydropower potential as well the number of the potential sites. So as to minimize the information gap topographical and hydrological site evaluation for the selected hydropower potential sites have been carried out, for 129 possible potentials sites which are identified by WAPCOS in 1990. The desk study site evaluation gets 29.45% of it not feasible and there are 91 possible sites. The total theoretical potential of Abbay River Basin according to WAPCSO is 13854MW, however, these 91HP sites gives 12148MW.**

**For convenience of discussion, these 91 possible hydropower potential sites are categorized and mapped on the GIS environment, in addition the potential of the sub-basin are assessed. Dabus sub-basin stands first among the 16 sub-basins by 13 hydropower potential sites and these sites give 3524MW. Similar studies can be conducted for other major drainage basin of the country to know the potential of the country.**

## 1.Introduction

Sustainable energy development is essential and necessity for socioeconomic development of a country. Satisfying the energy needs of the population through sustainable energy based approach helps to avoid deforestation and improvement of living standard in developing countries.

In the recent times, the non-renewable and exhaustible sources of energy are getting depleted at a very fast rate, which has focused attention to the non-exhaustible and renewable sources of energy. Hydropower is one of the most common renewable sources, abundantly available in the hilly region provided that there is adequate rainfall that could form rainfall.

Ethiopia has significant water resources, which can be appropriately utilized to enhance the socio-economic development of its people [MoWR, 2002]. Based on topography, Ethiopia is subdivided into twelve major drainage basins. Among these, Abbay River Basin (ARB) is one of the major and largest river basins and it is sub-divided in to 16 sub-basins. ARB is by many criteria the most important river basin. The hydrology of the river basin is dominated by river Abbay which rises in the centre of the catchments and develops its course in a clock wise spiral

## 2. Description of the Study Area

The study area, Abbay River Basin (ARB), which is found in the northwest part of Ethiopia, between 7°45' and 12°45'N, and 34°05' and 39°45'E [Awulachew 2000]. This river basin is, by most criteria, the most important river basin in Ethiopia. It covers about

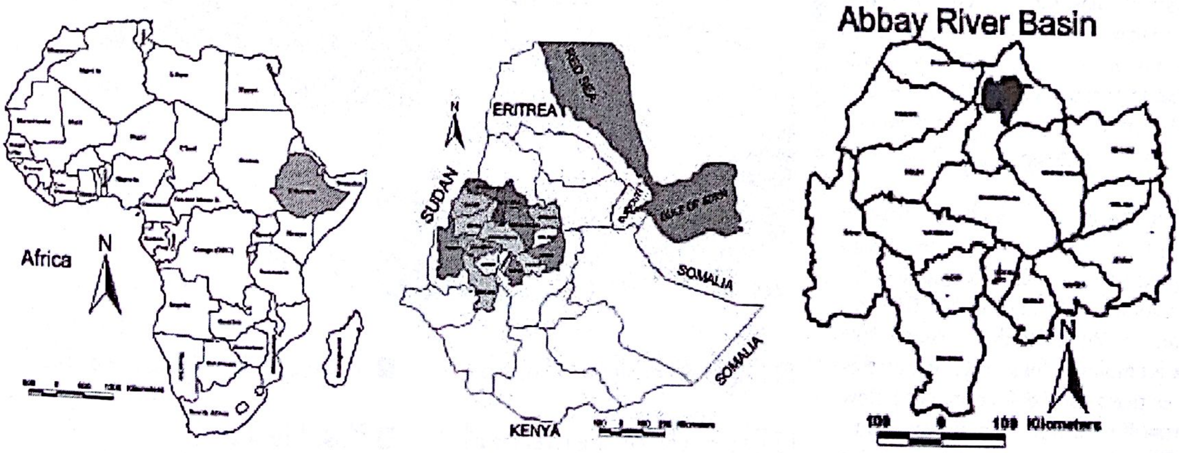



*Figure 2.1 Map showing location of the study area (Africa, Ethiopian and Abbay River Basin & sub-basins)*

17.58% of Ethiopia's land area; 43.11% of its total average annual run-off of the country; and 25% of its population. It has an average of annual run-off of about 52.60 billion cubic meter. The location of the basins shown in figure 1.1 it constitutes 16 sub-basins including the largest lake in Ethiopia. The annual rainfall varies between about 800mm to 2,200mm with a mean about 1420mm. The mean temperature of the basin is 18.5°C with minimum and maximum average daily temperature of 11.4°C and 25.5°C respectively [ARBIDMPP, 1999].

## 3. Objective of the Study and Methodology

The main objective of this study is to evaluate the selected sites, identify the problem and also assemble & prepare an accurate geo-referenced source of data for the potential site of Abbay River Basin and locating the sites on a map.

The selection of hydropower potential site is governed by the topography of the area, hydrology of the catchments, geological condition, and distance from the grid system etc. It is the net sum of all these components which helps us to deciding the potential of the site and its economical feasibility.

The methods used include data collection from institutions such as Ministry of Water Resource, Ethiopian Mapping Authority, EEPCo, and etc; desk study to review previous studies, data processing & analysis of collected information using various tools such as statistical packages and GIS to obtain hydrological and physical parameters and spatial information. The data collected, computed and analyzed are used to identify the possible potential sites.

## 4. The Data

Data used in this study include monthly stream flow data of 90 stream gauging stations found in the basin for estimation of the dependable flow for power production. 50% dependable flow is employed for storage type hydropower plant and 90% dependable flow for runoff river type hydropower plant.

The other important data even for hydrology studies are the topographic map of the area. The available hydraulic head of the hydropower plant is determined by simple surveying techniques, moreover, drainage basins area are defined and important features such as slopes and stream patterns are measured.

## 5. Evaluation of Selected Hydropower Potential Sites

Evaluating selected hydropower potential sites requires a systematic studies of topographical, geological and water drainage patterns of the area. For topographical and hydrological evaluation there were a data whereas for geological evaluation the available data were not reliable. The 1:2000000 scale of the geological map is too large to come up with a reliable result so that the geological site evaluation is not conducted.

The site evaluation performed for sites which are selected / identified by WAPCOS, 1990. Most of the possible hydropower potential sites which are mentioned on other documents and reports do not have the description of the sites rather only the technically available power and number of possible potential sites except for WAPCOS and the ARBIDMPP reports. Because of the above mentioned reason, the other documents are not evaluated, and the case of ARBIDMPP the document did not assess all possible potential sites in the basin in addition there are potential sites which are similar site description with WAPCOS.

## 6. Site Evaluation Criteria

The general criteria employed for the evaluation of the selected hydropower potential sites are listed below: -

1. As far as possible, harness the available head on the site optimally or maximize the use of the available head. There should be also adequate discharge on the site for the developed hydropower

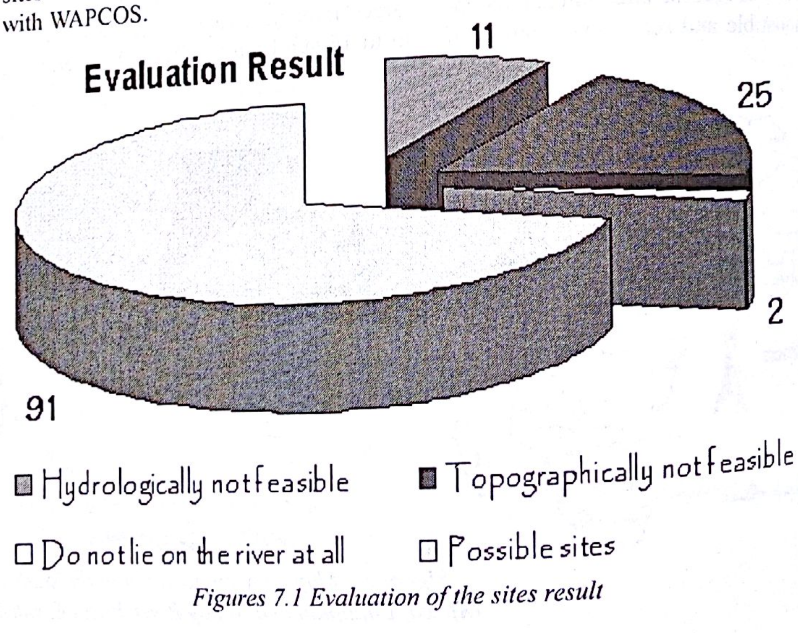
2. For storage type hydropower development the submergence and water surface area should be minimum, narrow gorge areas are advantageous

3. In case there is a confluence of two rivers in the selected reach, the site should be located on down stream of the confluence point to take the advantageous of the flow of both rivers

4. The site should be easily accessible, accessibility from the viewpoint of transportation

5. Distance from the load centre (National grid system)

Any combination of head and flow can be used to develop a hydropower, and more emphasis is given for these two main factors. Moreover, if hydropower is to be generated from dam water then selecting suitable dam sites requires careful consideration of economy, smaller length of the dam will result lesser the cost from dam fill point of view. Hence, the site has to be the one where the river valley has the neck formation.




*Figures 7.1 Evaluation of the sites result*

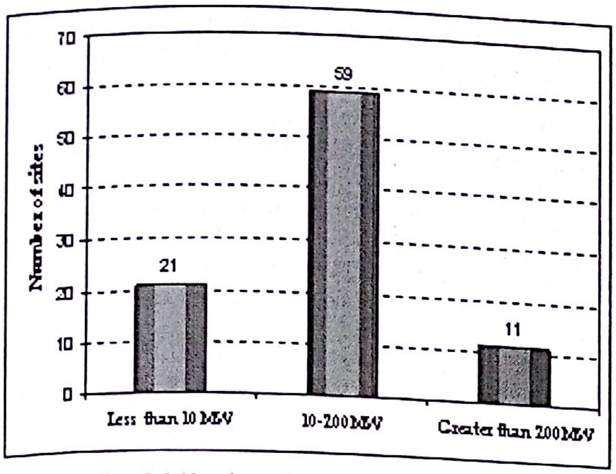



Fig. 8.1 Number of sites, by Capacity Groups

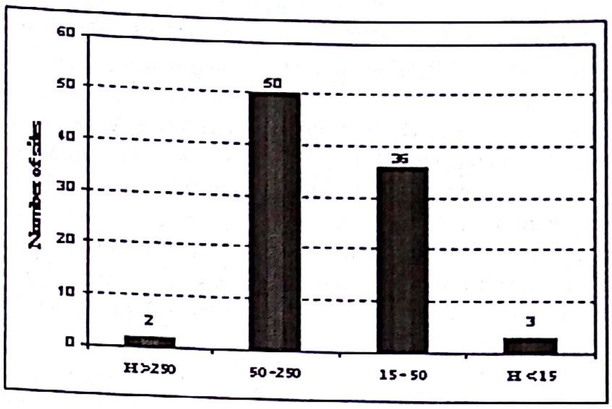



Fig. 8.2 Number of sites, by available head Groups

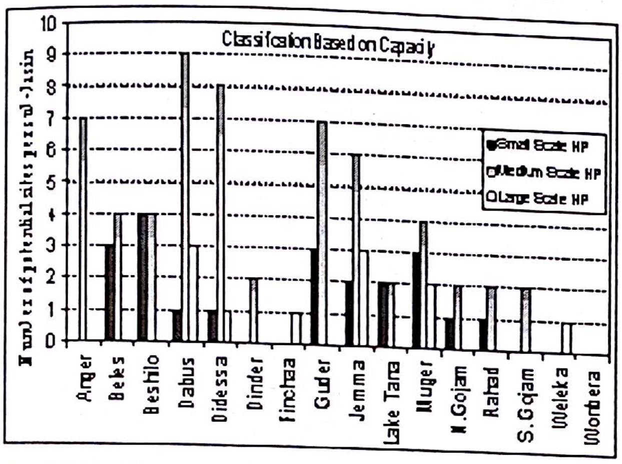



Fig. 8.3 Number of sites, by Capacity Groups, for the sub-basins

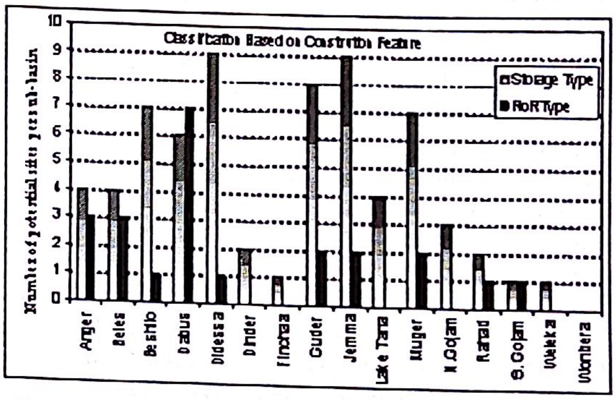



Fig.8.4 Number of sites, by construction feature, for the sub-basins

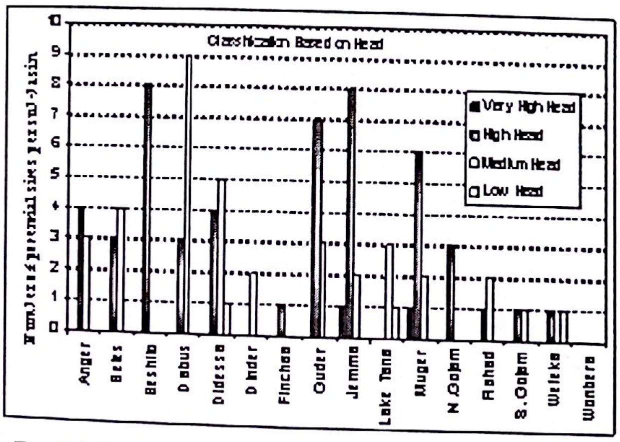



Fig. 8.5 Number of sites, by available head, for the sub-basins

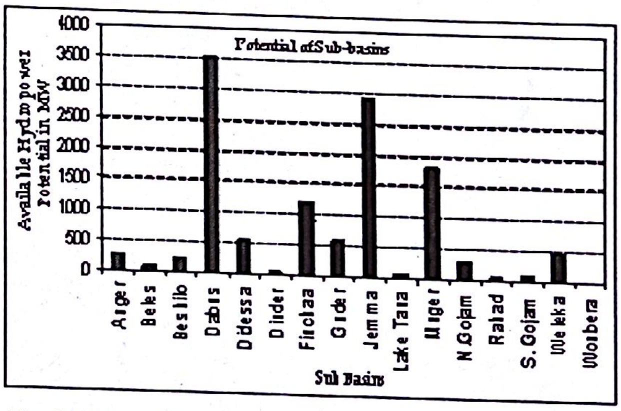



Fig. 8.6 Available potential the sub basins in MW9. Mapping of the Selected Sites

## 7. Evaluation Result Discussion

With the above site evaluation approach in mind, the following problems are identified.

The site may not lie on the river i.e. it lays on a bare land, such as site AB – 13 & AB – 48. Even though most of the selected hydropower potential sites needs co-ordinate adjustment, these sites did not lie on a river at all after co-ordinate adjustment even.

The sites lie on a small (flash) river, which emerges or originate from mountainous area, in such cases there is no sufficient amount discharge to generate power. Hence, the stream will dry when the rain die away.

The site lie on a plain area and difficult to get the suggested head around. The inappropriateness of the topographic feature of the area did not allow suggesting hydropower development

The down stream site affects the up stream site, site submergence. There are feasible hydropower potential sites topographical and hydrological; however the down stream site has an effect on the up stream site by submerging it. These potential sites are left as it is for alternatives site of the other site.

The evaluation result is discussed by categorizing into four groups, the first one site which fails hydrological, second sites which fail topographical, third sites which don't lie on the river at all and finally sites which are feasible (shown in the figure 7.1).

## 8. Evaluation Result

A total of 129sites have been evaluated which is identified by WAPCOS, 1990 in ARB. The majority of the sites (64.84%) have potential capacities greater than 10MW, but less than 200MW (Figure 8.1). The following charts describe the result of the evaluation in different categories. The capacities and available power potential of each sub-basin are also presented in summarized form.

The analysis of site evaluation results 91 possible hydropower potential sites thought out the 16 sub-basin and these sites are located on the Abbay River Basin map. The hydropower potential sites mapping will facilitate to discover the distribution of the site in the basin. The following map showing the possible hydropower potential sites of the Abbay River Basin.

## 8. Conclusion and Recommendations

· The topographical and hydrological evaluation lowers the selected sites (129) by about **29.45%** to **91** potential sites

· The total theoretical potential of ARB according to WAPCSO,1990 is **13854MW** however, the **91HP** sites gives **12148MW**

· Site evaluation based on geology of the area and also field visit may change the value, so further detail study should have to be carried out

· The evaluation has been done only from point of view of hydropower; however, the sites may serve as a multi-purpose project so that the sites should have to be evaluated from point of other water resource benefits.

· The same procedure can be followed for other major drainage basin of the country as well

· The study needs a detail hydrological study for each site to get the actual power potential of the sites

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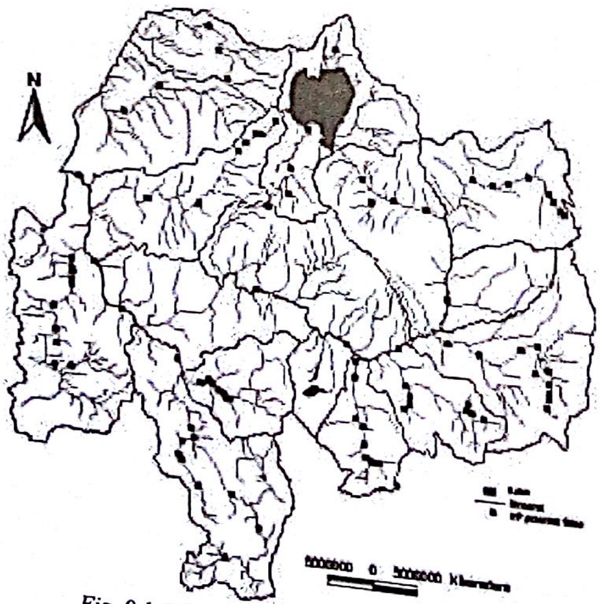


*Fig. 9.1 GIS based mapping of the potential site*

# Appropriate Gully Geometry for Its Control Plan

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**Abstract**

**A gully experiences a dynamic change in length, width and depth from the time of its appearance till its stabilization. A total of 448 cross sections on 139 gullies were investigated in the region between Ambo and Guder in Western Shewa in Ethiopia. A gully head is usually having a vertical wall. Assuming this geometry of gully head, equations were derived for calculating the volume of soil to be removed while sloping a gully head at a given angle, and the surface area of the sloped gully head. The volume of soil removed while shaping the gully heads were measured using a calibrated box. The surface areas of the sloped gully heads were measured using millimetre paper. The measured and computed values showed strong correlation. An equation for determining an actual perimeter of a gully cross section at an enlargement stage was investigated. The measured perimeters of gully cross sections were compared with the values calculated for the perimeters of triangular, trapezoidal and parabolic cross sections of channels. The linear relationships were justified by plotting the measured versus the calculated values. The comparison showed that the realistic shape of a gully at enlargement stage lies between a triangle and a trapezium. The perimeter of a gully can be used in gully reclamation work to determine the side slope surface area of a gully for estimating the amount and cost of materials (e.g. stones, bricks, fertilizers, seedlings, etc) and the labour cost required for covering the gully side slope. Soil conservation planners, extension workers, etc can use the derived equations for planning gully erosion control measures.**

*Key words*: **gully control plan, perimeter of gully cross-section, sloping gully head, surface area of gully side slopes, surface area of sloped gully head.**

## 1. Introduction

Tremendous quantities of soil are splashed into the air by the kinetic energy of raindrops (Schwab, et al, 1971 and 1993). The soil particles detached by raindrops are removed in a uniform thin layer from sloping land resulting sheet or overland flow occurring in thin layers. The overland flows concentrate to form micro-channels or streamlets called rills. Several rills join together to produce greater channel called gully (Smith and Wischmeier, 1957; Mitchell and Bubenzer, 1980; Wischmeier and Smith, 1978). A gully is a steep-sided eroding watercourse, which is subjected to intermittent flood. It is more common in semi-arid climates with infertile soils and sparse vegetation (Piest et al, 1975; Faber and Imeson, 1982; Nicklin, et al, 1986). In the development of a gully four stages are generally recognized, namely channel erosion, enlargement, healing and, stabilization stages (Bennett, 1957; Hudson, 1976). Gullies are classified as V- and U-shaped based on cross sectional shape and as ditch and waterfall types based on the activities of erosion (Bennett, 1957; Kirkby and Morgan, 1980). If the upper horizon of a soil is easily erodible than the lower horizon, a V-shaped gully is formed. If the upper and lower horizons are somewhat equally erodible, as in sandy loam soils or alluvial soils, a U-shaped gully is formed. The ditch type gets water on all sides and grows in length, width and depth. The waterfall gradually extends upslope the gully. Its height of vertical drop increases as the water cuts deeper.

Gully erosion control plan includes recording the possible causes of gully formation, prevention of gully by avoiding those possible causes, treatment of the watershed, diversion of runoff from gully head using diversion ditch, covering the gully head with protective materials after sloping it, and revegetation of the gully proper with the help of combination of engineering (such as check dams) and biological (such as vegetative cover) control measures. Volume of soil to be removed while shaping gully head, the surface area of the shaped gully head, and surface area of the side slope of a gully should be accurately estimated for proper design of gully erosion control measures. The objective of this study is to investigate appropriate mathematical expressions of the above-mentioned parameters for optimum gully erosion control plan. With these objectives in mind, comprehensive investigations were carried out on 448 gully cross sections of 139 gullies in the region between Ambo and Guder in Ethiopia. This region lies 125 km west of Addis Ababa. The long-term annual rainfall is 1100 mm.

## 2. Materials and Methods

### 2.1. Head Cut Control Plan

A waterfall gully head needs to be sloped at a certain angle (approximately 45o) and then be covered with stone riprap or other protective materials. If the vertical wall of a gully is sloped at an angle q, the cross sectional area (A) of a triangle ABO (Fig. 1) is:

A = ½d2 tan q (1)

The average width (w) of a gully head is the average value of the bottom width (b) and the top width (t). Therefore, the volume of the soil to be removed while sloping a vertical-walled gully head at an angle q is:

$$V = A*W = \frac{1}{2}d^2 \tan\theta\left(\frac{b+t}{2}\right) = \frac{1}{4}d^2 (b+t) \tan\theta \quad (2)$$

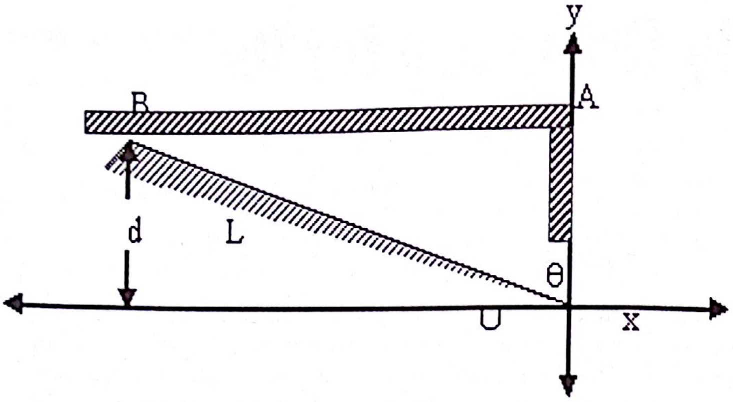


*Fig. 1 Gully head with a vertical wall*

A shaped gully head looks like a trapezium with top width (t), bottom width (b) and a length (L). The length (L) can be computed as follows (Fig. 1):

$$L = d/\cos q \quad (3)$$

The surface area (A) of a gully head that is going to be covered with stones is:

$$A = L\left(\frac{b+t}{2}\right) - \frac{d}{\cos\theta}\left(\frac{b+t}{2}\right) \quad (4)$$

The volume of soil that was removed during shaping the gully head was measured using a wooden box of dimension 0.4 m wide, 0.5 m deep and 1 m long. The box was calibrated for volumes 0.05, 0.1, 0.15, and 0.2 m3 by marking on the vertical wall of the box. The dimensions of the sloped gully heads were measured. Their surface areas were determined with the help of millimetre papers. Using Eq. (2), volume of the soil to be removed while shaping the gully head at 45o were calculated for gullies having active head ward erosion (Table 1). Surface areas of sloped gully heads were also calculated using Eq.(4) (Table 1).

### 2.2 Perimeter of a Gully

On each gully cross section, the bottom width (b), depth (d), top width (t) and the side slope length (perimeter) were measured using a measuring tape. As these dimensions vary along a gully length, measurements were taken at intervals of 20, 50 or 100 m depending on lengthwise uniformity of the dimension. The shape and development stage of each cross section were recorded.

All the 448 gully cross sections were not used in the analyses of the perimeter, because gullies at the stage of channel erosion are not yet large enough to represent the actual geometrical shape for calculating the perimeter and gullies at healing and stabilization stages do not usually need control measures. A gully at an enlargement stage represents a typical geometrical shape of a gully needing control measure. Therefore, only the cross sections at the enlargement stages were used for the analyses of the perimeter. Thus, 53 gully cross-sections were analysed. It should be noted that a gully could have two or more development stages along its length.

The perimeters of the considered cross-sections were measured by directly putting a measuring tape on the side slope of the gully. The perimeters of triangular, trapezoidal and parabolic cross sections of channels are calculated as (Schwab, et. al., 1993):

$$A = L\left(\frac{b+t}{2}\right) - \frac{d}{\cos\theta}\left(\frac{b+t}{2}\right) \quad (5)$$

$$P_{tra} = b + \sqrt{(t-b)^2 + 4d^2} \quad (6)$$

$$P_p = t + \frac{8d^2}{3t} \quad (7)$$

where $P_{tri}$ , $P_{tra}$, and Pp are perimeters of triangular, trapezoidal and parabolic cross sections, t is top width, d is depth and b is bottom width of a channel. The actual perimeter was verified through comparison of measured and calculated values.

## 3. Results and Discussion

### 3.1 Gully Head

The measured volumes were greater than the calculated ones in almost all the cases (Table 1). This is because of the fact that the volume of the soil increases on loosening. Dividing the total value of the measured volume by the calculated one, a loosening factor of 1.05 is obtained. Multiplication of the calculated value by 1.05 gives approximately the measured value. The Pearson's coefficient of correlation for calculated and measured values were 0.9613 for the volumes and 0.9909 for the areas indicating strong correlation. The derived equation can be used to estimate the volume of soil removed while shaping gully head and area of the shaped gully head to be covered with preventive materials. From this information, the cost of labour and materials for controlling gully head cut can be determined.

### 3.2. Perimeter of a Gully Cross Section

The perimeters of the triangular, trapezoidal and parabolic cross sections were calculated using eqns. 5, 6 and 7 respectively, in which the measured perimeters mostly lie between the calculated perimeters of the triangle and the trapezium (Table 2). The Pearson's correlation coefficient between the calculated and the measured values were 0.9921, 0.9972 and 0.9900 for the triangular, trapezoidal and parabolic cross sections respectively. The formula for the parabola showed more deviation from the measured values. Graphs of the measured versus the calculated perimeters justified the degree of linear relationships between the measured and the calculated values (Figs. 2, 3 and 4). Close observation and analysis of Table 2, coefficient of correlations, and Figs. 2, 3 and 4 justify that the actual perimeter of a gully lies between that of a triangle and a trapezium. Therefore, the realistic perimeter can be assumed to be the average of eqns. (5) and (6) as follows:

$$P = \frac{1}{2}\left(\sqrt{t^2 + 4d^2} + b + \sqrt{(t-b)^2 + 4d^2}\right) \quad (8)$$

*Table 2. Perimeters of gullies at enlargement stages*

| IdN | B (m) | D (m) | T (m) | Pm (m) | Pc in meters for Triangle | Trapezium | Parabola |
|---|---|---|---|---|---|---|---|
| 3.02 | 2.25 | 1.30 | 4.50 | 5.60 | 5.20 | 5.70 | 5.5 |
| 6.02 | 1.20 | 1.60 | 3.65 | 5.10 | 4.90 | 5.20 | 5.5 |
| 8.02 | 1.30 | 1.45 | 2.80 | 4.40 | 4.00 | 4.60 | 4.8 |
| 10.02 | 2.50 | 1.60 | 3.70 | 5.70 | 4.90 | 5.90 | 5.6 |
| 14.04 | 2.00 | 1.50 | 3.80 | 5.20 | 4.80 | 5.50 | 5.4 |
| 14.07 | 2.00 | 0.80 | 3.00 | 3.70 | 3.40 | 3.90 | 3.6 |
| 16.01 | 2.00 | 1.40 | 4.00 | 5.20 | 4.90 | 5.40 | 5.3 |
| 26.01 | 1.60 | 1.00 | 3.60 | 4.30 | 4.10 | 4.40 | 4.3 |
| 30.04 | 2.25 | 2.35 | 5.50 | 7.70 | 7.20 | 8.00 | 8.0 |
| 33.01 | 2.00 | 1.40 | 6.00 | 6.80 | 6.60 | 6.90 | 6.9 |
| 35.02 | 2.05 | 2.20 | 5.80 | 7.60 | 7.30 | 7.80 | 8.0 |
| 41.01 | 1.70 | 1.10 | 4.00 | 4.70 | 4.60 | 4.90 | 4.8 |
| 46.01 | 1.30 | 0.75 | 2.80 | 3.30 | 3.20 | 3.40 | 3.3 |
| 48.02 | 2.00 | 1.15 | 4.00 | 4.80 | 4.60 | 5.00 | 4.9 |
| 48.05 | 1.70 | 1.90 | 4.70 | 6.30 | 6.00 | 6.50 | 6.8 |
| 52.03 | 1.70 | 1.30 | 4.00 | 5.00 | 4.80 | 5.20 | 5.1 |
| 57.03 | 1.00 | 1.30 | 4.10 | 5.00 | 4.90 | 5.10 | 5.2 |
| 59.02 | 2.00 | 1.00 | 4.50 | 5.00 | 4.90 | 5.20 | 5.1 |
| 61.02 | 1.40 | 1.17 | 3.60 | 4.50 | 4.30 | 4.60 | 4.6 |
| 63.02 | 1.40 | 1.00 | 3.35 | 4.00 | 3.90 | 4.20 | 4.2 |
| 67.08 | 1.80 | 1.00 | 3.60 | 4.30 | 4.10 | 4.50 | 4.3 |
| 67.13 | 1.20 | 1.10 | 3.60 | 4.30 | 4.20 | 4.50 | 4.5 |
| 67.21 | 2.20 | 1.40 | 4.00 | 5.10 | 4.90 | 5.50 | 5.3 |
| 68.02 | 1.30 | 1.20 | 3.60 | 4.50 | 4.30 | 4.60 | 4.7 |
| 70.01 | 1.20 | 1.10 | 3.40 | 4.20 | 4.10 | 4.30 | 4.4 |
| 77.02 | 2.60 | 1.60 | 4.40 | 6.50 | 5.40 | 6.30 | 6.0 |
| 80.03 | 1.60 | 1.70 | 4.20 | 6.00 | 5.40 | 5.90 | 6.0 |
| 81.03 | 3.00 | 1.20 | 5.00 | 5.80 | 5.60 | 6.10 | 5.8 |
| 83.03 | 1.20 | 1.40 | 4.00 | 5.00 | 4.90 | 5.20 | 5.3 |
| 85.01 | 2.50 | 3.10 | 6.60 | 9.50 | 9.10 | 9.90 | 10.5 |
| 89.01 | 2.00 | 1.60 | 4.20 | 5.70 | 5.30 | 5.90 | 5.8 |
| 90.01 | 2.00 | 1.50 | 4.40 | 5.50 | 5.30 | 5.80 | 5.8 |
| 93.01 | 2.20 | 2.00 | 4.60 | 6.60 | 6.10 | 6.90 | 6.90 |
| 96.03 | 0.80 | 0.80 | 3.00 | 3.50 | 3.40 | 3.50 | 3.60 |
| 99.02 | 1.20 | 1.50 | 4.20 | 5.30 | 5.20 | 5.40 | 5.60 |
| 100.01 | 1.30 | 2.00 | 4.80 | 6.50 | 6.30 | 6.60 | 7.00 |
| 101.02 | 1.00 | 0.90 | 3.00 | 3.60 | 3.50 | 3.70 | 3.70 |
| 105.01 | 1.40 | 1.30 | 4.30 | 5.20 | 5.00 | 5.30 | 5.40 |
| 105.02 | 1.00 | 0.90 | 3.00 | 3.60 | 3.50 | 3.70 | 3.70 |
| 106.02 | 1.40 | 1.10 | 4.50 | 5.20 | 5.00 | 5.20 | 5.20 |
| 110.04 | 1.50 | 1.20 | 4.0 | 4.80 | 4.70 | 5.00 | 5.00 |
| 111.05 | 1.50 | 1.20 | 4.00 | 4.80 | 4.70 | 5.00 | 5.00 |
| 112.02 | 1.50 | 1.50 | 4.00 | 5.20 | 5.00 | 5.40 | 5.50 |
| 117.01 | 1.70 | 1.20 | 3.50 | 4.50 | 4.20 | 4.70 | 4.60 |
| 119.03 | 1.20 | 1.20 | 4.00 | 4.80 | 4.70 | 4.90 | 5.00 |
| 121.01 | 1.40 | 1.30 | 3.50 | 4.60 | 4.40 | 4.70 | 4.80 |
| 126.05 | 1.70 | 2.10 | 5.30 | 7.10 | 6.80 | 7.20 | 7.40 |
| 128.02 | 0.90 | 0.60 | 3.00 | 3.30 | 3.20 | 3.30 | 3.30 |
| 129.02 | 1.00 | 2.30 | 5.30 | 7.30 | 7.00 | 7.30 | 8.00 |
| 133.02 | 0.90 | 0.60 | 2.80 | 3.10 | 3.10 | 3.20 | 3.10 |
| 135.05 | 1.40 | 2.50 | 5.00 | 7.40 | 7.10 | 7.60 | 8.30 |
| 138.02 | 1.00 | 3.30 | 6.50 | 9.50 | 9.30 | 9.60 | 11.00 |
| 139.02 | 1.40 | 0.50 | 3.00 | 3.30 | 3.20 | 3.30 | 3.20 |

*Note. b = bottom width; d = depth; t = top width; Pm = measured Perimeter; Pc= computed perimeter; and IdN = Identification number of Gully cross section.*

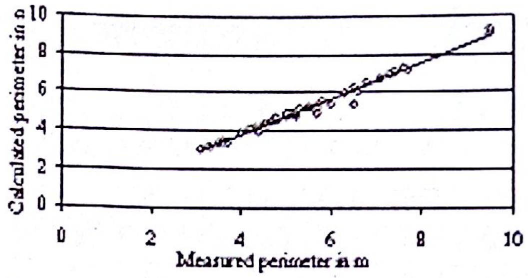


*Fig. 2. Measured versus computed perimeter of a triangular gully cross section*

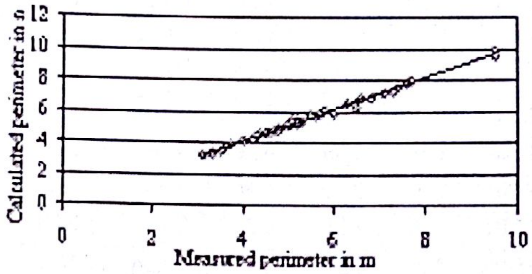


*Fig. 3. Measured versus computed perimeter of a trapezoidal gully cross section*

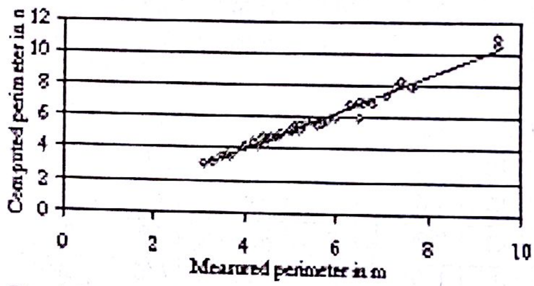


*Fig. 4. Measured versus computed perimeter of a parabolic gully cross section*

Multiplication of the perimeter of a gully by its length gives the surface area of the gully side slopes. Knowing the gully side slope area enables us to estimate the amount of seeds or seedling required to cover the side slope and the required manpower.

## 4. Conclusion

The wall of a waterfall gully head can be assumed to be vertical. The derived equations give better estimation of the number of labour power and amount of material required in shaping and covering gully heads. The calculated volume of soil to be removed while shaping the gully head should be multiplied by a loosening factor of 1.05 to get the measured volume. The actual perimeter of a gully cross section at an enlargement stage is the average of

*Table 1 Calculated and measured volumes of soil removed and shaped surface areas while sloping gully heads at 45o*

| IdN | b (m) | d (m) | t (m) | Vc ($m^3$) | Vm ($m^3$) | Ac ($m^2$) | Am ($m^2$) |
|---|---|---|---|---|---|---|---|
| 12.01 | 3.20 | 0.70 | 4.30 | 0.92 | 1.0 | 3.71 | 4.0 |
| 16.02 | 1.80 | 1.10 | 4.20 | 1.82 | 2.0 | 4.67 | 4.5 |
| 23.01 | 1.20 | 1.20 | 2.70 | 1.40 | 1.5 | 3.31 | 3.0 |
| 26.01 | 1.60 | 1.00 | 3.60 | 1.30 | 1.5 | 3.68 | 3.5 |
| 30.01 | 1.20 | 2.20 | 6.00 | 8.70 | 9.0 | 11.20 | 11.0 |
| 31.01 | 0.50 | 1.10 | 1.90 | 0.73 | 1.0 | 1.87 | 2.0 |
| 32.01 | 3.00 | 2.20 | 11.0 | 16.94 | 17.5 | 21.78 | 21.4 |
| 34.01 | 3.00 | 3.00 | 9.00 | 27.00 | 28.0 | 25.46 | 25.0 |
| 35.01 | 1.60 | 1.70 | 3.60 | 3.76 | 4.0 | 6.25 | 6.0 |
| 38.01 | 1.50 | 1.90 | 4.50 | 5.42 | 5.5 | 8.06 | 8.0 |
| 39.01 | 1.50 | 2.00 | 6.40 | 7.90 | 8.0 | 11.17 | 10.7 |
| 44.01 | 1.40 | 1.30 | 6.00 | 3.10 | 3.00 | 6.80 | 7.10 |
| 45.01 | 3.00 | 2.30 | 8.60 | 15.34 | 16.0 | 18.87 | 18.5 |
| 48.01 | 2.70 | 1.50 | 5.00 | 4.33 | 4.5 | 8.17 | 7.9 |
| 50.01 | 2.00 | 1.00 | 3.80 | 1.45 | 1.5 | 4.10 | 4.0 |
| 59.01 | 2.00 | 1.00 | 4.50 | 1.63 | 1.5 | 4.60 | 4.5 |
| 60.01 | 1.50 | 1.20 | 3.00 | 1.62 | 2.0 | 3.82 | 3.5 |
| 64.01 | 1.00 | 1.00 | 1.70 | 0.68 | 1.0 | 1.91 | 2.0 |
| 70.01 | 1.20 | 1.10 | 3.40 | 1.39 | 1.5 | 3.58 | 4.0 |
| 71.01 | 3.00 | 1.40 | 6.00 | 4.41 | 4.5 | 8.91 | 8.5 |
| 77.02 | 2.60 | 1.00 | 4.40 | 1.75 | 2.0 | 4.95 | 5.0 |
| 81.01 | 2.30 | 1.70 | 8.30 | 7.66 | 8.0 | 12.74 | 12.4 |
| 84.01 | 1.50 | 2.60 | 8.60 | 17.07 | 18.0 | 18.57 | 18.2 |
| 87.01 | 1.60 | 1.40 | 3.20 | 2.35 | 3.0 | 4.75 | 5.1 |
| 89.01 | 2.00 | 1.60 | 1.20 | 2.05 | 2.0 | 3.62 | 3.2 |
| Total | | | | 140.72 | 147.50 | 206.55 | 203.00 |

those of a triangle and a trapezium implying its shape to be between the two geometric figures. The multiplication of the actual perimeter by the length of a gully gives the actual side slope surface area of the gully. The computed surface areas are helpful in calculating the total material and labour cost for covering gully side slopes with plants or other protective materials if unit prices of materials, daily labour cost per person and daily work performance in m2 per person are known. The derived equation is helpful for the design of gully reclamation works.


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# Situational Assessment of Water Supply and Sanitation in Konso Special District: Special Attention to Environmental Aspects.

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## Abstract

**Recently a change in strategy was introduced through demand led user's participation as a solution for long term solution for achieving sustainable rural water and sanitation services. On account to the need for situational assessment as the main feedback, for planning process and to recommend any intervention strategy this study is designed. This paper discussed the proportion of rural water systems that function, the coverage rate, utilization rate, and the level of user's involvement in the management of rural water facilities in Konso Special District. The methodologies employed for data collection were house to house survey, focus group discussion and water quality analysis through laboratory and sanitary survey methods. The main results of this study the coverage rates for water supply (14.8 percent) and sanitation access rate (11.0 percent) are the same to the countries coverage rates 14 percent and 13 percent respectively. Other useful performance indicators are the convenience of the water system; functioning and usage rates; water quality and quantity of water used were looked to reestablish future strategies to integrate technical, environmental, social, institutional and financial aspects to improve sustainability of the projects.**

## Introduction

Water supply and sanitation (WSS) in both rural communities and large urban centers has received much attention during the last two decades, but it is only recently that attention has focused on finding ways of improving the relatively poor levels of service found in rural areas. There is therefore great demand from technical, social, and public health professionals and national policy makers to develop assessment sustainability status of rural water supplies so as the issues be better understood, documented, and tested. The sustainable technological options, management arrangements involving various stake holders, appropriate professional support to local operators, and improving cost recovery by aggregating demand has been applied since the mid 90's, whether these are properly implemented and managed are not well understood. However, at present various project managers are still often developing solutions without using the experience of others, often repeating the same execution with out perceiving the failure.

**From Supply Driven to Demand Responsive Approach**

The traditional approach of service delivery is a top down, supply driven approach. It is aiming to solve the sector problem by building more concrete, pipes and taps. The need and preference of the community on activities such as design, appraisal and construction are centrally decided by government officials who have little or no contact with the community while most project activities such as cost recovery operation and maintenance responsibility, and control and asset ownership are poorly defined and communicated with users. Thus the potential benefits from the sector are far from reaching and water systems used in appropriately or remain unused at all and significant numbers of supplies were not maintained for long period of time. The idea that communities should operate and maintain water supply systems them selves came partly from an erosion of belief in the idea that central governments were any good at supplying things for their populations, and partly from the positive belief that communities have the skills and motivation to meet their own essential needs.

## Institutional Perspectives

To supply adequate and safe water and proper sanitation different countries have tried out different management practices, so as to utilize the scarce financial, human, water and other resources.

**The most preferred institutional set up is the one the properly address the following key issues.**

- water recourse allocation and management
- integration of water supply, sanitation and hygiene promotion
- financial management, investment planning and tariff setting
- the simulation of private sector as partner
- the aspects of legal frame work on organizational autonomy, transparency, and accountability
- decentralization of responsibilities
- the availability and practice of know how transfer (or human resources development), and
- the efficiency of management to operation and maintenance (o & m).

In developing countries failure to achieve to work on proper institutional options at all level can result lack of clear direction and vision at all level, lack of motivated trained staff, fragmented and overlapping of duties, lack of legislative procedures and regulations on operation and maintenance, management and cost recovery issues and ineffective utilization of budgets.

Different countries have tried different strategies to allocate the scarce resources to keep demand of the people. Many countries have had institutional reforms, so they assessed policies and strategies led organizational restructuring to make the water and sanitation sector decentralized more demand – responsive.

## Financial Aspects

A financially sustainable project is a project /program where the beneficiary pays back all the expenses of capital and operational costs. Although it is common to hear sayings as "water is a gift of God; Water is a "human right" or "don't tax cleanliness" water supplies costs money, especially when there exist some additional works such as treatment, pumping or piping of water. Sanitation improvement is not different from water, thus the construction of pit latrines or sewers all costs money. In many countries government and community attitudes are changing and beneficiary of water and sanitation services are paying for services they have got. In Ethiopian, water supply projects are requesting about 10 percent of capital costs and all the costs of operating the systems. The remaining source of funds includes government budget, foreign leans, and institutional lenders and subsides from urban systems.

## Technical aspects

Technical issues are all aspects of technological options, the design and construction of water supply and sanitation facilities (technical standards), and the operation and maintenance criteria.

A sustainable technology choice always consider the technical skills needed with in or outside the community, the compatibility to the communities preference and expectations, comparative advantages such as cost easy availability of spare part, extension capacity etc. Commonly low cost technologies are preferred but it has to be appropriate, that is, it has to fulfill criteria of water quality, quantity and serve in a reliable way for the design life of the water supply system. Another most important aspect in the technology choice is standardization of technologies at national or regional level so as to improve the quality of consternation, and more efficient operation and maintenance service requests. Standardization in ruler water supply system means – to limit the number of pipe size or to make the choice for a hand pump with in the range of two or three and village level operation and maintenance can be possible.

## Environmental Aspects

The environmental aspect addresses the quality and quantity of water available for public consumption. WHO guidelines state that, drinking-water must not contain waterborne pathogens, more specifically, the coliform indicator bacteria (E. coli or thermotolerant coliforms) should not be present in 100 ml samples of drinking-water at any time, for any type of water supply, treated or untreated, piped or unpiped (WHO 1984). In laboratory analysis if guideline values are exceeded, immediate investigative action must be taken, including repeat testing, and thorough inspection of the treatment plant and its operation, the raw water source, and general hygiene of the water distribution system. In rural areas guidelines for water quality are difficult to achieve for reasons of technological choices, construction quality, skills of local operators, and the community in general. In rural areas, the per capita quantity of water consumption recommended by WHO is 15 -20 liters per capita per day but for various reasons it is rarely reached.

The main purposes of assessing the situation of water supply and sanitation are, to offer planners and policy makers in water supply with real pictures of the function management and usage of rural water services, to develop community oriented insight among technical personnel in rural water projects, to verify the proper implementation and significance of the newly introduced demand led project planning, and to determine the functioning interims of physical quality, water quality and quantity for rural water points.

## Methodology

This study was carried out in Konso special district with in the Southern Nations-Nationalities and Peoples (SNNP) Region, south Ethiopia. Konso special district is divided in to five farmer associations, namely Karat, Fasha, Kolme, Gawada, Duro and Gumayde. The present study was conducted from December to April 2003 to investigate functioning utilization rate, quantity of water used, the quality of water, technical aspects, cost recovery mechanisms and community based management of the area. Relevant data were collected by the following four methods.

- House to house survey
- Direct observation to the various water supply projects and
- Focus group discussion to selected community members (elderly, women, other water users and mainly the water committee members).
- Laboratory analysis for water quality testing using the MPN (most probable method)

**Results**

The result of the research is presented as summary of the information collected in table 1,2,3

Based on the WHO definition of accessibility that limits the distance for rural settings with in one kilometer of walking distance.

## Discussion

The necessity of assessing of sustainability in rural water supplies and sanitation is primarily useful to formulate new or remake existing project rules and the organizational frame work that can be used to rural water supplies. To assess sustainability qualitative and quantitative data from various communities were collected and presented in the result part; in this section technical, environmental, financial and institutional factors are assessed independently and jointly on their role to sustainability.

## Technical aspects

Technical aspects can be looked as decisions in design (technological choice and level of services) and construction quality that are most obvious

*Table 1: Water supply by type, level of services, functioning status*

| S. No. | Name of the community | Level Service | Year of Construction | Water Lifting Mechanism | Functioning Assessed * | Functioning as record at regional bureau |
|---|---|---|---|---|---|---|
| 1 | Dera/ Gersale | MP | 1992 | Fuel Pump | Functional | Functional |
| 2 | Arfayde | MP | 1992 | Fuel Pump | Functional | Functional |
| 3 | Fasha | MP | 1993 | Fuel Pump | Not functional | Not functional |
| 4 | Lulte | MP | 1992 | Fuel Pump | Not functional | Not functional |
| 5 | Fuchucha | HP | - | Human Labor | Functional | Not functional |
| 6 | Sorobo | HP | 2001 | Human Labor | Not functional | Not functional |
| 7 | Kashale | HP | 1992 | Human Labor | Functional | Functional |
| 8 | Gesergio | HP | 1992 | Human Labor | Non Functional | Functional |
| 9 | Lehayte | HP | 2003 | Human Labor | Functional | Not functional |
| 10 | Borakora | HP | - | Human Labor | Functional | Functional |
| 11 | Besso | GS | 1994 | Gravity | Functional | Functional |
| 12 | Gewada Elho | GS | 1991 | Gravity | Functional | Functional |
| 13 | Near Gumayde | GS | | Gravity | Not functional | Functional |
| 14 | Gocha | GS | 2001 | Gravity | Functional | Not functional |
| 15 | Bide | GS | - | | Functional | Deficiently Functional |
| 16 | Aburcha | | | | Not functional | Deficiently Functional |
| 17 | Walungo | | 1992 | | Functional | Not functional |
| | | | | | | Functional |

*Functioning is used here to indicate the existence of some water at the tap and not to the meaning that some used the word to indicate when quality, quantity, reliability and convenience of water points are acceptable.*

*Table 2: Results of people using the facilities (coverage), Per capita water used per day, water quality results and sanitation coverage.*

| Name of the community | Number of people using Water Supply Facility | Percentage of the people using water supply facility | Amount of Water Used l/capita/day | Sanitary Survey result on contamination | Water Quality Number of Coliform bacteria/100ml water sample | Sanitation Coverage (access) percentage |
|---|---|---|---|---|---|---|
| Gersale | 292 | 100 | 6.3 | 0–2(low) | 0 | 17.1 |
| Arfayde | 34 | 57 | 10.3 | 0–2(low) | 0 | DNC |
| Lulte | 0 | 0 | 0 | | | 9.3 |
| Fuchucha | 184 | 100 | 7.7 | 3-5 (intermediate) | 1600 | |
| Sorobo | | | | 0–2(low) | 3 | |
| Besso | 400 | 66.3 | 3.4 | | | 17.3 |
| Gewada-Elho | | | | 9-10 (very high) | 1600 | |
| Gumayde Gocha | | | | 6–8 (high) | 230 | |
| Bide | 80 | 13.1 | DNC | | | 12.9 |
| Aburcha | 383 | 35.0 | 3.3 | | | 15.0 |
| Walungo | 100 | 29.4 | 4.2 | | | 5.1 |
| Borakora | | | | 0-2 (low) | 0 | |

**MPN refer to most probable number, one of the most accepted method to determine water quality.*
*DNC = data not correctly filled.*

*Table 3. Assessment result on accessibility of the water supplies, existence of active village water committee, trained operator and maintenance staff, and village level tariff collection.*

| S. No. | Name of the community | Accessibility of the water Supply to community* | Active Village Water Committee | Trained operator and maintenance staff | Village level tariff or Charge collection |
|---|---|---|---|---|---|
| 1 | Dera /Gersale | Accessible | Exist | Exist | Exist |
| 2 | Arfayde | Accessible | Exist | Exist | Exist |
| 3 | Fasha | Accessible | Not-exist | - | - |
| 4 | Lulte | Accessible | Not-exist | | -- |
| 5 | Fuchucha | Accessible | Exist | Exist | Exist |
| 6 | Sorobo | Inaccessible | Not-exist | Not-exist | Not-exist |
| 7 | Kashale | Accessible | Exist | Exist | Exist |
| 8 | Gesergio | Inaccessible | Not-exist | | |
| 9 | Lehayte | Accessible | Not-exist | Not-exist | Not-exist |
| 10 | Borakora | Inaccessible | Not-exist | Not-exist | Not-exist |
| 11 | Busso | Inaccessible | Not-exist | Not-exist | Not-exist |
| 12 | Gewada-Elho | Inaccessible | Not-exist | Not-exist | Not-exist |
| 13 | Near Gumayde | Inaccessible | Not-exist | | |
| 14 | Gocha | Accessible | Not-exist | Not-exist | Not-exist |
| 15 | Bide | Inaccessible | Not-exist | Not-exist | Not-exist |

**Based on the WHO definition of accessibility that limits the distance for rural settings with in one kilometer of walking distance*

determinants of water systems reliability. High technological contents and better service levels, although highly preferred create dependency to the receiver community. Low cost technological solutions on the other hand have difficulty to fulfill the needed guideline, such as inaccessible water supply points, reduced water quality, and fluctuating water quantity that is insufficient to satisfy the demand. Accessibility is defined by WHO as the percentage of population that has a recognizable water supply system with in one kilometer from the house hold. In this case as presented on table 3, twenty percent of the protected spring water supplies are sited in rugged areas that are not accessible to children or the house wife. Besides the majority of the protected springs lack continuity to provide water for year long and the water quality show frequent deterioration in physical or bacteriological risk. These springs have design, construction or operational problems one or more the following are identified in this survey: problem to allow water to flow out freely all the time to enter a reservoir or drain, access to contamination (e.g. from open defecation, latrines, cattle-gathering places, from surface run off, etc.), accumulation of silt, and leaks in the protective seal. Therefore for each protected springs by identifying their problems specific actions should be planned, these might be changing of the sites, making surface drains, the animal-proof fence and gate, repairing spring boxes, piping and valves; or checking water quality. Hand pump fitted shallow wells are functioning at 67 percent that is four out of six assessed have water on the tap. Although the hand pumps have better reachable distances (that is 43 percent) than the protected springs, some technical activities are remaining to make them technological homogeneous (standardization), reliable, accessible and to limit the number of users to the available resources. The motorized (engine) pumped water supplies selected for this study are found at Gersale, Arfayde, Fasha and Lulte villeges of farmer cooperatives. The Gersale and Arfayde water supplies are functional while the others were non functional for more than two years. The problems of these systems are identified by regional water bureau as the blocking of the main pipes by inserted stones. But there are disagreement between the community and implementing agency Water Construction Authority for taking the accountability to the failure. In any way the failure of the project after huge capital investment to system installation and construction of distribution system lie with approach to project processing that has to be responsive to the demands or give the chance for negotiation on all stages of the project so as to provide responsibility to all stakeholders.

## Environmental Aspects

As to WHO water quality guidelines, drinking-water must not contain E. coli or thermotolerant coliforms in 100 ml samples of drinking-water at any time, for any type of water supply, treated or untreated, piped or unpiped. The results on table 2 indicate that, except three water points others fail to fulfill the set guideline both bacteriological analysis and sanitary survey method. In the remaining contamination of water points are identified which can be due to entrance of buckets and other water containers and even people in to spring box, existence of latrine or other sources of pollution with in 10 meters, cracks in the concrete, lack of diversion ditch above the spring, lack of a surface water diversion ditch above the spring box, and poor drainage causing stagnant water around the water point. In order to achieve the recommended guideline for water quality actions must be targeted to improve technological choices, standard construction quality, training of local operators and the community in general on issues of protecting water sources and proper storage of water at home.

In rural areas, daily per capita consumption for personal and domestic purposes recommended by WHO is 15 -20 liters per capita per day. The per capita quantity of water consumption assessed in this study was 5.47 liters per day per capita which far below the recommended rate. The present finding is lower than the water consumption rates reviewed by Gebre Amanueal Teka (1993), he has indicated average rates of 11.5 L and 7 L for a village in Wellega and a peasant producers cooperatives in Gonder Region respectively. In comparison to the WHO recommended amount, lower volume of water found in this study can be due to lack of proper sitting of water points, the water points are not available for long period of hours, lack of reliability to water points and the lack of awareness towards the constructed water points. The possible actions that can be taken include hygiene education and promotion on the projects for users to participate in design, construction and management of projects.

## Financial Aspects

The main failure to the supply driven approach is financial insufficiency that has caused delay to demand in operation and maintenance and to provide the service to communities lacking the services. The Ministry of Water Resources as a rule follows a strategy of charging the users to pay ten percent of the capital costs of the project and the full expenditure of operational and maintenance costs. Usually the users pay the former by providing free labour and provision of construction material and a flat charging is arranged to cover the expenditure for later stage of the project. In this study all the visited water points have reported the participation of their communities' interims of free labour and provision of construction materials. In addition four of the eleven water points have arranged tariff collection methods such as money per service provided, monthly flat tariff collection or fund raising when breakdown time. The setting of an affordable but realistic tariff structure is the key feature of a demand responsive approach. Micheal (1994) has reported various forms of cost recovery practices of rural Ethiopia, as to his report the tariff for motorized water supplies was set at one birr (10 US cents) per 1000 litres and for handpump the tariff is 25 cents ( 2.5 US cents) per house hold per month. Those relevant government bodies at all level have to arrange for mechanisms to financial self sufficiency and follow the proper implementation of demand – led approach by changing the perception of water users on the purposes and ways of collecting money. Since user's willingness is related to satisfaction to the provided services, the cost recovery plan may require new sustainable projects. In such cases clear financial responsibility should be addressed and agreement should be reached on costs of initial payment and the continued financial autonomy of the projects. Low cost technologies (such as small scale protected springs) may be affordable to low income communities but the systems may not be sustainable.

## Institutional Perspectives

Institutional aspects refer to the organizational arrangements made to improve water supply, sanitation and community participation and hygiene promotion components, which includes legal policies, organizational management and financial resources to systems execution, operation and continuity in rural areas. Although these sector responsibilities are combined in cities and urban areas by Water Supply and Sewerage authority, the activities in rural areas are fragmented there fore the water supplies activities are, the mandate of Rural Water Supply Division with in the Ministry of Water Resources Commission, while sanitation and hygiene promotion is the authorization of Ministry of Health. To understand the institutional functions of rural water and sanitation sector require going through the organizational arrangements and functions at national, regional, district and community level. Thus at national level the ministry of Water Resources as legislative body functions in review and approval of policies and long-term activities. The Regional Water Bureau functions in the preparation of detailed planning, allocation of regional resources, design and construction of facilities, monitoring , supervision and support of local authorities, human resources training, and operation and maintenance backup activities. At district level the organization is limited to water desk level with in the district administration office (recently it is transferred to Rural Development Coordination Office) with activities responsible to design, construction, operation and maintenances of small scale water supplies and providing training of "wat- san" commit-

*Table 4. Comparison of usages for water supplies with sustainable factors and those lacking these factors.*

| Percentage of usage for water supplies with sustainable factors | | Percentage of usage for water supplies without sustainable factors | | Comparison of the two percentages |
|---|---|---|---|---|
| Name of the community | Proportion of usage | Name of the community | Proportion of usage | |
| Dera/Gersale | 299/299 | Lulto | 0/838 | |
| Arfayde | 341/597 | Busso | 430/649 | |
| Fuchucha | 184/184 | Bide | 80/442 | |
| | | Abaroba | 81/388 | |
| | | Walango | 103/350 | |
| Total percentage | 76.01 % | Total percentage | 29.79 % | Significant at 0.05 level |

tees and water point operators. In the past two decades there was some effort to expand organizational arrangements to community level by organizing the users as cooperatives to involve in planning and management of their water systems. As to the discussion made with section heads in the regional water bureau, district water desk staff, members of the water committee and some community members the partnership approach although a more effective solution, is still at infancy in practice. Commonly communities are called to give free labour, they are requested to provide land and other construction materials. But the users of the projects can participate in enormous activities in all stage of the water and sanitation project phases. As presented by Whyte (1986) the users can participate in planning phase activities such as communities can be request to make decisions on the geographical scope of the project, integration among projects, siting of facilities, type and design of equipment, testing of equipment, level of service, selection of water source, additional facilities (for watering cattle, laundry, etc.), financing water charges and timing of fetching for water. In addition to the above mentioned decisions that agencies are making with the users, there are crucial aspects of the project that will be covered in an agreement or legal contract so as to define responsibilities, community powers and authority, to limit misunderstandings, to recognize value of community participation, to bind parties contractually (including penalties for failure to fulfill agreement) and to accommodate turnover of project personnel. The adjustment of suitable legal contract between different parties and consideration of this as a necessary project rule still not performed in all communities. In only quarter of the communities have taken the planning phase responsibilities such as, community information motivation, collection of local materials, voluntary labour, safe storage of materials and equipment, acquisition of land and organization of ceremonies during planning phase, identification of problems, selection of community members for special tasks and trainings, data collection, and data evaluation. In all communities vital planning phases such as participation in planning, fund collection, signing of contracts, communication of progress to the people, and negotiations concerning rights of way are not well addressed.

In the operation and maintenance stage communities responsibilities including reporting periodically to agency, reporting urgent problems immediately, arranging collection of water charges and other payments, keeping accounts, paying loans and other financial dues, signing individual contracts, developing and applying regulations, organizing general meetings for elections, public reports, etc., paying home visits to non-payers, and other problem households, dealing with user's complaints, keeping minutes of committee meetings, keeping archives (log book), organizing demonstrations and official visits, selecting and appointing operators and other staff, delegating responsibilities to operators, supervising operators and organizing community contributions for upgrading, extension and repair of facilities. (Whyte, 1986). In considering system reliability, factors such as ownership and control by local water committee for systems, proper adjustment of the operation and maintenance tasks, and collection of water charges are implemented only to water points at Geresale, Arfayde, and to some extent Fuchucha and Kashale areas. In these systems water – sanitation committee are active hence the day to day operation of systems, required maintenance tasks, health education and communication issues, and financial handling systems are well going. In the above mentioned projects a fruitful partnership approach were established between district water desks, a non-governmental Agency- Farm Africa and the respective Water-Sanitation Committee are in close contact to achieve the needed partnership. Thus the water services in these communities are more reliable, that is, functional, providing the required quantity by the community although are not utilized as to the WHO guidelines interims of quantity and quality water. In water systems at Busso, Gewada, and Bide are not accessible and providing services much below the expectations of the communities. The utilization survey at village Bide 3.4 per cent and water quality survey result for Gocha, Gewada, and Bide can confirm the fact.

The higher level of usage that is 32.77 percent might be due to variable factors including high demand for water, high level of awareness, the inconveniences of alternative water sources, etc.

Coverage is expressed as the percentage of the total population served; commonly by public stand posts, and by point sources such as wells and springs. The results of this study indicate that coverage rate for water and sanitation are found to be 14.8 and 11.0 percents respectively. In comparison to the report by Ministry of Water Resources (MWR 2002) access to public stand posts is 14 percent and access to sanitation is 13 percent, which is found to be same as the findings in this study. The coverage rate for access to water and sanitation services of the rural areas were assumed in this study as lower than the national coverage rate, actually the access rate is not different. Besides communities with well formed project approaches that is sustainable technological choices and demand responsive participatory are comparatively have high coverage rate, greater utilization rate and better water consumption than those that are formed up by the traditional supply driven approach (table 4).

## Conclusion and Recommendation

· The coverage rate for access to water services of the rural areas were assumed in this study as lower than the national coverage rate, actually the access rate is not different.

· Sustainable technological choices and demand responsive participatory projects are comparatively have high coverage rate, greater utilization rate and better water consumption than the traditional centralized planning.

· Planning low-cost and unacceptable technological options such as seasonal, inaccessible and unmanageable protected springs should be discouraged for water quality and reliability reasons.

· In order to achieve the recommended guideline for water quality actions must be targeted to improve technological choices, standard construction quality, training of beneficiaries in the ways of protecting water sources and proper storage of water at home.

· The recently published policy has clearly indicated the direction for community empowerment and "People-centered" or "Demand–led" strategy as a guiding rule for sustainable water supply and sanitation programmes. But there is little commitment at all level towards implementing the policy.

· In most communities it is possible to recognize the existence of locally trained Water-Sanitation promoters, but only a small number of rural water supplies have established water –sanitation committee and trained operators.

· At national, regional and district levels one government body might be responsible for coordinating hygiene and sanitation promotion but resources have to be mobilized at community and household level activities. Constructing VIP type model latrines with in villages for communal use should not be taken as a method to initiate the community for similar action.

· It requires structural adjustment at district level towards involving skilled personnel on social marketing and participatory techniques which can bring a change in system reliability and improvement in coverage and usage. Existing improvement occurred because of cooperation and coordination the different agencies (especially the non governmental agency Farm Africa) that make every effort to redirect the established water projects to have demand responsive participatory projects.

· Available funds should be searched from all stakeholders to build sustainable water supply and sanitation facilities, rather than planning low-cost and unacceptable technologies.

· Despite the fact that the demand responsive approach is more time and money requiring, the advantages that it build capacity to community members, the easiness to reach more communities, and the achievement of sustaining established facilities are more valuable. Thus planners, engineers and other workers need to be trained with demand responsive participatory approach.

· All the visited water points have reported the participation of their communities' interims of free labour and provision of construction materials, however only half of these continue pay for sustaining the facilities.

## Recommendations

· In order to have a better picture on the impact of demand responsive approach on coverage rate, utilization rate and better water consumption as these are assessed in this study, large scale assessments have to be looked.

· Methods should be developed to make demand responsive approach more efficient in time and money.

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# Phytoplankton Biomass in relation to water quality in Lakes Abaya and Chamo, Ethiopia

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**Abstract:**

This report presents results of algal biomass and physico-chemical parameters analyzed during the last six months, which is part of the year round project. The report reveals the two study lakes' algal biomass is related to the nutrient availability and water transparency. The limiting nutrient is found to be $NO_3$-N. $NO_3$-N was varied from 0.18 to 1.00mgl$^{-1}$ and 0.15-1.10, whereas the algal biomass varied from 0-10.2 mgChlm$^{-3}$ and 86-101 mgChlm$^{-3}$ for Lake Abaya and Chamo, respectively. The average Lake's water transparency was 14.5cm for Lake Abaya and 27.8cm for Lake Chamo. It shows that, for Lake Abaya, the low water transparency is attributable to low algal biomass. The project is running until the end of year 2006 and more information is expected by then.

## 1. Introduction

The water quality of a water body affects the abundance, biomass, species composition, productivity and physiological condition of aquatic organisms. Therefore, a good quality of water is demanding for species to flourish in an ecosystem. Three methods are under use for the assessment of water quality: physical, chemical and biological.

Biological methods give comparative advantages over the other two for its low cost, ease with which it is conducted, etc. According to APHA et.al., 2000 the common biological methods used for assessing water quality include the collection, counting and identification of aquatic organisms; biomass measurement; measurements of metabolic rate; etc. The information gathered may help to identify the nature, extent and biological effects of pollution; document short- and long-term variability in water quality; correlate the biological mass or composition with water chemistry or condition; etc.

In this study, algal biomass is used as reference parameter. Most algae, particularly, planktonic algae have long been used as indicator of water quality. Thus, the objective of the present study was, to investigate the temporal variations in the biomass of phytoplankton in relation to some physico-chemical variables in Lakes Abaya, and Chamo and predict its relation to aquatic productivity.

## 2. The Study Area

The two study lakes Lake Abaya and Lake Chamo are the most southern lakes found aroud Arba Minch town. The region around these lakes is characterized by moist sub-humid climate with an annual rainfall of about 900mm (Yosef Tekle-Giorgis, 2002). The region experiences alternating dry and wet seasons, with the dry period being between November and February and peak rainfalls occurring during April and May and again during October and November.

Lake Abaya (fig. 1), is located between latitudes 6°02' and 6°35'N, and longitudes of 37°40' and 37°5'E in the Southern Ethiopia, east of Arba Minch town. The lake has surface area of 1,160 km², which is the second largest lake (next to Lake Tana) in Ethiopia.

Lake Abaya is the first largest of the Ethiopian rift valley lakes, with maximum depth of 13m and length of 60 km at elevation of 1169 m a.s.l. Lake Abaya receives inflow from a number of large rivers (such as river Bilate) and it overflows to lake Chamo during the high water periods.

Lake Chamo (Fig.1) is a tectonic southernmost lake of the Ethiopian Rift

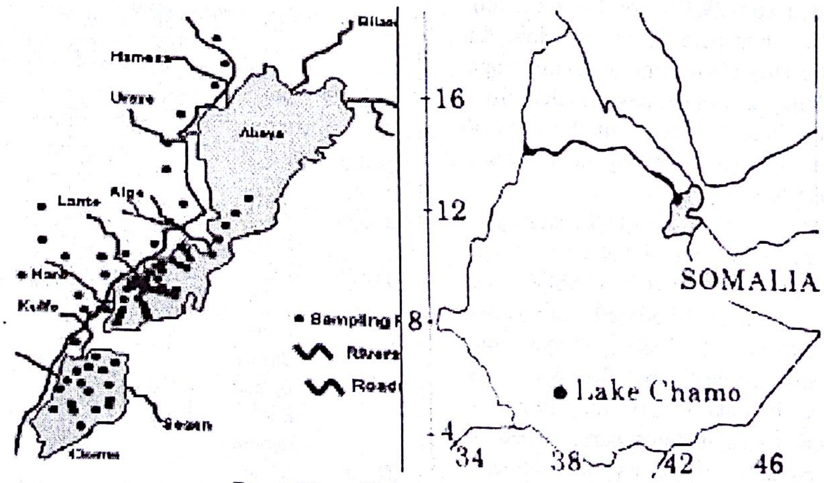

*Fig. 1 Map of lakes Chamo and Abaya*

Valley (5° 45' N and 37° 30' E) which is fed by a perennial river, Kulfo, that enters it from the north and a number of small but non-perennial rivers including Rivers Sile and Sego. The lake is characterized by gently sloping shoreline covered by extensive emergent and submergent vegetation.

## 3. Materials and Methods

Surface water samples were collected from the two lakes regularly and from the feeder rivers occasionally. In-situ measurements were done for some parameters: Lake Water transparency was estimated using Secchi disc. Surface water temperature and pH were measured with a portable digital pH meter. Alkalinity was determined by titration with standard HCl. Electrical conductivity was determined in lab. with conductivity meter. Phytoplankton biomass was estimated as Chlorophyll a concentration based on the monochromatic method (Lorenz, 1967, as outlined in Wetzel and Likens 2000).

Various chemical parameters were analyzed by using Hack spectrophotometer 2000. Samples filtered through glass fiber filters (GF/C) were used for the analyses of chemical parameters except alkalinity, total phosphate and total solids.

## 4. Results and Discussion

### 4.1. Physico-Chemical features

Some physical characteristics of the two study lakes and the feeder rivers measured over the study period are given in table 1. The mean surface water temperature is 32.8°C for Lake Abaya and 29.5°C for Lake Chamo. Lake's transparency is very low for Lake Abaya (14.5cm), owing to its high turbidity that might have resulted from turbid feeder rivers. In the case of Chamo, it has relatively higher value (mean=28cm).

Table 1 also presents the aggregate chemical features of Lakes measured over the study period. Total Solids (TS) varied from 751-850mg/L and 1298-1429mg/L for Lakes Abaya and Chamo, respectively. The high TS value for Lake Chamo may have resulted from plankton materials. Electrical conductivity ($K_{25}$) varied between 958-1200 and 1876-1976 iS cm$^{-1}$ for lake Abaya and Chamo, respectively,

*Table 1. Surface water temperature, $Z_{SD}$, pH, total alkalinity, Conductivity ($K_{25}$), total solids and turbidity measured over the study period*

| Sampling date | Station | Water T. | $Z_{SD}$ (cm) | pH | Total alkalinity (mg l$^{-1}$) | $K_{25}$ (µS cm$^{-1}$) | TS (mg l$^{-1}$) | Turbidity (NTU) |
|---|---|---|---|---|---|---|---|---|
| 29-3-05 | Abaya | 34 | 14 | 8 | 506 | 1054 | 751 | - |
| | Chamo | 29 | 31 | 9 | 850 | 1950 | 1354 | - |
| | Bedessa | 30 | - | 8.1 | - | - | - | - |
| | Bilate | 31 | - | 8.4 | - | - | - | - |
| | Hamesa | 32.1 | - | 8.2 | - | - | - | - |
| 26-4-05 | Abaya | 30 | 12 | 8.7 | 480 | 958 | 850 | - |
| | Chamo | 30 | 25 | 9.4 | 821 | 1897 | 1298 | - |
| 24-5-05 | Abaya | 35 | 13.5 | 9.0 | 500 | 1200 | 820 | - |
| | Chamo | 32 | 23.8 | 9.3 | 912 | 1876 | 1386 | |
| 27-6-05 | Abaya | 32 | 15 | 8.57 | 467 | 1174 | 812 | - |
| | Chamo | 29.5 | 29 | 8.80 | 853 | 1962 | 1429 | - |
| 25-7-05 | Abaya | 33 | 17 | 8.5 | 490.7 | 1156 | 774.5 | 92.2 |
| | Chamo | 27 | 30 | 9.2 | 816 | 1976 | 1323.9 | 55 |
| | Bedessa | 31 | - | 9.1 | 194.7 | 63 | 42.2 | 1800 |
| | Bilate | 29 | - | 8.7 | 193.3 | 175 | 117.3 | 1500 |
| | Hamesa | 29.5 | | 8.0 | 153.3 | 73 | 48.9 | 1200 |
| 22-9-05 | Abaya | - | 15.5 | 8.92 | - | 1159 | 776.5 | 99.5 |
| | Chamo | - | - | 9.25 | - | 1949 | 1305.8 | 67 |

with higher values for Lake Chamo. Total alkalinity (in mgl$^{-1}$) is also relatively higher for Lake Chamo, which is closer to the earlier studies (e.g. Elizabeth Kebede *et al.* 1994 and Zinabu Gebre Mariam *et al.* 2002) for lake Chamo.

Table 2 and Fig.2 presents concentration of inorganic nutrients measured over the study period. Nitrate levels recorded in this study are much greater than those reported for lake Chamo even by the author of this paper and others (e.g. Amha Belay and Wood, 1982 217-445 ìg l$^{-1}$). Nitrite-nitrogen concentrations were usually found out to be zero although low concentartion (< 10 ìg l$^{-1}$) was reported last year. Similarly low concentrations of nitrite (2 -18 ìg l$^{-1}$) were recorded in 1979, for L. Chamo by Amha Belay and Wood (1982). The concentrations of nitrite-N were always much lower than those of nitrate-N and Ammonium-nitrogen as they usually are in African lakes (Talling and Talling, 1965; Girma

*Table 2. Concentration of inorganic nutrients recorded over the study period.*

| Sampling date | Station | $NO_2$-N (mg/L) | $NO_3$N (mg/L) | $NH_3$-N (mg/L) | $PO_4$-P (µg/L) | TP (µg/L) | $Cl^-$ (mg/L) |
|---|---|---|---|---|---|---|---|
| 29-3-05 | Abaya | 0.01 | 0.18 | 0.5 | 0.3 | 3.5 | - |
| | Chamo | 0.03 | 0.29 | 0.8 | 0.5 | 6 | - |
| | Bedessa | 0.08 | 7 | 0.9 | 4.1 | 8.2 | - |
| | Bilate | 0.1 | 9.2 | 0.85 | 5 | 8.7 | - |
| | Hamesa | 0.07 | 6.5 | 0.6 | 4.0 | 6.5 | - |
| 26-4-05 | Abaya | 0 | 0.3 | 0.3 | 0 | 4 | - |
| | Chamo | 0 | 1.1 | 0.6 | 0.9 | 5.9 | - |
| 24-5-05 | Abaya | 0.02 | 0.2 | 0.2 | 0.8 | 5.1 | - |
| | Chamo | 0.01 | 0.15 | 0.75 | 0.8 | 5.4 | - |
| 27-6-05 | Abaya | 0.071 | 0.4 | 0.23 | - | - | - |
| | Chamo | 0.058 | 0.4 | - | - | - | - |
| 25-7-05 | Abaya | 0 | 0.6 | 0.16 | ? | 4.2 | 97.8 |
| | Chamo | 0 | 0.75 | 0.56 | 5.3 | 5.6 | 135.1 |
| | Bedessa | 0.036 | 8.8 | 1.08 | 53.6 | 96 | 24 |
| | Bilate | 0.005 | 12.5 | 1 | 86 | 86.5 | 39 |
| | Hamesa | 0 | 7.0 | 1.1 | 73 | 99.5 | 42 |
| 22-9-05 | Abaya | 0 | 1.0 | 0.13 | 0 | 2.7 | |
| | Chamo | 0 | 0.85 | 0.05 | 0 | 2.2 | |

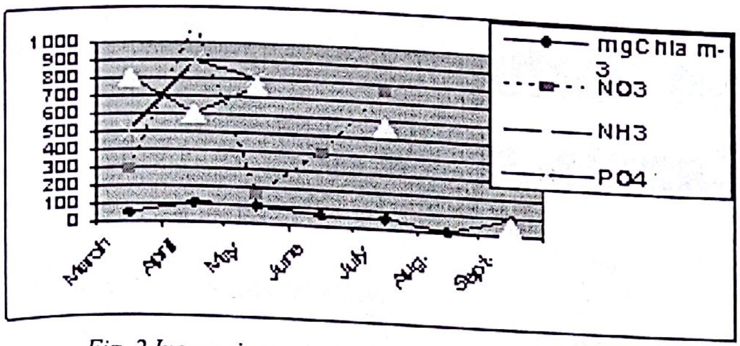


*Fig. 2 Inorganic nutrients in relation to algal biomass*

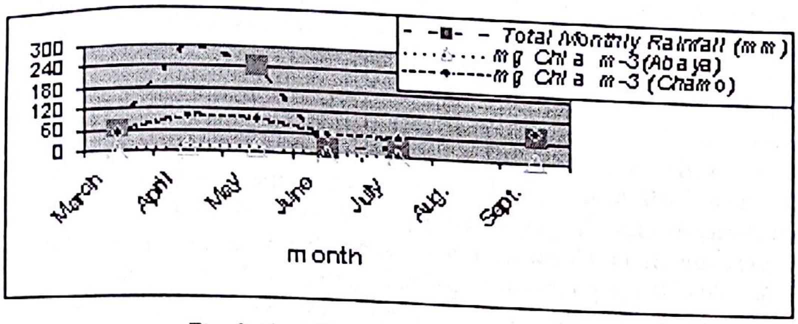


*Fig. 3 Algal biomass in relation to rainfall*

Tilahun, 1988). Ammonium-nitrogen ranged from about 0.13-0.5 mg $l^{-1}$ and 0.05-0.8 mg $l^{-1}$ in Lkae Abaya and Chamo, respectively. Surface concentrations of ammonium-nitrogen in lakes are often temporarily raised following the collapse of algal blooms and during increased circulation (Kalff, 2002).

### 4.2. Phytoplankton biomass

Phytoplankton biomass estimated as chlorophyll a concentration exhibited temporal changes (see Fig.-3) with larger value corresponding to high rainfall data. Phytoplankton biomass varied from 86 to 101 (mean=75.7) mg $m^{-3}$ for lake Chamo and from 0 to 10.2 (mean=4.4) mg $m^{-3}$ for lake Abaya. The average standing crop recorded for Lake Chamo in this study is larger than the previous study of this author but still comparable to those reported for lakes Abaya and Chamo (Amha Belay and Wood, 1982), Lake Abijata (Wood *et al.*, 1978) and Lake Ziway (Amha Belay and Wood, 1984). The reason for the increased value could be the increased rainfall in this period.

## 5. Conclusions and Recommendations

The lakes inorganic nutrient concentration is increased. This might have resulted from inflow of flood-driven materials from the surroundings. Therefore, the disposal of untreated wastes and application of fertilizers and other chemicals need to be checked. To establish the exact level of water quality, further repeated and extended study is demanding.

This project is running until the end of year 2006 and more information is expected by then.

## Acknowledgements

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# Study on Hydraulic Performance of Some Irrigation Canals at Wonji/Shoa Sugar Estate

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**Abstract**

**This study was conducted to examine the hydraulic performance of some irrigation canals at Wonji/Shoa Sugar Estate. Four canal systems; namely, the secondary supply, tertiary supply, field supply canal (malang1) and furrows were considered for hydraulic measurements. Accordingly, the discharge of secondary supply was estimated using a continuity equation (from velocity measurement using float method and wetted cross sectional area measurement of five different canals). The discharges in the tertiary & field supply canals and furrows were measured using Parshall flumes of 15 and 7.5 cm throat width, respectively. Further, seepage measurements were conducted at tertiary canals using inflow-outflow discharge measurements. The bed widths of each of the canals and all flow dimensions for the furrows were also measured in the field. Water velocity was low, 0.3 m/s, which requires the water to travel up to three hours to reach to some sugarcane fields from reservoirs. Besides it causes a loss of irrigation water through seepage. The average seepage loss was found to be 40 % for 500 m long tertiary canal, which is quite high. Results indicate that there is a high variation of discharges in canals of the same category. The discharges in the secondary supply canals were found to have varied between 95.1 and 182 l/s, while for tertiary supplies the flow variation was between 10.4 and 46.6 l/s. All the discharges were quite lower than what it was intended during the design period. It was further noted that though the design flow in tertiary canals was 75 l/s, there was no probability of obtaining the same discharge in the canals. The flow in the field supply canals was also no different; it varied from a minimum of 10 to 21.8 l/s. With regard to furrows a minimum inflow rate of 1.5 and a maximum of 3.2 l/s were measured. There was also no uniformity of canal dimensions in all the canal systems. In all the canals the bed width was quite varying both along a canal and across different canals. Therefore in order to establish a uniform flow of water along and across the canals and to effect uniform water distribution to the irrigated fields, the uniformity of canal dimensions, bed slopes, and delivery of water to the canals should be emphasized in the water conveyance system. Reducing the high seepage loss also requires due attention through improved conveyance of irrigation water at Wonji/Shoa Sugar Estate.**

**Key words: Hydraulic performance, Discharge, Seepage, Canal dimensions**

## 1. Introduction

Long-term success of irrigated agriculture depends primarily on how water resourses are utilized to bring the desired crop yield at acceptable cost of production. Efficient use of water application is becoming more and more essential as an increase of costs of application and increase in water requirements for the world's rapidly expanding population (Humbert, 1968).

In many irrigation projects only 40 % of the water delivered at the source finally reaches the field (FAO, 1971). By the same report application efficiency of most of the irrigation methods is generally around 60 % and this is further reduced due to water conveyance and distribution losses.

In Ethiopia, irrigated sugarcane development was commenced in 1950's at Wonji /Shoa Sugar Estate. Currently, the Estate cultivates about 7020 ha of sugarcane (together with out grower farms). The Estate is using water pumped from Awash River at a design pumping capacity of 5.5 $m^3/s$ (Muckerji, 2001). The pumps run continuously to store water in reservoirs spread at different locations in the Estate. The flow of Awash River is regulated by the release from the upstream Koka dam. Thus, the availability of water to the Sugar Estate depends on releases from the dam.

Water application is being effected through a series of earthen canals, reservoirs, distribution boxes, "*malangs*" (earthen canals of 75 l/s capacity, which run across the field to supply water to furrows) and furrows. The water flowing in the *malang* develops a head when blocked using a canvas dam. The *malang* is aligned in such a way that irrigation is possible only in one side of the *malang*. Sugar cane fields are irrigated from the water supplied directly from the pumps as well as from the reservoirs. Block ended furrow method of water application is used in the Estate. The furrow lengths are short with 32, 48 and 64 m, while the original furrow slope is 0.05 -0.1 % and the furrow spacing is 1.45 m.

Sugarcane fields are identified by Arabic Numerals as field 1, 2, 3, etc. The field numbers are given from North to South and West to East directions. Most of the fields have a more or less square shape (500 m by 500 m), thus one field has about 25 ha area.

Studies conducted in water management across the Ethiopian Sugar Estates indicated that there is inefficient water management that there are losses of water in application and conveyance systems (Rahmeto Anito, 1998; Habib Dilsebo, 2001; 2002; 2004 and Megersa Olumana, 2004). In the studies it was indicated that there are inaccuracy of furrow levelling, water appli-

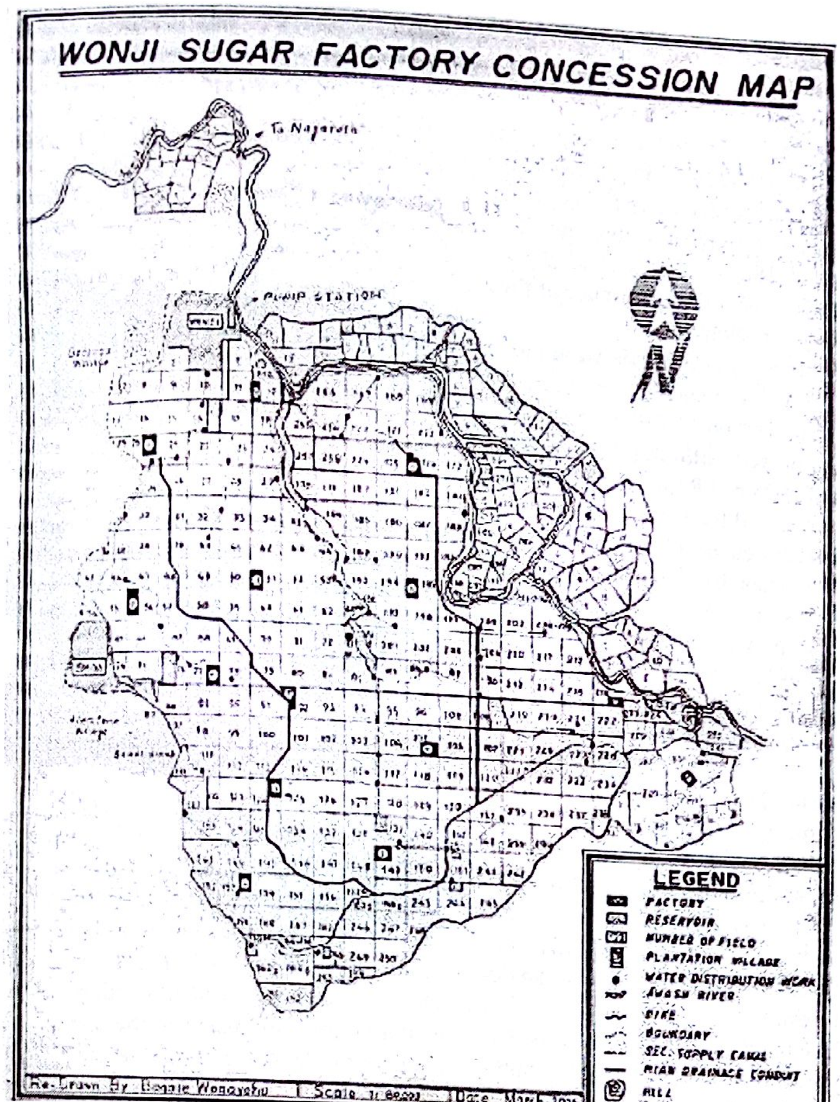


*Fig. 1. Wonji/Shoa Sugar Estate Concession Map*

cation (timing and amount), absence of flow measuring mechanisms in canals, siltation of reservoirs & canals and seepage through canals. Consequently, in view of the above facts this study was conducted at Wonji/Shoa Sugar Estate with the following major objective:

- To examine the hydraulic characteristics of canals (secondary & tertiary supply canals, malangs and furrows).

## 2. Materials and Methods

### 2.1. Description of the Study Area

Wonji/Shoa Sugar Estate is located at about 100 km distance on the Addis Ababa – Djibouti main road and 10 km to the South of Nazareth town.

The Estate has an elevation, latitude and longitude of 1540 m, $8^0$ 31' North and $39^0$ 12' East, respectively. The mean annual maximum and minimum temperatures are 27.6 and 15.2 °C, respectively. The Estate receives an average rainfall of 831.2 mm (Wonji Research Station).

This study was conducted on four canal systems; namely, secondary supply, tertiary supply, *malangs* (field supply canals) and furrows of Wonji/Shoa Sugar Estate sugarcane plantation.

### 2.2. Field Data Collection

#### 2.2.1. Hydraulic Measurement of Canals

The water velocity in a secondary supply canal was measured using float method in five canals. Two points were marked along the bank of a straight length of channel, in which a floating material was allowed to float on the advancing water surface. The float was set in the middle of the canal. 150 m long straight reach of a canal was divided into 15 segments of each 10 m length.

The time taken by the float material was measured in the field from which the water surface velocity was estimated. The trial was repeated 5 times at each canal. The average water velocity was estimated to 85 percent of the surface water velocity as outlined in Arora (2002).

The cross- sectional area was found to be a more or less trapezoidal in shape. Thus trapezoidal formula was used to calculate the wetted cross- sectional area. Flow in the secondary supply canals were then estimated using continuity equation:

$$Q=AV \quad (2.1)$$

Where:

Q = Discharge ($m^3/s$)

A = Canal cross- sectional area ($m^2$)

V = Velocity of flow (m/s)

The following hydraulic measurements were taken:

- Wetted flow dimensions (bed width, depth of flow and top width) of secondary canals at 15 cross sections of five canals at 15, 75 and 135 m distance from distributaries.
- Discharges in tertiary canals in 7 fields, done 24 times, using 15 cm throat width Parshall flume (Suryavansh et al, 1989).
- Individual furrow discharges on 11 fields at three furrows per field using a 7.5 cm throat width Parshall flume.
- Furrow slopes at four furrows for 220 m length each.
- Furrow dimensions for 32 cross sections (at 5, 25 and 45 m distance) along a furrow and 2 furrows per field at six fields.
- Bed widths of tertiary canals and *malangs* at 5, 105, 205, 305,405 and 505 m along a length from the road culvert and from tertiary canals, respectively. Each canal dimension was measured at 36 cross sections at six fields.

#### 2.2.2. Seepage Measurement

Seepage of tertiary canals was measured using inflow-outflow discharge method. 15 discharge measurements were carried out at two sections located at a distance of 100 - 450 m. The difference in discharges of the two sections was determined. The amount of water lost was then changed to seepage loss for 500 m long tertiary canal.

### 2.3. Data Analysis

- Average canal discharges and cross sections were analysed for their uniformity and adequacy of supplying the required amount of water to the irrigated fields.
- Frequency analysis was carried out on the probability of obtaining a 75 l/s discharge in the tertiary canals.

## 3. Results and Discussion

### 3.1. Secondary Supply Canals

Average velocity of water in the secondary canals was 0.17, 0.37, 0.38, 0.21 and 0.11 m/s as estimated from five canals. According to Arora (2002) such velocities are towards the lower side that they are prone to siltation. The maximum surface water velocity was 0.45 and the minimum was 0.13 m/s. The variation in flow velocity was attributable partly to the non-uniform canal cross section. Furthermore, the surface velocity is expected to vary because of some water waves. Thus, to maintain a uniform flow velocities in the canal, the canal dimensions should be kept as uniform as possible.

The discharges have varied from 95.1 to 182 l/s. The values may be tolerable as a secondary supply conveys the bulk of water required by fields adjoining them. Individual values are 95.1, 97.5 and 182 l/s. The wetted section has varied accordingly because of flow velocity variations.

There is a considerable variation of the bed width of canals as measured at different sections of the same. The maximum bed width was 84 cm and the minimum was 48 cm. On the other hand, bed widths of 54, 49 and 69 cm were obtained at 15, 75 and 135 m along a secondary canal, respectively (Table 3.2). A non-uniform canal cross-section affects the flow velocities. Thus, canal cross sections should be made as uniform as possible for uniformity of water flow in canals.

*Table 3.1: Discharges of secondary supplies adjoining different fields*

| Field | Discharge (l/s) |
|---|---|
| 72 | 95.1 |
| 92 | 98 |
| 31 | 182 |

### 3.2. Tertiary Supply Canals

Tertiary supply canals were primarily designed to convey a design discharge of 75 l/s. However, it was found from 24 measurements conducted in 7 canals that there is quite much disparity of the canal flow as opposed to the design flow.

The maximum discharge in the tertiary canal is 46.6 l/s, while the minimum is 10.4 l/s (Table 3.3). Individual figures indicated a maximum discharge of 58.3 l/s and a minimum of 10 l/s. Because of high discharge variation water distribution among fields, irrigation speed and ultimately sugarcane yields are expected to vary among fields. While the average canal discharge is 30 l/s, a frequency analysis carried out on discharges indicated that there is no probability of obtaining a canal discharge of 75 l/s and above.

*Table 3.3: Tertiary canal discharge as measured in different fields of Wonji/Shoa Sugar Cane Plantation*

| Field number | Number of measurements | Tertiary canal discharge (l/s) |
|---|---|---|
| 70 | 3 | 16.7 |
| 31 | 2 | 30 |
| 72 | 2 | 10.4 |
| 24 | 5 | 46.6 |
| 258 | 5 | 30.2 |
| 13 | 4 | 15.7 |
| 92 | 3 | 40.3 |
| Total | 24 | |

Measurements conducted at different sections of a tertiary canal indicated that there is a significant bed width variation along the canal and across different canals. In this regard, a bed width was found to be 2 times larger at two different sections of about 100 and 200 m distance between them at fields 212 and 21, respectively (Table 3.4). The non- uniform canal bed width may give a uniform discharge in the canal: but the flow depth variation affects water distribution in the canal.

The ranges of canal bed widths are 30, 11, 12, 49, 17, 53 cm for fields 212,61,15,215,178/179 and 21, respectively. With regard to bed widths across the canals the minimum of 30 cm was found while the maximum was 79 cm, which is 2.5 times more than the smallest.

*Table 3.2: Bed width of secondary supply canals as measured from different distance from canal inlet*

| Field no | Bed width (cm) of secondary canals at different distance from the canal inlet (m) | | | |
|---|---|---|---|---|
| | 15 m | 75 m | 135 m | 57 m |
| 72 | 55 | 52 | 63 | 57 |
| 92 | 85 | 57 | 110 | 84 |
| 31 | 40 | 35 | 68.5 | 48 |
| 13 | 41 | 49 | 50 | 50 |
| 71 | 48 | 51 | 54 | 51 |
| Average | 54 | 49 | 69 | |

### 3.3. Infield Water Supply Canals (*Malangs*)

The maximum discharge in the *malangs* is 21.8 l/s and the minimum is 10 l/s while the average is 15.4 l/s (Table 3.5).

Discharge variation in *malangs* causes a reduced irrigation speed. This is because 15 l/s discharge can irrigate only 5 to 6 furrows at a time at 2.7 l/s of average furrow discharge. This in turn affects the cost of irrigation labourers, who could have irrigated more had there been more water in the *malangs* than 15 l/s.

There is also bed width variation of

Table 3.4: *Tertiary canal bed widths at different lengths along a canal*

| Fields | Bed widths (cm) of tertiary canals at different distance from the road (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5m | 105m | 205m | 305m | 405m | 505m | Average |
| 212 | 30 | 60 | 52 | 56 | 42 | 58 | 50 |
| 61 | 47 | 36 | 38 | 41 | 44 | 45 | 42 |
| 15 | 25 | 26 | 29 | 36 | 28 | 37 | 30 |
| 215 | 87 | 60 | 43 | 61 | 40 | 38 | 50 |
| 178/179 | 49 | 46 | 35 | 44 | 50 | 52 | 46 |
| 21 | 101 | 76 | 48 | 89 | | | 79 |

*Table 3.5: Average* malang *discharges at different fields*

| Field no | *Malang* discharge (l/s) |
|---|---|
| 70 | 14.4 |
| 31 | 12.1 |
| 213 | 10.1 |
| 51 | 14.5 |
| 71 | 18.8 |
| 24 | 18 |
| 258 | 17.9 |
| 13 | 14.8 |
| 17 | 11.7 |
| 92 | 21.8 |

*malangs* both along a *malang* and between different *malangs*. The ranges in bed widths are 17, 14, 17, 23, 50 and 10 cm at fields 212, 61, 15, 215, 178/179, and 21, respectively. The minimum bed width is 33 cm at field 15 and the maximum is 57.5 cm at field 21 (Table 3.6).

The extremely low discharges in *malangs* cause an excessive delay in irrigation interval. One field is on average 25 ha (500 m* 500 m); accordingly, the average *malang* distance is 500 or 250 m sometimes. However, a canal of 15.4 l/s average discharge can only irrigate 6 furrows for about an hour at 2.7 l/s of average furrow discharge. In 9 hours of daily irrigation it is possible to irrigate only 54 furrows of 48 m furrow length. Thus, it takes about 6.4 days to irrigate one "*shulk*"(a plot of land, which is irrigated by one *malang*). Therefore it takes about 2 months to irrigate one field of 25 ha area against 20 days of average irrigation interval.

Accordingly, on average of 9 months of irrigation the cane will be irrigated only 4 to 5 times per year. This result is in agreement with Booker Tate's (2003) argument that there are only 4 watering per year against the required 8- 12 watering. The balance was supplemented from the high water table of sugarcane fields. Sometimes, the water must travel up to 3 hours to fields at the furthest location from reservoirs (about 3 km) before getting into the field, which further reduced the approximate 9 hours of irrigation to 6.

### 3.4. Furrows

One of the basic requirements in distribution of water along furrows is the furrow cross section. In furrow irrigation method infiltration of water in the furrow takes place both laterally and vertically, which makes the method dependent on furrow dimensions for water absorption. Consequently, the larger the furrow dimensions the larger the surface area a furrow will have to absorb more water and otherwise.

The minimum and maximum bed widths are 20 and 55 cm at fields 215 and 21, respectively. However, the widths are found to be mostly between 30 and 40 cm.

The minimum and maximum top width was found to be 55 and 114 cm at field 215 and 212, respectively. On the other hand, the flow depth was minimum (14 cm) at field 215 and maximum (34 cm) at field 212 as indicated in Table 3.7.

The water applied to the furrows is sometimes unable to reach the furrow end on slope related problems. Thus, under such a situation the irrigators will be forced to flood the field or bring the water in opposite direction i.e., to bring water from the furrow end.

There is a non-uniform furrow discharge in almost all furrows considered in this experiment. An average inflow rate of 2.4 l/s was obtained at 59 furrows. Furthermore, significant variation was observed in flow rates across the furrows. A minimum inflow rate of 1.5 and a maximum of 3.2 l/s were measured (Table 3.8).

Furrow slopes were found to range between 0.05 to 0.17 %. The values are acceptable as the design slopes are 0.05 to 0.1 %. But there are undulations of the field, which hampered free water advancement along the furrows.

### 3.5. Flow Condition in Canals and Furrows

A reasonable variation in discharge is expected because of seepage in unlined channels, thus there are associated top width and flow depth variations. However, it was found a considerable bed width variation, which is not function of the discharge. Hence, the flow in the canals does not represent uniform flow conditions.

The causes of non-uniformity are the canal bed and side slopes, canal dimensions and unregulated releases of water from distributaries to the canals. All the causes can be improved, if not removed, if proper caution is taken during engineering works of land levelling (keeping of uniform furrow slopes), canal alignment (maintaining uniform bed and side slopes), desiltation of canals (maintaining uniform canal dimen-

*Table 3.6: Bed widths of* malangs *along its length*

| Fields | *Malang* bed widths (cm) at different distance from tertiary canal (m) | | | | | |
|---|---|---|---|---|---|---|
| | 5m | 105m | 205m | 305m | 405m | 505m |
| 212 | 51 | 60 | 59 | 58 | 43 | - |
| 61 | 52 | 41 | 41 | 38 | 42 | 41 |
| 15 | 30 | 34 | 39 | 50 | 42 | 33 |
| 215 | 32 | 35 | 40 | 45 | 55 | - |
| 178/179 | 52 | 55 | 20 | 40 | 70 | - |
| 21 | 55 | 65 | - | - | - | - |

ance of irrigation canals and also seepage from reservoirs.

*Table 3.7: Furrow dimensions at different distances from malang*

| Field | Furrow dimensions (cm) as at different distances (m) along a furrow | Furrow 1 | | | Furrow 2 | | |
|---|---|---|---|---|---|---|---|
| | | 5 m | 25m | 45m | 5m | 25m | 45m |
| 212 | | | | | | | |
| | B.W(Bed width) | 28 | 35 | 39 | 33 | 33 | 30 |
| | T.W(Top width) | 99 | 83 | 114 | 107 | 107 | 95 |
| 61 | F.D(flow depth) | 24 | 23 | 34 | 33 | 25 | 29 |
| | B.W | 39 | 35 | - | 32 | 29 | - |
| | T.W | 100 | 96 | - | 93 | 82 | - |
| 15 | F.D | 23 | 23 | - | 20 | 21 | - |
| | B.W | 30 | 31 | 28 | 27 | 25 | 31 |
| | T.W | 81 | 100 | 82 | 84 | 88 | 89 |
| 215 | F.D | 25 | 30 | 23 | 32 | 28 | 22 |
| | B.W | 35 | 25 | 25 | 20 | 27 | 33 |
| | T.W | 60 | 55 | 65 | 60 | 63 | 64 |
| 178/79 | F.D | 21 | 18 | 23 | 21 | 27 | 14 |
| | B.W | 35 | 40 | 30 | 34 | 35 | 29 |
| | T.W | 85 | 65 | 75 | 64 | 67 | 60 |
| 21 | F.D | 27 | 18 | 23 | 20 | 19 | 25 |
| | B.W | 50 | 45 | - | 30 | 55 | - |
| | T.W | 100 | 100 | - | 80 | 90 | - |
| 212 | F.D | 28 | 23 | - | 26 | 29 | - |

*Table 3.8: Average furrow discharges measured at different fields at WSSE*

| Field No | Furrow discharge (l/s) |
|---|---|
| 70 | 2.1 |
| 31 | 2.5 |
| 213 | 1.8 |
| 51 | 2.9 |
| 72 | 1.5 |
| 71 | 2.1 |
| 24 | 2.6 |
| 258 | 2.5 |
| 13 | 2.1 |
| 177 | 3.2 |
| 17 | 2.4 |

sions and bed slopes) and water applications (proper estimation of application depth, discharge and, cutoff time).

### 3.6. Waterlogging

It was found in this study that the average water velocity for secondary supply canal was 0.3 m/s, which is too low. Under such low flow velocities water seeps along the canal banks. The problem is observed in many fields during field visits. The seepage created shallow water table as recorded in a number of observation wells installed in the Estate. It was also reported that the average ground water table at Wonji is only 0.94 m below the ground surface (Habib, 2002) By the same report, shallow sugarcane root depth was found where there is a shallow water table.

Discharge measurements conducted along tertiary canals indicated that there is an average seepage loss of about 40 % for 500 m long tertiary canals. Thus, it appears that the water table development is directly caused by seepage of water due to poor convey-

## 4. Summary and Conclusion

The following points are summarized as salient findings of the study:

1. Secondary & tertiary supply canals and *malang* bed widths are non-uniform both along and across the canals. The same non- uniformity was observed in furrow cross-sections.

2. The secondary & tertiary canals, *malang* and furrow discharges are non-uniform across the canals. Furthermore, the discharges in all the canals were too low to adequately and timely effect the irrigation water application. There was no probability of obtaining the design flow of 75 l/s in tertiary canals.

3. The flow velocities in the secondary supply canals were found to have been 0.3 m/s on average such that it will take up to 3 hrs for the water to reach to the furthest field (3 km) from the reservoir. Further, a 0.3 m/s was found to cause siltation in the canals and seepage all along its path. The seepage amount was found 40 % for 500 m long tertiary canal. This is very high figure.

4. The furrow slope ranged from 0.05 to 0.17 %, which is acceptable in furrow irrigation.

## 5. Recommendations

Based on the results obtained from this experiment the following recommendations are forwarded.

1. For uniform water flow parameters in the *malangs*, tertiary & secondary canals, canal cross- sections and bed slopes should be made uniform. Besides, the canal dimensions should be surveyed and maintained precisely after every harvesting and at the annual canal maintenance program. Flows should be regulated when released to the canal systems.

2. There is high water table in the estate, which results in ill effects of waterlogging. The high water table condition arising from seepage of irrigation water needs to be alleviated through appropriate conveyance mechanisms.

3. Poor conveyance system and low

water velocities in the canals should be improved by canal rehabilitation (maintaining discharges and cross-sections of canals uniformity) and redesign programs of canal cross-sections as per the requirement of water delivery.

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# Regional Moisture Availability Analysis for SNNP Region,Ethiopia

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**Abstract**

**Sustainable food production needs identifying areas that need especial treatment in relation with the natural phenomena such as variation of climatic elements. The identification may help to differentiate the most susceptible area from the less susceptible area with respect to moisture deficits and thus to manage accordingly. Identification of the deficiency of moisture helps to quantify the magnitude of water that has to be supplemented by irrigation by utilization of the near by available water resource like rivers, lakes, rainfall runoff, spring and so on. Soil moisture status has been determined using empirical relations developed by Hargreaves. The Hargreaves moisture availability index wass used to determine the moisture availability index of the SNNP region and classify the entire region in to different moisture zones. As per the classification the SNNP Region is classified to zone I, Zone II, Zone III, Zone IV where the zone I is the most moisture deficient and zone IV is the least moisture deficient.**

## Introduction

The availability of water to plants is undoubtedly the most important aspect of agricultural food production. Hence Prior to Planning water resource development project for agriculture purpose the extent of supply (availability) and demand (requirement) should be analyzed. The feasibility and sustainability of the projects depends on how reliable supply from sources (rainfall, runoff, rivers, and ground water) is and how it can best be managed to satisfy the demand. It is after ward that the feasibility of implementation of the project can be decided beside the consideration of other technical aspects.

## Objective

The objective of the study was to analyze the regional moisture availability and characterize the entire SNNP region in to different moisture zones.

## Methodology

Meteorological data such as rainfall, relative humidity, wind speed, sunshine hours, and temperature and station geographic locations were collected from different data providers. As it is usual to most of Ethiopian stations, there were a lot of missing data in all meteorological parameters. For the estimation of the missing data empirical relation, regression analysis or average method was used based on recommendation from literatures. The moisture availability was analyzed from the evaporative demand of the atmosphere (evapotranspiration) and the available rainfall. Penman Montheith and Thornthwaite formulae are selected to compute the potential evapotranspiration of the stations with their available meteorological data.

The Penman Monteith method is selected as it is the method by which the evapotranspiration of the reference surface (ETo) can be unambiguously determined, and it provides also consistent ETo values in all regions and climates (FAO ,1998).

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \ldots.[1]$$

T = mean daily air temperature at 2m height [°c]

$U_2$ = wind speed at 2m height [m/s]

Cropwat 5.7 soft ware that was developed by FAO were used to determine the ETo by using governing climatic parameters such as average temperature, wind speed, sunshine hours and relative humidity and geographic location. Since no sufficient data could be available in most of the stations,the potential evaptranspiration for all the stations in the region can not be computed. Hence Stations with complete meteorological data such as Arba

*Table 1 ETo Penman Montheith (cm/month)*

| | A,Minch | Jimma | Gore | A.Mariam | N.Borena |
|---|---|---|---|---|---|
| Jan | 14.52 | 9.6 | 9.9 | 12 | 14.7 |
| Feb | 16.05 | 10.5 | 10.5 | 12.9 | 16.5 |
| Mar | 16.8 | 11.4 | 11.4 | 12.6 | 14.7 |
| Apr | 14.31 | 11.1 | 11.4 | 12 | 11.7 |
| May | 13.83 | 10.8 | 10.2 | 10.8 | 10.5 |
| June | 13.35 | 9.9 | 8.4 | 9.6 | 9.9 |
| Jul | 12.09 | 9.3 | 7.5 | 9.3 | 9 |
| Aug | 13.32 | 9.3 | 12 | 10.2 | 10.2 |
| Sep | 15.18 | 10.2 | 8.4 | 8.4 | 11.4 |
| Oct | 13.56 | 9.3 | 9.3 | 10.5 | 10.5 |
| Nov | 13.02 | 9.6 | 9.6 | 10.2 | 12 |
| Dec | 13.8 | 9.3 | 9.3 | 9.9 | 13.5 |
| Total | 169.83 | 120.3 | 117.9 | 128.4 | 144.6 |

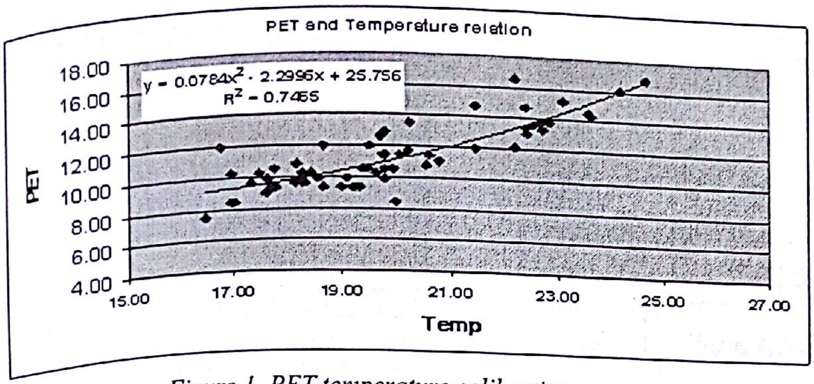



*Figure 1 PET temperature calibration curves*

*Table 2 MAI determined from Hargreaves equation*

| S.No | Station name | 75%DP | PET | MAI |
|---|---|---|---|---|
| 1 | A.mariam | 768.3 | 1179.9 | 0.65 |
| 2 | A.Kulito | 845.4 | 1268 | 0.67 |
| 3 | A.Kele | 836.3 | 1482.5 | 0.56 |
| 4 | Argacha | 1168.6 | 1225.4 | 0.95 |
| 5 | Abaminch | 756.9 | 1738.4 | 0.44 |
| 6 | Areka | 11035 | 1278.7 | 0.86 |
| 7 | Awassa | 820.8 | 133.5 | 0.63 |
| 8 | Bilate | 828.1 | 1671.7 | 0.50 |
| 9 | Bodity | 1106.8 | 1154.6 | 0.96 |
| 10 | Burji | 814.2 | 1349.3 | 0.60 |
| 11 | Dilla | 1187.1 | 1325 | 0.90 |
| 12 | F.Genet | 1169 | 1140.9 | 1.02 |
| 13 | Gidole | 772 | 1506.8 | 0.51 |
| 14 | Hossaina | 1058.6 | 1104.2 | 0.96 |
| 15 | M.Abaya | 554.4 | 1780.5 | 0.31 |
| 16 | Sodo | 961.1 | 1227.7 | 0.79 |
| 17 | Y.Chefe | 1168.4 | 1161.6 | 0.79 |
| 18 | Y.Alem | 1120.7 | 1011.80 | 1.11 |
| 19 | Jimma | 1330.8 | 866.69 | 1.54 |
| 20 | Gore | 1700 | 816.56 | 2.08 |
| 21 | Masha | 1832.1 | 710.84 | 2.56 |

Minch, Jimma, Gore, and Negele Borena were used to evaluate ETo. The remaining stations are having only temperature data. The computed potential evepotranspiration using Penman Montheith method is shown in table 1

The results of reference evapotranspiration in table 1 and mean monthly temperature of the same stations were used to develop temperature based equation(figure 1).This equation was then used to estimate evapotranspiration for those stations where only temperature records area available.The results are given in table 2.

$$PET_{PT} = 0.0784T^2 - 2.3T + 25.76$$

Thornthwaite (1948) derived an equation to be used under the condition of limited water availability. This equation produces monthly estimates of ET.

$$ET = C * T^a \text{ ....................[2]}$$

Where

ET = potential evapotranspiration (cm)
C= coefficient which is the function of the location of the station
T = mean monthly temperature in °c
a = an exponent and can be estimated as

$$a = (67.5*10^{-8})* I^3 - (77.1*10^{-6})* I^2 + 0.0179*I + 0.492 \text{ ..............................[2b]}$$

Where $T_j$ is the mean temperature of the $j^{th}$ month.

Assuming each month has 30days Equation 2 can be simplified as

$$PET = 1.62*\left(\frac{10T}{I}\right)^a \text{ ..............[2.C]}$$

As it can be seen from the figure 1 the temperature based equation shows results that have similar trend as that of Thornthwaite which has also temperature as only meteorological parameter influencing ET.

Hence the PET value determined using the formula developed by relating the temperature element and with PET value obtained by Penman Montheith method is considered for further analysis.

## Design rainfall

In the region a total of 24 stations having 24 years of annual record (1981-2004) have been considered in the analysis.

The probability of occurrence P (%) for each observation has been calculated by Weibull plotting position formula

$$P(\%) = \frac{M}{N+1} * 100 \text{ .............[3]}$$

P = probability in % of the observation of the rank m

M = the rank of the observation

N = total number of observations used

Based on the long term precipitation data 75% dependable rainfall was determined.

As per Hargreaves (1974) suggestion moisture availability index (MAI) can be used to group climatic regions.

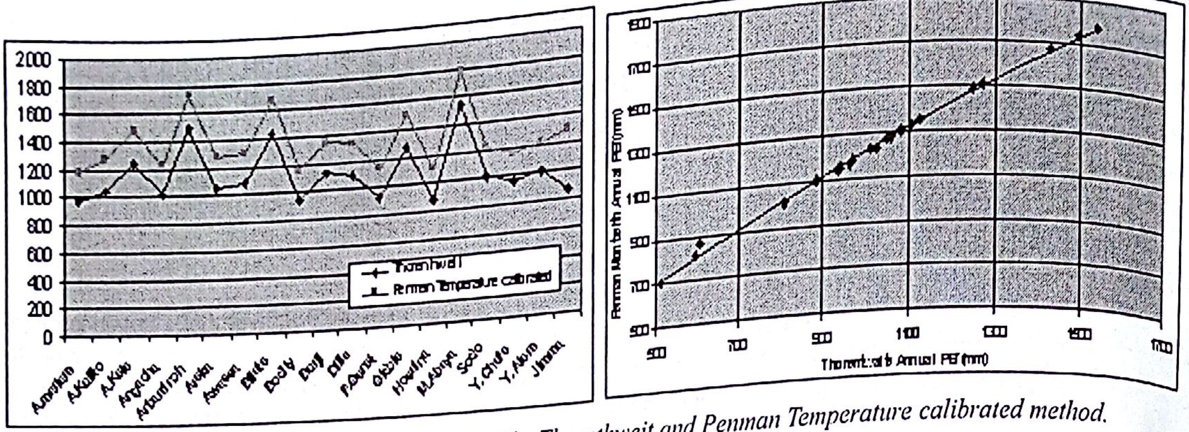



*Figure 2 Comparison of PET value obtained by Thornthweit and Penman Temperature calibrated method.*

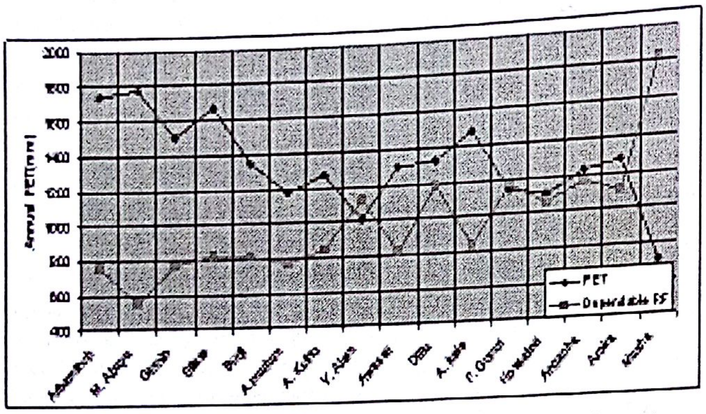
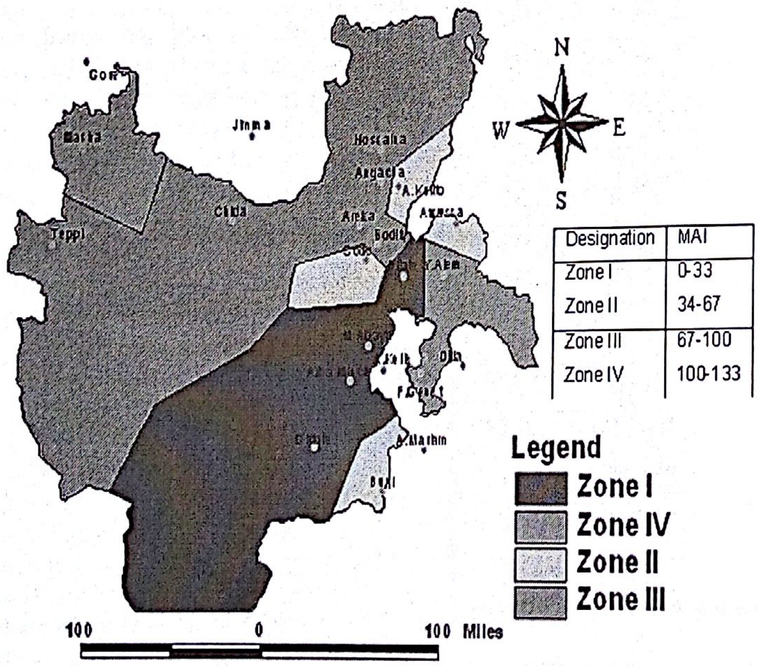



*Figure 3 PET value tend analysis of the selected station in the region*




| Designation | MAI |
|---|---|
| Zone I | 0-33 |
| Zone II | 34-67 |
| Zone III | 67-100 |
| Zone IV | 100-133 |

*Figure 4 Regional soil moisture availability index map*

MAI is the relative measure of the adequacy of precipitation in supply of moisture requirement. It is expressed as

$$I = \sum_{j=1}^{j=12} (Tj/5)^{1.51} \quad ........... (1.4)$$

MAI =moisture availability index
PD= Dependable rainfall
PET =Potential evapotranspiration.

Hargreaves proposed the following climatic regions based on MAI.

| MAI(%) | Classes |
|---|---|
| 0-33 | Very deficient |
| 34-67 | Moderately deficit |
| 68-100 | Some what deficient |
| 101-133 | Adequate |
| >134 | Excessive |

## Regional classification

The Entire region is classified in to three moisture Zones based on their moisture availability index and being accompanied with governing parameter like land use where the moisture zones are taken as Zone1, Zone2, Zone3.

## Conclusion and Discussions

From Figure it can be seen that the PET value has shown more variation than the dependable rainfall. This shows that there exists a greater variation of the evaporative demand of the atmosphere within the region. In zone I and zone II moisture zone the rainfall is seen to be less variable among the stations when compared to stations in zone III moisture zone. This has general implication of less magnitude and less variation of rainfall in the most deficient moisture zones.

Based on the results computed on figure 4 significantly more than 50% of the region falls in moisture deficient zone. Although the degree varies, all areas with MAI less than 100% can be considered deficient zone. The south eastern part of the region around Lote, Kamba, M.Abaya, A.Minch, Gato, and areas some part of western region around Tepi fall in very moisture deficient zone.

The moisture deficiency is very significant in the east, south east, south and south western part where as less moisture deficiency can be observed at the north and north western part of the region. The moisture deficit zones are characterized by high PET value and lower rainfall

The amount of required supplemental water for crop production in the region can not be the same every where in the region. The amount of water needed should be analyzed in relation with respective moisture zones.

## Recommendation

Further study and analysis need to be added with respect to different seasons with explicit consideration for dry and wet seasons.

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# A proposal for identifying river-water degradation after sediment flocculation

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## Abstract

**This paper provides an introductory connotation of suspended sediment in flocculation, information's on relative effects of the floc particles on water body and a proposal for identifying the quality of river-water affected by flocculated sediments. As the suspended sediment particle cannot be considered as an individual absolute particle, but as a composite mixture of inorganic matters, organic or microbial community, extra-cellular polymeric fibrils due to bacterial population and water in trapping, the mixing of water with sediment particles in river system should be viewed in the direction of evolution of these micro-systems. The quality of the aquatic system is therefore dependent on the physical, chemical and biological functions of the entities. The present discussion is carried out based on different literatures/findings; and the proposal for future research is produced S– from the concept enumerated herein. The researchers can prompt to the analyses for water quality assessment from this new approach.**

*Key words* — **flocculated sediment, river water, water degradation, EPS fibril, microbial community**

## Introduction

Increased sediment yields from river basins resulting from catchment disturbance and land use change have been increasingly recognized as a major environmental problem in many areas of the world (Walling, 1997). Abernethy (1990) suggests that the annual sediment yields of many rivers in developing countries can be expected to double over a period of 20 years in response to population growth and associated land use change. Eckholm (1976) contended that "excess sediment is the major form of human-induced water pollution". The sediment particles, especially in suspension, come in contact with other aquatic elements in the river. Peart (1997) examined that the higher suspended sediment concentrations downstream at 'Kam Tin' River of Hong Kong were because of the disposal of domestic, agricultural and industrial waste in the river; similarly, the occurrence of higher suspended sediment levels in the Lam Tsuen River were due to impact by conservation activity. Sharma (1997) also observed that the aquatic sedimentation phenomenon in arid region too is greatly influenced by land disturbance due to overgrazing. Therefore, the resulting increased sediment loads in a complex mixing environment of the water body can give rise to important practical and economic problems in terms of degradation of reservoir and impairment of irrigation schemes, water treatment facilities (cf. Clark *et al*., 1985), etc.

The amount of suspended sediments in river-water depends upon the diffusion, transport and aggradations characteristics of the individual particle and its morphological behavior. The general inference of the quality of the aquatic system is that more is the mixing of suspended sediment particles with other constituent elements in the water body, more will be the degradation of the river water. The degradation is termed in a sense that the water quality will be poor in the sense the aquatic system is affected by bacteriological, chemical, biological and physical processes, and it will affect the surrounding environment. Therefore, the hydrological events happening in the river basin have a dominating role in altering the quality of river water.

The traditional definition of sediment particles in suspension is the holding up of small segments of the particles, transported by moving water, by turbulent upward eddies. It implies that sediment particles are individual entities with no other function to be eroded, transported and settled within aquatic systems as individual non-cohesive particles (Droppo, 2003). In today's multi-disciplinary approach to ecosystem assessment, such a physically-based definition no longer represents the significance of suspended sediment within the environment as a physical, chemical and biological moderator of aquatic systems (Clifford, 2002). Flocs have been shown to be the dominant mode transport within any aquatic system that carries a significant proportion of cohesive sediment (Petticrew & Droppo, 2000). The flocculation significantly alters the river water characteristics due to the cumulative effects of a change in the effective particle size, density, porosity and shape over that of primary particle ( Li & Ganczarczyk, 1987; Ongley *et al*., 1992; Philips & Walling, 1995; Nicholas & Walling, 1996). The sediment particle in suspension may be, therefore, termed as flocculated sediment, and the discussion on the bio-effects of the particles on river water will be intended to the flocculation nature only of the particle.

In the present paper, a general discussion is carried out on how does the sediment structure — its compositional matrix and the morphological characteristics such as size, porosity, density etc., influence the aquatic system. Leppard (1985) and Decho (1990) remark that while flocs can function as individual micro-ecosystems, they have also been shown to have an ability to regulate the surrounding water quality. However, no experiments for identifying their relative influences are being conducted in the present report, and hence no analytical results could be produced here. It is hoped that the present discussion and the proposal submitted herewith will provide a new thought to the researchers to observe and quantify the phenomenal change in the aquatic system, specially the river water, due to presence of flocculated sediment.

### Identifying flocculated sediment

Droppo (2001) defines floc as an "individual micro-ecosystem represented as a composite particle composed of a matrix of water, inorganic and organic (viable and non-viable) particles, with autonomous and interactive physical, chemical and biological functions or behaviors operating within the floc matrix". A typical floc structure is composed of some sub-flocs made up of thousands of other individual grains of different sizes (Fig. 1). When suspended sediment is viewed as being composed of such 'micro-ecosystem', then the interpretation of the suspended sediment and the role it plays within the water body changes.

Therefore, the suspended sediment in flocculation will behave in the aquatic system differently than the primary absolute particle because of significant differences in size, surface area, density, porosity, shape and settling velocity. To understand and measure the sediment mixing in the water body, suspended sediment must be viewed and interpreted based on its natural flocculated state and not as absolute (primary) particles. Petticrew & Droppo (2000) remarked that flocculation of cohesive sediment is a universal phenomenon, and the floc is the dominant mode of sediment transport for rivers with a significant cohesive sediment load. The process of flocculation is the only phenomenon that can explain the presence of the cohesive particles on the flowing environment.

In flowing water, the suspended load will consist of much larger particles than the colloidal size, and the size of particles in suspension is governed by the intensity of turbulent mixing. The movement of even the very fine particles in flowing fluid is dominated by turbulent agitation. But when such fine particles come, for example, into a lake, the settling may be counteracted by large- and small-scale thermal motion. The large-scale motions are caused by thermal convection. In the small scale, the liquid molecules are in a state of continuous agitation caused by their thermal energy. The thermal energy is also transmitted to the solid particles and the resulting motion is known as the Brownian movement. It is important for particle sizes to be below 1m. The particles may also have electrical charges. If the particles have the same charge, they repel each other and thus counteract sedimentation. However, if an additional agent causes the particles to lose their charges then by mutual attraction of mass they will tend to join together and thus form larger particles or flocs and these settle out more rapidly. For example, kaolin clays consist of hydrous silicates of aluminium having a calcium-magnesium base. The particles have like electric charge in fresh water and repel each other. But if these are carried into any water body having dissolved salts, then they come into water containing salt concentration. The sodium ions of the chlorides are exchanged with the calcium and magnesium ions from the particles. The particles lose their charges, attract one another and form flocs (cf. Raudkivi, 1967).

The individual inorganic grains which make up the floc are on average approximately 5 mm in diameter with a corresponding Stokes' settling velocity

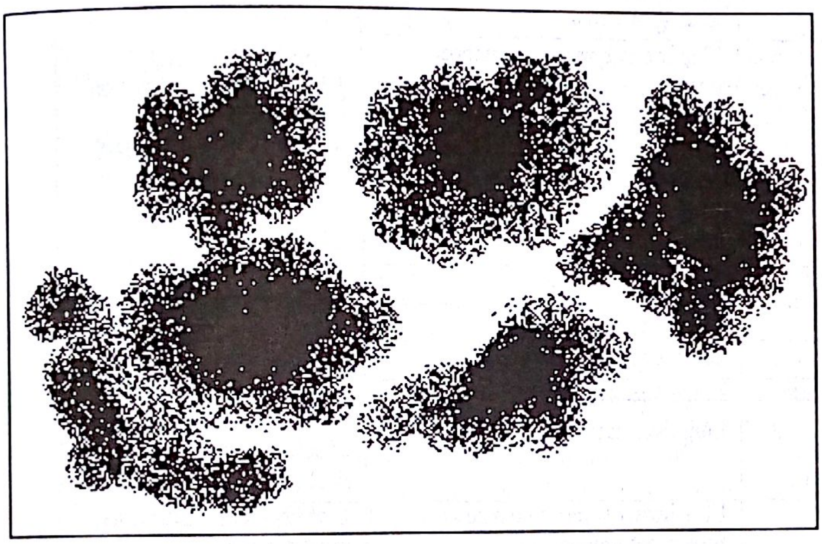

*Fig. 1. A floc composed of a number of individual grains (sub-flocs)*

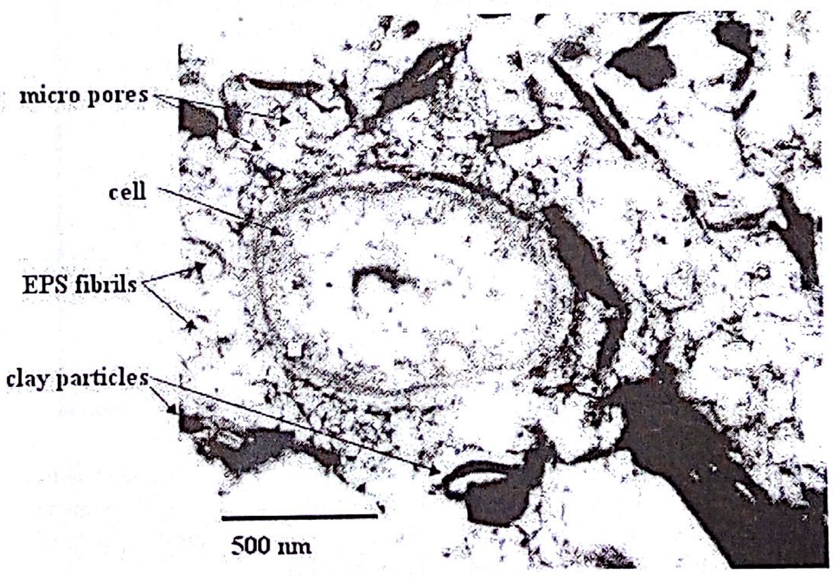


*Fig. 2. Micrograph of a typical floc showing various interactions*

*Table-1: Characteristics of constituent entities of flocculated sediments and their effects on water body*

| *Constituents of flocculated sediments* | *Characteristics ** | *Effects on water body ** | *Directions for investigations* |
|---|---|---|---|
| Inorganic particles | Negative charge | Electrochemical flocculation (floc hydrodynamic) – effects on mixing of water | 1. study of electrochemical flocculation<br>2. study of floc density<br>3. study of bacterial growth and contamination effects on water body |
| | Diverse structure | Electrochemical effects | |
| | High density | Increases floc density – effects on mixing of water | |
| | Nutrient/ contaminant source | Biological food source, bacterial colonization | |
| | Large surface area | Nutrient/ contaminant adsorption, -- contaminant transport, -- effects on mixing of water | |
| Microbial community/ organic particles | Negative charge | Electrochemical flocculation (floc hydrodynamic) – effects on mixing of water | 1. study of electrochemical flocculation<br>2. study of floc density<br>3. study of bacterial growth and contamination effects on water body<br>4. study on water trapping |
| | Attachment | Floc hydrodynamic -- effects on mixing of water | |
| | Low density | Floc hydrodynamic reduction process | |
| | Fibril production | *Detail on next description* | |
| | Large surface area | Nutrient/ contaminant adsorption, trapping of water, -- contaminant transport, -- effects on mixing of water | |
| Microbial EPS fibrils | 3-D dense network | 3-D dense network | 1. study of electrochemical flocculation<br>2. study of floc density<br>3. study of bacterial growth and contamination effects on water body<br>4. study on water trapping |
| | Attachment | Attachment | |
| | Low density | Low density | |
| | Large surface tension | Large surface tension | |
| | Large surface area | Large surface area | |
| Floc pores | Macro pores | Floc hydrodynamic change -- biological removal, -- transformation of contaminants | 1. study on characteristics of floc pores |
| | Micro pores | Trapping of water -- effects on bio-chemical and diffusion process | |
| | Pores within pores | Trapping of water -- effects on bio-chemical and diffusion process | |
| Water | Free water | Floc hydrodynamic change -- effect on mixing of water, -- contaminant mixing | 1. study of water characteristics such as cohesion and adhesion |
| | Bound water | Effects on bio-chemical and diffusion process | |
| | Low density | Floc hydrodynamic reduction process | |

of 0.02 mm $s^{-1}$ (Droppo, 2003). As flocs become smaller, they approach the particle size of the constituent particles and as such Stokes' law would represent the movement function of the particle inside water body. But, for large floc particle, Droppo (2001) remarked that Stokes' law will give erroneous values for particle movement due to the floc structure. Therefore, the size and shape of the flocculated sediment will affect the mixing phenomena in water column and thus the quality of the river water.

When floc size increases, the number of contacts between particles increases and the porosity is increased, but the density is decreased. Fig. 2 illustrates the water trapping consequences inside the small pores developed within the floc due to the secretion of extracellular polymeric fibrils (EPS) by the bacterial population of the flocs. vi Leppard (1997), states that the average diameter of an EPS fibril is 4-20 nm, and therefore, each pore will have a high surface tension for the retention of water. Large macro pores are possible within large open matrix flocs, with the effect of increased settling velocity due to the movement of free water through the floc pores reducing mechanical drag on the floc (Masliyah & Polikar, 1980). So, this water holding property of the micro contituents will influence the sediment movement and the water quality.

### The effects of flocculated sediment on water body

The mixing of suspended sediments in the water column is greatly influenced by floc structure. A floc, according to Droppo (2001), can be derived of four different structural components, viz., inorganic particles, biota and bioorganic particles with an EPS subclass, pore structure and water. The characteristics of the above components and their behavioral effects are summarized in Table. The informations are gathered from Droppo (2003); Droppo (2001); Phillips and Walling (1995); Nicholas and Walling (1996); Ongley *et al.* (1992); Walker and Bob (2001). The descriptions in the Table 1, simply, demonstrate the complex link between the physical, chemical and biological structures (gross and fine scale) of a floc, and the outward physical, chemical and biological behavior. The characteristics of the sediment-components elaborate the influencing pattern of floc building and subsequent mixing in the aquatic system. The possible effects on water in the river system by the suspended sediments can be studied in the direction as stated in the Table 1.

From the discussion, it can be remarked that the flocs are continuously interacting with their environment, as the medium in which they are transported provides the flocs with building materials, energy, nutrients and chemicals for biological growth, chemical reactions and morphological evolution.

The bacteria play the major role in floc development and mixing. As the bacteria and the EPS are both sticky in nature, subsequent collisions in suspension will result in additional particles (organic and inorganic) entering into the floc matrix forming larger faster settling particles. The EPS fibrils are very fine and form dense porous networks within the floc. These will facilitate further nutrient and contaminant adsorption (further bacterial food source) due to their large surface area. The small pores in the micro-ecosystem will result in the trapping of water.

## Proposal

The proposal presented to determine the river water degradation due to flocculated sediment is as follows:

· Determine suspended sediment concentration (gm $m^{-3}$) in each column of water and then that corresponding to total volume of the particular river

· Determine suspended sediment concentration by the following formula at different reaches of the river for various hydrological events in the contributing watersheds, but at a gap of time, and analyze the concentration phenomena in three-dimensional pattern to know the concentration profile in the aquatic system

The sediment concentration in three- dimensional diffusion case

$$C(x,y,z;t) = \frac{M_3}{\left(\sqrt{2\pi}\sigma\right)^3}\exp\left(-\frac{r^2}{2\sigma^2}\right)$$

(Csanady, 1973)

(1) with

$$M_3 = M_0 = \int_{-\alpha}^{+\alpha}\int_{-\alpha}^{+\alpha}\int_{-\alpha}^{+\alpha} C(x,y,z;t)\,dx\,dy\,dz$$

(2)

where $M_3 = M_0$ is the instantaneous point source (i.e., total mass of substance being introduced instantaneously into the aqueous medium), in unit of (gm); $\sigma^2$ is the variance where $\sigma^2 = 2\xi_m t$, t is the time (sec) of entry or injection of sediment laden water, $\xi_m$ is the mass diffusivity of sediment flow mixture in square cm per sec; and $r^2 = x^2 + y^2 + z^2$ is the radius of a sphere, being the distance from the origin. The concentration will be in $gm/m^3$.

· Determine probable number (by count) of flocculated sediments ( sediment particles in suspension and in floc-nature) in each sediment concentration.

The concentration of flocculated sediments obtained as count per cubic metre will be compared with the concentration obtained from equation (1).

· Determine probable amount of inorganic particles, organic particles, EPS fibrils, water content etc., in each flocculated sediment particle

· Derive probable cohesive nature of "contaminants" in each constituent such as inorganic particle, organic particle, EPS fibril, water content etc., and 'probable' growth and decay of contaminants due to numerous reactions

· Calculate total contamination either in volume or in weight basis for the river, and analyze it with the concentration count.

## Inference

As the flocculated sediment is a micro-ecosystem consisting of a number of components in the aquatic environment, it has great influence in the mixing of water body and in affecting the system in physical, chemical and biological ways. Therefore, the bio-effects on water can be studied keeping in consideration of the above nature and characteristics of different constituents of the said particles.

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# Participatory Gully Stabilization using Temporary Structures Combined with Grasses at Gare Area, Western Shewa, Ethiopia

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## Abstracts

Loss of arable land due to soil erosion is a widespread phenomenon in the highlands of Ethiopia, which accounts for about 45% of the country's total land area. The study area, Gare Areara, is also found in the highlands of the country where soil erosion is a serious problem. High human and livestock population, intense rainfall, continuous cultivation, overgrazing and deforestation also characterize the area. This study was targeted to evaluate the effectiveness of temporary structures and multipurpose grasses for gully stabilization, and to develop farmers' participation in gully stabilization and to increase their awareness in the importance of soil and water conservation measures. The trial was conducted on two gullies at Gare Arera. The first gully received Loose-rock check dam (LRCD) and the second double fence wooden check dam (DWCD). Four grasses: *Pennisetum schimperi, Eleusine species, Vetiveria zizanioids* and *Pennisetum purpreum* were planted at the beginning of the main rain season. The survival rate and their resistant for free grazing were monitored. The amount of soil deposited by the check dam was measured and sediment concentration of run-off leaving the check dams was measured using hydrometer.

The result of this study revealed that *Eleusine sp* has the highest average survival rate (94.5%) and resistant to free grazing. *Vetiveria zizanioids* and *Pennisetum purpreum* have an average survival rate of 82% and 84.5% respectively where as *Pennisetum schimperi* has 69.5%. Besides this, *Eleusine sp* and *Pennisetum schimperi* are resistant for free grazing. The average volume of soil deposited in loose rock check dam (LRCD) was 1.69m³/check dam where as in double fence wooden check-dam was 4.45m³/check dam. This means, the average soil deposited is higher in double fence wooden check dam as compared to the loose rock check dam. This is due to the difference in the dimension of the two gullies.

The average sediment concentration of the run of leaving loose rock and double fence wooden check dam are 6.64g/l and 12.64g/l respectively. Whereas the average sediment concentration of the run-off from untreated gully, that is located between the two gullies, is 29.15g/l. This shows LRCD reduces the sediment concentration (soil loss) by 77% while the DWCD reduce the sediment concentration by (soil loss) 56% (table 4). Therefore, LRCD is more effective than the DWCD in reducing sediment concentration (soil loss). However, farmers in the study area prefer DWCD because of two reasons. The first reason is that the construction of DWCD is simple as compared to LRCD while the second reason is that the availability of stone in the study area is limited.


## Introduction

Loss of arable land due to soil erosion is a widespread phenomenon in Ethiopian highlands, which accounts for about 45% of the country's total land area (SCRP, 1991). Ethiopia has been described as one of the most serious soil erosion area in the world (Blaikie, 1985) with national estimated average soil loss of 42t/ha/yr (Hurni, 1989). It can be even higher on steep slopes with a soil loss rate greater than 300t/ha/yr (USAID, 2000). The study area is also found in the highlands of the country where soil erosion is a serious problem. High human and livestock population, intense rainfall, continuous cultivation, overgrazing and deforestation also characterize the area. Farmers in the area cultivate all of their lands regardless of its suitability and capability and hence there is severe soil erosion particularly gully incision. Gullies in the area dissect farmlands, roads and grazing lands and thereby void these lands and interfere farm operations.

The mechanics of gully erosion can be reduced to two main processes: Down cutting and head cutting. Down cutting of the gully bottom leads to gully deepening and widening while head cutting extends the channel in to ungullied headwater areas and increase the stream net and its density by developing tributaries. Thus effective gully control must stabilize both the channel gradient and channel head cuts. The most commonly applied engineering measure is the check dam. Forces acting on a check dam depend on design and type of construction material. Non-porous dam with no weep holes, such as those built from concrete, sheet steel, wet masonry and fiberglass receives a strong impact from the dynamic and hydrostatic forces of the flow. These forces require strong anchoring of the dam in to the gully bank, to which most of the pressure is transmitted. These types of dams are too expensive and require complex design.

In contrast porous dams (temporary structures), release part of the flow through the structure, and thereby decrease the head of flow over the spillway and the dynamic and hydrostatic forces against the dam. Much less pressure is received at the bank than with nonporous dams. Since gullies generally are eroded from relatively soft soil, it is easier to design effective porous check dams than nonporous ones. These dams are simple, low cost and constructed with locally available materials like rock and wood. In addition to mechanical measures, biological measures (trees/shrubs and grasses) for gully stabilizations are paramount important. The quality of these biological measures in terms of use, survival rate, resistance to free grazing and availability should be taken in to account while selecting a given species. The most known grass species for gully stabilization and strip cropping is *Vetiveria zizanioids*. However, it is susceptible for free grazing in the case of Ethiopian farming system where free grazing is dominating. In this type of farming system there is a need to obtain a grass species, which is compatible for free grazing.

Because of its nature (high labor demand and requirement of common water ways) gully treatment requires collective action (Reijntjies et al, 1992). In the mean time farmers should be acquainted with the methods by which gully can be stabilized and appreciate the importance of collective action. As a result the experiment focuses on temporary structures combined with grasses with the participation of farmers.

Therefore, the objectives of the study are:

· To evaluate the effectiveness of temporary structures and multipurpose grasses for gully stabilization

· To develop farmers' participation in gully stabilization and to increase their awareness in the importance of soil and water conservation measures.

## Study area and Methodology

The trial was conducted in Gare Arera, Western Shewa located about 9°02'N and 38 °07'E. It has "a Woina Dega "ecology and is found at elevation ranging 2300-2500 m.a.s.l. with bimodal rainfall pattern (Kindu M., 1997). The mean annual rainfall (1981-2004) is 1100mm where as the mean maximum and minimum temperature is 24°C and 8°C respectively. Soil types recognized by farmers in Gare Arera are dima (reddish brown), Megala (brown), Koticha (black) and Kossie (dark gray).

The trial was conducted on two gullies and the slope, width and depth of the two gullies were measured. The first gully received Loose-rock check dam (LRCD) (+) *Pennisetum schimperi* (+) *Eleusine sp* (+)*Vetiveria zizanioids* (+) *Pennisetum purpreum*. The second gully received double fence wooden check dam (DWCD) (+) *Pennisetum schimperi* (+)*Eleusine sp* (+) *Vetiveria zizanioids* (+) *Pennisetum purpreum*.

The effective height of the check dam was determined and spacing between check dams was calculated using formulae (Heede and Mufich 1973.), i.e. $S = \frac{HE}{KG\cos\alpha}$, where *S*=check dam spacing, *HE* is the effective dam height as measured from gully bottom to spillway crest, *G* represents the gully gradient as a ratio, $\alpha$ represents the angle corresponding to the gully gradient (G=tan ) and *K* is a constant. The equation is based on the assumption is that the gradient of the sediment deposited is (1-K) G. K depends on G, where: *K=0.3 for Gd•0.20 and K=0.5 for G>0.20.*

Check dams were constructed before the main rain season begins and grasses were planted at the beginning of the main rainy season on the side and bed of gullies between check dams and the survival rate and resistant to free grazing is evaluated.

The gully depth, width, length and gradient were measured at different season. The change in depth, width, and slope were measured. From these data the volume of soil deposited in each check dam is calculated, and this has been combined with good periodic photographs. Heede and Mufich (1973) developed an equation that relates the volume of sediment deposits to spacing and effective height of dam (*HE*) .$V_s$=0.5*HE**S*Cos * $L_{HE}$, where $V_s$ represents the sediment volume *($m^3$)*, $L_{HE}$ represents the average length of the check dam *(m)*. Run-off samples were taken at the tail of each gully for sediment analysis and samples were analyzed using hydrometer method.

Farmers in the area were participating in the construction of check dams and planting of grasses species. Farmers' field days were also organized to create awareness about the importance of soil and water conservation in general and gully stabilization in particular.

## Results and discussions

### Characteristics of the experimental gullies

It is difficult to obtain identical gullies in the natural environment. This is because of the variations in the catchments characteristics (size, land use, slope, and soil type) and the soil erodibility where the gully is formed. As a result, dimensions of two gullies in similar climatic situation are not identical. Table 1 shows the character-

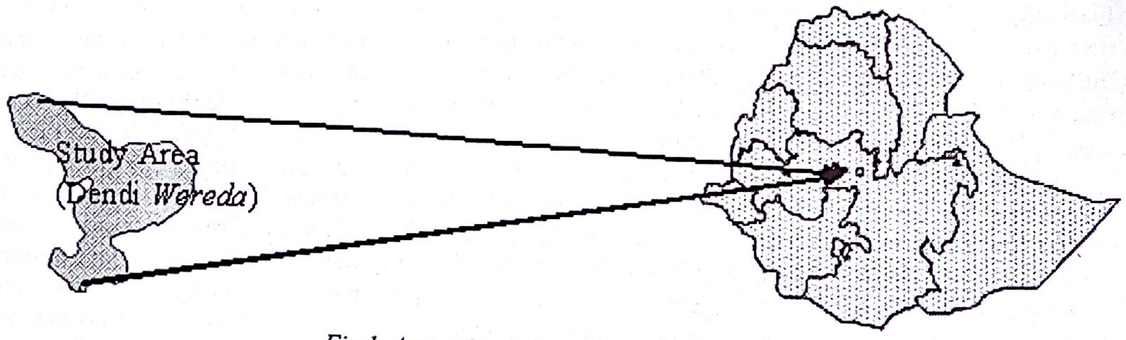


*Fig 1. Approximate location of the study area*

istics of the two gullies where the experiment was conducted.

**Gully No. 1** is a gully where loose rock check dams were constructed whereas **gully No.2** is the gully where double fence wooden check dams were constructed.

**Survival rates of grasses**

Engineering structures for gully stabilization or reclamation requires growth of vegetation specially grasses on the sides and beds of the gully. But obtaining appropriate grass species that is effective for this purpose is one of the challenges for species selection. The measure of its effectiveness is characterized by its survival rate and resistant to grazing. The following table (table 2) shows the survival rate of two exotic (*Vetiveria zizanioids* and *Pennisetum purpreum*) and two indigenous (*Pennisetum schimperi and Eleuisine sp*) grass species.

From table 2, *Eleusine sp* has the highest average survival rate (94.5%) whereas *Vetiveria zizanioids* and *Pennisetum purpreum* have an average survival rate of 82 % and 84.5 % respectively. However, *Vetiveria zizanioids* and *Pennisetum purpreum* are palatable for animals and very susceptible for free grazing as compared to *Pennisetum schimperi and Eleuisine* sp. Therefore, the result shows that; for free grazing crop-livestock farming system, *Eleuisine* sp is the most important grass species for gully stabilization along with engineering measures because of its highest survival rate and resistant to free grazing.

**Soil deposition**

The amount of soil deposited above the check dam, as a result of a particular conservation structure (check dam), is not only depending on the conservation structure itself but also, on the gradient of the gully bed, dimensions of the gully, amount and rate of run-off (which is a function of rainfall and catchments characteristics) and sediment concentration of the run-off. The following table (table 3) shows the amount of soil deposited above the check dam ($m^3$/check dam).

As shown in table 3, the average soil deposited in loose rock check dam (LRCD) was 1.69 $m^3$/check dam whereas in double fence wooden check dam it was 4.45$m^3$/check dam. The average soil deposited is higher in double fence wooden check dam as compared to the loose rock check dam. However, this is not because double fence wooden check dam is more effective than LRCD in trapping sediment from run-off, rather it is due to the variation in the characteristics of the gully (see table1). Therefore, sediment concentrations of the run-off leaving the two types of structures are used for indicators of effectiveness to compare the two treatments.

**Sediment concentration**

The result of sediment concentration analyzed from run-off leaving the structures is used as an indicator of the effectiveness of the structure. This is because, the higher the concentration of the sediment in the run-off leaving the structure, the less the effectiveness of the structure is. The result shows, sediment concentration of the run-off leaving the loose rock and double fence wooden check dam is lower as compared to the control (gully with out structure). The average sediment concentration of the run of leaving loose rock and double fence wooden check dam are 6.64g/l and 12.64g/l respectively. Whereas the average sediment concentration of the run-off from untreated (controlled) gully, that is located between the two gullies, is 29.15g/l. This shows LRCD reduces the sediment concentration (soil loss) by 77% while the DWCD reduce the sediment concentration (soil loss) by 56% (table 4). Therefore, LRCD is more effective than the DWCD in reducing sediment concentration.

**Farmers' participation**

Community participation in the construction and maintenance of gully is essential, as it has several advantages. Voluntary labor can permit significant savings in cost; it can also help to develop a sense of ownership and a climate of cooperation that will facilitate the responsible use and satisfactory maintenance of the structures. The researchers, without the involvement of the local people, carried out the planning and design of the structures, as it

*Table 3 Average deposited soil ($m^3$/check dam)*

| Check dam type | Years | | | | |
|---|---|---|---|---|---|
| | 2001 | 2002 | 2003 | 2004 | Average |
| DWCD | 2.34 | 2.04 | 5.13 | 8.27 | 4.45 |
| LRCD | 2.33 | 1.34 | 1.06 | 2.02 | 1.69 |

*Table 1: the characteristics of the two experimental gullies*

| Characteristics of gully | Gully 1 | Gully 2 |
|---|---|---|
| General gradient of gully (%) | 18 | 8 |
| Length of gully (m) | 61.9 | 67.5 |
| Maximum width of gully (m) | 4.3 | 6.20 |
| Average width of gully (m) | 2.04 | 3.12 |
| Maximum depth of gully (m) | 1.6 | 2.05 |
| Average depth of gully (m) | 0.92 | 1.02 |
| No. Of check dams constructed | 8 | 10 |

*Table 2: Survival rates of different grass species (%)*

| Planting Season | Grass species | | | |
|---|---|---|---|---|
| | *Vetiveria zizanioids* | Pennisetum purpreum | *Pennisetum schimperi* | Eleuisine sp |
| 2001 | 86 | 89 | 72 | 93 |
| 2002 | 78 | 80 | 67 | 96 |
| Mean | 82 | 84.5 | 69.5 | 94.5 |

*Table 4: Sediment concentration (g/l) of run-off leaving the structures compared to the untreated gully*

| Check dam type | Years | | |
|---|---|---|---|
| | 2002 | 2004 | Average |
| Wooden check dam | 6.48 | 18.8 | 12.64 |
| Stone check dam | 6.15 | 7.12 | 6.64 |
| With out check dam (control) | 17.69 | 40.6 | 29.15 |

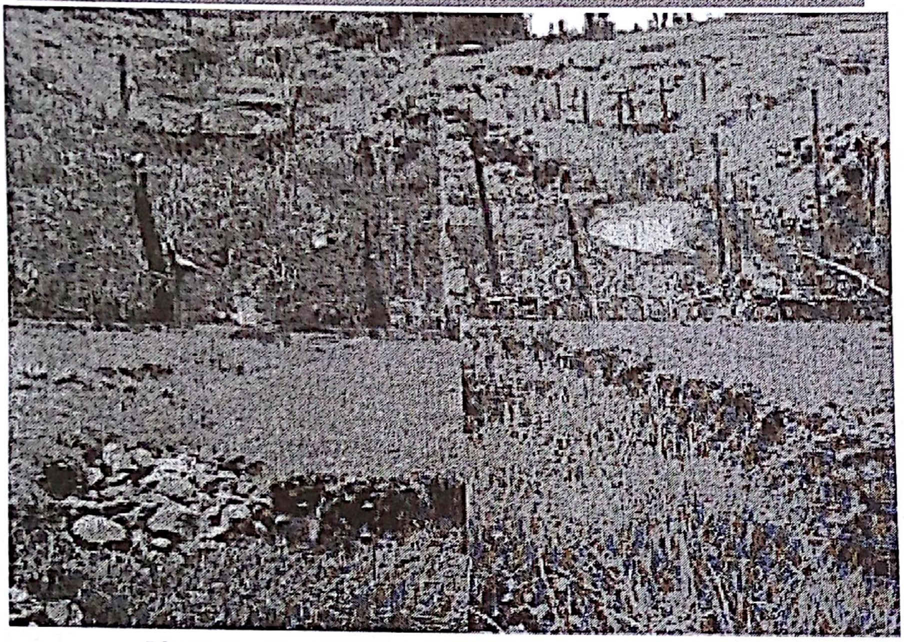

*Photo showing LRCD and DWCD combined with grasses*

was difficult to participate farmers in complex designs and calculations. In the first two years, (2001 and 2002), the participation of farmers were very active in the construction and maintenance of the gully. Thereafter, farmers resist participating in construction works as the stabilization of the two gullies benefits only two farmers (owner of the land where gullies are stabilized).

**Challenges of Gully Stabilization**

According to farmers, the following are some of the challenges of gully stabilization in the area:

- Ruining of structures and low survival rate of stabilizing grasses due to uncontrolled (Free) grazing
- It requires collective action due to its high investment (labor and material) demand
- Problem of property rights: Since most gullies are formed in waterways and roads, the ownership of these gullies are not known
- Lack of construction material (Stone and wood): Lack of wood is one of the problem resulted from deforestation. Besides this the distribution of stone cover is highly variable. There are many areas lacking stone and wood but with severe gully erosion problem
- Require several years to stabilize: It requires patience, maintenance and frequent follow-ups
- Gullies are perceived by farmers as wastelands

## Conclusion and recommendation

This study showed that among the four grasses *Eleusine species* and *Pennisetum purpreum* have high survival rates. *Eleusine species* has high resistant to free grazing during the dry season so that its re-growth rate at the beginning of the following rain season was satisfactory. Although *Pennisetum purpreum* has high survival rate, it is highly susceptible to free grazing and difficult to re-grow for the following rain season. Therefore, *Eleusine species* is the best alternative grass species for gully stabilization. However, there is a need to study method of propagation /in the nursery/, and its importance as hedgerow in the farmland as terrace stabilizer and other associated problems like pest harboring

As long as they are properly constructed and maintained, both double fence wooden and loose rock check dams are equally important in trapping sediment from run-off in medium sized gully. Therefore, depending on their availability, it is possible to stabilize and reclaim gullies by wooden or rock check dams.

Because of its nature, gully stabilization requires collective action. Although the on-site costs/benefits belong to some individuals, the off-site costs are the public/community. Therefore, it is recommend that public investment and different forms of incentives such as technical support and training are essential in order to increase the participation of farmers in soil and water conservation activities requiring collective action.

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# Rainfall-Runoff Modeling Using Remote Sensing and GIS: USDA-SCS Method

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## Abstract

Satellite image of IRS LISS III + PAN & Arial photograph at a scale of 1:20000 are used to prepare land use/land cover map of Kamahi Devi watershed, Punjab, India. The soil & slope maps obtained from Punjab remote sensing center were digitized after scale adjustment was made using optical pantograph. Database was created using ARCINFO 8.3 software in order to generate input parameters for SCS-CN method of rainfall runoff estimation.

The study has shown that an average of 160 mm of runoff was obtained from a rainfall of 703mm in the year 2004. Moreover, about 63% of the total area was found to have high & very high runoff potential (>150mm). Empirical models were formulated to compute daily runoff from daily rainfall, & power function is found to be the best fit ($R^2$= 0.9717). Moreover, the study has shown that Remote Sensing & GIS are efficient tools for spatial modeling.

## Introduction

Proper planning & implementation of development works require prior quantification of soil erosion & runoff in watersheds. Quantitative assessment of hydrological parameters such as volume of runoff, serves as a base for adopting suitable water harvesting and soil & water conservation measures in the watershed (Suresh *et al* 2004).

Several attempts have been made to measure the amount runoff from agricultural lands directly using runoff plots & gauges. However, it is not a feasible operation to conduct such on farm experiments in a sufficiently large number of replication. Hence there comes a need to use mathematical models that are proved to adequately estimate the real systems. There are sets of models that can interrelate information about rainfall, soil, topography & land use of a watershed like Soil Conservation Service Curve Number (SCS-CN) method (USDA-SCS 1972) for runoff estimation.

SCS-CN method uses daily rainfall & considers the hydrological soil group, which reflects a composite picture of soil texture, land use, slope & impact of existing soil & water conservation measures that are used to find out Curve Number (CN) for runoff prediction.

However, collecting spatial information to meet the data requirements of such mathematical models as SCS-CN method has been major difficulty in soil & water research.

Fortunately, amongst all the greatest scientific advances of the 20th Century, exploration of outer space has been the most spectacular & significant one. The advent of satellite era, heralded by the launch of satellite in the fifties, has introduced in its wake an entirely new technology of satellite remote sensing (RS) & a whole range of its application for the benefit of mankind. It, therefore, has given opportunities for people who are involved in watershed study, planning & development by virtue of its fast, relatively cheap, appreciably reproducible & reliable data acquisition capabilities

Since, such digital data from sensors borne by the aircraft, satellites & digital data generated from ground based investigations are enormous, there is a great need for a well organized information system for data processing.

In view of this, Geographic information system (GIS) technologies are proliferating throughout the world in myriad applications as powerful tools to store, retrieve, manipulate, analyze & display spatially related digital & associated attribute data. This gives the GIS an ideal feature for extracting spatially related input parameters for models involved in watershed study. Keeping this in view the study was conducted to assess rainfall-runoff using remote sensing & GIS with the following objectives:

- To estimate the amount of rainfall runoff generated from the watershed.
- To develop runoff potential class map of the watershed
- To assess the potential of remote sensing & GIS to drive input parameters for rainfall runoff modeling

## Modeling rainfall-runoff

A model is an abstraction of reality (Mulligan 2004), which represents a complex system in simplest way that is adequate for the purpose of the modeling. Watershed parameters such as size of the catchment, slope, soil type, land use, vegetation within channels, & storage capacity of the watershed are of great importance in runoff modeling (Tripath *et al* 2002).

Surface runoff volume can be predicted from daily rainfall using Soil Conservation Service Curve Number (SCS-CN) method (USDA-SCS 1972). It is based on the recharge capacity of the watershed & is determined by antecedent moisture conditions & physical characteristics of the watershed (Murty 1998). SCS-CN method takes into consideration the initial abstraction (Ia) that accounts for the initial quantity of interception, depression storage, & infiltration, which must be satisfied by any rainfall before runoff can occur.M The governing relationship & basic equation used in SCS Curve Number Method (USDA-SCS, 1972) is as follows:

$$\Rightarrow Q = \frac{(p - Ia)^2}{(p - Ia + S)}$$

Where: Qd = daily runoff depth; P = daily rainfall depth; Ia = Initial abstraction S = Potential maximum retention Patra (2001) indicated that on an average Ia=0.2S.

$$Q = \frac{(p - 0.25)^2}{(P + 0.8S)}$$

The retention parameter is defined in terms of curve number (CN), which itself depends on land use, soil type & hydrological soil condition (Young et al 1989 & Durbude et al 2001).

The potential maximum retention, S (cm) is related to curve number (CN) as follows (USDA-SCS, 1972):

$$S = \frac{2540}{CN} - 25.4S$$

where CN = Curve number ; S = potential maximum retention

## Materials and Methods

### The study area

Kamahi Devi watershed is found in Hoshiarpur district, Punjab state of India. It lies between the geographic coordinates 31o50' 15" N to 31o59' 54" N of latitude & 75o47' 31" E to 75o52'45" E of longitude covering a total area of 5724.7 ha.

### Data used

Black & white photographs on 1: 20,000 scale for the year 1991& IRS 1D LISS III satellite data were used to extract spatial data required by the model.

### Rainfall Characterization

A 5-year moving average was computed to isolate the trend in rainfall data and to determine of dry and wet periods.

### Preparation of Thematic Layers

The black & white aerial photographs were interpreted stereoscopically for preparation of land use map. Simultaneously, satellite data was visually interpreted &land use map was made ready for digitizing at a scale of 1:25000.

Analogue soil map at a scale of 1:50,000 was obtained from Punjab Remote Sensing Center (PRSC). The map was then transferred to a 1:25,000 scale base map using optical pantograph & was made ready for digitizing.

Drainage map was prepared by visual interpretation of aerial photographs. Moisacing of all the maps prepared from individual stereopairs was done after scaling to 1:25,000 scale using optical pantograph. The watershed was divided into 9 sub-watersheds by assuming a local outlet point for each of the sub-watersheds

### Creation of Digital Database

A master TIC file was created & projected to polyconic. The coverages were then transformed to copies of the projected TIC file with output units in meters. The thematic maps at 1:25,000 scale including land use map, soil, drainage, sub-watershed maps were digitized using digitizing tablet in Arc info GIS software & coverage were formed accordingly.

Broken lines were connected using the line-snapping algorithm. A cleaning operation was executed for topology creation in ARC/INFO software. The dangle node errors were removed interactively in ARC EDIT module. Feature Attribute Tables (FAT) were created for all coverages after all the off shoot & under shoot errors had been removed.

## Result and Discussion

### Dry and wet periods

In hydrology, rainfall data are plotted chronologically with time on x axis & precipitation on y axis, while a rain event is associated with randomness. To overcome the random component, a simple moving average is used. This helps to isolate the trend in rainfall data. A 5-year moving average was computed based on 31 years annual rainfall data & was plotted as a time series. The years from 1988 to 2002 are found to be wet years as their moving averages remain above the mean value for more than three consecutive years. On the other hand, the years 1974 to 1988, & 2002 to 2004 are characterized as dry years.

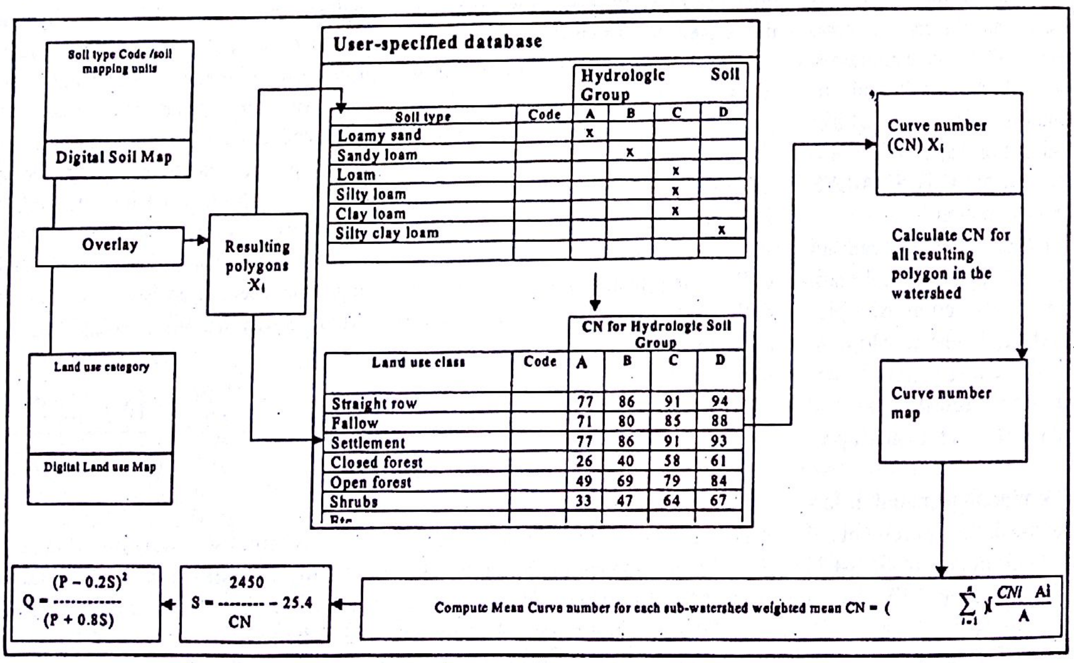


*Fig. 1 Flow digram of the methodology followed for runoff modeling*

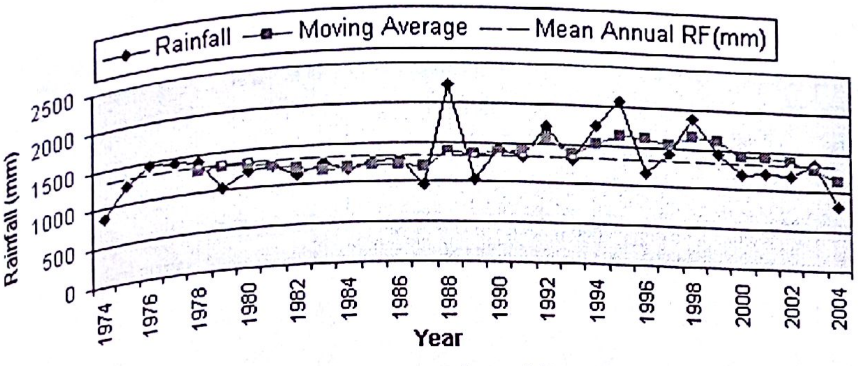


*Fig. 2 five-year moving average of rainfall (Pong Dam Station)*

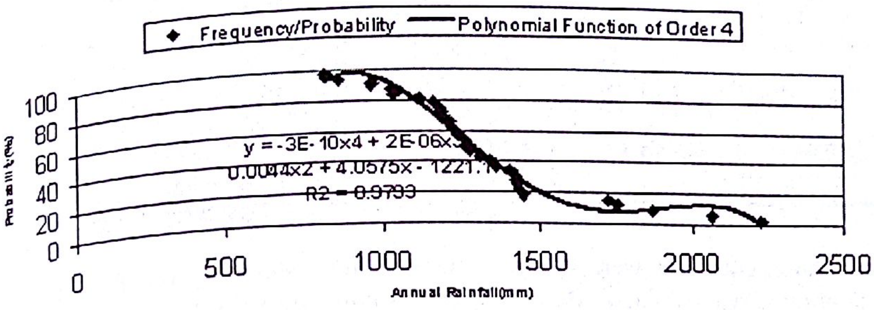


*Fig 3 Curve for emprical model to estimate probabilitity of rainfall*

**Rainfall probability analysis**

Probability analysis on annual time series rainfall data revealed that there is about 40.6% probability that any design annual rainfall is equal to or exceeds the mean annual rainfall.

**Time of concentration**

The length, width & slope of a watershed are important hydrological parameters that determine the time of concentration & peak runoff rate. The time of concentration is the time required for runoff to reach the final outlet point from remotest point of the watershed.

Drainage density & time of concentration are found to be negatively correlated (r = -0.78). Hence sub-watersheds with high drainage density develop quick peak runoff rate with relatively smaller loss.

**Daily runoff**

Analysis of the daily rainfall of the year 2004 has shown that there were 64 rainy days. However, only 30 days were found to exceed the anticipated initial abstraction (Ia).The weighted mean maximum retention (S) of the watershed was found to be 51.59 which implies that the first 10.3 mm (0.2 S) of any daily rainfall is used to fill the initial abstraction. There is a strong relationship between daily rainfall & daily runoff (r=0.98).

The relationship between daily rainfall & runoff was found to be best explained by power curve as $Y = 0.0001 X^{3.1337}$ with $R^2 = 0.97$. The rate of increase of runoff at lower values of rainfall is less because most of the rainfall has been used to fill the moisture deficit & the depression storages of the soil.

**Runoff potential of sub watersheds**

The weighted CN value was computed for each sub-watershed based on which the corresponding maximum retention parameter was calculated. Analysis of the annual runoff volume obtained from summation of all the daily runoff values for the year 2004 has shown that sub-watershed 6 has given maximum runoff depth generating 209.97 mm of runoff. Sub watersheds 4 & 9 with 200.22 mm & 191.09 mm of runoff followed it. On the other hand, sub-watersheds 1 & 2, at the lower plain of the watershed are found to give the least annual runoff (88.58 mm & 106.79 mm respectively). Hence, it is evident that catchments with extensive flat area gave less runoff with low peak runoff rate.

Analysis of the relationship b/n drainage density & runoff volume has shown that they are positively correlated (r=0.906). This signifies the existence of good positive correlation among these hydrological parameters implying that when the drainage density is more, the disposal of runoff from

*Table 1: Some hydrological characteristics of Kamahi Devi watershed*

| SWS | Area ($m^2$) | Perimeter (m) | Watershed length (m) | Width (m) | Mean slope (%) | Drainage Density | Time of concentration (min) |
|---|---|---|---|---|---|---|---|
| 1. | 6026970.0 | 15978.7 | 4434.6 | 1357.0 | 1.70 | 33.99 | 32.09 |
| 2. | 9108800.0 | 20139.7 | 8281.3 | 2331.0 | 2.00 | 26.64 | 41.42 |
| 3. | 9705520.0 | 14867.8 | 6726.7 | 2627.0 | 16.05 | 60.30 | 34.57 |
| 4. | 8517750.0 | 13768.9 | 6378.0 | 2721.5 | 19.05 | 55.75 | 31.12 |
| 5. | 4522920.0 | 8886.0 | 3883.0 | 2351.0 | 19.07 | 58.45 | 21.15 |
| 6. | 3254590.0 | 7600.5 | 3493.0 | 1577.0 | 12.90 | 64.69 | 22.95 |
| 7. | 7325210.0 | 12571.9 | 5439.0 | 2779.9 | 15.70 | 56.86 | 29.92 |
| 8. | 6251050.0 | 11212.4 | 5350.0 | 2917.3 | 11.90 | 50.14 | 32.87 |
| 9. | 2534670.0 | 9452.8 | 3185.0 | 1044.0 | 10.00 | 59.93 | 23.57 |

Table 2: Computed runoff for sub-watersheds in Kamahi Devi watershed

| S.W.S | Area (m²) | Mean CN | Maximum Retention /S/ | Runoff (mm) | Runoff (m³) | Rainfall Volume (m³) | Percent runoff |
|---|---|---|---|---|---|---|---|
| 1. | 6026970.0 | 78.8 | 68.34 | 88.58 | 533869.0 | 4240576.0 | 10.8 |
| 2. | 9108800.0 | 80.8 | 60.36 | 106.79 | 972728.8 | 6408951.7 | 13.0 |
| 3. | 9705520.0 | 86.0 | 41.35 | 174.05 | 1689245.8 | 6828803.9 | 21.2 |
| 4. | 8517750.0 | 87.5 | 36.29 | 200.22 | 1705423.9 | 5993088.9 | 24.4 |
| 5. | 4522920.0 | 85.4 | 43.42 | 164.56 | 744291.7 | 3182326.5 | 20.1 |
| 6. | 3254590.0 | 88.0 | 34.6 | 209.97 | 683366.3 | 2289929.5 | 25.6 |
| 7. | 7325210.0 | 85.5 | 43.08 | 166.10 | 1216717.4 | 5154017.8 | 20.3 |
| 8. | 6251050.0 | 83.7 | 49.46 | 140.30 | 877022.3 | 4398238.8 | 17.1 |
| 9. | 2534670.0 | 87.0 | 37.95 | 191.09 | 484350.1 | 1783393.8 | 23.3 |
| Mean | 84.4 | 51.59 | 160.18 | 8907015.1* | 60888692.4* | | |

*Table 3: Runoff potential of Kamahi Devi Watershed*

| Runoff (mm) | Potential | Area (ha) | Percentage |
|---|---|---|---|
| 0-100 | Low | 602.7 | 10.53 |
| 100-150 | Medium | 1536.0 | 26.83 |
| 150-200 | High | 2408.8 | 42.08 |
| > 200 | Very high | 1178.2 | 20.56 |
| Total | | 5724.7 | |

a basin is quicker & more and vice versa.

Regression equations were formulated in order to relate drainage density & annual runoff volume. Linear, power & polynomial curves have shown more or less similar coefficient of determination. However, linear relation can be preferred for its simplicity.

## Conclusion

- Remote sensing data has a very high potential to supply the spatial & temporal data required by SCS–CN method for estimating runoff. ARC GIS is powerful software for processing, analysis & data base management in watershed modeling.
- The area has ample potential for runoff water harvesting so that more ponds can be constructed at bottom of well-treated hilly lands in order to use the runoff & reduce its impact on soil loss.
- Climatic parameters (especially rainfall) are the most important components in watershed study. Hence the relationship established between rainfall,

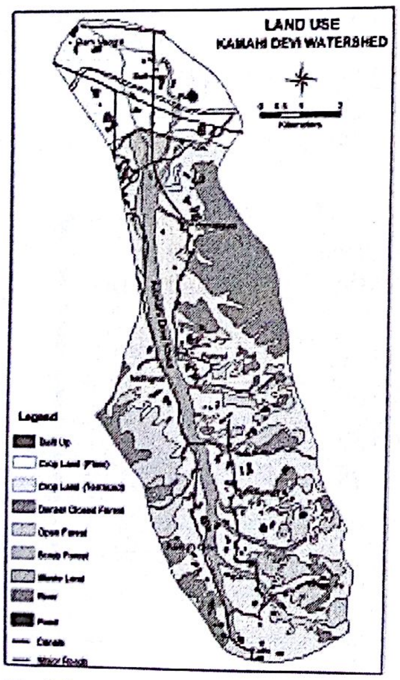


*Fig 5 Drainage System and sub-water sheds of kemahl Devi Watershed*

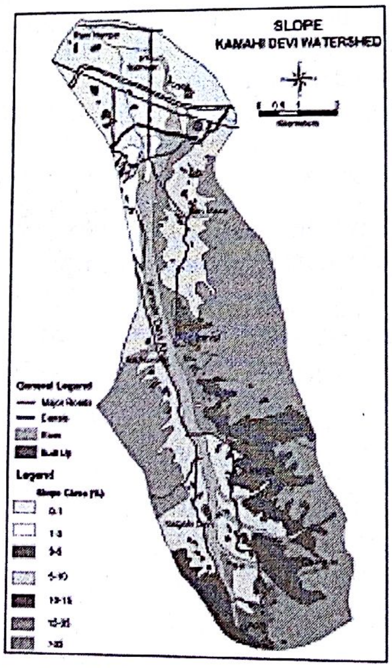


*Fig 6 Hydrological Soil Group (HSG) map of kemahl Devi Watershed*

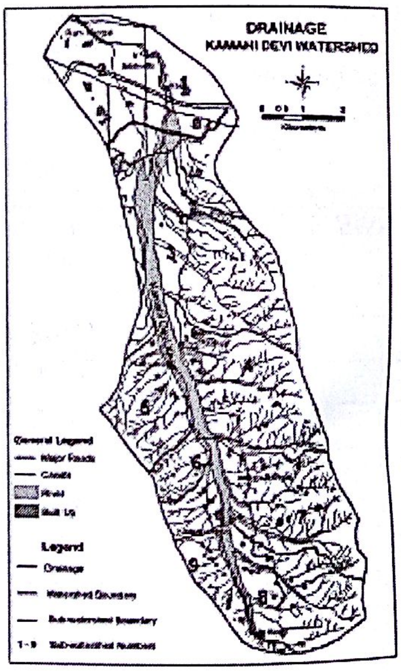


*Fig 7 Land use map Kamahi Devi watershed*

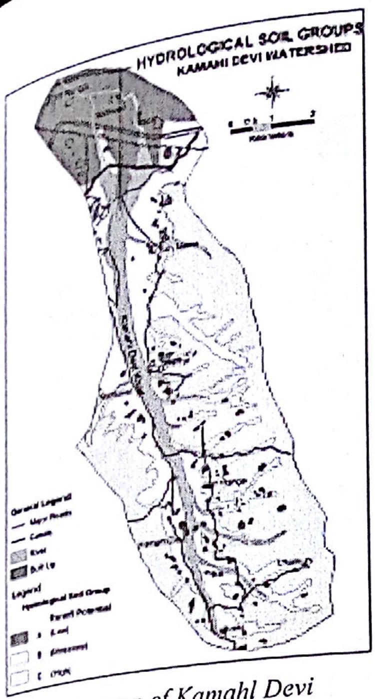


*Fig 8 slope map of Kamahl Devi watershed*

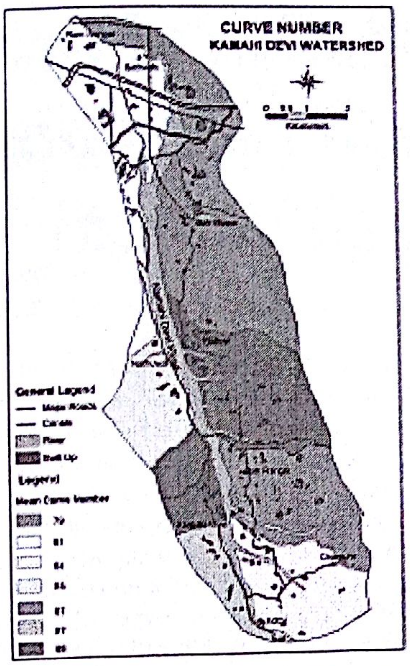


*Fig 9 Curve Number map of Kamahi Devi watershed*

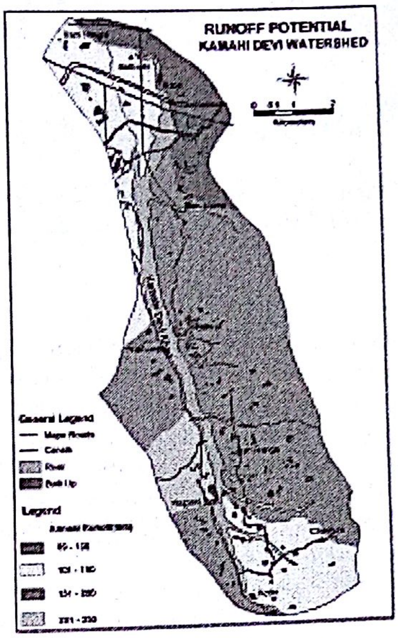


*Fig 10 Runoff potential map of kamahl Devi watershed*

runoff and drainage density can be used for the study area. However, better result can be obtained if rainfall intensity data and directly measured hydrological data are used for comparison. Hence, further study can be conducted in this regard.

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# Testing and Validation of Curve Number Method for Runoff Prediction in Ethiopian Highland Vertisol

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## Abstract

**Vertisols are one of the dominant soil formations in the highlands of Ethiopia. Vertisols are prone to waterlogging and soil erosion and consequently require land preparations/tillage systems to facilitate surface drainage and conserve soil and water. However, few studies have so far been attempted towards testing and validation of suitable models for runoff prediction in the area. The objective of this study, therefore, was to test the validity of USDA- SCS curve number method of runoff predication in the Vertisol of Gimbichu Wereda in the central Highlands of Ethiopia. Runoff data were collected for seven (1998-2004) seasons from triplicated randomized complete blocks of the four land preparation methods (viz., broad bed and furrow (BBF), green manure (GM), reduced tillage (RT) and ridge and furrow (RF)), on permanent natural 3% slope of runoff plots at Chafe Donsa sub-station of Debre Zeit Agricultural Research Center. Validity tests of the USDA-SCS curve number method of runoff prediction using runoff records of the area indicated that this prediction method need careful calibration and validation to suit rainfall and land use patterns in the area.**

## Introduction

Vertisols are the fourth most important soil order in Ethiopia (Jutizi and Mesfin, 1987). They constitute over 10% of the Ethiopian land mass and account for 12.7 million hectares in the country of which 7.6 million hectares are in the central highlands (Mesfin, 1998). Land preparation is a problem on these soils at the beginning of the rainy season due to insufficient moisture content and turning very plastic and sticky when they are too wet. This results in a substantial reduction in the length of the effective growing period, which is potentially over 150 days. Consequently, yields from Vertisols are limited because of waterlogging and the traditional late planting is followed with a view to avoid waterlogging. To mitigate the problem, farmers in different parts of the country within Vertisol areas have adopted different practices to improve the drainage problems of the soils using different land preparation methods.

Thus, in the Ethiopian highland Vertisols, efficient management of rainwater for increasing water availability to the crops during the growing seasons, and collection of the excess rainwater by water harvesting techniques with the view to develop water resources in the region on a long-term basis, is essential (Selamyihun, 2004). In the Ethiopian highlands, the predominant source of water is rainfall. However, due to temporal and spatial variation in the occurrence of rainfall, about one-fourth of the country is subject to drought of various intensities every year (NMSA, 1996). It is estimated that even after developing all available water resources for irrigation, about 85% of the cultivated area will remain as rainfed (MWR, 1998).

Nevertheless, effective planning and management of water resources often require adequate information on various hydrologic variables in the specified region. Among these variables are rainfall, runoff and soil erosion associated with them. In order to design appropriate water harvesting and conservation structures, it is important to estimate runoff amounts. For some, it is necessary to know the peak rate of runoff and for others it is necessary to know the volume of runoff. For example, if a diversion ditch or waterway has to be designed, the critical factor is the peak rate of runoff. Whereas, if a retention ditch or water harvesting reservoir has to be designed the expected volume of runoff should be estimated so that the ditch or reservoir can be made large enough.

Rainfall and runoff records of sufficiently long time series are needed for quantitative runoff assessment. For rainfall and runoff characterization of a site, a minimum of 30 years most recent data is needed (Singh, 1999). For most agricultural watershed in the Ethiopian Highlands however, installation of runoff monitoring structures are not economical, thus concurrently measured rainfall and runoff data are scanty (Selamyihun, 2004). Hence, the use of rainfall-runoff models remains important. Even though, the application of hydrologic models to physical systems is a powerful tool for various purposes, but the actual applicability of said models to a specific watershed must be known before a model can be used appropriately. That is, the question, can the model be used on the study watershed and be expected to give usable results? Must be answered before a model can be chosen for a specific watershed (Johnson, 1998).

Nowadays, usage of models for predicting runoff from agricultural ecosystem is becoming increasingly popular. Since most computer based hydrologic models are just mathematical representations of soil-water-plant-atmosphere continuum, testing and validating them are essential before application (Boardman and Favis-Mortlock, 1998). The most generally available data in Ethiopia are the amounts measured by non-recording rain gauges, and for such data, testing the validity of simple empirical models like curve number method is quite sensible. Thus, the main objective of the study was to test the validity of United States Department of Agriculture-Soil Conservation Service (USDA-SCS) curve number method on a Vertisol of Chafe Donsa- Gimbichu woreda.

## Materials and Methods

**Site and experimental description.** The sub-station of Debre Zeit Agricultural Research Center of the Ethiopian Agricultural Research Organization located at Chafe Donsa in Gimbichu Woreda was the site where the experiment was conducted for recording and collecting data for this study. The site is 35 km North-West of Debre Zeit town located at 8Ú 58'North latitude and 39Ú 6' East longitudes. Mean site elevation is about 2448 m above sea level; with about 954 mm mean annual (1998-2004) rainfall and mean annual (1998-2003) temperature of 16.4 °C (Tesgera, 2005). Derived from weathered basalt, deeper than one meter, with 69% clay content at the surface layer, the Vertisol of the area is classified as pellic Vertisol (Tamirate, 1992). The drainage of the area is described as moderate to imperfect with slight sheet and gully erosion.

In 1998, twelve natural runoff-soil loss plots were installed 2 m apart on a 3% uniform slope at Chafe Donsa. The plots were 22 m long and 6 m wide. Design and installation of the plots were done according to the procedure outlined by (FAO, 1993) and (Pathak, 1999). Rainfall was measured using a non-recording rain gauge. Close to the rain gauge, the runoff plots were installed on which runoff data were recorded under the following land preparation methods:

Broad Bed and Furrow (BBF), which refers to a seedbed type used to drain excess water and advance planting dates on Vertisols. After four tillage passes, it was constructed by the broad bed maker (BBM), which is oxen-drawn traditional wooden plough that has been modified for the construction of raised beds and furrows. With an effective bed area of 80 cm and 20cm dead furrows, it facilitates surface drainage through the furrows between the beds (Jutzi and Mesfin, 1987) so that the crops grow on the beds. This represents a recommended surface drainage system to be used in Vertisol areas (Teklu, 1997).

Green Manure (GM) refers to a practice where a forage legume is grown as a cover crop during the heavy rain season, in order to protect the soil surface from raindrop impacts and runoff. Vetch *(Vicia desicarpa)* was sown in May using the short rain. This was chopped and ploughed under, while still green ten days before planting and incorporated into the soil by two tillage operations. The test crops were sown after the final tillage in the same manner as RF, except for *tef*. The practice is one of the major thrusts for reducing soil erosion, when late sowing is unavoidable. It is also believed to improve soil organic matter content and thereby the soil quality, and hence crop productivity.

Ridge and Furrow (RF) (Control) is constructed with the traditional thyne-plough after the seed is broadcast by hand such that the crops grow on the ridges, permitting the excess water to stagnate in the furrow or to drain out of the field. These are parallel narrow structures about 20 cm high and 30 cm wide. This is a traditional practice to combat the problem of water logging in Vertisols combined with late planting and hence taken as a control for this experiment.

Reduced Tillage (RT) plots are kept intact and fallow until they are sprayed with non-selective herbicide (Roundup) at 4 l ha$^{-1}$ ten to fifteen days before sowing the test crops. The seeds are broadcast and covered by a single operation using the local plough for wheat (*Triticum aestivum L.*) and lentil *(Lens culinaries Medik L.)*, while *tef (Eragrostis tef L.)* is broadcast on freshly tilled field. The practice is aimed at minimizing pre-sowing soil disturbance, reduces organic matter oxidation, and maintains some surface cover to reduce soil erosion.

The treatments were kept permanent while three crops wheat (*Triticum durum* var. *kilinto*), lentil (*Lens culinaris* var. *NEL-358*), and *tef* (*Eragrostis tef* var. *DZ-01-354*) were rotated uniformly following their traditional sequence. All agronomic practices were done following farmers' practices. The treatments were arranged in a randomized complete block design with three replications on permanent plots along 3% slope (Tesgera, 2005).

**USDA-SCS Curve Number method.** The Curve Number method (SCS, 1972), also known as the Hydrologic Soil Cover Complex Method, is a versatile and widely used procedure for runoff estimation. In this method, runoff producing capability is expressed by a numerical value varying between 0 - 100. The underlying theory of the SCS-CN procedure is that runoff can be related to soil cover complexes and rainfall through a parameter known as a Curve Number (CN).

The principle behind this methodology (SCS, 1972) is that, the depth of excess precipitation or direct runoff is always less than or equal to the depth of precipitation, likewise after runoff begins the additional depth of water retained in the watershed is less than or equal to some potential maximum retention. There is some amount of rainfall Ia for which no runoff will occur, so the potential runoff is (P-Ia). The basic mathematical relationship is that the ratio of actual retention to potential retention is equal to the ratio of runoff to rainfall minus initial abstraction:

$$Q/(P-Ia) = F/Sr \qquad (1)$$

Where Q = total direct runoff, P = precipitation, Ia= initial abstraction, F = cumulative infiltration, Sr = maximum retention. All variables are in millimeters.

$$F=P-Ia-Q \qquad (2)$$

After runoff begins, all rainfall becomes either runoff or retention and for all practical purposes both sides approach unity as P'!". Field data indicated that initial abstraction is a linear function of storage.

$$Ia=kSr \qquad (3)$$

The value of k varies from 0 to 0.3 and approximately equal to 0.20 of storage under standard condition (SCS, 1972) and the equation then becomes:

$$Q = (P-0.2Sr)^2/(P+0.8Sr), \text{ for } P > 0.2Sr \qquad (4a)$$

$$Q=0, P<0.2Sr \qquad (4b)$$

By reducing the relationship to only one parameter, Sr, it was possible to develop the Curve Number concept. SCS developed a relationship between storage, Sr, and CN, by a simple relation designed to give a CN range of 0 to 100. The relationship was established as:

$$CN = 25400/(254+Sr) \quad (5)$$

The assignment of curve number values to soil cover complexes was achieved by a combination of empirical data fitting and interpolation. Data were plotted as rainfall versus runoff (P versus Q) and overlain with plotted curve numbers for Ia = 0.2Sr, and the median curve number was selected. The curve numbers thus represent the averages of the median site values for hydrological soil groups, cover, and hydrologic conditions (SCS, 1972). Thus, the runoff for a given soil cover complex can be estimated by knowing the CN (from lists provided by the SCS) and the precipitation for the event under consideration, via the use of equations 4a and 5. The runoff then becomes a direct function of rainfall and CN.

Because the occurrence of infiltration reduces the potential storage capacity of a soil profile, a means to account for the change in Sr must be considered. In the SCS method, the change in CN (which is related to the change in Sr) is based on an antecedent moisture condition (AMC) determined by total rainfall in the five days preceding the storm. The SCS developed three distinct classes or levels of AMC: AMC-I (dry conditions) being assigned as the 'lower limit of moisture or upper limit of Sr', AMC-III (wet conditions) is the 'upper limit of moisture or the lower limit of Sr', and AMC-II considered as the average soil moisture condition (SCS, 1972). As a result of there being only distinct classes, there resulted in turn only discreet values of CN values rather than a continuum.

**Model testing and validation procedure.** Model testing and validation was achieved by running the model continuously over a longer period of time, whereby the effects of parameter change on later months was assessed immediately, rather than requiring a separate simulation for verification. That is, by simulating over one month, and at the same time, applying those parameter values to successive months yields an essentially built in period of simulation and verification (Johnson, 1998). By attempting to calibrate the parameter values over the longer simulation period, a verification of those values in other months is immediately obtained.

**Model performance.** For model performance test, a least-squares regression line was fitted to the data and tested against the ideal conditions of the slope of the line being equal to 1.0 and the intercept being zero (Morgan, 1995). This is, by calculating coefficient of determination ($R^2$). In addition, model performance was evaluated using model efficiency (ME) as described by Nash and Sutcliff (1971). Nash-Sutcliffe model efficiency is an indicator of the model's ability to predict about the 1:1 line. Model efficiency (ME) of Nash and Sutcliffe (1971) is defined as follows:

$$ME = \frac{\sum_{i=1}^{n}(O_i-\bar{O})^2-\sum_{i=1}^{n}(C_i-O_i)^2}{\sum(O_i-\bar{O})^2} \quad (6)$$

Where $O_i$ is the $i^{th}$ items in the observed value, $C_i$ is the $i^{th}$ items in the calculated/simulated value, and L is mean of observed values for number of data points, n. Like that of coefficient of determination a value of one indicates perfect agreement between measured and predicted values; lower values indicate less correlation. Model efficiency can be negative and in this case the average measured value is better estimate than the model prediction.

Moreover, according to Ramanarayanan *et al.* (1998) the relative difference between the average model predicted and observed data is calculated to evaluate the model outputs. The relative difference in average model outputs for a given time scale is calculated as:

$$\gamma_r = \left(\frac{Observed - Predicted}{Observed}\right)*100 \quad (7)$$

Where "$_r$ is the relative difference (percent). Negative value indicates overestimation while the positive value indicates underestimation of the model.

## Results and Discussion

The USDA-SCS curve number method of runoff prediction was calibrated and validated using seven years (1998-2004) data of daily rainfall and runoff obtained from natural runoff plot experiment on a Vertisol at Chafe Donsa. Three primary parameters during the calibration process of the model were varied: (1) curve numbers; (2) antecedent moisture condition (AMC); and, (3) coefficient of soil storage system (k). The general approach to calibration in this study was one of trial-and-error in which various values for each parameter were tried and their effects were noted and appropriate changes were made to improve agreement between simulated and recorded values of flow. The trial-and-error method of continual running and rerunning of the model for calibration and verification was facilitated by the creation of various batch files and using built-in functions of Excel program. That is, all the equations (Equation 1-5) for estimating direct runoff from model were linked on spreadsheet using Excel program both for model calibration and validation.

Reasonable values of model parameters based on runoff plot characteristics were chosen as an initial set of values. The model was run, the result compared, and the appropriate parameters were changed to achieve a better fit. Simulation dates ran from July to September of each study year. However, the relationship between curve number and runoff is non-linear and depends on the amount of rainfall amongst others. The curve numbers for each treatment plot were varied during the calibration processes in this study. Four sets of curve numbers were evaluated: (1) CN's based on AMC II (normal conditions); (2) CN's based on AMC I (dry conditions); and, (3) CN's based on AMC III (wet conditions); and, (4) CN's based on the average of the three AMCs. The third and final parameter adjusted for calibration purposes was coefficient of soil storage system. Adjustments to k-values were based on desired increases and reductions in the plot's initial abstraction.

For each treatment plot the model was calibrated and validated to obtain parameters values at four sets of AMCs. However, the final best overall resultant fits were achieved at average of the three AMC classes. Thus, the final parameters value obtained as a result of model calibration and verification (Table 1) were used for testing model performance for

*Table 1. Summery of SCS- curve number model parameters for each treatment plots*

| Treatment | AMC | CN | k | Treatment | AMC | CN | k |
|---|---|---|---|---|---|---|---|
| BBF | I | 68.8 | 0.30 | RF | I | 68.8 | 0.30 |
| | II | 84.0 | 0.30 | | II | 84.0 | 0.30 |
| | III | 92.4 | 0.20 | | III | 92.4 | 0.20 |
| GM | I | 75.5 | 0.25 | RT | I | 75.5 | 0.20 |
| | II | 88.0 | 0.25 | | II | 88.0 | 0.20 |
| | III | 94.4 | 0.15 | | III | 94.4 | 0.20 |

*Table 2. Treatment wise results of CN model calibration and validation*

| Treatment | No. of events | $R^2$ | ME | Average runoff (mm) | | ?$_x$ (%) |
|---|---|---|---|---|---|---|
| | | | | Observed | Predicted | |
| BBF | 100 | 0.833 | 0.801 | 0.946 | 1.439 | -52.156 |
| GM | 114 | 0.700 | 0.612 | 1.722 | 2.706 | -57.198 |
| RF | 111 | 0.642 | 0.452 | 0.913 | 1.643 | -79.939 |
| RT | 111 | 0.675 | 0.467 | 1.479 | 2.349 | -58.826 |

each treatment plots.

The best linear fit between observed and predicted runoff was obtained when Ia was set at kSr for respective AMC. Except for RT land preparation treatment the precision of USDA-SCS curve number model of runoff prediction was improved when a higher Ia values of kSr were used for AMC as opposed to the standard value of Ia = 0.2Sr for all treatment plots (SCS, 1972). Similarly, Selamyihun (2004) has reported improved curve number method of runoff prediction when Ia value of 0.1Sr for AMC II & I as opposed to the standard value of Ia = 0.2Sr on Vertisol of Ginchi in the central Ethiopian Highlands.

The results of model calibration and validation (Table 2) show better model performance for BBF and GM treatment plots with larger ME values than for RF and RT treatment plots. The observed and predicted average daily runoff for the period 1998 to 2004 from BBF treatment plot were 0.95 and 1.44 mm, respectively. Thus, the relative difference between the observed and predicted runoff was -52% indicating that the model overestimated average daily runoff from this treatment plot. Calibration of the two input parameters improved the precision of the curve number runoff predictions as measured by ME. On the whole, the model overestimated average daily runoff from all the treatment plots.

## Conclusion

The results from the tests of the USDA - SCS curve number method for runoff predictions using the seven-years data collected from natural runoff plot experiment depicted that this model may not be used in the area without the proper modifications/validation to suit the rainfall and landuse/cover patterns in the Vertisols of Gimbichu Woreda.

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# Assessment of Small Hydropower Potential in Muger, Jemma and Waleka Sub-basins of Abay Basin (Central Ethiopia)

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**Abstract**

**Electrical energy is becoming an essential commodity for the modern life. Every sector, weather industry, technology, transportation, public utilities or the domestic life, is now dependent on electrical power. The dependency on electrical power is becoming more and more, which has resulted into increasing demand for it. Therefore, with the increasing demand for power, the activities on small hydropower projects are accelerated in recent times all over the world. The small hydropower schemes are the appropriate solution to power demand as these require small capital investment and can be completed in a very short period of time, with minimum adverse environmental impacts. The main objective of the present study was to identify potential Small Hydropower sites in Muger, Jemma, and Waleka drainage Sub-basins of Abay basin. In total 36 potential SHP sites has been identified during the present study. Out of these 36 sites, observed discharge data was available for only 18 sites. For 9 small hydropower (SHP) potential sites, flow-duration is worked out from observed daily discharge data. However, for 9 other potential sites the observed discharge data has been projected from adjacent gauged stations by percent area ratio method for those which demonstrate similar catchment characteristic. Initial estimation of the power potential of 18 SHP sites has been computed for 75% dependable discharge and taking turbine efficiency to be 90% and efficiency of the generator as 95%. Thus, the total power potential, as estimated for 18 identified sites comes out to be 5325 kW. Therefore, these 18 potential SHP sites can be ground verified and be taken up for further investigations for development. Further, for remaining 18 potential SHP sites discharge measurements may be taken up to work out the power potential.**

## 1.Introduction

In the recent times the non-renewable and exhaustible sources of energy are getting depleted at a very fast rate, which has focused attention to the non-exhaustible and renewable sources of energy. Hydropower is one of the most common renewable sources of energy abundantly available in the hilly region. However, large hydropower plants are not being taking up for execution in sufficient number as these involve huge amount of funds and also the planning and construction period is very high. Therefore, with the increasing demand for power, the activities on small hydropower projects have accelerated in recent times all over the world. The small hydropower schemes are the appropriate solution to power demand as these require small capital investment and can be completed in a very short period of time. The small hydropower is environmentally friendly and has substantial economic advantages (AHEC, 2001).

The electrical energy in Ethiopia which is available through interconnected grid system is available only to the major cities and towns. However, the major population lives in small towns and villages and do not have access to the interconnected grid system. Such localities may be provided with electricity through small hydropower, locally generated from nearby potential streams.

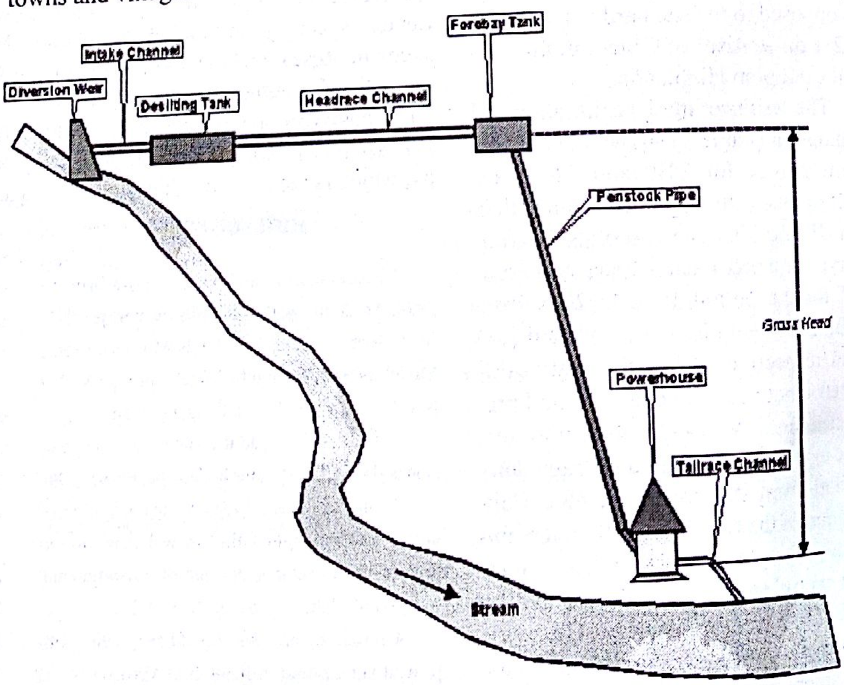


*Fig.1. A typical Small hydropower system*

A typical Small hydropower system incorporates five major components; the civil work, the water turbine, AC or DC generator, electrical and mechanical control system and transmission system. The civil works consist of desilting tank (to allow sedimentation of stones and silt to avoid turbine damage), headrace channel (to guide water to the fore bay tank), weir (to divert part of river or stream), penstock (to guide the water from the fore bay tank directly to the turbine), and the power house (containing the turbine, shaft drive system, electric generator, and control unit) Fig.1

## 2.History of Small Hydropower (SHP) in Ethiopia

The first SHP site was identified by an Italian solider near Debre Birhan town at Beresa Stream, some times in early twenties (as reported by local people). As reported, this power station was generating a power of less than 100 kW by utilizing a head of 50m. This power station was functional till 1977 and the operation was then stopped as the town Debre Birhan was connected to the national grid. Presently, the country has three SHP Schemes namely, Yadot, Sor and Dembi SHP sites. These Self Contained Systems have a total installed capacity of 6.15 MW.

## 3.Power Scenario in Ethiopia

According to the Italian consultant's (CESEN, 1986), the gross hydro potential of the whole Ethiopia territory is of the order of 650 TWh/year. Between one third and one half of this potential is contributed by the Blue Nile Basin (280 TWh/year). The Blue Nile and Omo basins together contribute around 400 TWh/year to the gross potential. Sizable quantities of hydro energy are also available in the Baro basin, in the Bilate-Sagan-Dawa, Genale-Gestro basins, the Wabe Shebele, and Awash basins.

## 4. The Study Area

The present study area is located in Abay drainage basin, in the central part of the country. Muger, Jemma, and Waleka drainage Sub-basins of Abay have been identified for the present study. The study area covers about 30,585.2 km$^2$ and is bounded within 9$^0$23' – 11$^0$05' latitude and 37$^0$12' – 39$^0$33' longitude. These basins are partly in Addis Ababa, Amara and in Oromia region. Figure 2. shows the geographic extents of the study area. There are 5 Zones, 93 Weredas and 68 towns excluding Addis Ababa in these sub-basins. The access to these sub-basins is through all types of road with a total length of 2,155 km.

## 5.Climate of the Study Area

The climates in Muger, Jemma, and Waleka (MJW ) Sub - basins are mainly of three types Which are represented as; (i) Aw – Tropical Climate (ii) Cwb – Warm temperate Climate I and (iii) Cwc – Cool Highland Climate. More than 85% of the Sub-basins fall in warm climate zone whereas; the remaining parts are cool and tropical climate.

## 6. Physiographical Setting of the Study Area

The present study area is a part of Central Highland plateau of Ethiopia. It is bounded between the left margin of Main Ethiopian Rift and Abay gorge. The highest elevation of the area is at the Main Ethiopian Rift escarpment and the lowest point is located in Abay Gorge, with a difference of more than 2000m. Muger sub-basin is located on the western part of the study area. The physiographical setting of the sub-basin is mainly undulating topography. Jemma sub-basin forms a part in Abay drainage basin. This sub-basin has a flat to undulating terrain. Jemma river gorge have a elevation difference of 1200m. Waleka-Sub basin is located in the northern part of the study area. This sub-basin forms moderately to high undulating topography. The highest point in the sub-basin is located within this sub-basin at the escarpment of Main Ethiopian Rift, namely Tarmaber ridge.

## 7. Geology of the Study Area

The major rock units exposed in the Muger, Jemma, and Waleka (MJW) Sub-basin belongs to Alghe Group (AR1), Adigrat Formation, Abay Formation (Jb), Antalo Formation (Jt), Amba Aradom Formation (Ka), Ashangi Formation ($P_2$a), Aiba Basalts ($P_3$a), Alajae Formation (PNa) and Tarmaber -Megezez Formation (Ntb) (Mengesha, et al., 1996).

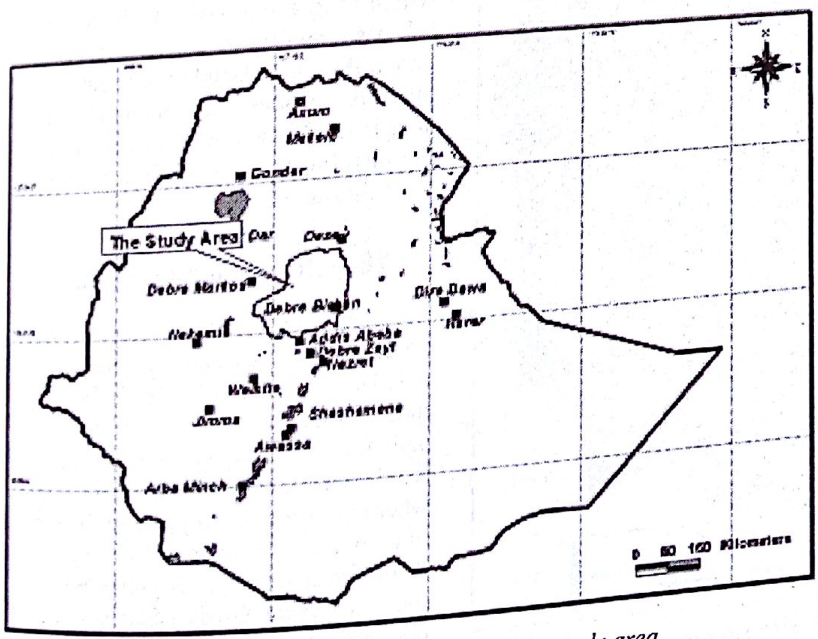


*Fig. 2. The geographic extents of the study area*

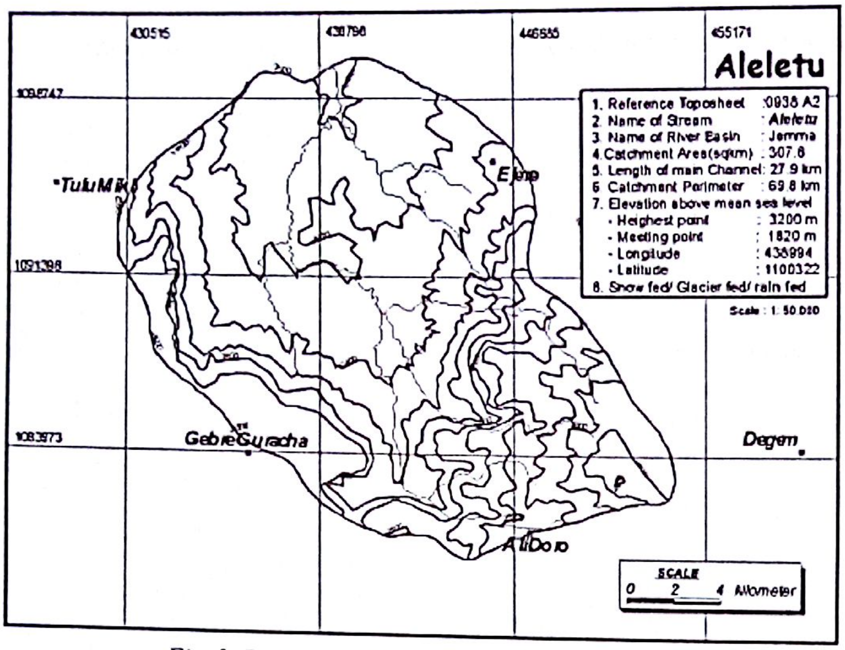


*Fig. 3. Delineated catchment for Aleletu SHP Site*

## 8.Potential Small hydropower sites

To identify the Small Hydropower (SHP) pot- ential sites for the present study, Ethiopian Mapping Authority (EMA) topo-sheets on 1:50,000 scales has been utilized. In total 41 topo sheets were examined to identify the potential SHP sites in the study area. The site selection has been made following certain criteria, which is listed below;

i) Channel should be perennial in nature, in EMA topo-sheets perennial streams are marked with blue colour and the stream name is written in capital letters.

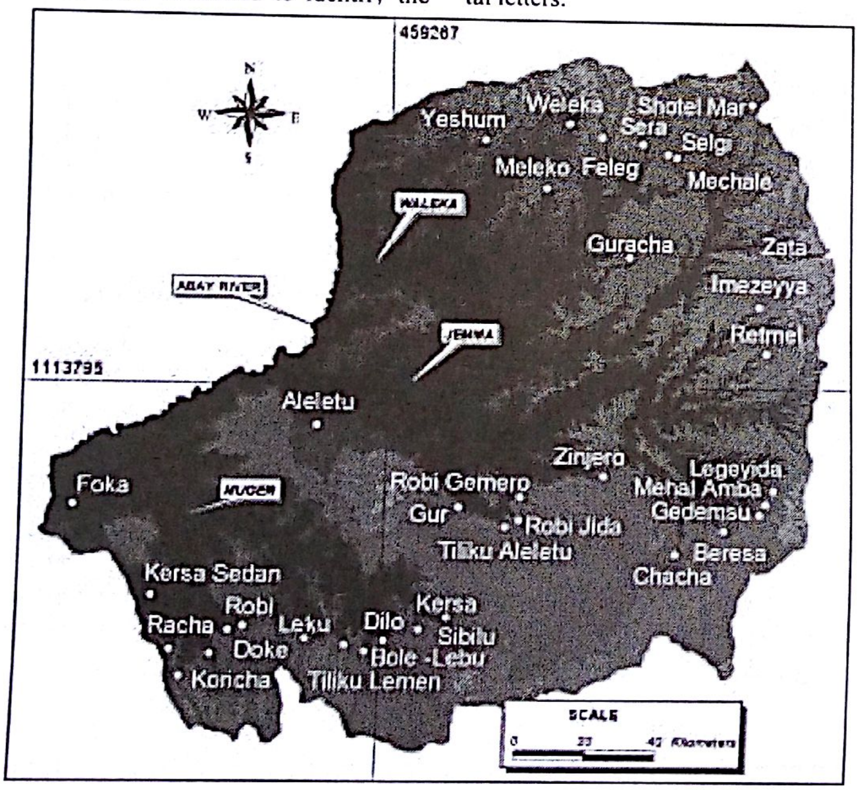


*Fig. 4. Distribution of identified potential SHP sites in the study area.*

ii) The catchment should have an area of at least 25 km². This will ensure a sufficient good amount of discharge for power generation.

iii) Main channel should have a minimum length of about 10 km.

iv) Availability of head should be at least 60 m as lower head and discharge does not yield significant power potential.

v) The headrace channel must be less than 5km in length.

vi) The potential site should be well accessible and should be located near to the cluster of population, so as to ensure proper power utilization.

## 9. Potential Catchment Delineation

The potential catchment is delineated from the EMA (Ethiopian Mapping Authority) topo-sheets at a scale of 1:50,000. Figure 3. shows one sample-delineated catchment for Aleletu SHP Site. The Catchment delineation includes catchment boundary, perennial stream, drainage network, roads or foot paths, towns, highest and lowest elevation points and contours in 100m inte rval within the catchment boundary. These delineated catchments were used for the calculation of catchment area, perimeter and the stream length. During the present study a total of 36 potential SHP sites has been identified. Out of these 36 sites, 13 sites fall within Muger sub-basin, 14 in Jemma sub-basin and the rest 9 sites forms a part within Waleka sub-basin. Table 1. presents the identified potential SHP sites in the study area. Figure 4. shows the distribution of identified potential SHP sites in the study area.

## 10.Determination of Head

The power potential is directly proportional to the discharge and the available Head. The term 'Head' is the altitude difference between the forebay and the powerhouse site. In other words head is the vertical height from where the water is dropped on the turbine to generate hydropower (Fig. 1.). In the present study, for power potential assessment Gross head has been determined from the topo-sheet on 1:50,000.

*Table 1.List of identified potential SHP sites in the study area*

| S No | Name of SHP Site | Name of stream | Location*(UTM) | | Sub-Basin | Nearest Town | DW* Elev. (m) |
|---|---|---|---|---|---|---|---|
| | | | Northing | Easting | | | |
| 1 | Aleletu | Aleletu | 1100847 | 541630 | Miger | Ejere | 1820 |
| 2 | Beresa | Beresa | 1069557 | 556306 | Jemma | Debre Birhan | 2725 |
| 3 | Bole-Lebu | Bole-Lebu | 1033823 | 455118 | Miger | Mulo | 2735 |
| 4 | Chacha | Chacha | 1062529 | 542252 | Jemma | Mendida | 2215 |
| 5 | Dilo | Dilo | 1037152 | 460208 | Miger | Mulo | 2210 |
| 6 | Doke & Huluko | Doke & Huluko | 1040035 | 416349 | Miger | Ketket | 1860 |
| 7 | Feleg | Feleg | 1186753 | 520249 | Walka | Kurkura | 2430 |
| 8 | Foka | Foka | 1076370 | 371578 | Miger | Jemo Lefo | 1595 |
| 9 | Gedemsu | Gedemsu | 1074311 | 566482 | Jemma | Dinbaro | 2795 |
| 10 | Gur | Gur | 1076165 | 480031 | Jemma | Debre Libanos | 2480 |
| 11 | Guracha | Guracha | 1151245 | 527885 | Jemma | Dogolo | 2555 |
| 12 | Ime zeyya | Ime zeyya | 1136716 | 566498 | Jemma | Mehal Meda | 2815 |
| 13 | Kersa Seden | Kersa Seden | 1049966 | 394200 | Miger | Shikute | 2415 |
| 14 | Kersa | Kersa | 1043963 | 477862 | Miger | Gorfo | 1550 |
| 15 | Koricha | Koricha | 1033080 | 411445 | Miger | Gola | 2200 |
| 16 | Legeyida | Legeyida | 1077525 | 568221 | Jemma | Dinbaro | 2775 |
| 17 | Leku | Leku | 1037547 | 437932 | Miger | Welenkobi | 2235 |
| 18 | Mechela | Mechela | 1181789 | 538576 | Jemma | Were Illu | 2610 |
| 19 | Mehal Amba | Mehal Amba | 1081709 | 570597 | Jemma | Godo Beret | 2695 |
| 20 | Meleko | Meleko | 1171863 | 503832 | Jemma | Kelela | 2375 |
| 21 | Racha | Racha | 1034032 | 399600 | Walka | Shikute | 2495 |
| 22 | Retmet | Retmet | 1123374 | 567974 | Jemma | Molale | 2875 |
| 23 | Robi Gemero | Robi Gemero | 1079127 | 497510 | Jemma | Lemi | 2170 |
| 24 | Robi Jida | Robi Jida | 1072373 | 497299 | Jemma | Weberi | 2210 |
| 25 | Robi | Robi | 1041259 | 420415 | Miger | Ketket | 2430 |
| 26 | Selgi | Selgi | 1181407 | 541630 | Walka | Were Illu | 2610 |
| 27 | Sera | Sera | 1184844 | 531321 | Walka | Kurkura | 2550 |
| 28 | Shotel Mat | Shotel Mat | 1197061 | 563775 | Jemma | Kabe | 2710 |
| 29 | Sibilu | Sibilu | 1040301 | 470093 | Miger | Mulo | 2215 |
| 30 | Tiliku Aleletu | Tiliku Aleletu | 1070480 | 496544 | Jemma | Weberi | 2215 |
| 31 | Tiliku Lemen | Tiliku Lemen | 1035569 | 449258 | Miger | Welenkobi | 2415 |
| 32 | Weleka | Weleka | 1190953 | 510232 | Walka | Lugama | 2275 |
| 33 | Werenbulchi | Werenbulchi | 1026557 | 402984 | Miger | Gola | 2610 |
| 34 | Yedaum | Yedaum | 1185989 | 485505 | Walka | Genet | 2090 |
| 35 | Zeta | Zeta | 1153154 | 586682 | Jemma | Rabel | 3355 |
| 36 | Zinjero | Zinjero | 1085404 | 521207 | Jemma | Deneba | 2110 |

* *These co-ordinates indicates the location from where the water will be diverted for the power generation – it indicates Diversion weir site- please refer Figure 1.0*

## 11. Estimation of Dependable Discharge

For the development of any small hydropower scheme an essential first step is to determine whether there is sufficient and reliable amount of water available to make the scheme economically viable. As a standard practice a gauging station should be set up and the discharge should be observed for at least two lean seasons. In the present study 36 potential SHP sites has been identified.

For none of these potential streams, gauged data is available at or near the proposed diversion sites. However, observed discharge data is available either, in the upstream or downstream locations on the same stream or in the adjoining catchments.

Figure 5. shows the location of gauge stations on various streams and the location of identified potential SHP streams. During the present study, for initial estimate of the power potential the observed discharge data from nearby locations have been projected at the proposed sites to work out the dependable flows. However, it is strongly recommended to observe the actual discharge, at least covering two lean seasons, before finalizing these sites for final development.

### 11. 1 Flow-Duration Curve Analysis

Flow duration curve is used to describe the time availability of flow at a certain point in a river. Flow duration curve is a simple plot of flow versus the percent of time that particular flow can be expected to be exceeded (called the "percent exceedance") (Fritz, 1984).

In the present study area 25 gauge stations on various streams are present. Out of these, only 16 gauged stations have recorded daily discharge data for 2 to 42 years, daily or weakly. The observed discharge data for 9 gauged stations were procured from Ministry of Water Resources which has been utilized to work out dependable flows for 18 identified potential SHP sites. For rest of the gauging stations the observed discharge data is not available. In the present study, ranked flow technique has been employed to compute flow duration curve at proposed diversion weir sites for 18 identified poten-

Table 2.List of Potential SHP sites and corresponding Gauging Stations

| S.N. | Potential SHP Site: Name of * SHP Site | Location of Diversion weir Site (UTM): Northing | Location of Diversion weir Site (UTM): Easting | Gauging Station: Name of Stream | Location of Gauging Station (UTM): Northing | Location of Gauging Station (UTM): Easting | Distance of Gauging Station from Potential SHP site: Distance (km) | Direction |
|---|---|---|---|---|---|---|---|---|
| 1 | Beresa | 1069461 | 556378 | Beresa | 1067065 | 555855 | 2.06 | N |
| 2 | Chacha | 1062030 | 542311 | Chacha | 1052072 | 550857 | 13.36 | NW |
| 3 | Dilo | 1036980 | 459889 | Sibilu | 1019587 | 472939 | 21.54 | NW |
| 4 | Felg | 1185050 | 520818 | Mechela | 1185192 | 537000 | 17.11 | W |
| 5 | Gedemsu | 1074791 | 565943 | Beresa | 1067065 | 555855 | 13.79 | NE |
| 6 | Gur | 1075715 | 479404 | Robi Jida | 1063657 | 499745 | 23.45 | NNW |
| 7 | Guracha | 1151370 | 527729 | Jogolo | 1168154 | 548586 | 27.11 | SW |
| 8 | Kersa | 1044061 | 478642 | Duber | 1044802 | 484752 | 6.95 | W |
| 9 | Mechela | 1182120 | 539819 | Mechela | 1185192 | 537000 | 4.57 | SE |
| 10 | Shay | 1081466 | 570607 | Shay | 1131535 | 559842 | 6.75 | SW |
| 11 | Robi Gumero | 1078415 | 496129 | Robi Jida | 1063657 | 499745 | 15.39 | N |
| 12 | Robi Jida | 1073132 | 495827 | Robi Jida | 1063657 | 499745 | 9.05 | N |
| 13 | Selgi | 1181641 | 542292 | Selgi | 1187009 | 544270 | 6.75 | SW |
| 14 | Sera | 1185094 | 532537 | Mechela | 1185192 | 537000 | 4.6 | W |
| 15 | Sibilu | 1040327 | 469875 | Sibilu | 1019587 | 472939 | 20.50 | N |
| 16 | Tiliku Aleletu | 1069729 | 493474 | Robi Jida | 1063657 | 499745 | 8.84 | NNW |
| 17 | Weleka | 1190707 | 510064 | Mechela | 1185192 | 537000 | 27.04 | W |
| 18 | Retmet | 1123374 | 567974 | Shay | 1131535 | 559842 | 12.32 | NW |

**For the present study name of the SHP sites have been given same as the name of the stream on which the SHP scheme is identified.*

tial streams. For 9 small hydropower (SHP) potential sites, flow-duration curve is prepared from observed daily discharge data. However, for 9 other potential sites the observed discharge data has been projected from adjacent gauged stations by percent area ratio method for those which demonstrate similar catchment characteristic. Table 2. presents the list of potential streams and the corresponding gauging stations from which the observed discharge has been utilized to work out the flow duration.

Further, for remaining 18 potential sites, the flow-duration could not be worked out as neither, observed discharge data on the same stream or in the adjacent catchment with similar characteristics was available nor, sufficient metrological data was available to workout the discharge empirically. A sample computation of flow duration for Beresa stream is presented in Fig. 6.0. Similar computation of flow duration has been made for the remaining 17 potential streams.

## 12.Estimation of Power Potential

In the present study, initial estimation of the power potential has been computed for 75% dependable discharge and taking turbine efficiency to be 90% and efficiency of the generator as 95%. The head losses caused by the frictions and bends in the penstock have been taken equal to 10% of the gross hydraulic head (Table. 3.0). Thus, the equation used for the computation of Power potential is given as eq.1.0 (Fritz, 1984);

$$P_h = 9.81 * Q * Hn * nt * ng.. \quad \text{(eq.1.0)}$$

Where; 'Q' is discharge taken equal to 90% of the 75% dependable Flows. 'Hn' is the Net Head taken 90% of the Gross Head; Head Losses are taken 10% of Gross head. 'nt' is the efficiency of turbine which is taken equal to 90%. 'ng' is the efficiency of generator which is taken equal to 95%. Thus, a perusal of Table 3.0 indicates that the total power potential for 18 identified SHP sites, for which observed discharge data is available, is 5325 kW. However, for the remaining 18 potential SHP sites observed discharge data is not available to compute the power potential. Further, it is anticipated that these sites would also exhibit equally good power potential when the observed discharge data will be made available.

## Conclusion

In Ethiopia the electrical energy is mainly available through interconnected grid system which is available

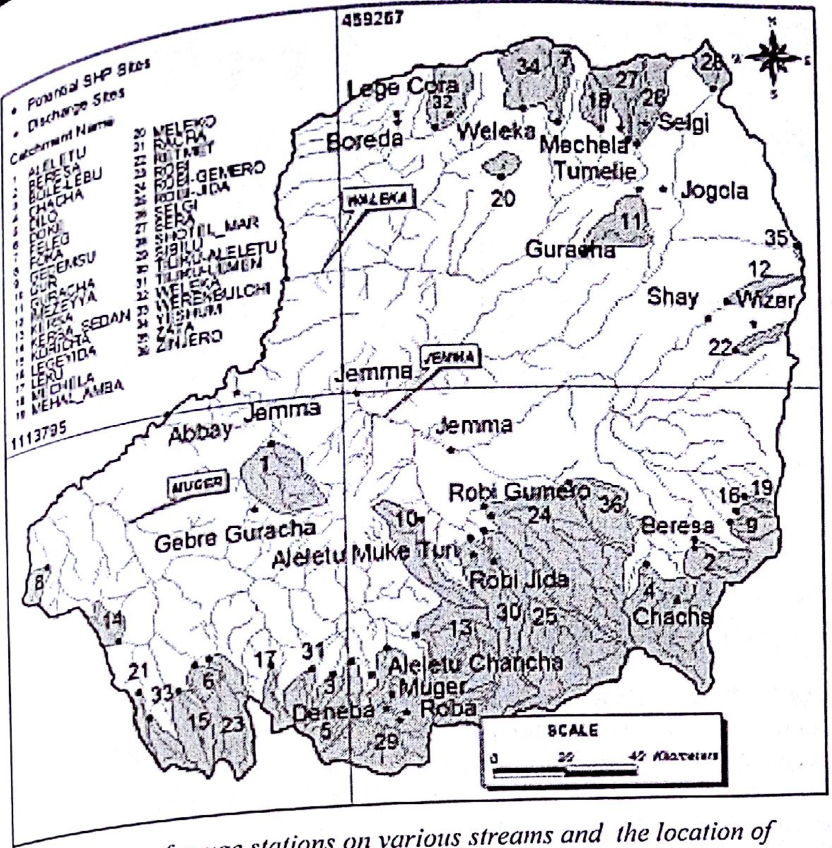


*Fig. 5. Location of gauge stations on various streams and the location of identified potential SHP Sites*

only to the major cities and towns. Whereas, the major population lives in small towns and villages and do not have access to the interconnected grid system. Such localities may be provided with electricity through small hydropower, locally generated from nearby potential streams. In the present study an attempt has been made to workout the power potential available in the Muger, Jemma and Waleka sub-basins of Abay. A total of 36 potential SHP sites has been identified, out of which, 13 sites fall within Muger sub-basin, 14 in Jemma sub-basin and the rest 9 sites forms a part within Waleka sub-basin. Out of these 36 sites, observed discharge data is available for only 18 sites. For 9 small hydropower (SHP) potential sites, flow-duration curve is prepared from observed daily discharge data. However, for 9 other potential sites the observed discharge data has been projected from adjacent gauged stations by percent area ratio method for those which demonstrate similar catchment characteristic. Initial estimation of the power potential of 18 SHP sites has been computed for 75% dependable discharge and taking turbine efficiency to be 90% and efficiency of the generator as 95%. Thus, the total power potential, as estimated for 18 identified sites comes out to be 5325 kW. However, for the remaining 18 potential SHP sites observed discharge data is not available to compute the power potential. Further, it is anticipated that these sites would also exhibits its equally good power potential when the observed discharge data will be made available. Therefore, these 18 potential SHP sites, for which discharge data is available can be ground verified

*Table 3.Computed hydropower potential for identified SHP sites in the study area*

| S.No | Name of the SHP Site | Gross head (m) | Net* Head (m) | 75% Dependable Discharge (cumecs) | Discharge for Power Generation (cumecs) | Efficiency | | Power Potential (KW) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Turbine | Generator | |
| 1 | Beresa | 255 | 229.5 | 0.17 | 0.25 | 0.9 | 0.95 | 500 |
| 2 | Chacha | 405 | 364.5 | 0.20 | 0.27 | 0.9 | 0.95 | 1000 |
| 3 | Dilo | 325 | 292.5 | 0.08 | 0.12 | 0.9 | 0.95 | 300 |
| 4 | Felg | 115 | 103.5 | 0.11 | 0.13 | 0.9 | 0.95 | 125 |
| 5 | Gedemsu | 260 | 234 | 0.05 | 0.06 | 0.9 | 0.95 | 150 |
| 6 | Gur | 250 | 225 | 0.02 | 0.05 | 0.9 | 0.95 | 100 |
| 7 | Guracha | 235 | 211.5 | 0.012 | 0.028 | 0.9 | 0.95 | 50 |
| 8 | Kersa | 305 | 274.5 | 0.067 | 0.084 | 0.9 | 0.95 | 200 |
| 9 | Mechela | 135 | 121.5 | 0.20 | 0.24 | 0.9 | 0.95 | 250 |
| 10 | Imezeya | 120 | 108 | 0.22 | 0.25 | 0.9 | 0.95 | 250 |
| 11 | Robi Gumero | 345 | 310.5 | 0.08 | 0.14 | 0.9 | 0.95 | 400 |
| 12 | Robi Jida | 385 | 346.5 | 0.071 | 0.126 | 0.9 | 0.95 | 400 |
| 13 | Selgi | 195 | 175.5 | 0.046 | 0.064 | 0.9 | 0.95 | 100 |
| 14 | Sera | 255 | 229.5 | 0.1 | 0.1 | 0.9 | 0.95 | 200 |
| 15 | Sibilu | 240 | 216 | 0.27 | 0.31 | 0.9 | 0.95 | 600 |
| 16 | Tiliku Aleletu | 400 | 360 | 0.048 | 0.069 | 0.9 | 0.95 | 200 |
| 17 | Weleka | 80 | 72 | 0.28 | 0.30 | 0.9 | 0.95 | 200 |
| 18 | Retmet | 160 | 144 | 0.18 | 0.26 | 0.9 | 0.95 | 300 |
| | | | | | | **Total potential in the study area** | | **5325** |

**Net head = Gross Head – Head Losses, for initial estimation of Net head the head losses have been estimated to be 10% of the gross head*

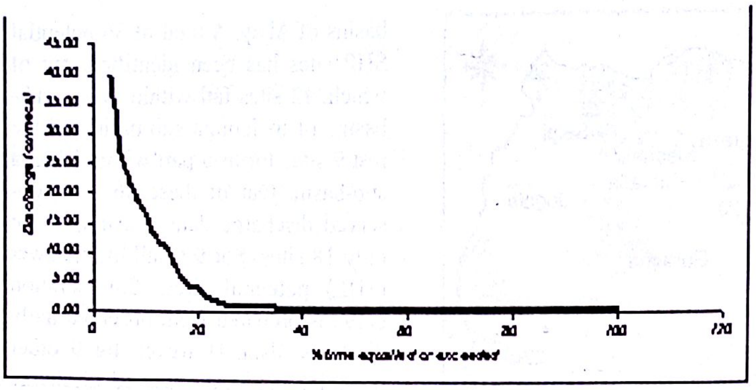

*Fig. 6. Flow duration curve for Beresa stream.*

and be taken up for further investigations for development. Further, for remaining 18 potential SHP sites discharge measurements may be taken up to work out the power potential.


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# Surge Flow Effect on the Performance of Furrow Irrigation at Awash-Melkassa

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**Abstract**

**The field experiment was conducted during 2003/2004 off-season at Melkassa Agricultural Research Center farm. The experimental plot had a size of 155 m X 50 m with 0.6% slope and clay loam soil texture. The treatments involved in this experiment were irrigation flow regimes (surge and continuous), surge time management factors (cycle times and cycle ratios) and inflow rates. Three flow rates (0.6 $ls^{-1}$, 0.8 $ls^{-1}$ and 1 $ls^{-1}$), three cycle times (20 min, 25 min and 30 min) and three cycle ratios (0.32, 0.50 and 0.67) were selected. A total of nine irrigations were evaluated under both surge flow and continuous flow for the selected optimum combination of treatments. Observed and calculated irrigation system performance parameters were used to compare surge flow with continuous flow. Surge flow performed better on irrigation events that took cycle time of 25 min, cycle ratio of 0.32 and inflow rate of 0.6 $ls^{-1}$. Under these irrigation events, surge flow used only 35% of water and time that were used by the continuous flow irrigation. It was also found effective in reducing the run-off volume in most of the trials up to a maximum of 88% for the same events.**

**Keywords/phrases: Continuous flow, Ethiopia, furrow irrigation, infiltration, performance, surge flow, Awash-Melkassa**

## Introduction

The future development of surface irrigation greatly depends upon improved design and management systems/practices. This should include measures to improve the existing surface irrigation systems. Since agriculture usually imposes the largest water demand, improved irrigation efficiency should become the centerpiece of conservation strategies (FAO, 1989). Therefore, developing or adopting new approaches and interventions subsequently can ensure economical use of water resources maintaining the maximum possible production with reduced costs for reservoir, pumping, and leaching and drainage requirements.

Surge flow (intermittent application of water into the field) is one of the very successful alternative approaches of headland management that has been applied for about two decades offering a better opportunity for the development of furrow irrigation (FAO, 1989). The idea was first introduced by Stringham and Keller (1979) while attempting to develop an alternative cutback method for furrow irrigation and to automate the system. Their initial work indicated that, under surge irrigation, faster advance rate (reduced inflow advance time) was observed and it had the potential to achieve better irrigation performance. Most of the subsequent research evidences have also confirmed the advantages of surging as compared to continuous flow irrigation (Bishop et al.1981; Yonts et al., 1996; Latif and Ittfaq, 1998). Some test results, however, found that surge irrigation was ineffective in reducing the advance inflow times on soils with relatively higher clay content (Manges and Hooker, 1984) except at low flow rates (Rogers and Lamm, 1984). Therefore, the relative advantages of surge flow can be influenced by various physical phenomenon and management settings (Jalali-Farahani et al. 1993b).

Test results regarding surge flow effect varied with wider range that could complicate understanding the phenomena (Jalali-Farahani et al. 1993a; Heydari et al., 2001). On the other hand, there is no documented information with regard to the experience of surge irrigation practices in Ethiopia. Practical (quantified) information on the major indicative factor i.e infiltration pattern and the irrigation performance can give comprehensive insight on the relative effect of surge flow. FAO (1989) strongly suggested that tests should be conducted in areas where experience is lacking in order to establish the feasibility and format for using surge flow.

Generally, the purpose of this research is to introduce the idea and to set out indicative information on the performance of surge flow-furrow irrigation against the continuous flow under local condition.

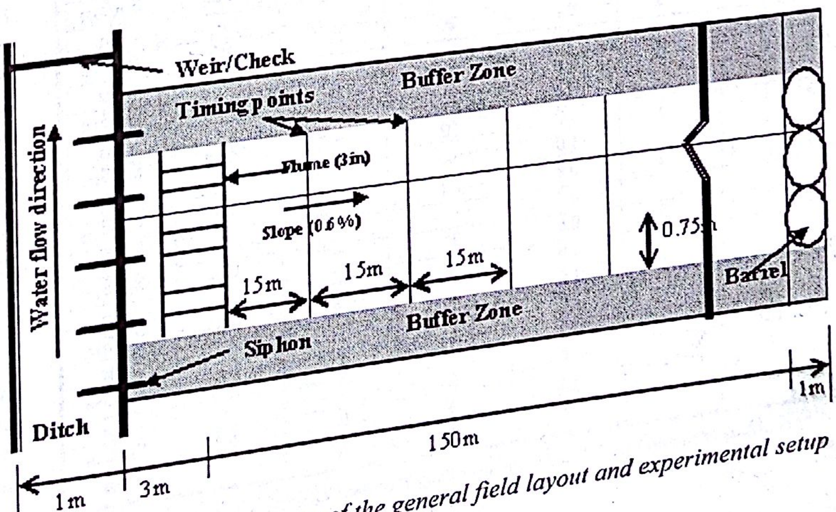


*Figure 1. Schematic diagram of the general field layout and experimental setup of a furrow set*

## Materials and Methods

The field experiment was conducted during 2003/2004 off-season at Melkassa Agricultural Research Center (MARC) farm, 107 km South-East of Addis Ababa. The area is situated at an altitude of 1550 m asl. The average annual rain fell is 767 mm. The average monthly maximum and minimum temperatures are 28.55°C and 13.79°C, respectively. The soil of the experimental field has a dominantly clay loam texture with an average bulk density of 1.12 gm/cm³.

## Field Layout and Experimental Settings

The selected experimental field had a size of 155 m X 50 m and slope of 0.6%. The field was divided into three furrow sets consisting of five furrows having center-to-center spacing of 75 cm. The general field layout and experimental set up for a furrow set is presented in Figure 1; it is the same for all furrow sets. The middle three furrows were used for monitoring irrigation events under continuous flow (one furrow) and surge flow (two furrows) with the intention to replicate the surge flow treatments as it was the main concern of this study. The two outer furrows (buffer furrows) were used to simulate practical furrow irrigation minimizing unexpected side ways moisture movement beyond the monitored furrows.

The treatments involved in this experiment were irrigation flow regimes (surge flow and continuous flow), surge time management factors (cycle times and cycle ratios), and inflow discharge. Cycle time is defined as the duration of time between successive inflows and cycle ratio is the ratio of surge inflow time and cycle time. Three possible flow rates (0.6 $ls^{-1}$, 0.8 $ls^{-1}$ and 1 $ls^{-1}$) could be selected for both flow regimes. Under surge flow, cycle times of 20 min, 25 min and 30 min, and cycle ratios 0.32, 0.50 and 0.67 were also selected taking into account the minimum management criterion and the existing field condition. Field research was conducted to evaluate the surge effect under some possible management settings as well as to generate useful information in wider scope with limited resources. Certain proper combinations of flow rate, cycle times and cycle ratios were selected and assigned to the furrows systematically for specific trials as shown in Table 1. The furrows taking specific treatment combination are designated by $C_{ij}$ and $S_{ijk}$ to imply the continuous flow and surge flow irrigation events respectively. The first subscripts stand for the number of irrigation event whereas the second subscripts denote the furrow sets with the same flow rate. The third subscript under surge flow trials stands for specific furrow within the furrow set.

*Table 1. The treatment combination, the corresponding trial and furrow ID*

| Irri. Event | | Furrow Set | Flow Rate (lt/s) | Cycle Time (min) | On-time (min) | Cycle Ratio (fraction) | Furrow ID* |
|---|---|---|---|---|---|---|---|
| Trial ID | No. | | | | | | |
| $IF_{11}$ | 1 | 1 | 1.0 | 25 | 8 | 0.32 | $S_{111}/S_{112}$ |
| | | | 1.0 | - | - | - | $C_{11}$ |
| $IF_{12}$ | 1 | 2 | 0.8 | 20 | 10 | 0.5 | $S_{121}/S_{122}$ |
| | | | 0.8 | - | - | - | $C_{12}$ |
| $IF_{13}$ | 1 | 3 | 0.6 | 25 | 8 | 0.32 | $S_{131}/S_{132}$ |
| | | | 0.6 | - | - | - | $C_{13}$ |
| $IF_{21}$ | 2 | 1 | 1.0 | 30 | 20 | 0.67 | $S_{211}/S_{212}$ |
| | | | 1.0 | - | - | - | $C_{21}$ |
| $IF_{22}$ | 2 | 2 | 0.8 | 20 | 10 | 0.5 | $S_{221}/S_{222}$ |
| | | | 0.8 | - | - | - | $C_{22}$ |
| $IF_{23}$ | 2 | 3 | 0.6 | 25 | 8 | 0.32 | $S_{231}/S_{232}$ |
| | | | 0.6 | - | - | - | $C_{23}$ |
| $IF_{31}$ | 3 | 1 | 1.0 | 25 | 8 | 0.32 | $S_{311}/S_{312}$ |
| | | | 1.0 | - | - | - | $C_{31}$ |
| $IF_{32}$ | 3 | 2 | 0.8 | 30 | 20 | 0.67 | $S_{321}/S_{322}$ |
| | | | 0.8 | - | - | - | $C_{32}$ |
| $IF_{33}$ | 3 | 3 | 0.6 | 20 | 10 | 0.5 | $S_{331}/S_{332}$ |
| | | | 0.6 | - | - | - | $C_{33}$ |

**The identifications of furrows with in a furrow set taking the same surge flow treatments are put together.*

## Field Measurements

The field measurement during each irrigation trial involved flow geometry at the inlet section, advance and recession times, and run-off volume at the furrow end. Cumulative advance and recession times since the first introduction of irrigation water were recorded at each 'timing point' along individual furrows corresponding to specific treatments. 'Timing points' or advance-recession stations were established along the furrows at a 15 m interval (15 m-150 m) using pegs and rope. Under surge flow treatments, the final advance distances and times were also taken for each successive surge when the waterfront stopped advancing. These field data were collected by visual sighting with the help of stopwatch and tape meter.

During each field trial a more or less constant head of irrigation water in the ditch was maintained by moving adjustable flashboard up and down with respect to the rectangular weir crust. The irrigation water was supplied to each furrow using a 5cm calibrated rigid siphon. Inflow discharges were controlled appreciably by moving siphons back or forth until the required amount was attained such that a fixed flow rate could be supplied for the whole irrigation event. Under the surge flow treatment, the water was manually managed to make an intermittent flow during subsequent wetting and drying periods. The rate of inflowing water per furrow was monitored thoroughly using a 3 in standard Parshall flume.

Irrigation was continued until the advance phase had been completed. Suitable cutback strategy was applied for surge flow irrigations adjusting the cycle time of the last surge till the advance phase ended. The out-flowing water was collected at the furrow tail end using buried barrels. Three irrigations were evaluated on each furrow set. Based on existed field practice, the time interval between two consecutive irrigations was from 8 days to 10 days. The furrow sets were irrigated one after the other every another day. Generally, a total of nine irrigations were evaluated under surge and continuous flow treatments.

## Methodology

Observed and calculated irrigation system performance parameters were used to compare surge flow with the continuous flow irrigation. The total infiltrated volumes of surge and continuous flow irrigations were determined for individual irrigation events based on volume-balance method (Eqn.1).

$$Q_o t = V_i + V_{ro} \quad (1)$$

where $Q_o$ = observed inflow rate ($m^3/min$), t = observed inflow time (min) $V_i$ = infiltrated volume ($m^3$) and $V_{ro}$ = observed runoff volume ($m^3$). In order to have a clear picture about the impact of surge flow on the infiltration process, it may entail to determine the soil infiltration characteristics. The potential of surge flow for improved irrigation performance was evaluated quantitatively and qualitatively according to its relative infiltration pattern. The modified Kostiakov-Lewis infiltration function (Eqn.2) for individual irrigation trials was determined priory. The infiltration constants 'a', 'k' and the basic infiltration rate 'F' for each irrigation event were solved based on the optimization procedure, minimizing the error between measured and estimated advance distances (McClymont and Smith, 1996).

$$Z = kt_o^a + Ft_o \quad (2)$$

where Z = cumulative infiltration per unit length of furrow ($m^3/m$), $t_o$ = infiltration opportunity time (min.), k = fitting parameter ($m^3/min^a/m$), a = fitting parameter, 0<a<1, (dimensionless), F = steady or basic infiltration for the soil ($m^3/min/m$),

Continuous flow infiltration pattern was determined for each irrigation trial using identified infiltration functions. Under surged flow, per surge infiltration pattern was examined for each irrigation trial based on Numerical version of Cycle Ratio Time Model (NCRTM) as described by Benham et al. (2000). The incremental infiltrated volume per unit length of furrow for individual pulses were determined from the difference between the infiltration function evaluated at a certain recession time and advance time referenced to the initial wetting at that station. The accuracy of predicting the surge flow infiltration process was evaluated according to the results found from these equations:

$$\Delta V_i = \sum_{j=1}^{f}\left[\frac{\Delta Z_{ij} + \Delta Z_{ij-1}}{2}\right] \times \left[X_{ij} - X_{ij-1}\right]$$

and $$V = \sum_{i=1}^{n} \Delta V_i \quad (3)$$

where $\Delta Z_{ij}$ = the incremental infiltrated volume per unit length of furrow for the $i^{th}$ surge at the $j^{th}$ timing-point, in $m^3/m$, $\Delta V_i$ = the infiltrated volume per surge ($m^3$), f = the index of the $i^{th}$ surge's final advance distance, X (m), V = total predicted infiltration volume ($m^3$), and n = the number of surges.

The effect of surge flow on the soil infiltration capacity, distribution uniformity and runoff amount of each irrigation event was evaluated on unit furrow basis examining the infiltration patterns and using the following indices:

$$DU = \frac{I_{av(0.75L-L)}}{I_{av(L)}} \text{,and}$$

$$TWR = \frac{V_{ro}}{V_{ap}} \quad (4)$$

where DU = distribution uniformity (fraction), TWR = tail water ratio (fraction), $I_{av(0.75L-L)}$ = average infiltrated depth at the lower quarter of the furrow length (mm), $I_{av(L)}$ = average infiltrated depth for the whole field length (mm), $V_{ap}$ = volume applied to the furrow ($m^3$), and $V_{ro}$ = volume of runoff ($m^3$) (FAO, 1989).

## Results & Discussion

**Determination of Soil Infiltration**

Almost in all of irrigation events, coincidence of the first surge and early continuous advance curves was observed. This indicates similar advance rate for both flow regimes during the initial wetting phase. Figure 2 illustrates the scenario up to 45 m of advance distance where the first surge commenced to recess.

The modified Kostiakov-Lewis infiltration function constants (a, k and F) for individual irrigation events were determined applying non-negative Newton pattern search optimization in *MS-SOLVER*. Optimum results of infiltration parameters obtained from the solving operation are presented in Table 2 along with their respective observed and predicted infiltration for both surge and continuous flow irrigations. The accuracy of predicting infiltrated volumes using continuous infiltration function and NCRTM algorithm were tested before going to further application for infiltration pattern analysis. Simple regression analysis indicated the prediction was good with slope = 0.96 and $R^2$ = 0.97 for the continuous flow, and slope = 0.99 and $R^2$ = 0.95 for surge flow irrigation.

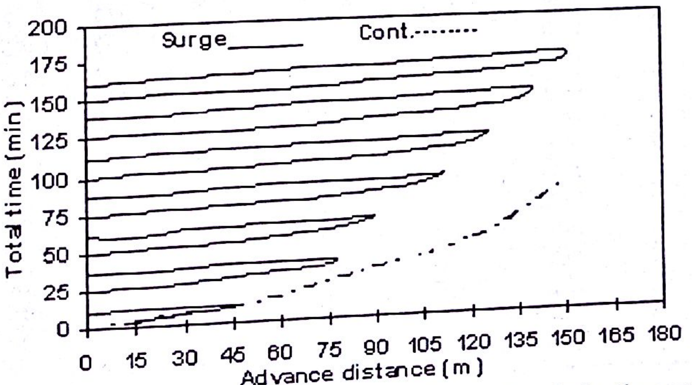


*Figure 2. Advance and recession trajectories of surge flow irrigations and the corresponding continuous flow advance curve ($IF_{23}$, Q = 0.6 $ls^{-1}$, cycle time = 25 min and inflow on-time = 8 min)*

*Table 2. The values of the soil infiltration parameters, the observed and predicted infiltrated depths for individual trials*

| Trial ID | a | k ($m^3/min^a/m$) | F ($m^3/min/m$) | Continuous flow | | Surge flow | |
|---|---|---|---|---|---|---|---|
| | | | | $V_o$ (mm) | $V_p$ (mm) | $V_o$ (mm) | $V_p$ (mm) |
| $IF_{11}$ | 0.3223 | 0.00463 | 0.000046 | 23.49 | 21.95 | 17.92 | 17.72 |
| $IF_{12}$ | 0.4259 | 0.00304 | 0.000127 | 33.38 | 30.67 | 34.00 | 32.10 |
| $IF_{13}$ | 0.4055 | 0.00284 | 0.000097 | 33.39 | 31.25 | 22.98 | 23.00 |
| $IF_{21}$ | 0.3053 | 0.00187 | 0.000238 | 15.32 | 15.31 | 17.33 | 16.66 |
| $IF_{22}$ | 0.3803 | 0.00344 | 0.000145 | 20.98 | 22.12 | 21.25 | 23.80 |
| $IF_{23}$ | 0.4025 | 0.00246 | 0.000121 | 26.88 | 28.36 | 17.92 | 17.93 |
| $IF_{31}$ | 0.3001 | 0.00214 | 0.000139 | 12.89 | 11.56 | 12.01 | 11.00 |
| $IF_{32}$ | 0.2928 | 0.00114 | 0.000209 | 10.19 | 10.80 | 11.91 | 13.96 |
| $IF_{33}$ | 0.6345 | 0.00039 | 0.000089 | 9.22 | 7.49 | 9.60 | 7.22 |

Note: *'a', 'k' and 'F' are modified Kostiakov-Lewis infiltration function constants, $V_o$ = observed infiltrated depth and $V_p$ = predicted infiltrated depth.*

## Performance of Surge Flow Irrigation

The potential of surge flow for improved performance in furrow irrigation system can be generally expressed by the faster advance attributed to amount of the soil intake rate reduction between successive surges. The infiltration pattern under surged flow was developed based on the results obtained from NCRTM. It was observed that the surged flow infiltration pattern had generally similar phenomenon for all irrigation events and one of these ($IF_{11}$) is presented in Figure 3 for illustration. Figure 3a shows the differential infiltration with respect to opportunity times at the stations in interest for four consecutive surge cycles. It can provide the insight that the maximum reduction in infiltration rate occurred during the second wetting period and no significant difference was observed further. This supports Izuno's et al. (1985) infiltration function inferring that infiltration after the first wetting is no longer time dependent and occurs at steady rate when water is present. The infiltration rate was reduced maximally during this period by 66% on average for the first irrigations ($IF_{11}$, $IF_{12}$ and $IF_{13}$). Figure 3b shows the distribution profile of the cumulative infiltration after each successive surge. It indicated that nearly uniform infiltration occurred after the first surge with decreased rate of wetting the dry portion. The rebounding tendencies of the consecutive infiltration lines just near the previously wetted front end shows change in moisture regime.

*Table 3. Observed and determined performance indicators in furrow basis for all trials under surge flow and continuous flow irrigations*

| Trial ID | NC | Vap (mm) | InT (min) | RO (mm) | ROT (min) | DU | TWR |
|---|---|---|---|---|---|---|---|
| $*IF_{11}S$ | 5 | 25.87 | 40.00 | 0 | 0 | 0.72 | 0 |
| $IF_{11}C$ | | 24.89 | 46.70 | 1.422 | 15.65 | 0.91 | 0.057 |
| $IF_{12}S$ | 8 | 34.13 | 80.00 | 0.133 | 4.12 | 0.48 | 0.004 |
| $IF_{12}C$ | | 34.13 | 80.05 | 0.498 | 9.10 | 0.60 | 0.015 |
| $IF_{13}S$ | 9 | 23.02 | 72.00 | 0.062 | 7.20 | 0.52 | 0.003 |
| $IF_{13}C$ | | 33.96 | 106.15 | 0.587 | 14.42 | 0.63 | 0.017 |
| $IF_{21}S$ | 2 | 18.84 | 35.37 | 1.538 | 13.07 | 0.72 | 0.082 |
| $IF_{21}C$ | | 16.71 | 31.33 | 1.387 | 13.64 | 0.79 | 0.083 |
| $*IF_{22}S$ | 5 | 28.11 | 50.00 | 0 | 0 | 0.58 | 0 |
| $IF_{22}C$ | | 27.38 | 51.30 | 0.729 | 14.10 | 0.74 | 0.027 |
| $IF_{23}S$ | 7 | 17.96 | 56.00 | 0.049 | 4.87 | 0.56 | 0.003 |
| $IF_{23}C$ | | 27.53 | 86.02 | 0.640 | 15.53 | 0.63 | 0.023 |
| $IF_{31}S$ | 3 | 12.80 | 24.00 | 0.791 | 11.09 | 0.84 | 0.062 |
| $IF_{31}C$ | | 14.04 | 26.38 | 1.182 | 13.17 | 0.84 | 0.084 |
| $IF_{32}S$ | 2 | 12.80 | 30.00 | 1.511 | 25.15 | 0.90 | 0.118 |
| $IF_{32}C$ | | 11.11 | 26.02 | 0.916 | 16.73 | 0.83 | 0.082 |
| $IF_{33}S$ | 3 | 9.60 | 30.00 | 0.001 | 6.43 | 0.54 | 0 |
| $IF_{33}C$ | | 9.78 | 30.67 | 0.596 | 15.30 | 0.78 | 0.061 |

Note: *NC = Number surge cycles, InT= Inflow time, ROT = Runoff time, Vap = amount of applied water, RO = Runoff, DU = Distribution uniformity, TWR = Tail water ratio, S = Surge flow and C = Continuous flow. * The last surge cyles of $IF_{11}$ and $IF_{22}$ were ignored since they could not be completed because of pump failure.*

Distribution uniformity (DU) and tail water ratio (TWR) values are presented in Table 3 along with the observed applied volumes, run-off volumes, and inflow and outflow times corresponding to each treatment combinations. More volume and time was needed under surge flow irrigation events ($IF_{21}$ and $IF_{32}$) taking cycle time and cycle ratio of 30 min and 0.67, respectively. A greater irrigation water and inflow advance time saving under surge flow was observed on $IF_{13}$ and $IF_{23}$ irrigation event, as compared to the continuous flow. Surge flow used only 35% water and time of the continuous flow during the second irrigation ($IF_{23}$). This does not mean that surge flow was more effective during the second irrigation but it might be due to the occurrence of relatively little surface cracking observed during the drying periods. Under laboratory study, clayey soils manifested a higher relative saturated permeability at lower matric suction during which the effects of air entrapment and surface cracking were minimal (Jalali-Farahani et. al., 1993b).

Table 3 shows that the role of surged flow for uniform water distribution along the furrow length was outweighed by the continuous flow almost

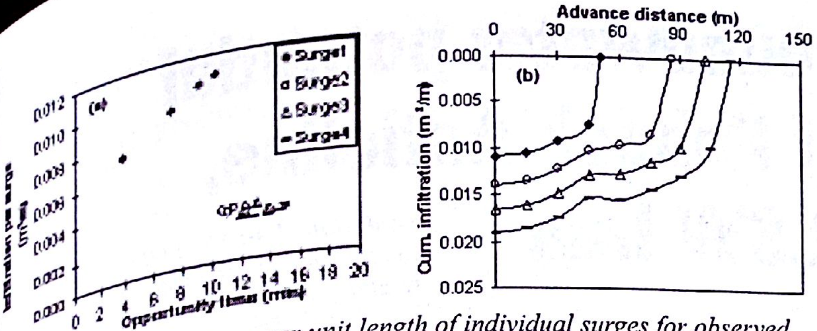


*Figure 3. Infiltrated volume per unit length of individual surges for observed opportunity times (a), and distribution of cumulative infiltrated volume per unit length after successive surges along the furrow (b), up to the fourth surge cycle.*

for all trials. This implies that the effect of surge was worsening on clayey soils with relatively steeper slope and shorter furrow length. Surge flow was found promising in minimizing the tail water or 'run-off' as noted by Yonts et al. (1994). The amount of tail water reduced was 84% and 88% under surged flow of $IF_{13}$ and $IF_{23}$ irrigation events, respectively compared to the continuous flow. In every aspect of evaluation, results indicated that surge flow performed better using a 25 min cycle time combined with a cycle ratio of 0.32 (8 min inflow on-time) and flow rate of $0.6 ls^{-1}$ for this particular study otherwise the effect would be negative.

## Conclusion

In general sense, surged flow under-performed compared with continuous flow at the study area. The soil type and the physical phenomenon before and during irrigation were observed as important factors that affect the ultimate performance of surged flow irrigations. The occurrence of minor cracks during the earlier drying phase, due to the clayey nature of the soil and relatively steeper slope with short furrow length, were ostensibly believed to be the major factors that could reduce or worsen the effect of surged flow irrigation. Surge flow performed better on irrigation events that took cycle time of 25 min, inflow on-time of 8 min and inflow rate of $0.6 ls^{-1}$. Under these irrigation events, surge flow used only 35 of water and time that was used by the continuous flow irrigation. A maximum run-off reduction of 88% was observed on the same irrigation events. Results found from this particular study showed that intermittent flow will be effective on clayey soils using low inflow rate, short inflow on-times and at lower soil-matric condition.

Results found from this study should not deprive the potential use of surge flow irrigation on medium to coarse-textured soils and in high intake conditions especially following planting and major cultivation, and as an efficient cutback strategy. A careful selection of optimum management factors combination plays a great role to achieve the expected surge flow relative advantages on the performance of furrow irrigation system. This study suggests that further research should be conducted on surge flow under another different condition for better understanding of the system.

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# Evaluation of Groundwater potential Zones in parts of Pabdeh Anticline, Zagros Fold Belt,SW Iran

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**Abstract**

**The Pabdeh anticline belongs to the Zagros Fold Belt in the southwest Iran. This area is exposed in karst region in Iran. Remote sensing and geographical information system (GIS) are rapidly increasing role in the field of hydrology and water resources development. In this study remote sensing and GIS techniques applied to determine the water potential zones of the area. Location of the potential zones in the study area is determined on the basis of lineaments, chemical properties of the water resources, drainage network, elevation and lithology of the area. The study shows 52 suitable locations as potential zone to sustainable water management. The study reveals that Recent alluvial is the best for the water reservoir in case with a thick layered. It also reveals that Asmari formation with 31 % of the area could be second choice for the water reservoir beside alluvials. This study also emphasizes that, though marls and sandstone of Aghajari formation has high porosity and permeability but practically situated in the third step after marls, dolomite and limestone Asmari formation in respect to numbers of location to water potential zones. This study also shows the advantages of remote sensing and GIS for Karst study.**

## Introduction

Ground water is a precious of limited extend (Saraf et al, 2004). Karst terrain is a complicated and widespread phenomenon on the surface of the earth. Karst can be defined as terrain with distinctive characteristics of relief and drainage arising primarily from the solution of soluble bedrock by natural water. Karst topography is most commonly found in carbonate rocks, including limestone and dolomite of Pabdeh area in the Zagros fold belt south west Iran. This area is characterized by closed surface depression and a well developed drainage system. On the other side, the remotely sensed data and GIS techniques are becoming an increasingly provided for the hydrology and hydrological studies of karst area. One of the greatest advantages of using remote sensing data for hydrological investigations, monitoring and karst water potential zones is ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, predication and validation (Saraf, 1999). Satellite data (Figure 1) was digitally process to enhance the objects and identify different lithology. The various layers and themes were extracted within the GIS environment to analyze the recharges areas. Several field checks were carried out and calibrated to the satellite data. Water samples were chemically studied and used as a theme for analyzing in GIS environment to create a water potential map of the area.

Basically, for this study we assume that 1- the area is tectonically active and generates lineaments and fractures which control the ground water. So for this reason the study of total length of the fracture, number of fractures and number of junctions was carried out 2- chemical properties of the spring water 3- drainage basin and drainage network 4- lithology and 5- elevation (digital elevation model). Based on these assumptions the most suitable zones were extracted in GIS environment.

However, there are five reasons of the present study: 1- identification of rechargeable areas and water potential zoning 2- the influence of structures and tectonics to ground water in karst area 3- porosity and permeability of the Aghajari formation that can not be a reason for the recharge water area. Thus porosity and permeability is not only the factor for the water reservoir. The reason for low recharge is chemical properties of the water in each formation 4- five selected themes are sufficient to extract the water potential zones with accurate result and finally (5) to emphasis the usefulness of remote sensing and GIS techniques for karst study and ground water potential zoning.

## Study area

The Pabdeh anticline lies between 49° 15' 00" – 49° 30' 00 "E and 32° 00' 00"- 32° 25' 00" (Figure 1). The Pabdeh anticline falls within the Pabdeh-Lali district of north Kuzestan province in the southwest of Iran. It is parts of the Zagros Mountains.

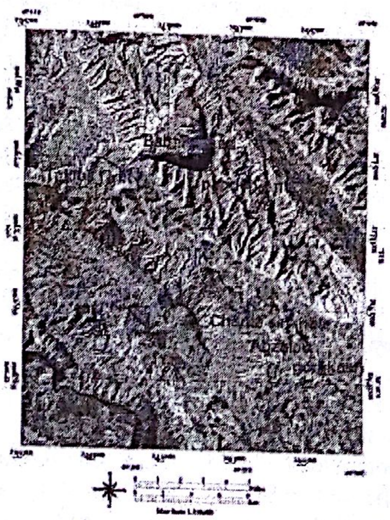


*Figure1. Landsat ETM image FCC 7-5-2*

## Geological Setting and Geomorphology

Geologically the study area comprises of gray marls, red marls, limestone, dolomite, conglomerates, sandstone, sandy lime, calcareous and alluvial. The age of the study area is ranges from Lower Cretaceous to Recent and Subrecent. Lithologically the Papbdeh area consists of different lithounits. This includes Ilam-Sarvak, Pabdeh-Gurpi, Pabdeh, Mishan, Asmari, Gachsaran, Aghajari, Lahbari member of Aghajari, Bakhtyari formation, Subrecent conglomerate, alluvial and Recent deposits (Figure.2). Each litho type has different texture, structure, porosity and permeability. Thus the rock types in the study area play an important role to groundwater potential.

The digital interpretation and GIS analysis for the study of geology in the Pabdeh area shows that the Asmari formation comprises a greatest lithounits and with Recent conglomerate. It is covered about 2% of the study area (Figure.3). This analysis could be used as one of the themes to evaluate the water potential zones in the study area.

Geomorphologically,Zagros Mountains as folds are exhumed, variation in the resistance of these strata produce topography characterized by large anticline where elliptical Asmari hogbacks encircling breached anticlines, and where exhumation has been greatest, by rugged topography sculpted from Mesozoic carbonates in the inner cores of the anticlines (Oberlander, 1965).

Synclinal folding tends to close fractures and thicken rock units along the axes of synclines, it is common for synclines to become rugged in the Zagros Fold Belt as the topography of a fold and thrust belt is eroded down.

In the Zagros Fold Belt, young folds and thrusts belt and rivers are generally controlled by the structures. Rivers and drainages flow along the axes of anticlines, synclines, faults and fractures. This can be seen in Tang-e-Baba Ahmad (Figure.2) of Pabdeh anticline in the study area. As the stream system evolves by head ward migration and stream capture, the stream may eventually flow across the regional structure in the Zagros Fold Belt. These structures exhibit tight fold with NW-SE trend and closely space fracture systems. These styles of geological setting facilitated severe erosion and formation of rugged and immature topography with closed drainage system. The drainages also are controlled by fractures and faults system towards NE-SW direction. The hogback ridges in the study area may be characterized by high resistance to erosion and structural discordance with the tectonic grain of the Zagros Fold Belt.

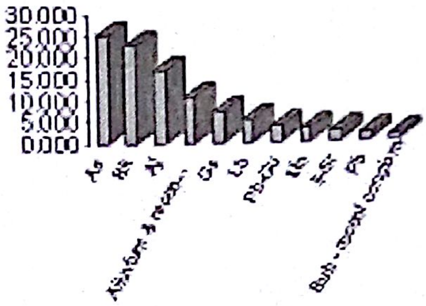



*Figure3. Diagram of the lithounits percentages of the study area*

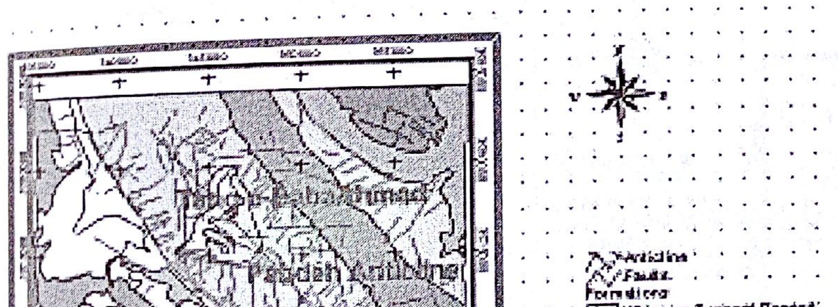



*Figure2. Digital geological map of the study area. Prepared in GIS environment.*

### Structures

Structure is used here in structural geological sense and is concerned with the attitude and deformational effects of bedrock. Limestones and dolomites of Pabdeh anticline at or near the surface tend to deform by brittle fractures. This tendency to form complex joint sets (Figure.4) is directly responsible for the secondary permeability required for the development of subsurface solution drainage.

Large-scale structures or tectonics not only have led to the development of specific landforms (i.e. sinkholes, dolines, etc.) in Pabdeh area like Charite sinkhole (Figure.1) but have also influenced the rates and degree of karstification.

Faults in the study area are closely spaced along which there is relative sliding movement of the blocks. Most of the litho tectonic units have responded to crustal shortening by brittle failure. The important faults in the study area have been named after settlement features developed in the neighborhood of the failure surfaces. Faults in the study area are commonly: 1- thrust fault, 2- strike faults, 3- normal faults, and 4- reverse faults.

Fracture density can give information about the groundwater efficiency in the area. Fracture map of the study area (Figure.5) was prepared in GIS environment using Arcview 3.2 software. The fracture system was used as one of themes to delineate and extract the groundwater location suitability and water potential zones of the study area in GIS environment. Further frac-

*Figure4. Complex joints and fractures in Aghajari formation, Pabdeh anticline, ZFB, SW Iran*

ture theme also could be used in GIS environment to create iso fracture map (Figure.6) and incidence map (Figure.7). This type of analysis plays an important role beside other themes in GIS environment to identify water potential zones.

The interrelationship between iso fracture, springs, surface water and suitable location water potential zones extracted in this study is interpreted. The ground water follows main faults, lineaments and fractures in N-S and E-W directions. It also reveals that the resources water in back limb of the fold is probably not related to the forelimb. This fact is also satisfied by the determining of the chemical properties (i.e. water elements) in the laboratory. Thus, the recharge ground water in both limbs of the fold has different resources and reservoir. Further more the fact is also supported by the geomorphological analysis in GIS environment. It has been seen that the study area comprises three watershed basins (Figure ).

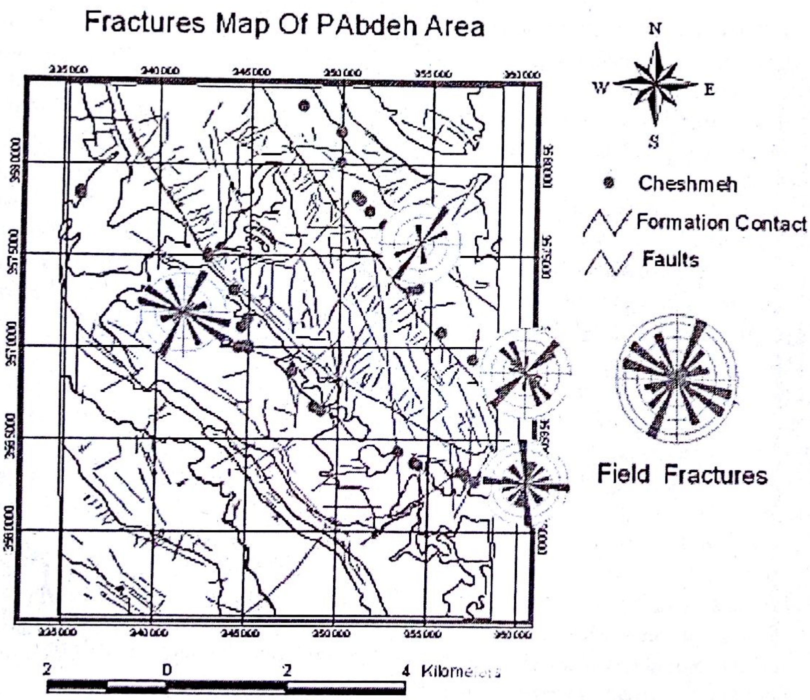



*Figure 5. Structural map of the Pabdeh anticline, Zagros Fold Belt, south west Iran*

## Methodology

Remote sensing and GIS were used to extract the ground water suitable areas in karst. On this purpose to identify the fracture system, remote sensing data has been used and it has been further correlated with the available geological map of geological survey of Iran with several field checks (Figure.4). Shape, tone, texture, vegetation linearity, topography, erosion, landuse, was used as interpretation keys to extract the lineaments and lithology from the image by using environmental visualization image (ENVI 3.6) software. Various enhancements such as linear2%, edge enhancement and sharpen filtering were carried out to highlight objects on the image.

Portion of the LANDSAT frame No. 167-038 representing the study area (Figure.1) was digitally divided into cell by using Arcview 3.2 software. The cell boundaries were drawn parallel and perpendicular to the satellite path. The cell grid was superimposed on the digital fracture map generated from the LANDSAT image. The number of fractures in each cell was digitally plotted in the center of the cell as cell value. The iso fracture density contours were plotted (Figure.7) using spatial analysis in GIS environment ( Arcview 3.2 software) to evaluate groundwater suitability area and thus water potential zones. The lithological study was carried out on the basis of information from the image, available geological map and several field checks. Then on the basis of available information lithological contact in each lithounits was digitized by using ENVI 3.6 software and further converted to the GIS formats. The knowledge of chemical properties of water can give idea about quality of water for drinking or any other uses. For this reason springs (Figure.6 and 7) in the study area was located using field checks and global positioning system (GPS). The chemical properties of samples also carried out on the laboratory to determine available elements (i.e EC, Mg, Cl, Ca, Ph, Na and K) in water to correlate with available water in the study

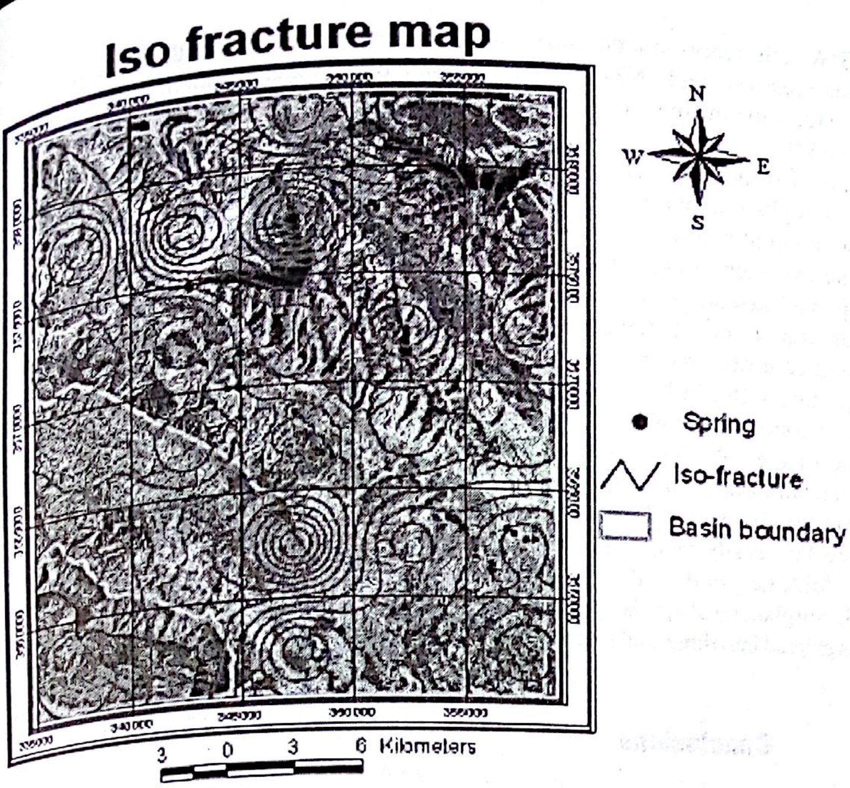



*Figure 6. Iso fracture map of pabdeh anticline, Zagros Fold Belt south west Iran. The map showing relationships between iso fracture contour and springs*

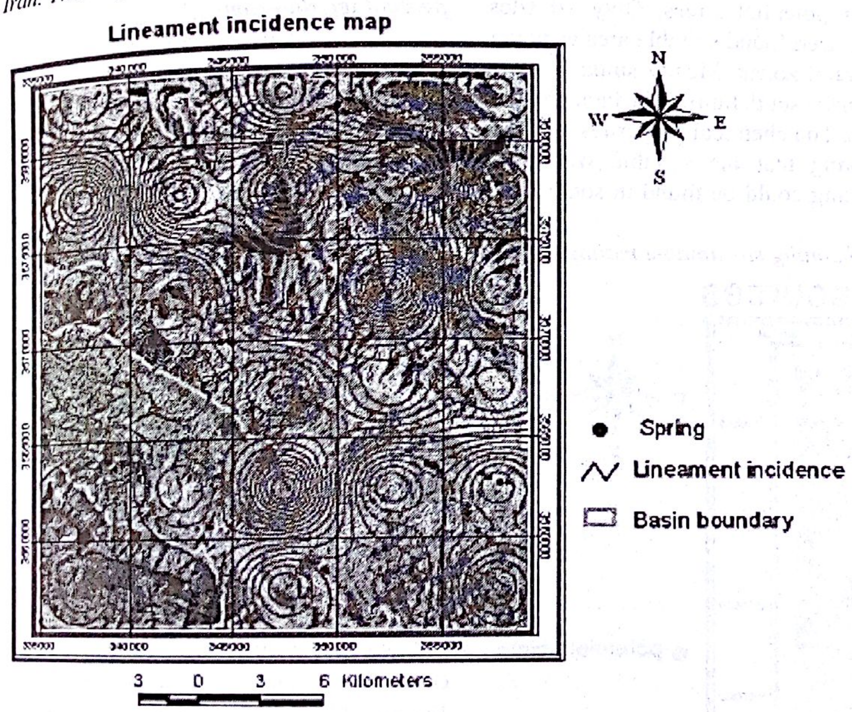



*Figure7. Showing lineament incidence map of the study area.*

area. GIS has been also used to create digital elevation model (DEM) as a parameter to integrate water potential zones mapping. DEM was generated using x, y and z attributes of digital topographic map on scale 1:25000 provided by the Iranian survey organization. The analysis was carried out in Arcview 3.2 and Rivertools 2.4 softwares.

The DEM of the study area was used for morphometric analysis by using Rivertools and Arcview 3.2 softwares. Morphometric parameters (Pirasteh et al 2002) such as flow grid, basin outlet, RT treefile were based to extract watershed basin, drainage orders, drainage segment orders, drainage density and etc.

**Flow grid generation*- the objective of the first step in the conditioning phase is to create an adjusted "depression-less" is raise to the lowest elevation value on the rim of the depression. Each cell in the depression-less digital elevation data set will then be part of cells leading to an age of the data set. A path is composed of cells that are adjacent horizontally, vertically, or diagonally in the raster (eight-way connectedness) and that steady decrease in value. The purpose of this routine is to extract a flow grid from a DEM grid.

** *Basin outlet*- This is a graphic routine that allows one of specify the basin that one wants to analyze by providing Rivertools with the precise location of the basin's outlet. In the present study the complete DEM was used and therefore an outlet was specified in the GIS environment on DEM on the basis of the remotely sensed data and filed checks.

****RT Treefile*- This routine creates a Rivertools "treefile" for one or more of the basins in the DEM, from a Rivertools flow grid. The treefile is a vector format file, which can store data for many disjoint basins. Every pixel in the particular basin is the outlet pixel for a sub-basin that is contained in that basin. Detailed morphometric analysis of the drainage network was done for the watershed to deduce and interpret its influences on the fault development and tectonic process.

GIS has been also used to identify water potential zones and suitable area for groundwater development by using spatial analysis and map calculator methods in Arcview 3.2 software. Broadly the following steps have been done:

· Identification of lineaments from satellite data

· Discrimination of lithounits on the image with available geological map and field checks

· Determination of water elements in the laboratory

· Creating DEM to be used in map calculator as a parameter to delineate water potential zones and suitable groundwater area

- Spatial analysis of the watershed basin and drainage network using Rivertools 2.4 version software
- Creating iso fracture map, incidence map and intersection map of the area
- Calibration of available data and calculating required themes which affect on identification of water potential zones in GIS environment using map calculator
- Identification of most suitable area and water potential zones

## Results and Discussions

A remote sensing and GIS based method is found to be very useful in suitability analysis for water potential zones in Karst terrain. For such analysis the first task is to identify the themes facilitating suitable ground water area. The iso fracture density map exhibits contour trend with linear and circular anomalies. The orientation of the anomaly axes were plotted on the basis of highs and lows. The dominant trend have emerged which roughly coincide with the orientation of the ZSB. The anomaly axes are oriented N13°E-S13°W and N77°W-S77°E. The N13°E – S13°W axis represents the direction of compression and N77°W–S77°E axis reflects the mean elongation trend of the ZSB.

The isofracture distribution in terms of highs and lows exhibit correlation with variable response of the ZSB.

The iso fracture map indicates that springs and ground water in the study area are mainly in both the limbs of the fold and controlled by fracture system. The ground water in both the limbs of the fold conducts the water toward the plunge of the fold. Therefore the two features/landforms of karst such as Charite sinkhole and Abzaloo doline (Figure 1) is easily seen in the forelimb of the fold (i.e. south limb).

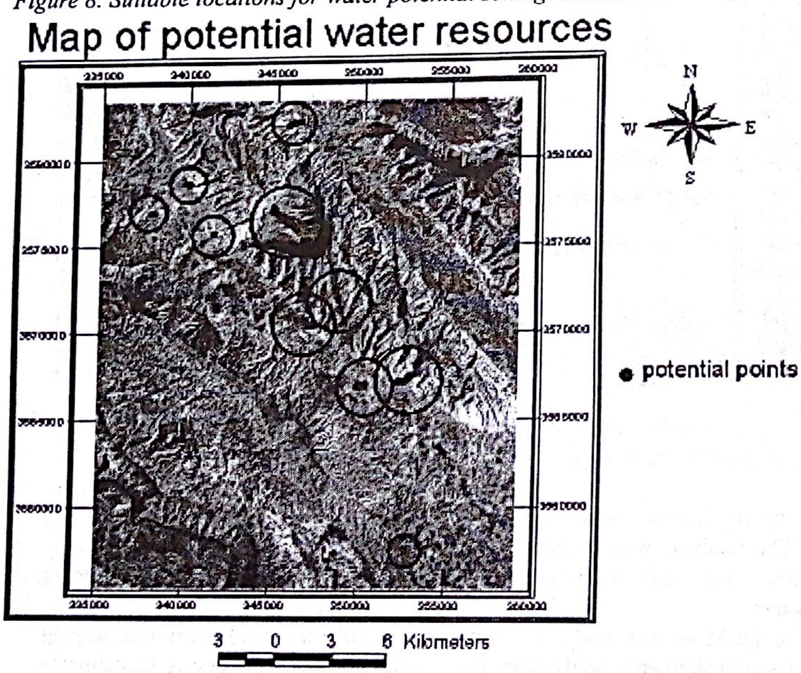
Geomrphologically, it is seen that the area is spliced into three watershed basins.

## Conclusions

On the basis of study carried out in the present watersheds, it has been observed that limited scope for groundwater potential zones. Only 10 sites have been found suitable area as water potential zones. Mostly suitable areas are in the south limb of the Pabdeh anticline. The chemical properties are also showing that the suitable water for drinking could be found in south limb of the anticlinal fold rather than north limb of the Pabdeh anticline. Therefore there is a need for giving more stress on development of surface and ground water. Lineaments, drainage density, chemical properties, lithology and DEM are useful in identifying the recharge sites.

However, this study with the help of spatial analysis in GIS environment indicates that the recent alluvial is more suitable for the water potential zone to sustainable water management

*Figure 8. Suitable locations for water potential zoning sustainable management*



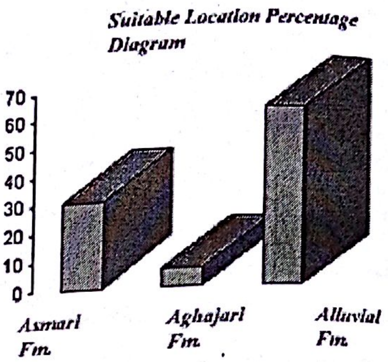




*Figure 9. Suitable locations percentage diagram*

## Acknowledgements

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# Environmental Impact Assessement of Irrigation Development at Amibara Irrigation Projet In Ethiopia

*Moltot Zewdie, EIAR, Melka Werer*

## Abstract

The study was conducted at Amibara irrigation project area, within the Middle Awash Valley of Ethiopia. It was to assess the environmental impact of irrigation development and its severity in threatening the sustainability of the irrigated farm. More over it suggested possible intervention and mechanisms to be devised in order to mitigate such problems. The assessment was based on describing and analysis of long time data on ground water level and soil salinity from randomly sampled 120 surface soil and 25 ground water samples, literature and informal survey based on observation and interview of 52 people using checklist for the ecological data. The study area was severely affected by soil salinity from secondary salinization with high ECe that reach 154dS/m at some spots, shallow ground water level of less than 1m below surface soil, complete deforestation, and devastation of the range land. Such situation causes a drastic change in an overall the environment and natural ecology. The underlined causes of such impacts were the direct consequence of the irrigated agriculture and related activities. In order to take measures in accordance with the problems that alleviate further degradation of the irrigated field and sustains the production and productivity of the irrigation development, government intervention through introduction of agro pastoral production system, double cropping and improved water management systems were put as a way out options.

## Introduction

Interest on the environmental impacts of water resource development has increasingly become an important consideration since the date 1960's. The over all interest in the environment in general get to its peak in 1980's (Wooldridge 1991). But environmental conservation was still given a lip service in many countries. The techniques for environmental impact assessment (EIA) were developed only during the post 1965 era, and in fact the term EIA itself gained widespread use only during this period.

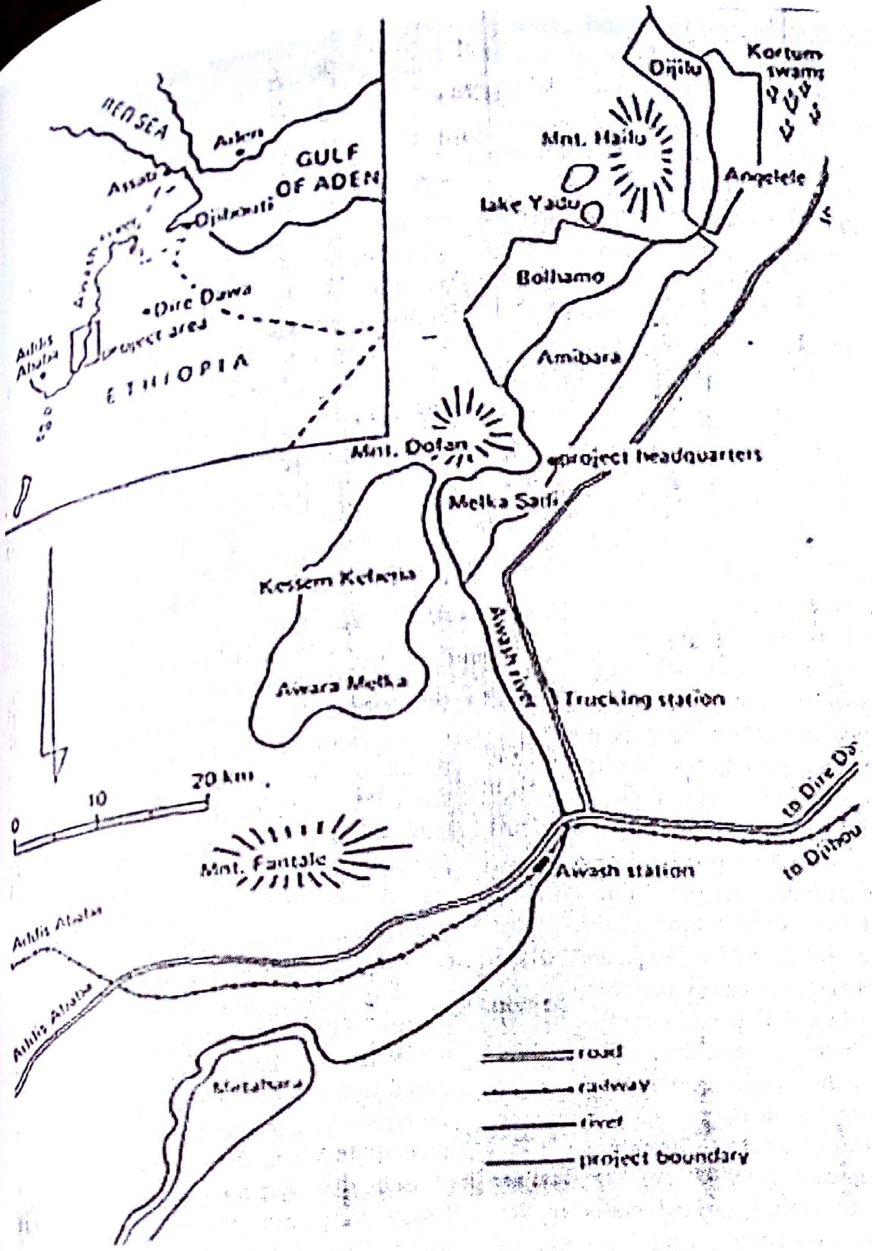
In the early times once man started crop production along the riverbanks and lakes, irrigation practice become common in many parts of the world including Ethiopia. In the late 1960's the investment in irrigated farming system had covered a wide area in the Awash Valley. In the Middle Awash valley the Amibara-Melka Sadi farm was established by the Amibara irrigation project two (AIP II) in 1971 based on the survey report of Halcrow in 1965. The net area proposed for irrigation was 14,600 ha where 2100ha under cultivation by that time and the rest covered by natural pasture. At the start it was proposed to extend to the whole potential irrigable area of the locality, which was unfortunate. Let alone to expand it could not able to maintain what was already developed. In 1990's it faced substantial decrease in cultivated land size. The major reasons were the environmental degradation and loss of cultivated land through salinization and even disruptive to human habitation though there were some social factor that may not be ignored like; political change and resource conflict.

This irrigation development was established in an area where the life system of the original dwellers was completely different from the newly introduced one. The people's livelihood was completely supported by livestock rearing and has no know-how of irrigated farming. The development pushes and restrict then to the wet season grazing for all over the years. This situation developed negative attitude among the pastorals for the development that extend from occasional damage on the farm to claim for the return of the cultivated land. More over de-vegetation at the time of establishment, mismanagement of irrigation water and mono cropping play major role in reducing the cultivated land size till to date.

Since the irrigation development was established under such social and natural conditions its of paramount importance to assess the impacts it brought to the environment so as to device a way out intervention to sustain the existing development and learn lesson for future. The impact of such wide development program was not yet seen with respect to environment of the area, which has a great potential both land and water resource for future development if conditions get improved. In order to assess and indicate the environmental impacts of the irrigation development in AIP II area and mitigate the problems through suggesting intervention measures and improve the positive impacts of the irrigation development, this study was conducted under the following objective.

## Objective

To assess environmental impact of irrigation development and the problems, with respect to living condition of the community and land productivity or change of the natural system. Suggest the possible interventions to avert the problems and keep on the sustainability of the farm.




*Location map of Amibara irrigation project area in the Middle valley of Ethiopia*

## Methodology

### Data Collection

The environmental data like; flood hazard, groundwater level and salinity, soil salinity, ecological changes were collected by direct sampling, interview and secondary data from MAADE and Awash basin water resource authority.

In addition to the survey data, secondary data on surface and ground water hydrology and primary data on soil chemical properties were collected. The long-term record on surface and groundwater were collected from WARC and Awash Basin Water Resource Agency. The information collected was focused on the environmental changes as a result of the irrigation development. Here when environment was mentioned, it included the water, soil and vegetation resources in the pre and post irrigation development periods. Since the irrigation development was based on a diversion structure and single cropping system (practiced in the high flow regime) it did not affect the low flow characteristic of the river on down stream user and the aquatic life. More over the farm did not use chemicals like fertilizer and herbicides that may affect the environment. As to the insecticide and pesticide (agrochemicals) used in the farm changes over years with the type of disease or pests and insect occurrence so that difficult to analyze the effect, which need long time study to show the cumulative effect. Hence, such types of environmental impacts were not included in this study.

### Data Analysis

Assessment of the over all impacts of irrigation development on the natural environment: soil, vegetation, ground and surface water level and flow nature were analyzed using descriptive statistics based on pre and post irrigation development condition. The natural condition with and with out the irrigation developments were assessed using literature, long-term data, direct sampling and laboratory analysis.

The spatial and temporal fluctuation of groundwater level in the study area was analyzed-based on brief analysis of informal survey on the subsurface drainage manholes in the irrigated fields

The contribution of high ground water table to the fast secondary Stalinization was also assessed in detail as;

1. The ground water was analyzed for its salt content from 25 piezometr well water samples in gm/lit. The conversion factor, 0.64ECw = gm/lit, was used (Majumdar W.K,2002)

2. Using the potential evaporation demand of the area over 7 months of off season (no irrigation period) and assuming that it was fulfilled by the capillary rise of the groundwater, the salt precipitate in the soil profile was calculated in gm/m$^2$.

Brief assessment on the ecology was done based on an interview using a checklist and sample addressing 52 people of Afar

## Result and Discussion

The result and discussion part incorporated the impact of irrigation development on the environment in relation to flood disaster, degradation of natural resources like soil salinity water logging, deforestation.

### Flood Hazards

As to the information from the elders on the area addressed during the informal survey, the flood was not as such harmful during the pre irrigation development period. They reason-out that the river flooded the area from many overtopping (takeoff) sites that could possibly reduce its power and make it harmless. A report by FAO (1965) indicated the Awash River flow rises up to 700m$^3$/sec, which was almost double of the 1999 flood of 398m$^3$/sec that resulted in great disaster over the area. This implies that the river training work following the irrigation development contributes to the change of the flow characteristics of the river, which confirms the suggestion of the people.

Despite the construction of the flood control structure, the river flow over top and /or breach the dyke and resulted in great disasters on properties. For instance in 1999, 98% of WARC compound (living houses stores and office) were flooded, while 91% were highly damaged. In the MAADE 90% of the Melka Sadi and more than 70% of the Melka Werer cotton farms were completely flooded, which result in total loss of production in the flooded area (Report on flood disaster by WARC and MAADE, 1999/2000).

The unpredicted (unexpected) occurrences of such high flood made the disaster very sever because the victims were not warned to take precaution to evacuate their property from the area. Beyond the immediate disaster on properties, it also aggravates the Salinization process through rapid and abrupt ground water rise (less than 2m to 1m depth from surface) due long time stagnation over the flooded area. More over the psychological impact on the people in fear of being flooded from overtopping of the river every year in the summer season (especially in August) was so considerable.

**Groundwater fluctuation**

The study area has been located on fluvisols flanking the Awash River. It was in proximity to river way (on the flood plains of the river) and has level (flat land feature). The soil survey during the study for the irrigation development revealed that, the depths to groundwater level in most of the irrigated farms of the Middle Awash and local areas were reported to be deeper than 10m (AIP II 1982, Swales Haider, 1974, Fekadu, *et.al* 1999). The repeated flooding on the flood plain in the pre irrigation development period was balanced by the uptake of the reverian forest, which were present on the area that possibly keeps the water table to such deeper depth.

Since the establishment of irrigation development there was a rise of groundwater level in the irrigated fields. The survey on manholes in Melka Sadi Amibara irrigation farm in 2004 revealed that there was a significant rise of ground water level that may affect plant growth, which was shallower than 1m. The rise was continuous and rapid since the beginning of the irrigation development till the installation of the drain system 1992. Though in the latter periods the drainage system helps to restrict the ground water level deeper than 2 m the salinization problem was still there. This could be most possibly due to the long duration off-season in association with high evaporation demand (1700mm per 7 months of off-season) of the atmosphere. Such high evaporation potential of the area could possibly tap the saline groundwater from deeper level (2.0m–4.0m) (Garg 2001, FAO 1984 and Todd 1959).), that is below the reach of the subsurface drainage system that highly contribute to secondary salinization. Hence the single cropping system of the irrigation development facilitate the salinization process through allowing net upward flow of capillary water from the saline ground water to the evaporation zone during 7 months of idle time.

Temporal water logging is also the problem of the farm too. In adequate land leveling (earthwork) in the scheme, associated with vertic soil of the area cause localized water logging following excess irrigation, wild flooding and intense rainfall. It was reported by Halcrow (1985) and Hider (1985) where 72 % of the Melka Sedi cotton farm estimated to suffer by water logging from the above-mentioned causes.

## Soil and water Salinity

The laboratory analysis of ECe for 120 soil samples from AIP II area indicated that, the ECe became as high as 49dS/m and seldom 154 dS/m on some areas. Based on this sample analysis 20% of the sampled area has salinity (ECe) of greater than 4 dS/m while 15% of the sampled area has soil salinity of higher than 8.0dS/m. As to the yield potential analysis (Ayers and Westcot, 1985) such salinity level of the farm can reduce the yield potential of most crops grow in the area to a significant level (cotton to 98%, sugarcane to 80%, maize to 40% banana to 10%).

On the other hand the salinity level analysis made on soil and ground water samples revealed that the ECe level decreases down the soil profile, which shows capillary rise as the major source of soil salinity. This up ward flow of ground water (capillary rise) contains a significant amount of salt (on average 2.448g/lit). Such up ward salt influx deposited 3.515 kg/m$^2$ of salt in the soil profile and on the surface after evaporation during the 7 months of off-season only, assuming that the evaporation potential of the area was totally fulfilled from the capillary rise. Most possibly such amount of salt lifted to the soil profile and surface accounts to net salt accumulation, because there was no down ward flow of water to leach it back to the ground water during this season.

Hence, the major reason for salinization of the soil of this particular area shifts to secondary salinization. It was stated that the soil of the area was categorized to class A and its ECe does not exceed 4dS/m except for some spots (Tadele, 1993, Halcrow 1989, FAO 1965). More over the irrigation water source (Awash River Water) has no restriction to irrigation as the long time monitoring confirms (0.28- 0.98dS/m). So its possible to confirm that irrigated agriculture was the causal problem for the soil salinity.

*Table 1 ECe (dS/m) values of soil sample from salt affected fields of Melka Sedi and Melka Werer Farms of AIP II area 2004*

| Field code | Location | Soil sampling depth | | |
|---|---|---|---|---|
| | | 20-60 | 60-90 | 90-120 |
| F1/1/11 | MS | 40.9 | 26.42 | 19.2 |
| F10/04 | MW | 4.22 | 4.13 | 2.77 |
| 4C3 | MS | 14.12 | [illegible] | 16.54 |
| 4C10 | MS | 26.00 | [illegible] | 15.00 |
| F9/22 | MW | 15.1 | 17.75 | 16.12 |
| D2.00 | MW | 26.10 | [illegible] | 11.20 |
| B79 | MW | 0.9 | 2.22 | 8.65 |

*Source: WARC 2004*

*Fig 2 Salt affected field in the Melka Sadi unit farm (Photo by Moltot Zewdie, 2004)*

## Ecology

From brief assessment of informal survey, interview and referring literature on the ecology, the post and pre irrigation development period situations were out lined with respect to the ecological change.

As stated by Halcrow (1989), the livestock and the pastoralists, who managed them, form a very important and fundamental part of the environment before the development. They were in reasonable balance with the environment before the irrigation development. Based on this study it was clear that, formerly this area, supporting a far lesser population of livestock and corresponding human population, would have been more productive of shrubs, grass and trees than today. Taking substantial areas of traditional dry season grazing land for irrigation development exacerbated the ecological degradation creating more pressure on the remaining land.

There was no alternative grazing option to rest the wet season grazing so as to give enough regeneration time. This situation resulted in further devastation of the productivity of the range through overgrazing and continuous depletion of the seed bank, which can ultimately, brings total degradation of the ecosystem.

From the survey, the area was highly productive of consumable dry matter by virtue of its being on the flood plain of Awash River. As a result it serves for over 9 months of the dry season grazing, beyond supporting the pastoral livestock for such long dry season, can also gave enough time for the wet season grazing land regeneration. This can avoid the devastation of the wet season grazing.

The major causes for the degradation of the ecosystem were the land clearing for irrigation development, concentration of the pastoral livestock on the wet season grazing through out the year and the immigrants that engaged in cutting the remaining surrounding forest for charcoal production. As a result of such human actions there were tree and grass species, which severely declined to disappear from the range (Table 2). These plant species were the rich fodder sources of Afar livestock, hence the devastation of such vegetation treated the life system of the pastoralists very sever and exacerbate their exposure to drought frequently.

## Conclusion and Recommendation

The irrigation development brought a change in the flow characteristics of the river Awash through flood protection structure that intern resulted in flooding of the area and losses of properties. In order to mitigate such frequent and sever flooding problem in addition to frequent monitoring and maintenance of the dyke, flood early warning system must be set on the river basin.

The irrigation development with its poor irrigation water management practices brought shallow water table and high soil salinization problems. The salinization and water logging of cultivated land through ground water table rise treated the productivity of the area to the extent possibly led to abandon of a considerable land size every year. The single cropping system with its long off-season months was also the underlined reason for facilitating secondary salinization. An improved irrigation system was so in urgent need to sustain the irrigated farming in the area more over, double cropping and reducing one directional flow of ground water (capillary rise) to balance the upward influx of salt through leaching need to be introduced.

The reduction of natural flood plain dry season grazing due to irrigation development resulted in reducing livestock holdings per household and productivity as well. The unproductive and few livestock per household that was not supported by any other activity made the communities life very miserable and made them to develop nega-

*Table 2 highly declined (devastated) vegetation species in the range land and cleared from the irrigated land*

| Si. No. | Grass species | | Tree and bush species | |
|---|---|---|---|---|
| | Scientific name | Local name | Scientific name | Local name |
| 1 | Vossia Cuspidate | Sitabu | Dobera glabra | Gerssa * |
| 2 | Chrysopogon hmmulsus | Durfu | Acacia nilotica | Keselto |
| 3 | Cynodon dactylon | Rarieta | Gerewa ferruginea | Hedayito |
| 4 | Setaria acromelanea | Misa | Salvadora percica | Adayto |
| 5 | Sporobolus pellucidus | Hamilto | Acacia oerfota | Geriento |

*Source: WARC low land forages and Forestry Research Section and survey 2005 *No regeneration* tive attitude to wards irrigated farm by blaming it for the problem created. Hence it's important to make governmental intervention in introducing agro pastoral production and irrigated pasture program in order to assist the subsistence living system of the people and avoid the negative attitude of the community for sustainability of the irrigated farming and future expansion of similar development in the area.

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# Reference Evapotranspiration Model for Arba Minch in Gamo Gofa Zone

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## Abstract

*The objective of this study was to develop a suitable time-scale model for estimating mean weekly reference evapotranspiration for the location viz., Arba Minch in Gama Gofa Zone, Ethiopia. The most standard FAO Penman – Monteith combination method was adopted for estimating daily reference evapotranspiration from the daily measured meteorological parameters for a period of 16 years from 1989 to 2004. The first 12 years of the study period (1989 – 2000) were considered for developing the reference evapotranspiration model. The last four years of the study period (2001 to 2004) were considered for validating the reference evapotranspiration model developed. The model developed would be of immense utility in developing proper operational strategies for the management of irrigation schemes in the area.*


## Introduction

Supply to irrigation from any system should match the demand. The demand is governed by the evaporative power of atmosphere and the characteristics of the crop. Crop water requirement is an important practical consideration for designing and managing irrigation systems.

The irrigation water requirement can be computed using crop co-efficient concept, which is the empirical ratio of reference crop evapotranspiration to crop evapotranspiration (Jensen,et.al., 1990). Reference evapotranspiration is the evaporative power of the atmosphere, which is independent of crop type. The reference surface provides a reference to any other cropped surface from which crop evapotranspiration can be computed.

Among various methods recommended by FAO (Doorenbos and Pruitt, 1977) for estimating crop evapotranspiration, the Modified Penman method was preferred since it considered many climatological parameters. Subramaniam and Rao (1985) compared the values of crop evapotranspiration computed using Modified Penman method with lysimeter measurements and found that the Penman method was suitable for Indian climatic conditions. Mohan (1991) concluded that the Penman method could be used for south Indian climatic conditions.

In May 1992, FAO organized a consultation of experts and researchers in collaboration with the International Commission for Irrigation and Drainage and with the World Meteorological Organization, to review the FAO methodologies on crop water requirements and to advise on the revision and update of procedures. The panel of experts recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotraspiration and advised on procedures for calculating the various parameters.

The FAO Penman-Monteith method was developed by defining the reference crop as a hypothetical crop with an assumed height of 0.12m, with a surface resistance of 70 sm$^{-1}$ and an albedo of 0.23, closely resembling the evaporation from an extensive surface of green grass of uniform height, actively growing and adequately watered. The method overcomes the shortcomings of the previous FAO Penman method and provides values that are more consistent with actual crop water use data worldwide (Allen, et. al., 1998).

## Study area and Database

The present study on reference evapotranspiration has been made for the station viz., Arba Minch in the Gama Gofa Zone of Ethiopia.

The latitude and longitude of the location are 6° 04¢ N and 37° 36¢ E. The place is located 1300 m above sea level. The daily maximum temperature is found to be generally in the range 20°C to 35°C and the daily maximum temperature is found to be generally in the range 10°C to 25°C. The mean relative humidity at Arba Minch is generally found to lie between 50% and 60%.

Daily meteorological data measured at the Observatory located in the Arba Minch University Campus was obtained for the period from 1989 to 2004. The meteorological data collected on a daily basis includes the following: rainfall (mm/day), bright hours of sunshine, mean wind speed (km/hour), maximum and minimum temperatures (°C), and maximum and minimum relative humidity.

Table 1 shows the details of the meteorological observatory at Arba Minch in the Gama Gofa Zone, Ethiopia.

*Table 1 - Details of Meteorological Observatory at Arba Minch University Campus*

| Station | Co-ordinates | | Altitude above sea level (m) | Height of wind speed measurements (m) | Angstrom Values | | Data period |
|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | a | b | |
| Arba Minch | 6°04'N | 37°36'E | 1300 | 2.0 | 0.25 | 0.50 | 1989-2004 |

*FAO Penman-Monteith method*

The FAO Penman-Monteith methods to estimate $ET_o$ can be expressed as

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma[900/(T+273)]u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where, $ET_o$ = reference crop evapotranspiration (mm day$^{-1}$)

$R_n$ = net radiation at the crop surface (MJ m$^{-2}$ day$^{-1}$)

G= soil heat flux density (MJ m$^{-2}$ day$^{-1}$)

T = mean daily air temperature at 2m height (°C)

$u_2$= wind speed at 2m height (m s$^{-1}$)

$e_s$= saturation vapour pressure (kPa)

$e_a$= actual vapour pressure (kPa)

D= slope of vapour pressure curve (kPa °C$^{-1}$)

g= psychrometric constant (kPa °C$^{-1}$)

The equation uses standard climatological records of solar radiation (sunshine), air, temperature, humidity and wind speed. To ensure the integrity of computations, the weather measurements should be made at 2 m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water.

The FAO Penman-Monteith equation is a close, simple representation of the physical and physiological factors governing the evapotranspiration process.

## Methodology

Daily reference ET was determined using the Penman-Monteith method for all the 365 days in each year of the study period 1989 to 2004 for the stations viz. Arba Minch. Then, the weekly reference ET in all the 52 weeks of each year of the study period was computed. The mean weekly reference ET in all the 52 weeks of a year, averaged over the years 1989 to 2000, were obtained.

Suitable equations in the time-scale were fitted to the mean weekly reference ET plot obtained. The equations fitted to represent the mean weekly reference ET plot were validated by comparing them with the observed weekly reference ET plots of the test (virgin) years 2001 to 2004.

## Results and Discussion

Figure 1 shows the mean weekly reference ET plot obtained with the best fitting sixth degree polynomial. From Figure 1, it is found that the mean weekly ET tended to increase from 34.3 mm in the first week (January 1 – 7) of the year up to 44.5 mm in the eleventh week (March 12 – 18) of the year. Then, it tends to decrease and reaches a value of 27.3 mm in the 30th week (July 23 – 29) of the year. Then again, there is an increasing trend in the mean weekly reference ET up to the 37th week (September 10 – 16) of the year attaining a high of 39 mm. During the period between the 38th week and 42nd week of the year, the trend in mean weekly reference ET is decreasing with the value reaching a low of 32.5 mm. During the last ten weeks (43rd to 52nd) of the year, the fluctuations in mean weekly reference ET are found to be in a narrow range of 32.8 to 34.4 mm. The maximum and minimum mean weekly reference ET are found to be 44.5 mm and 27.3 mm occurring in the months of March and July respectively.

Polynomial of sixth degree of the form shown in equation (2) fitted best to the plot of mean weekly reference ET in a year. The first 12 years of the study period (1989-2000) were taken for obtaining the mean weekly reference ET curve.

$$ET_o = a_0 + a_1T + a_2T^2 + a_3T^3 + a_4T^4 + a_5T^5 + a_6T^6 \quad (2)$$

where $ET_o$ represents the mean weekly reference ET in mm; T represents the calendar week of the year. For example, T = 1 represents the first week (January 1 – 7) of the year, T = 2 represents the second week (January 8 – 14) of the year, etc. The coefficient of determination $R^2$ is found to be 0.7848. But, it is found from Figure 1 that the fitted polynomial underestimates the observed high values (including the maximum) and overestimates the low values (including the minimum) of mean weekly reference ET.

Hence, in order to best represent the mean weekly reference ET plot obtained, the variations in Figure 1 are inspected and the trends seen are shown in Table 2.

Linear fit of the form shown in equation (3) is fitted to each of the first four parts (I, II, III and IV) of the observed mean weekly reference ET plot.

$$ET_o = aT + b \quad (3)$$

where $ET_o$ and T are as mentioned previously. a and b are constants. Polynomial of the sixth degree of the form shown in equation (2) fitted best to the last part (V) of the observed mean weekly reference ET plot. Figures 2 to 6 show respectively the parts I, II, III, IV and V of the mean weekly reference ET plot along with the best fitting curve obtained. The equations fitted to the

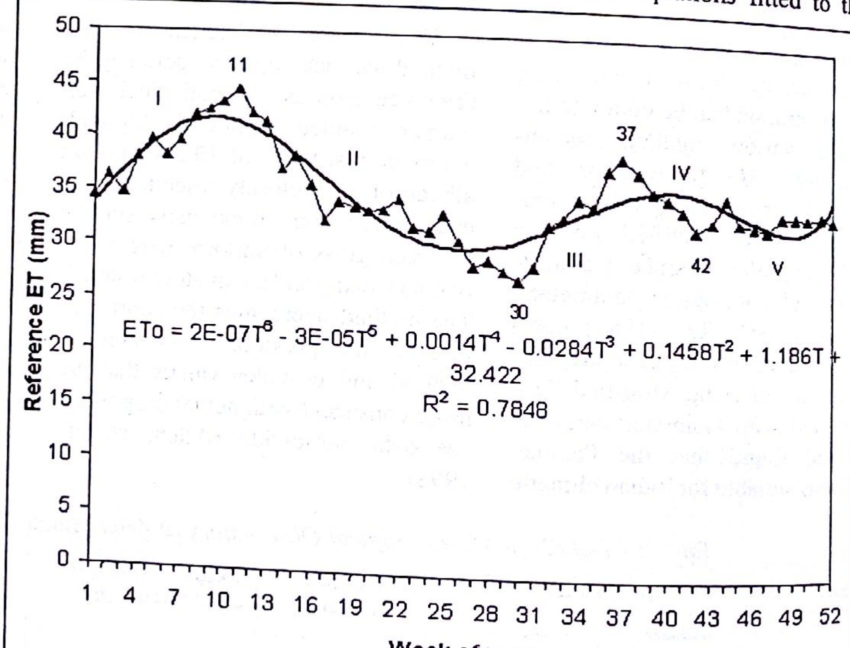


**Figure 1- Polynomial Fit to Mean Weekly Reference ET Plot**

*Table 2 – Trends Seen in the Variations of Mean Weekly Reference ET Plot*

| Part of mean weekly reference ET curve | Calendar weeks of the year | Period | Trend observed | Best fitting curve obtained |
|---|---|---|---|---|
| I | 1 - 11 | January 1 – March 18 | Increasing | Linear |
| II | 12 - 30 | March 19 – July 29 | Decreasing | Linear |
| III | 31 - 37 | July 30 – September 16 | Increasing | Linear |
| IV | 38 - 42 | September 17 – October 21 | Decreasing | Linear |
| V | 43 - 52 | October 22 – December 31 | Fluctuating with minor variations | Polynomial (sixth degree) |

*Table 3 – Equations Fitted to the Different Parts of the Observed Mean Weekly Reference ET Plo*

| Part of mean weekly reference ET curve | Best fitting equation | $R^2$ |
|---|---|---|
| I | $ET_o = 1.0019T + 33.36$ | 0.9301 |
| II | $ET_o = -0.6724T + 47.66$ | 0.8491 |
| III | $ET_o = 1.5139T - 17.03$ | 0.9234 |
| IV | $ET_o = -1.1909T + 82.80$ | 0.9686 |
| V | $ET_o = -0.00178472T^6 + 0.514175T^5 - 61670 1T^4 + 394153T^3 - 141580T^2 + 2709890T - 2.15923\times10^7$ | 0.9204 |

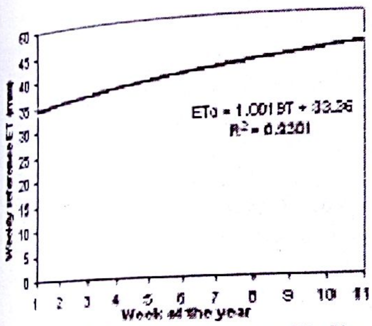


Figure 2 - Straight Line Fit to Mean Weekly Reference ET Plot (from the first 11 weeks of the year)

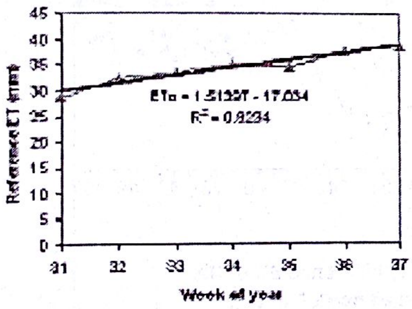


Figure 4 - Straight Line Fit to Mean Weekly Reference ET Plot (from the weeks 31 to 37 of the year)

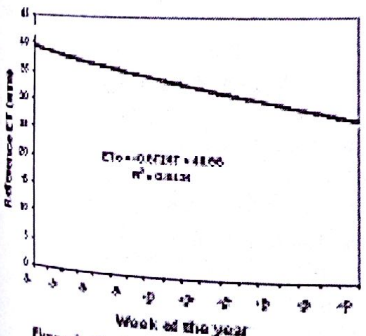


Figure 3 - Straight Line Fit to Mean Weekly Reference ET Plot (from the weeks 12 to 30 of the year)

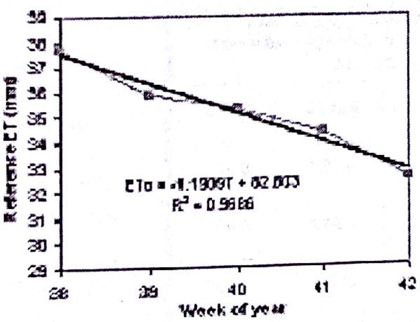


Figure 5 - Straight Line Fit to Mean Weekly Reference ET Plot (from the weeks 38 to 42 of the year)

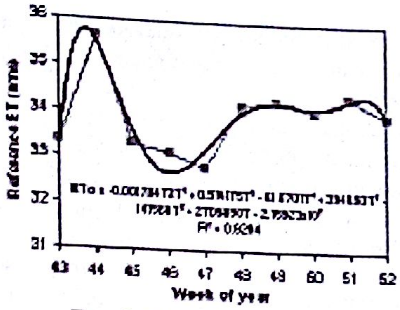


Figure 6 - Polynomial Fit to Mean Weekly Reference ET Plot (from the weeks 43 to 52 of the year)

different parts of the observed mean weekly reference ET plot are shown in Table 3.

To validate the equation fitted to each part of the observed mean weekly reference ET plot the closeness between the equations fitted to each part of the mean weekly reference ET plot and the observed weekly reference ET in the corresponding part for years 2001 to 2004 were studied individually. This was done by comparing the one-to-one correspondence between the mean weekly reference ET values generated using the fitted equations and the observed mean weekly reference ET during the corresponding periods of the virgin years 2001 to 2004 (virgin years means years not considered in obtaining the mean weekly reference ET curve), in terms of the correlation coefficient.

Figure 7 show the closeness of computed weekly reference ET for different weeks of the year with the observed weekly reference ET for different weeks of the test years 2001 to 2004.

Table 4 shows the validation of the equations fitted to the different parts of the mean weekly reference ET plot.

## Summary and Conclusion

In general, in any year the weekly reference ET at Arba Minch tended to increase from the beginning of January till mid-March. Then, it tends to decrease with slight fluctuations till the end of July. After July, the weekly reference ET tended to increase reaching a high in mid-September. Then, again there is a decline in the reference ET that is felt till the end of October. During the last two months (November and December) of any year, there is no specific trend in the weekly reference ET and the values tend to fluctuate in a narrow range.

The maximum weekly reference ET is generally observed in mid-March and the minimum weekly reference ET falls in the end of July or early August.

The equations fitted to different parts of the observed mean weekly reference ET plot can be used for developing operational strategies for effective management of water resources systems catering to irrigation requirements of the command areas in the climatologically similar locations.

Year Closeness between fitted equation to different parts of mean weekly reference ET plot and the corresponding observed weekly reference ET measured as correlation coefficient

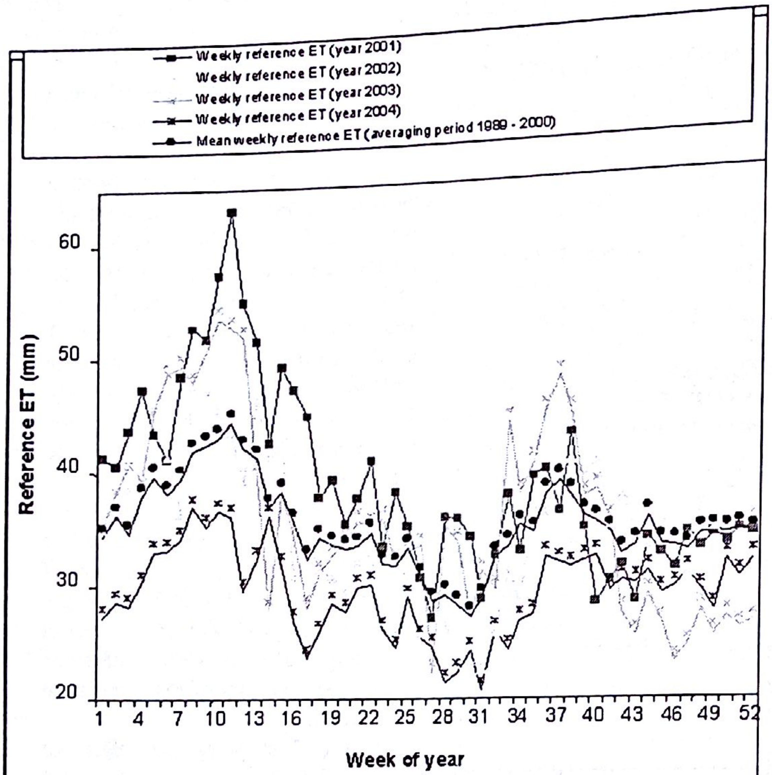


**Figure 7 - Closeness of mean weekly reference ET of the year with the observed weekly reference ET of test years**

*Table 4 – Validation of Equations Fitted to Different Parts of the Mean Weekly Reference ET*

| Year | Closeness between fitted equation to different parts of mean weekly reference ET plot and the corresponding observed weekly reference ET measured as correlation coefficient | | | | |
|---|---|---|---|---|---|
| | Part I | Part II | Part III | Part IV | Part V |
| 2001 | 0.950 | 0.869 | 0.943 | 0.989 | 0.941 |
| 2002 | 0.910 | 0.829 | 0.903 | 0.948 | 0.900 |
| 2003 | 0.849 | 0.768 | 0.842 | 0.887 | 0.839 |
| 2004 | 0.885 | 0.804 | 0.878 | 0.923 | 0.875 |

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# Adsorption Studies on Waste Water Generated from Arbaminch Cafeteria

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**Abstract**

**Activated carbon adsorption is one of the techniques in waste water treatment using which the stringent discharge quality standards can be made. Investigations have been undertaken to determine the feasibility of commercially available activated carbon. Parameters such as carbon dosage, optimization of time, pH were studied with regard to reduction of BOD and COD. Studies on adsorption isotherms were carried out using Langmuir, Freundlich and BET methods and data obtained during the adsorption test was interpreted to describe the performance of the carbon. The effect of ions such as $Cl^-$, $SO_4^{2-}$, $CO_3^{2-}$ and $HCO_3^-$ on the adsorption isotherms were studied. The presence of these ions in the waste water did not affect considerably the adsorption of pollutants on activated carbon.**

## Introduction

Adsorption is defined as the taking up of molecules by the external or internal surface of solids by the surface of liquids. Adsorption occurs on these surfaces because of attractive forces of the atoms and molecules that make up the surfaces. When impurities are adsorbed from a liquid onto a surface, the adsorption process occurs at the solid-liquid interface and the reactions occurring at the interface determine the rate and extent of adsorption.

There are many applications of adsorption in both industrial and pollution control processes and many solid adsorbents, including activated alumina, silica gel and activated carbon are used. Among these, the use of activated carbon to adsorb materials from liquid has attracted significance in water and waste water treatment.

## Production of activated carbon

Activated carbon has a great capacity for the adsorption of organic molecules. It is produced by exposing selected carbonaceous materials to a series of treatment processes referred to as dehydration, carbonization and activation. These processes burn away impurities in the raw materials and leave a highly porous residue that has an extremely large surface area per unit volume. Since adsorption is a surface phenomenon, the large surface/volume ratio of activated carbon is its primary attribute as an adsorbent.

Activated carbon has been produced from many different carbonaceous materials, including coal, wood, coconut shells and peat. The first step in production, dehydration is accomplished by heating the materials at temperatures up to 170°C to remove excess water. In some cases, Zinc chloride or Phosphoric acid may be used in addition to heat as a dehydrating agent. Following dehydration, heating is continued, usually in the absence of air, at temperatures up to 400-600°C.This treatment, known as carbonization, causes decomposition of the material and drives off impurities such as tars and methanol. The escape of these volatile substances causes pores to form within the material and leaves a product usually referred to as a char. Although surface area is opened up during carbonization, char possesses relatively little adsorptive power due to the presence of amorphous residues (tars), which block their pores. These residues are removed and the pores are cleaned and enlarged by the process of activation, which is the final step in activated carbon production. Activation is normally achieved by treating the carbon product with mixtures of $CO_2$, air and stream at temperatures of 750-950°C so as to burn off the amorphous residues.

Pore spaces within the carbon are well developed following activation and can be classified according to size as macro pores, transitional pores and micro pores. According to Dubinin et al. (1964), macro pores has an effective radius of 5000 to 20000A° and open directly to the outer surface of the carbon particle. Transitional pores with radii of 40 to 200A° develop off the macro pores. Micro pores develop off the transitional pores and have an effective radii if 18 to 20A° or less.

## Factors affecting Adsorption

Molecules of solute are removed from solution and taken up by the adsorbent during the process of adsorption. The majority of the molecules are adsorbed onto the large surface area within the pores of a carbon particle and relatively few are adsorbed on the outer surface of the particle. The transfer of solute from solution to adsorbent continues until the concentration of solute remaining in solution is in equilibrium with the concentration of solute adsorbed by the adsorbent. When equilibrium is reached, the transfer of solute stops and the distribution of solute between the liquid and solid phases is measured and well defined.

The equilibrium distribution of solute between the liquid and solid phases is an important property of adsorption systems and helps define the capacity of a particular system. The kinetics of the system has attained utmost importance in waste water treatment systems which describe the rate at which this equilibrium is reached. The rate of adsorption determines the detention time required for treatment and thus the size of carbon contacting systems.

Process kinetics describe the rate at which molecules are transferred from solution to the pores of the carbon particle. Three distinct steps must take place for adsorption to occur.

1. The adsorbed molecule must be transferred from the bulk phase of the solution to the surface of the adsorbent particle. In doing so, it must pass through a film of solvent that surrounds the adsorbent particle. This process is referred to as film diffusion.

2. The adsorbate molecule must be transferred to an adsorption site on the inside of the pore. This process is referred to as pore diffusion.

3. The particle must become attached to the surface of the solute, i.e., be adsorbed.

Many factors influence the rate at which adsorption reactions occur and the extent to which a particular material can be adsorbed. The important ones are

1. Agitation
2. Characteristics of the adsorbent (Activated carbon)
3. Solubility of the adsorbate
4. Size of the adsorbate molecules
5. pH
6. Temperature

The rate of adsorption is controlled by either film diffusion or pore diffusion, depending on the amount of agitation in the system. If relatively little agitation occurs between the carbon particle and the fluid, the surface film of liquid around the particle will be thick and film diffusion will be likely the rate limiting step. If adequate mixing is provided, the rate of film diffusion will increase to the point that pore diffusion becomes the rate limiting step. According to Weber (1972), pore diffusion is generally rate limiting for batch type contacting systems which provide a high degree of agitation.

Research studies have shown that within a homologous series of organic compounds, adsorption usually increases as the size of the molecule becomes greater (Hassler, 1974).This can be partly explained by the fact that the forces of attraction between a carbon and a molecule are greater the closer the size of the molecule is to the size of the pores in the carbon (Culp and Culp, 1971)

A comprehensive review of the literature reveals that in the past, the adsorption process has not been used extensively in waste water treatment, but demands for a better quality of treated waste water have led to an intensive examination and use of the process of adsorption on activated carbon. Activated carbon treatment of waste water is usually thought of as a polishing process for water that has already received normal biological treatment. The carbon in the present study is used to remove a portion of the dissolved organic matter. Depending on the means of contacting the carbon with the water, the particulate matter that is present may also be removed.

## Experimental Procedure

The sample of waste water was collected from Arba Minch cafeteria thrice in a month and analyzed for their contents. The TS, TDS, TSS, BOD, COD and TOC were determined. An adsorption study was set up in the laboratory by adding a known amount of activated carbon to six flasks which contained 200 ml of the waste water. The weight of carbon added is in varying quantity from 200mg to 2g and the flasks were agitated for 2 hours. An additional flask containing 200ml of wastewater but no carbon was run as a blank.

## Optimization of Carbon Dosage:-

The activated carbon taken in varying quantities in the range of 0.2g, 0.4g, 0.6g, 0.8g, 1.0g, 1.2g, 1.4g, 1.6g, 1.8g, 2.0g, 2.2g, 2.4g, in each of the flasks and it is kept in the shaker for 5 hours. Later it was filtered and the filtrate was analyzed for BOD and COD. The data was given in table 1 and represented in fig.1. From the graph the optimum dosage of carbon was determined and found to be 1g.

*Table-1 Optimization of Carbon Dosage*

| Carbon dosage in gms | % Adsorption |
|---|---|
| 0.170 | 67.0 |
| 0.265 | 79.5 |
| 0.398 | 87.5 |
| 0.548 | 92.0 |
| 0.740 | 94.8 |
| 0.965 | 96.5 |
| 1.0 | 96.5 |
| 1.2 | 96.3 |
| 1.4 | 96.2 |
| 1.6 | 96.2 |

*Table-2 Optimization of pH*

| pH | % Adsorption |
|---|---|
| 3 | 95.3 |
| 4 | 96.4 |
| 5 | 96.8 |
| 6 | 96.9 |
| 7 | 96.8 |
| 8 | 96.5 |
| 9 | 96.5 |
| 10 | 96.4 |

*Table-3 Optimization of Time*

| Time in hour's | % Adsorption |
|---|---|
| 0.5 | 88.4 |
| 1.0 | 90.2 |
| 1.5 | 92.6 |
| 2.0 | 93.4 |
| 3.0 | 96.0 |
| 3.5 | 96.8 |
| 4.0 | 96.9 |
| 5.0 | 97.0 |
| 5.5 | 96.8 |

## Optimization of pH

The sample was taken a beaker along with an optimum dosage of 1.0g activated carbon. The content was kept in the mechanical shaker for 4 hours during which the pH was adjusted to 3.0.Then the filtrate was analyzed. The procedure was repeated for various pH values of the sample. In this study, the adsorption that is COD reduction was found to be maximum at pH 6.0 as shown in table 2 and represented in fig 2.

## Optimization of Time:-

The percentage of COD reduction by activated carbon was found to vary with time. COD reduction was studied with 1.0 g of carbon contained in different conical flasks. The content was stirred in the mechanical shaker to attain adsorption equilibrium and the filtrate was analyzed. The result are depicted in table 3 and represented in fig 3. It was observed the maximum removal COD required 4 hours of effective shaking.

*Table 4. Adsorption data for Langmuir isotherm*

| Flask No | Wt. of carbon (mg) (m) | Volume of sample (ml) | COD (mg/l) (C) | Wt. of Adsorbate (mg) | x/m (mg/mg) |
|---|---|---|---|---|---|
| 1 | 804 | 200 | 4.70 | 49.06 | 0.061 |
| 2 | 668 | 200 | 7.0 | 48.6 | 0.073 |
| 3 | 512 | 200 | 9.31 | 48.1 | 0.094 |
| 4 | 393 | 200 | 16.6 | 46.7 | 0.118 |
| 5 | 313 | 200 | 32.5 | 43.5 | 0.139 |
| 6 | 238 | 200 | 62.8 | 37.4 | 0.157 |
| 7 | 0 | 200 | 250 | 0 | 0 |

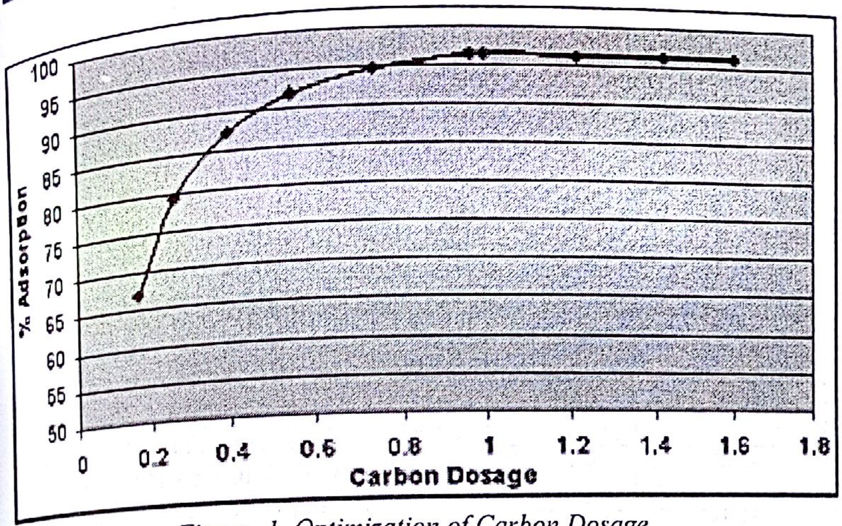


*Figure- 1. Optimization of Carbon Dosage*

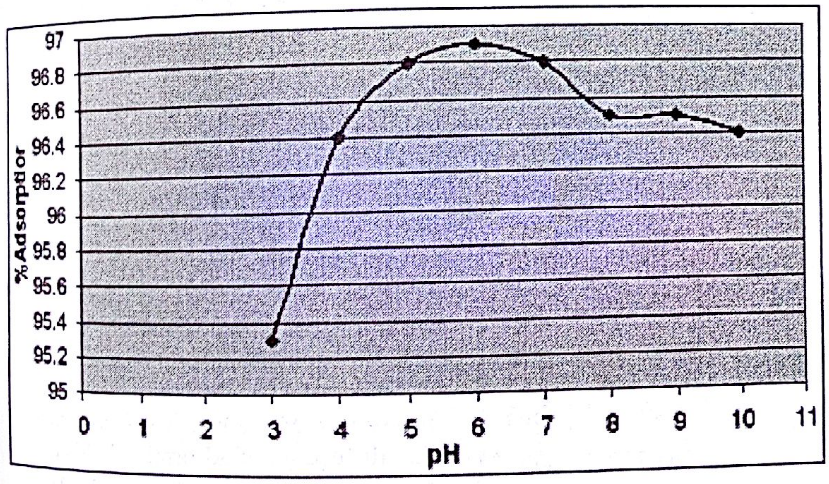


*Figure-2 Optimization of pH*

Adsorption treatment was analyzed as per the standard procedure (APHA,1985). The chemicals used were of analytical grade throughout the present study.

## Results and Discussion

The sample of wastewater collected from the Arba Minch cafeteria contained a high amount of suspended solids and it was observed that the BOD and COD of the wastewater were found to be 100 and 200 mg/l respectively indicating a high pollution load which needs to be treated before being discharged. Table 2 indicates the reduction of BOD and COD after activated carbon treatment. The COD removal was about 3.5mg/l indicating about 97% The adsorption data obtained in table 4 were plotted according to Langmuir equation. A straight line was obtained

The pH at which adsorptions is carried out has been shown to have a strong influence on the extent of adsorption. This is partly due to the fact that hydrogen ions themselves are strongly adsorbed and partly that pH influences the ionization, and thus the adsorption of many organic compounds. Organic acids are more adsorbable at low pH, where as the adsorption of organic bases is favored by high pH.

In the present study, the optimum pH for maximum adsorption was determined by laboratory testing.

## Application of Adsorption Isotherms.

Adsorption isotherm tests is one of the most important tests in selecting a particular type of carbon for a water, waste water and industrial treatment systems. Several mathematical relationships have been developed to describe the equilibrium distribution of solute between the solid and the liquid phases and thus aid in the interpretation of adsorption data. These relationships apply when the adsorption tests are conducted at constant temperature and are referred to as adsorption isotherms. Three of the most common are the Langmuir isotherm, the Freundlich isotherms, and the Brauner Emmett-Teller (BET) isotherm.

Langmuir's isotherm is based on the assumption that points of valency exist on the surface of the adsorbent and that each of these sites is capable of adsorbing one molecule. Thus, the adsorbed layer will be one molecule thick. Furthermore, it is assumed that all the adsorption sites have equal affinities for molecules of the adsorbate and that the presence of adsorbed molecules at one site will not affect the adsorption of molecules at an adjacent site. The Longmuir equation (Langmuir ,1918) is written as

Where x = amount of material adsorbed (mg or g)

m = weight of adsorbent (mg or g)

C = concentration of material remaining in solution after adsorption is complete (mg/l)

a and b = constants.

Taking the reciprocal of both sides,

$$\frac{1}{\left(x/m\right)} = \frac{1+ac}{abc}$$

or

$$\frac{1}{\left(\frac{x}{m}\right)} = \frac{1}{b} + \frac{1}{abc}$$

In the present study, the data obtained in table 4 are plotted according to the Langmuir equation. When $\frac{1}{\left(\frac{x}{m}\right)}$ was plotted against $\frac{1}{c}$ as shown in fig 4. A linear trace was obtained and the constants were determined from the slope and the intercept of the plot. The values of the contents a and b are determined as per the Langmuir equation and found to be 0.102 and 0.189 respectively.

## Freundlich Isotherm

Freundlich (1926) developed an empirical equation to describe the adsorption process. His adsorption isotherm is usually used to quantify the equilibrium relationship between the amount of impurity adsorbed on the carbon and the impurity concentration remaining in the solution. His development was based on the assumption that the adsorbent had a heterogeneous surface composed of different classes of adsorption sites, with adsorption on each class of site following the Langmuir isotherm. Freundlich equation is written as

$$\frac{x}{m} = KC^{1/n}$$

where x = amount of solute adsorbed (mg, g)

m = weight of adsorbent (mg, g)

C = concentration of solute remaining in solution after adsorption is complete (mg/l)

K and n = constants that must be evaluated for each solute and temperature.

Freundlich equation can be modified as

$$\log\left(\frac{x}{m}\right) = \log K + \frac{1}{n}\log C$$

The adsorption data obtained in table 5 was used to plot $\log \frac{x}{m}$ vs log C in which a straight line was obtained as shown in figure 5. The intercept gave the value of K and n is determined from the slope. The K and n are found to be 0.023 and 1.607 respectively.

*Table-5 Adsorption data for Freundlich isotherm*

| Flask No. | Wt. of carbon (mg) (m) | Volume in flask (ml) | Final COD mg/l | Wt. of Adsorbate adsorbed (mg) | x/m (mg/mg) |
|---|---|---|---|---|---|
| 1 | 965 | 500 | 3.5 | 48.25 | 0.05 |
| 2 | 740 | 500 | 5.2 | 47.40 | 0.064 |
| 3 | 548 | 500 | 8.0 | 46.0 | 0.084 |
| 4 | 398 | 500 | 12.5 | 43.75 | 0.11 |
| 5 | 265 | 500 | 20.5 | 39.75 | 0.15 |
| 6 | 168 | 500 | 33 | 33.5 | 0.20 |
| 7 | 0 | 500 | 100 | 0 | 0 |

*Table-6 Adsorption data for BET isotherm*

| Flask No. | Wt. of carbon (mg) (m) | Final COD (mg/l) (C) | $x/m$ (mg/mg) | (Cs-C) | $\frac{C}{(C_s - C)x/m}$ | $\frac{C}{C_s}$ |
|---|---|---|---|---|---|---|
| 1 | 804 | 4.70 | 0.061 | 245.3 | 0.314 | 0.0188 |
| 2 | 668 | 7.0 | 0.073 | 243 | 0.395 | 0.028 |
| 3 | 512 | 9.31 | 0.094 | 240.7 | 0.412 | 0.037 |
| 4 | 393 | 16.6 | 0.118 | 233.4 | 0.603 | 0.066 |
| 5 | 313 | 32.5 | 0.139 | 217.5 | 1.075 | 0.13 |
| 6 | 238 | 62.8 | 0.157 | 187.2 | 2.136 | 0.251 |
| 7 | 0 | 250 | 0 | 250 | .. | .. |

## BET Isotherm

Brauner, Emmett and Teller (1938) derived an adsorption isotherm based on the assumption that molecules could be adsorbed more than one layer thick on the surface of the adsorbent. Their equation, like the Langmuir equation assumes that the adsorbent surface is composed of uniform, localized sites and that adsorption at one site does not affect adsorption at neighboring sites. Moreover, it was assumed that the energy of adsorption holds the first monolayer but that the condensation energy of the adsorbate is responsible for adsorption of successive layers. The equation, known as the BET equation can be written as

$$\frac{x}{m} = \frac{ACxm}{(Cs - C)\left[1 + (A-1)\frac{C}{Cs}\right]}$$

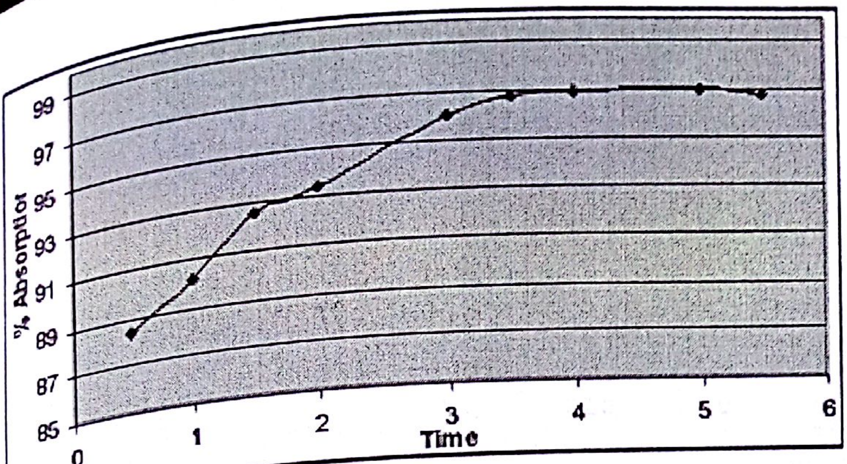


*Figure. 3 Optimization of Time*

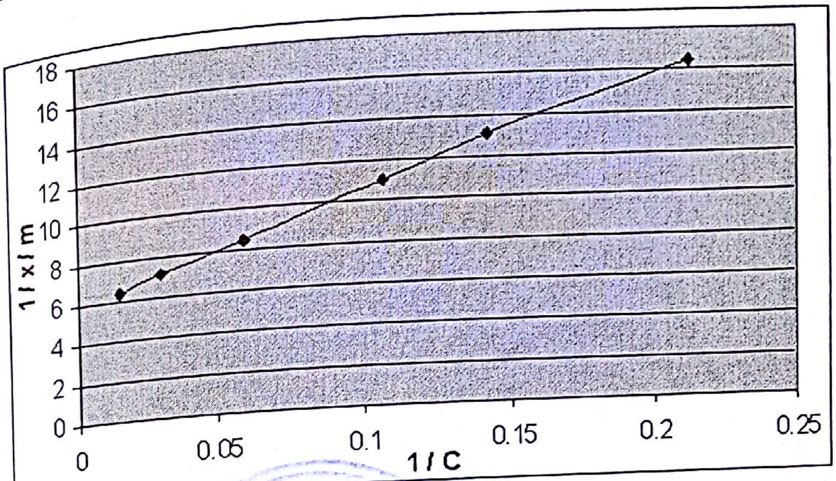


*Figure 4 Langmiur Plot*

$$-\frac{C}{(Cs-C)\frac{x}{m}}$$

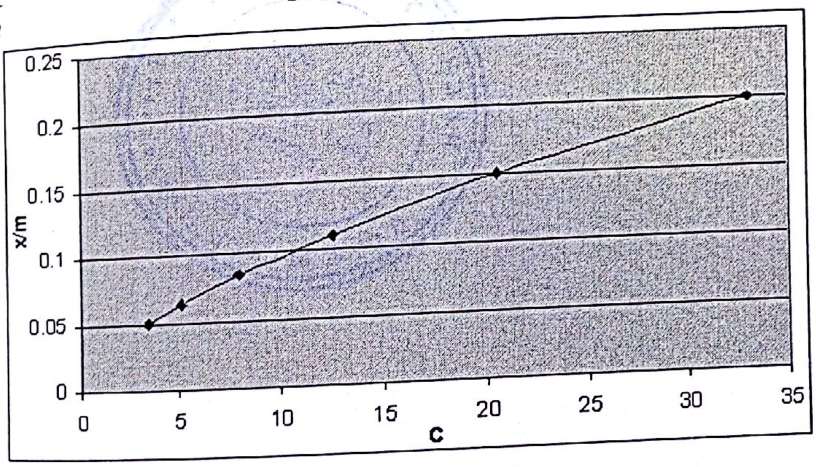


*Figure 5 Freundlich Plot*

When $x$ = amount of solute adsorbed (mg, moles)

$m$ = weight of adsorbent (mg, g)

$xm$ = amount of solute adsorbed in forming a complete monolayer (mg/g, moles/mg)

$Cs$ = saturation concentration of solute (mg/l, moles/l)

$C$ = concentration of solute in solution at equilibrium (mg/l, moles/l)

$A$ = a constant to describe the energy of interaction between the solute and the adsorbent surface.

Rearranging the BET equation yields

$$\frac{C}{(Cs-C)\frac{x}{m}} = \frac{1}{A(xm)} + \frac{A-1}{Axm}$$

The adsorption data obtained in the present studies as shown in table 6 that conform to the BET equation was used to plot again $\frac{C}{Cs}$. A straight line was obtained as represented in figure 6 in which the intercept gave the value of $\frac{1}{Axm}$ and the slope gave $\frac{(A-1)}{Axm}$.

The value of A and xm were calculated to be 2.119 and 2.62 respectively.

All three of the above equations have been successfully used to analyze adsorption data in the present investigation. In general, the Langmuir and BET equation do not apply as well as the Freundlich equation to mixed solutes or to dilute solution. Thus, the Freundich equation finds wide application in environmental engineering.

## Conclusion

1.The present study confirm that the presence of ions such as $Cl^-$, $SO_4^{2-}$, $CO_3^{2-}$, and $HCO_3^-$ in the waste water has no considerable effect on the adsorption of pollutants by the activated carbon.

2. The experimental data obtained for the system obey the well known Freunlich adsorption isotherm.

3. The optimum carbon dosage, pH and time were determined to be 1.0 g, 6.0 and 4 hours respectively

4. Under normal conditions, after treatment with activated carbon, the waste water COD reduced to 3.5 mg/l.

## Recommendations

Integrating this process into existing activated sludge systems at nominal capital cost Reduction of refractory priority pollutants,Colour and ammonia removal

Improved sludge settleability

When nitrification is inhibited by toxic organics, application of AC may reduce or limit this inhibition

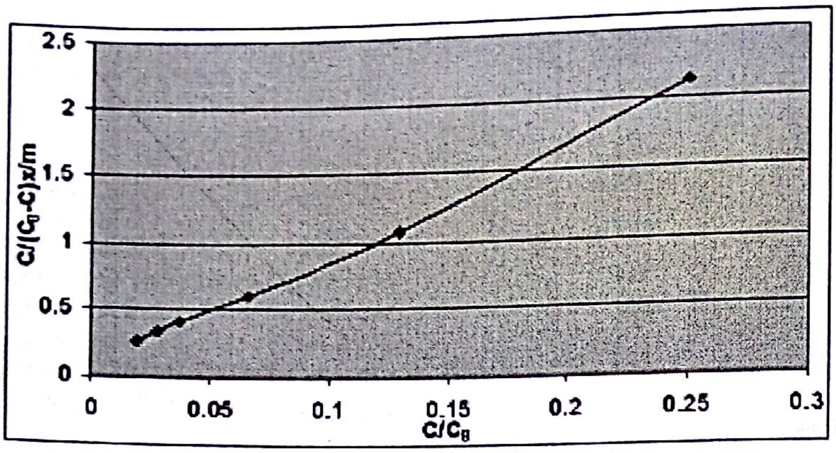


*Figure 6 BET Plot*

Additional biodegradation due to decreased toxicity

Degradation of normally nondegradable substances due to increases exposure time to the biomass through adsorption on the carbon

Replacement of low molecular weight compounds with high molecular weight compounds in improved adsorption efficiency and lower toxicity

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