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Arba Minch University

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contents

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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.

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Manuscripts in water science and technology are considered for publication. Manuscripts must be in English. Scientific and research papers, review papers, technical notes, short reports, letters to the editors are well accepted in **water.** Papers already published, or in press elsewhere, will not be accepted. The total length of a manuscript including figures tables and references should not exceed 7000 word equivalents (10 pages). The original and three copies should be submitted.
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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.
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-Kalb, J.E. (1978). Miocene to Pleistocene deposits in the Afar depression, Ethiopia. water.- *Ethio ,p.* J. *Sci.* 1:87-98.
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Tables, however small, should bear arabic numerals and be referred to in the text by their numbers, e.g. 'Table 4'. Each table must be typed on a separate sheet and should be placed at the end of the manuscript.
All illustrations should be given separately, not stuck on pages and not folded. They should be numbered as figures in sequence with arabic numerals. Each figure should have a descriptive legend. Black and white photographs can be submitted to **water**; they should be clearly numbered on the back in pencil.

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water will be distributed free of charge.
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.

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Dear Readers:

Water is among the vital natural resources that are essential for human survival and economic development. Utilization of this resource without considering the issue of sustainability is becoming unendurable.

Arba Minch Water Technology Institute, now Arba Minch University has been organizing annual symposium on "Sustainable Water Resources Development" since 9 years. This proceeding contains 21 selected papers that have been presented in the 8th cycle of the symposium that was held on October 4-5, 2004.

The papers fall under the broad categories of hydrology and water resources, irrigation, water quality, hydropower and reservoirs, watershed management and agro-meteorology. Hence issues related to sustainable water resources development are directly addressed by the papers.

It is our utmost believe that this proceeding containing the results and recommendations given to the respective problem areas is a valuable reference for professionals in the water fields.

Finally the editorial board thanks all authors for their contributions and GTZ for sponsoring the symposium and providing fund for publication.

Dr. Mekonen Ayana
Editor-in-Chief

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Welcoming Address For the 8th Symposium on

" Sustainable Water Resources Development,"

October 4-5/ 2004

Arbaminch

Distinguished Guest
Dear Participants
Ladies and Gentleman

By Dr. Mekonen Ayana

At the outset, on behalf of organizing committee and my self, let me take this opportunity to warmly welcome all participants to the 8th –Symposium on Sustainable Water Resources Development.

Arba Minch Water Technology Institute has organized these types of symposium for the last consecutive 7 years. The symposium in this year marks the 8th cycle, which takes place right after the transformation of Arba Minch Water Technology Institute to Arba Minch University.

Admittedly, the research findings presented here and the experiences that have been shared through discussions as well as the proceedings of the last symposia have contributed a lot in stimulating research in the field of water resources development.

The effort of enhancing productivity, sustainability and poverty alleviation in this country makes the need for applied research even more pressing.

Seeking for economical and technological development, this country is investing huge amount of money in research and development activities. This is an opportunity for strengthening and developing the research capacity needed to find solutions to problems that affect social and economic development.

Dear Participants,

Water is not only vital for human survival but also the foundation for sustainable socio-economic development and a health environment. Sustainable socio-economic development therefore demands sustainable management of water.

Sustainable development of water resources refers to "a holistic approach to development, conservation, and management of water resources, an approach that considers all components of the hydrologic cycle".

It is inherently intergenerational because it implies that we must use the water resources in ways that are compatible with maintaining them for future generations.

Water resources cannot be managed, however, unless we know where they are, in what quantity and quality, and how variable they are. This requires a continuous assessments and monitoring on which most of the papers in this symposium will focus.

Dear Participants,

Out of 36 papers submitted to the organizing committee 23 papers have been selected for presentation in this symposium. The papers are broadly categorized under

Hydrology and Water Resources.................4 Papers
Irrigation and Drainage..........................3 Papers
Water Quality.......................................3 Papers
Hydropower, Dams & Reservoirs...............4 Papers
Watershed Management & Environment........5 Papers
Agro-Meteorology.................................4 Papers

Once again on behalf of organising committee, I would like to thank all researchers who have responded to our call by submitting their research papers on time and have appeared personally to present their papers.

I also would like to commend the Arba Minch University to host this event and express my sincere thanks to GTZ for sponsoring the symposium.

Now, I would like at this stage to request Ato Zenebe Zewdie the Academic and Research Vice President of the University to give you're opening speech and thereby formally open the 8th symposium on Sustainable Water Resources Development.

I thank you all for your attention and wish you comfortable stay and fruitful discussions during the symposium.

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Opening Address For the 8th Symposium on " Sustainable Water Resources Development," October 4-5/ 2004 Arbaminch

By Ato Zenebe Zewdie

Distinguished guests Dear colleagues
Ladies and gentlemen,

On behalf of Arba Minch University I would like to welcome you all once again to this symposium. I feel honored for being invited to deliver an Opening speech to this 8th symposium on Sustainable water resources development.

Ladies and gentlemen:

The issue of water has long been and continues to be on top of the agenda. Indeed addressing sustainable water resources development entails the involvement of multifarious disciplines and encompasses numerous objectives. I am proud to see this symposium being conducted at the dawn of the university's establishment with inclusion of a number of faculties and a school of postgraduate studies. Thus there is a great opportunity for the water technology institute to diversify and intensify the quality of its engagement. This symposium provides an essential forum in which a multitude of issues on water resources are analyzed, discussed, and shared among professionals to yield a common vision and new directions of thought which would ultimately contribute to the nation's effort to develop and manage its water resources sustainable. The themes to be covered in the symposium are expected to include, among other things, Hydrology and water resources, Irrigation and drainage, water quality, Hydropower, dams and reservoirs, watershed management and environment and agro- meteorology. It will include studies on water resources (both surface and ground water) in its whole domain, its occurrence qualitatively and quantitatively in its natural boundaries and a number of cross cutting issues.

I would like to stress that if any of the research in this country is not entwined with the problems of the nation, it is not qualified to contribute to its development. Not less importantly, a research out put that does not reach to the end users to whom it is targeted is a mere waste of endeavors. I hope the deliberations during the two day symposium will be lively, interactive and successful both in the exchange of information and experience valuable for all the participants and will have a practical significance to the country's development efforts and to the scientific community in general.

Dear ladies and gentle men,

The university is more willing than ever to continually organize interdisciplinary and interactive platforms of such type. We are committed to strengthen collaboration with each of your institutions; initiate joint research and share your wealth of experiences.

May I take this opportunity to convey my thanks to those involved in the organization and conduct of the symposium without whom our gathering would be unthinkable?

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

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Identification and Delineation of Hydrological Homogeneous Regions The Case of Blue Nile River Basin

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Abstract

Blue Nile River Basin has been regionalized into similar flood producing characteristics based on statistical values of at site data. The basin was delineated in to five homogeneous regions. Accordingly, region one comprises the widest portion of the basin, covering 37.6 % of the area. It includes the upper Guder catchment, middle and lower Didesa, lower part of the main Abbay basin and Dinder catchment. Region two covers Beles, Gilgel Abbay, Fincha and lower Guder sub catchment. Region three includes upper Didesa, Anger, and upper part of main Abbay (Blue Nile Falls). Region four, which is the smallest portion of the basin area, about 3.3 %, embraces southern part of Gojam high lands, extreme upper course of Gilgel Abbay and Bir-Temcha catchment. This basin is typically characterized by hilly and mountainous topography. Region five incorporates Gumera, Rib, Beshlo, Jema, Dabus and Muger catchments. Except one station (on Idris River) in region three, all regions have shown satisfactory results for homogeneity tests. For the developed five regions the most likely fit candidate distributions have been also selected. Accordingly, for region one Generalized Logistic & Log Normal distribution; for region two Gamma, Pearson III & Log Pearson III distributions; for region three, Log Normal distribution; for region four and region five, Generalized Logistic and Generalized Extreme Value were preferred as a candidate distributions.

1. Introduction

1.1. Background

Regionalization refers to grouping of basins into homogeneous regions. In other words, regionalization means identification of homogeneous regions, which contain stations of similar flood producing characteristics. Several studies have shown that, delineation of regions in the past has often relied on physiographic, political or administrative boundaries (Getachew, 1996). The resulting regions were assumed to be homogenous in terms of hydrologic response. This assumption actually is not true as it may have very different relief and stations within the same geographical region, which have high correlation that will cause some bias in the regionalization (Wiltshire, 1985; Cunnane, 1989, Roa & Hamed, 2000). The importance of homogeneity has been demonstrated by Hosking et al (1985), Wiltshire (1986). Homogeneity implies that regions have similar flood generating mechanisms. 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 for estimation of flood magnitude for water resource project planning and design.

1.2. Description of Study Area

The Blue Nile (Abbay) River Basin, from now on wards called BNRB, lies in the western part of Ethiopia, between 7° 45' and 12° 45'N, and 34° 05' and 39°45'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)

In this study 78 stations were considered for the analysis. The distribution of the stations within the basin is high at the central, northern & southern part of the basin. Where as, the north-west part of the basin does not have sufficient stations. Generally, the distri-

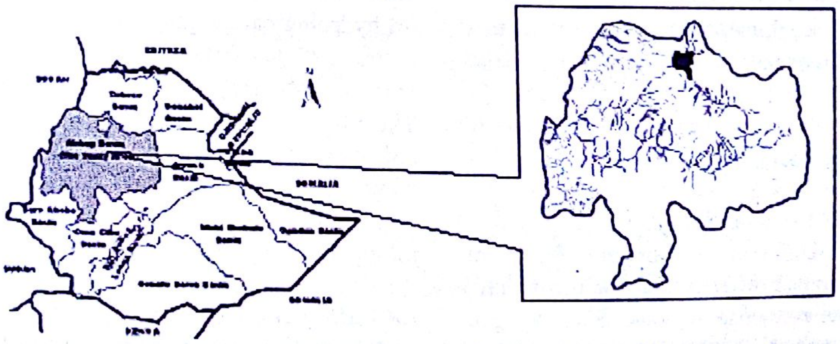

Fig 1.1: Map of the Ethiopian's River Basins with the study basin

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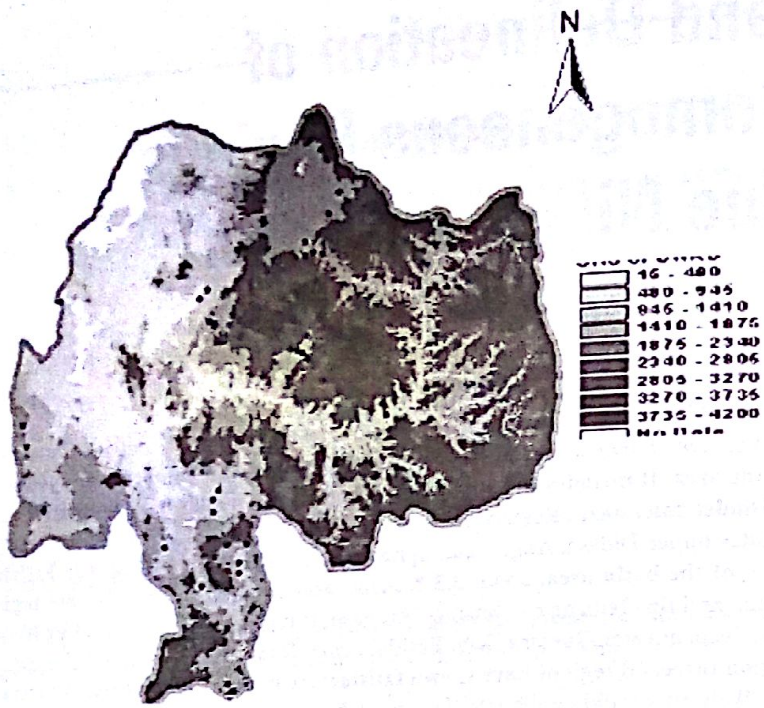

Fig 1.2: The distribution of hydrological gauging stations within Abbay basin

butions of the gauging stations used in this study have shown in Figure 1.2.

2. Methodology

1.1 Methodology and procedure

The method used for regionalization is Index flood method which comprises the observed flow data at the region were pooled to provide a more precise estimate of standardized statistical parameters in the regionalization procedure. Generally the study involves the following procedures:

Collection of hydrological and meteorological data, topographical map and digitized map of the basin.

Checking of data for consistency and independence

Computation of statistical parameters of selected stations within the basin.

Regionalization of the basin in to homogeneous regions based on statistical values using GIS – Arc View.

To carry out homogeneity tests for the established regions

1.2 Previous Study

Different researchers have attempted different approach to identify homogeneous regions. Such as geographical region/space (The Flood Study Report NERC, 1975, Matalas et.al, 1975); Catchment characteristics (Wiltshire, 1985); Climatic characteristics (Pearson, 1991b). For BNRB, Admassu (1989) conducted a comprehensive investigation related to flood frequency analysis. On this paper regionalization of homogeneous regions was made on the basis of monthly rainfall pattern and geographical proximity. This may not be guaranteed as they may have different statistical response within the same rain fall pattern of the identified regions.

1.3 Source and Availability of Data

For the purpose of this study, various data have been collected from different agencies, which include time series data, topographical data and digitized map of the study area. From time series data, peak series flow data is the most important one for this study. From 78 hydrological gauging stations in average of 25 years of data were collected from the Ministry of Water Resource. The digitized maps of the basin were collected from MoWR GIS Department. The topographical map with scale of 1:250,000 were gathered from Ethiopian Mapping Authority.

1.4 Filling and Extension of Data

Regression analysis was used to fill the missing monthly data and to extend those short lengths recorded data with satisfactory correlation coefficient of minimum 6.2 and maximum 0.997. The correlation was done based on neighboring station and geographical proximity

1.5 Consistency of Data

Double mass curve analysis was used to check the consistency of data. The selection of the station depends on the geographical location of the stations i.e. its neighboring stations were used to check the reliability of that station data and correction were made accordingly. In this study to minimize the effect of outliers, L-Moment and Probability Weighted Moment statistical computation methods have been used.

3. Regionalization of Blue Nile River Basin

1.1 Flood Statistics of Blue Nile River Basin

Flood statistics of Blue Nile River basin stations were computed using both conventional moment and L-moment methods. However, L-Moment method is a powerful and efficient method to compute any statistical parameters, because such methods can give unbiased estimate of sample parameters and also cannot be easily influenced with the presence of outliers. (Roa & Hamed, 2000)

Generally, the statistical parameters computed include:

Mean $\left(\overline{Q}, \ell_1\right)$

Standard deviation (σ)

Coefficient of variation (C_v, LC_v)

Coefficient of skew ness (C_s, LC_s)

Coefficient of kurtosis (C_k, LC_k)

Conventional Moment

Moments about the origin or about the mean are used to characterize probability distributions. Moments about the origin are the expected values of powers of a random variable. For a distribution with a probability density function f(x), the r^{th} moment about the origin is given by

$$\mu'_r = \int_{-\infty}^{\infty} x^r f(x)\, dx , \qquad \mu'_1 = \mu = mean \quad (1)$$

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The central moments

$$\mu_r = \int_{-\infty}^{\infty}(x-\mu'_1)^r f(x)dx, \qquad \mu_1 = 0 \; \ldots\ldots$$

(2)

Sample moments m'_r & m_r

$$m'_r = \frac{1}{N}\sum_{i=1}^{N} X_i^r, \qquad m'_r = \bar{X} = Samplemean$$

....

(3)

$$m_r = \frac{1}{N}\sum_{i=1}^{N} (X_i - \bar{X})^r, \qquad m_1 = 0$$

....

(4)

These sample moments are often biased and may be corrected (cunnane, 1989)

$$m_2 = \frac{1}{N-1}\sum (x_i - \bar{x})^2 \; \ldots\ldots (5)$$

$$m_3 = \frac{N}{(N-1)(N-2)}\sum (x_i - \bar{x})^3 \; \ldots (6)$$

$$m_4 = \frac{N^2}{(N-1)(N-2)(N-3)}\sum (x_i - \bar{x})^4 \; \ldots (7)$$

The conventional moment ratioss are defined

$$C_v = \mu_2^{1/2} / \mu'_1 \; \ldots\ldots\ldots\ldots$$

(8)

$$C_s = \mu_3 / \mu_2^{3/2} \; \ldots\ldots\ldots\ldots$$

(9)

$$C_K = \mu_4 / \mu_2^2 \; \ldots\ldots\ldots\ldots$$

(10)

Where

C_v - Coefficient of variation

C_s - Coefficient of skewness

C_k - Coefficient of Kurtosis

L-Moments

Advantages of L-Moments

L- Moments are analogous to conventional moments but are estimated by linear combinations of an ordered data set, namely L-statistics. (Roa & Hamed, 2000)

The following are advantage of L-moments: (Cunnane, 1989)

I. Compared to conventional moments, L-moments can characterize a wide range of distributions

II. Sample estimates of L-moments are so robust that they are not affected by the presence of outlier in the dataset.

III. They are less subjected to bias in estimation

IV. L-moments yield more accurate estimates of the parameters of a fitted distribution. Even some times parameter estimated form samples are more accurate than maximum likelihood.

Hosking (1986) defined the L-moments of a real value random variable X in terms of probability weighted moments (PWMs) as:

$$L_r = (-1)^{r-1}\sum_{k=0}^{r-1} P_{r-1,k} M_{1k} \; \ldots (11)$$

Where

$$P_{r,k} = (-1)^{r-k}\binom{r}{k}\binom{r+k}{k}$$

....(12)

L_r = the r^{th} L- moment

$$M_{10k} = \sum_{j=0}^{k}(-1)^j\binom{k}{j} M_{1j0}$$

....

(13)

Hosking (1986), gave the unbiased estimators of M_{10k} and M_{1j0} as:

$$\hat{M}_{10k} = \frac{1}{N}\sum_{i=1}^{N}\left[\binom{v-1}{k}\Big/\binom{N-1}{k}\right]x_i \qquad k=0,1,2\cdots N-1 \; \ldots\ldots\ldots (14)$$

$$\hat{M}_{1j0} = \frac{1}{N}\sum_{i=1}^{N}\left[\binom{N-v}{j}\Big/\binom{N-1}{j}\right]x_i \qquad j=0,1,2\cdots N-1 \; \ldots\ldots\ldots (15)$$

Where V = rank of observed flow data in ascending order

The first few moments are:

$L_1 = M_{100}$

$L_2 = M_{100} - 2 * M_{101}$

$L_3 = M_{100} - 6*M_{101} + 6*M_{102}$

$L_4 = M_{100} - 12*M_{101} + 30*M_{102} - 20*M_{103}$

$$\tau = L_2 / L_1 \qquad (16)$$

$$\tau_r = L_r / L_2, \quad r \geq 3 \; \ldots\ldots (17)$$

Like the conventional moments, L-moments can be used to specify and summarize probability distributions. In particular L_1, the first L- moment, is the mean of a statistical distribution and is identical to the first conventional moment, and L_2 is a linear measure of spread or dispersion analogous to standard deviation. L-moment ratios, which are analogous to conventional moment ratios, are defined by Hosking (1990) (Roa & Hamed, 2000) as:

Where;

L_1= measure of location

τ = measure of scale and dispersion (LC_v)

τ_3 = measure of skew ness (LC_s)

τ_4 = measure of kurtosis (LC_k)

Instead of τ and τ_r, t and t_r are used for sample L- moment ratios.

To compute the above parameters using L-moment method is some what cumbersome with spread- sheet (Excel). There fore FORTRAN program (FFA-AS / statistics) has been developed for calculation. These parameters, later on, are basic important for regionalization, selection of distribution and robust method of estimation

Fig 3.2: Identified homogeneous stations

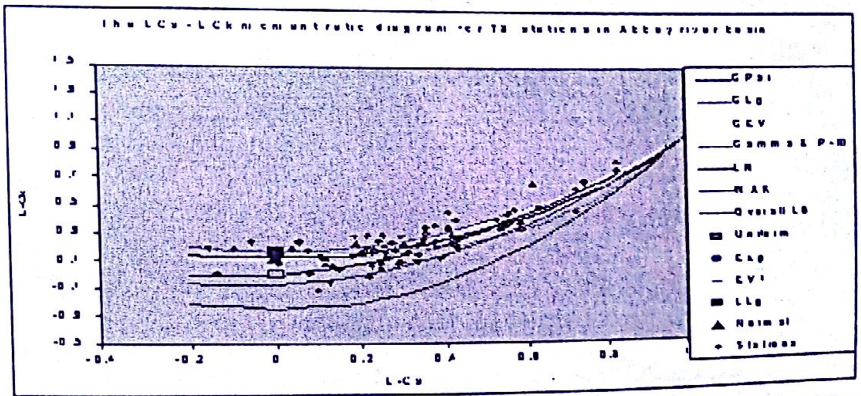

Fig 3.1: LMR diagram of gauging stations of Abbay basin for standardized flow

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and various tests. Detail computed statistical values are shown on the table below.

1.1 Bases for regionalization

The index- flood method (Hosking, 1993) is based on the hypothesis that floods from different catchments within a region normalized by their mean annual flood come from a single distribution. An essential prerequisite for this procedure is the standardization of the flood data from sites with different flood magnitudes. The most common practice is to standardize data i.e. division by an estimate of the at-site mean, thus

$$X_i = Q_i / \bar{Q} \quad \text{.......................} \quad (18)$$

Where $\bar{Q} = \frac{1}{N}\sum_{i=1}^{N} Q_i$

Then the Quantile Q_T is estimated as

$$Q_T = \bar{Q}\,\bar{X}_T \quad \text{..............................} \quad (19)$$

The mean annual flood is the index-flood.

1.2 Identification of Regions

The (LC_S, LC_K) of standardized flow values of each stations has been plotted on L-moment ratio diagram (LMRD) of various distribution functions as shown below.

Those stations close to a single distribution were considered as homogeneous stations. Thereby, five groups of stations were identified as shown on the map below.

1.3 Delineation of Homogeneous Regions

The tool used in delineation of homogenous regions where GIS (Arcview 3.3) software. On the digitized map of the basins, all stations under analysis were identified according to their geographical location (latitude and longitude). For each stations the statistical values (LC_s , LC_k) which were computed in section 4.2 where given. In addition, the preliminary identification of the region using LMRD mentioned above where identified on separate field to geo-code with different color. It is assumed that (LC_S, LC_K) values of one station varies linearly with (LC_S, LC_K) values of the neighboring stations. So from GIS screen, the distance between one station and its neighboring station was determined and (LC_S, LC_K) values where interpolated to fix the boundary between two stations of different regions. The procedures followed in the delineation of the boundary of the region were as follows:

I. To compute the (LC_s, LC_k) value of each station

II. To identify the location of stations along the distributions of LMRD

III. To identify the group based on step II

IV. To interpolate between LC_s and LC_k Values of two stations of different groups to fix two boundaries, one from the LC_s and the other from LCk values.

V. The boundary of the region is fixed between the mid ways of the two boundaries found in step IV.

1.1 Homogeneity Tests

The preliminary identified regions have to be checked by various homogeneity tests.

The tests used in this study were:

i) Discordance measure test
ii) Cv – based Homogeneity test.
iii) LCv – based Homogeneity test.
iv) Statistical comparison

I. Discordance measure

The discordance measure intended to identify those sites that are grossly discordant with the group as a whole. The discordance measure D estimates how far a given site is from the center of the group. (Roa & Hamed, 2000)

If is the vector containing the t, t_3 and t_4 values for site (i), then the group average for NS sites within the region is given by

$$\bar{U} = \frac{1}{NS}\sum_{i=1}^{NS} U_i \quad \text{..............} \quad (20)$$

The sample covariance matrix is given by

$$S = (NS-1)^{-1}\sum_{i=1}^{NS}(U_i - \bar{U})(U_i - \bar{U})^T \quad \text{......} \quad (21)$$

The discordance measure is defined by

$$D_i = \frac{1}{3}(U_i - \bar{U})^T S^{-1}(U_i - \bar{U}) \quad \text{..} \quad (22)$$

A site (i) is declared to be unusual if D_i is large. A suitable criterion to classify a station as discordant is that D_i should be greater than or equal to 3.

II. CV – Based Homogeneity Test

In regionalization, assumptions must be made about the statistical similarity of the sites in a region. To investigate whether those has been met or not many researchers as Lettenmailer (1989), Lettenmailer et.al (1987) and Cunnane (1989) have used the values of mean coefficient of variation (CV) and the site – to – site coefficient of variation of the coefficient variation (CC) of both conventional and L – moments of the proposed region. (Melsew, 1996) According to the researchers, the higher the values of CV and CC the lower the performance of index flood method for the considered region. According to Lettenmailer (1985), this is due to the dominance of the flood quantile estimation variance by the variance of the at – site sample mean. Hence for better performance of the index flood method, CC should be kept low (Melsew, 1996). In this research

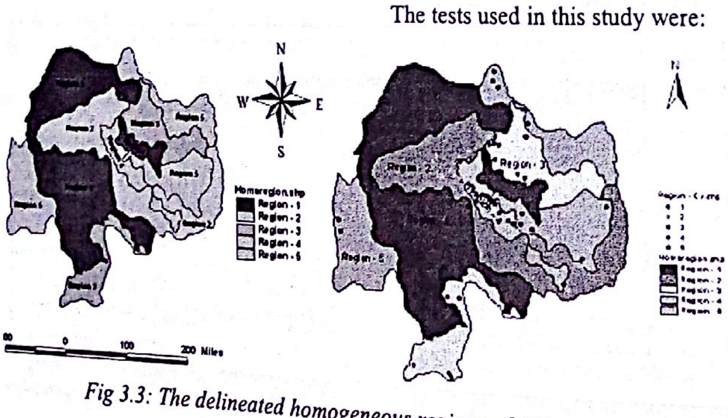

Fig 3.3: The delineated homogeneous regions of Abbay basin

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also both conventional and L – moments have been used to calculate Cv, LC, and their respective CC, value. The procedures are described below.

i) For each site in a region calculate mean, standard deviation and coefficient of variation Cv

$$\overline{Q_i} = \frac{\sum_{j=1}^{n_i} Q_{ij}}{n_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (23)$$

$$\sigma_i = \sqrt{\frac{\sum_{j=1}^{n_i} (Q_{ij} - \overline{Q_i})^2}{n_i - 1}} \quad \ldots\ldots\ldots\ldots \quad (24)$$

$$CV_i = \frac{\sigma_i}{\overline{Q_i}} \ldots \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (25)$$

Where Q_{ij} = the flow rate of station j in region i

$\overline{Q_i}$ = the mean flow rate for site i

σ_i = Standard deviation of Q_{ij} for site i

Cv_i = Coefficient of variation of site i

For calculation of LCV use,

$$LCv_i = \frac{l_{2i}}{l_{1i}} \quad \ldots\ldots(26)$$

Where, LCv_i is the dimensionless coefficient of variation calculated from L – Moments and the respective expressions for L_1 and L_2 are as defined in section 4 – 2.

ii) For each region, using the statistics calculated in step 1, compute the regional mean, CV and LCv; standard deviation of CV and LCv, and finally the corresponding C using the following relations

$$\overline{CV} = \sum_{i=1}^{N} \frac{CV_i}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots(27)$$

$$\sigma_{CV} = \sqrt{\frac{\sum_{i=1}^{N} \left(CV_i - \overline{CV}\right)^2}{N}} \quad \ldots\ldots\ldots \quad (28)$$

$$\overline{Q} = \frac{1}{N} \sum_{i=1}^{N} Q_i \ldots \quad \ldots\ldots\ldots\ldots\ldots \quad (29)$$

Where:

N - number of sites in a region

$\overline{CV}$ - mean coefficient of variation of the region σ_{CV} - Standard deviation of at – site CV values.

The same procedure holds true for the corresponding L – moment values.

Criteria: The region declared to be homogenous if CC < 0.30.

III. Statistical Comparison

Statistical values, like coefficient of variation, coefficient of skewness and kurtosis show a clear distinct distribution on graph when plotted. Especially lower moments LCv & LCs and moment ratios are a good indicators of homogenous region.

Region	CC value		Conclusion
	Conv. CV-based method	L-moment CV-based method	
One	0.144	0.148	Homogeneous
Two	0.216	0.204	Homogeneous
Three	0.287	0.231	Homogeneous
Four	0.203	0.192	Homogeneous
Five	0.290	0.233	Homogeneous

Table 3.1: Result of CV – based homogeneity tests for the regions in BNRB

1.2 Result of Homogeneity Tests

Discordance test Summary

From the result one station (114012) in Region 3 is discordant. It is related with region 5. However, it is not possible to delineate with region 5 & also is not recommended to delineate this station as one region. As a result this station was considered as a discordant station, and specific flood frequency curve was developed for it which is exactly alike with region five.

Cv & LCv homogeneous tests

FORTRAN program is developed for these tests. The overall output of the program is summarized in Appendix F, Table F.2. In addition to this, the end result is revised in table 4.3 below. According to the result all stations of the respective regions satisfy homogeneity criteria for both conventional and L – moment CV – based homogeneity tests.

Statistical Comparison

In this case the homogeneity of the stations was checked by comparing various statistical parameters such as Cv, Cs, Ck, LCv, LCs and LCk within the region as shown in figure 4.3 and 4.4. When these statistical values are plotted as in figures 4.3 and 4.4, they show layers or group of regions that indicate different regions. Moreover, coefficient of variation was found to be a good indicator of homogeneity of stations; whereas higher moments are not efficient in indicating homogeneity of stations.

Name of the region Total area &Perimeter Location / Catchment General characteristics(particulars)

Region one Area 75164 km² Pe-

Table 3.2: Summary of land features, catchments characteristics, sub basin names for the established regions

Name of the region	Total area & Perimeter	Location / Catchment	General characteristics (particulars)
Region one	Area 75164 km² Perimeter 2727 km	Upper Guder-kale, middle & lower Didessa-Anger, lower part of main Abbay, Dinder & Shinfa-Rahad lower Tana catchments & high lands of Gojam	Elevation from 700m to 1500m & 3000 to 4000m at Gojam high lands,rainfall varies from 900 to 1600mm & also up to 2000mm at high land areas; Topography from level to undulating plains, rolling plains low plateau plains & gorges; Slope ranges from 0.1 to 15 % with land cover mostly shrub land
Region two	Area 41315 km² Perimeter 2154 km	Beles, Gilgel Abbay, Fincha, lower Guder-Kale Catchments, extreme upper course of Jema-Wenchit	Elevation from 1200 to 3000m; rainfall 1000 to 1600mm; slope of the area 0.5 to 30 %; topography from low plateau plains to mid plateau plains, level to undulating plains; land use open wood land, from moderately to dominantly cultivated, grass land.
Region three	Area 27784 km² Perimeter 1821 km	Upper Didesa-Anger, Bahir Dar, Tis Abbay (Blue Nile Falls), Mota region	Elevation from 1500 to 3800m, rainfall 1000 to 1400mm & up to 2000mm at high land, slope 0.5 to 70 %; topography low plateau, plains hills & mountains; moderately to dominantly cultivated land and also forest, woodland, grassland cover
Region four	Area 6515 km² Perimeter 526 km	Bir-Temcha, southern part of Gojam high lands, Extreme upper course of Gilgel Abbay	Elevation 2000 to 3700mm; rainfall 1200 to 2000mm; slope 10 to 70 %; land use cultivated from moderately to dominantly; topography hills & mountains, rolling plains, & low plateau plains
Region five	Area 49222 km² Perimeter 2654 km	Gumera, Rib, Bijena-Beshlo, Jema-Wenchit, Dabus, Muger-Urga'A	Elevation from 1000 to 3500m; rainfall 1000 to 1600mm; slope 0.1 to 50 %; land use grassland, swamp, shrub land, moderately to dominantly cultivated; topography level to undulating plains, low plateau, gorges, high plateau plains

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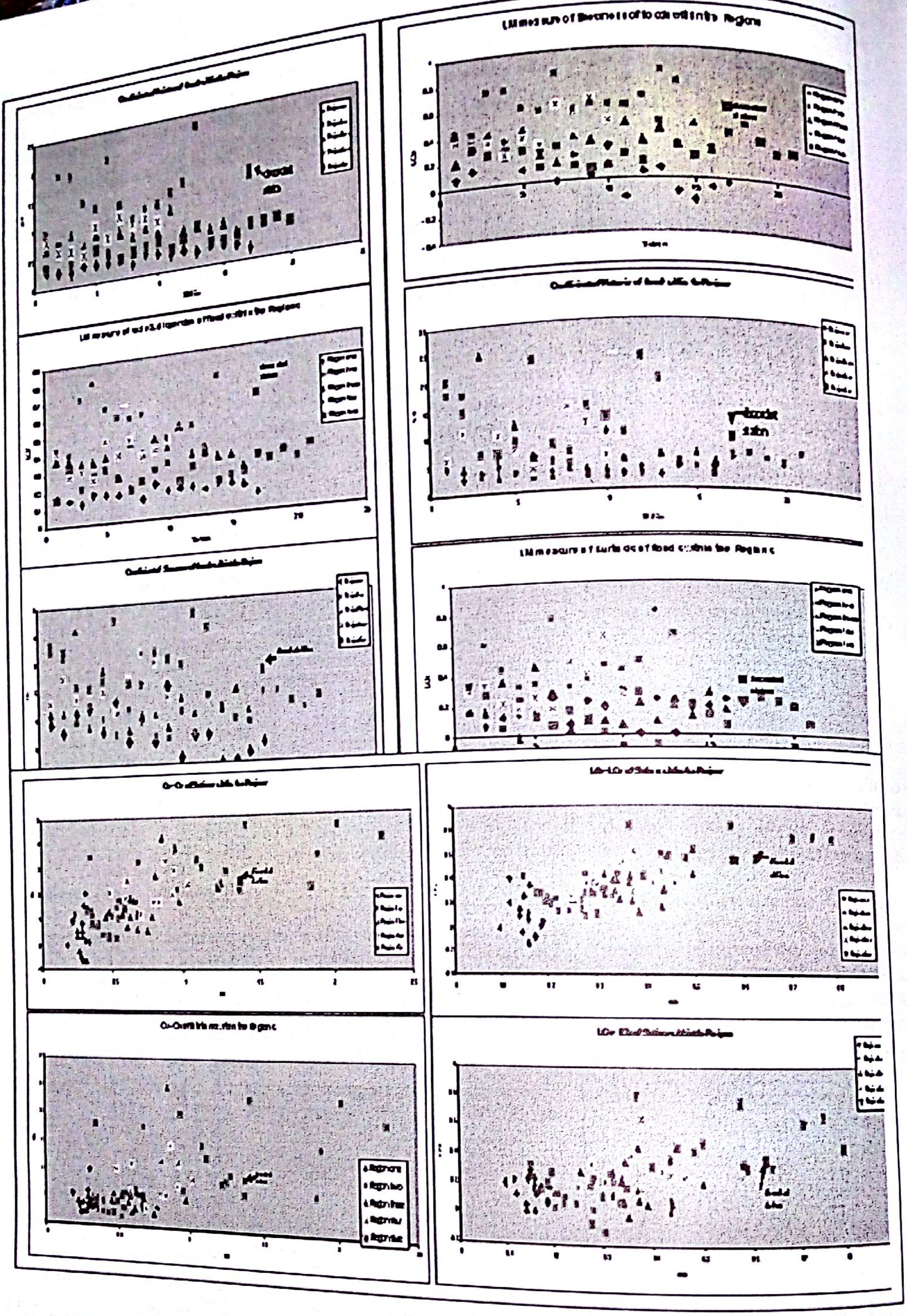

Fig 3.4: Graph for statistical values comparison (Cont'd)

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rimeter 2727 km Upper Guder-kale, middle & lower Didessa-Anger, lower part of main Abbay, Dinder & Shinfa-Rahad lower Tana catchments & high lands of Gojam Elevation from 700m to 1500m & 3000 to 4000m at Gojam high lands;rainfall varies from 900 to 1600mm & also up to 2000mm at high land areas; Topography from level to undulating plains, rolling plains low plateau plains & gorges; Slope ranges from 0.1 to 15 % with land cover mostly shrub land

Region two Area 41315 km² Perimeter 2154 km Beles, Gilgel Abbay, Fincha, lower Guder-Kale Catchments, extreme upper course of Jema-Wenchit Elevation from 1200 to 3000m; rainfall 1000 to 1600mm; slope of the area 0.5 to 30 %; topography from low plateau plains to mid plateau plains, level to undulating plains; land use open wood land, from moderately to dominantly cultivated, grass land.

Region three Area 27784 km² Perimeter 1821 km Upper Didesa-Anger, Bahir Dar, Tis Abbay (Blue Nile Falls), Mota region Elevation from 1500 to 3800m; rainfall 1000 to 1400mm & up to 2000mm at high land; slope 0.5 to 70 %; topography low plateau, plains hills & mountains; moderately to dominantly cultivated land and also forest, woodland, grassland cover

Region four Area 6515 km² Perimeter 526 km Bir-Temcha, southern part of Gojam high lands, Extreme upper course of Gilgel Abbay Elevation 2000 to 3700mm; rainfall 1200 to 2000mm; slope 10 to 70 %; land use cultivated from moderately to dominantly; topography hills & mountains, rolling plains, & low plateau plains

Region five Area 49222 km² Perimeter 2654 km Gumera, Rib, Bijena-Beshlo, Jema-Wenchit, Dabus, Muger-Urga'A Elevation from 1000 to 3500m; rainfall 1000 to 1600mm; slope 0.1 to 50 %; land use grassland, swamp, shrub land, moderately to dominantly cultivated; topography level to undulating plains, low plateau, gorges, high plateau plains 1.3

Selected Distributions for the Identified Regions

For the identified regions above, using L-Moment ratio diagram the parent distributions in which the flood data series come from is selected from the regional average of LCs and LCk value as shown on the graph 3.5.

Accordingly, for region one Generalized Logistic & Log Normal distribution and for region two Gamma, Pearson III & Log Pearson III distributions are selected. For region three, Log Normal distribution is chosen. Generalized Logistic and Generalized Extreme Value are selected as candidate distributions for region four and region five. The selection of best fit distribution with its robust parameter estimation method from the candidate distributions for each region is another task which needs further investigation.

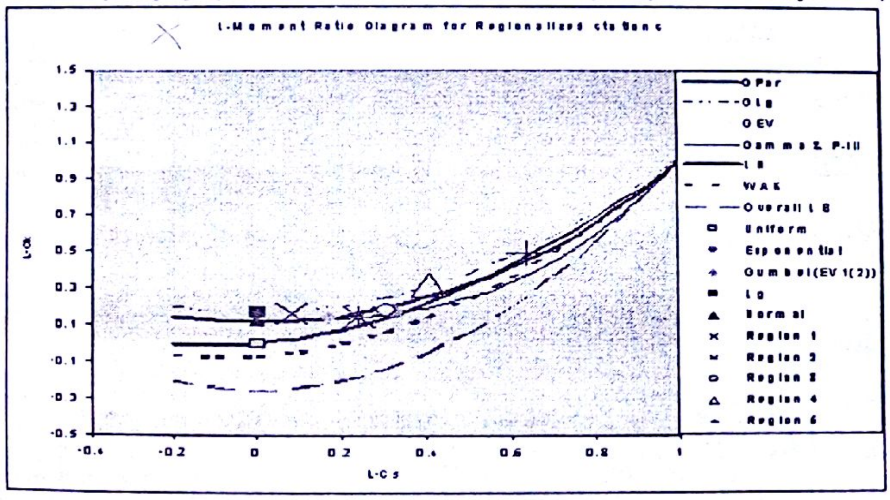

Fig 3.5: Regional average LMRD for the established regions

4. Conclusion and Recommendation

4.1 Conclusion

Despite many attempts made by research hydrologists to delineate homogeneous regions, no general methodology is accepted yet universally. Here, regionalization was made on the statistical values (LCs and LCk) of index flood of each stations based on the concept that stations from the same region, their index flood series come from the same parent of distribution. The proposed five regions satisfied the homogeneity test applied in the study except one station (114012) in region three is discordant with the existing region and homogeneous with region five.

Peak flow data series of each station of the same region will fit the same type of distribution. This is the advantage gained from regionalization concept that has been used in this study. The types of distributions most likely to fit data of each region were identified from the regional average statistical value of L – Moment ratio.

4.2 *Recommendation*

· Delineation of homogeneous regions based on statistical parameter of gauged site could be one of an alternative method of regionalization to identify stations of similar flood producing characteristics.

· Lower moments such as Cv, LCv, and graph of Cv-Cs, LCv-LCs, Cv-Ck, LCv-LCk are found to be good indicator of homogenous stations in this study.

· The selection of best fit single distribution and also vigorous parameter estimation method require further investigation.

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Optimal Design of Water Harvesting Ponds for Upper Basin of Awash River in Ethiopia

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Abstract

The pond geometry and its dimensions are important decision variables which affect initial cost of construction, seepage and evaporation loses. The study in the upper basin of Awash River is conducted to have number of ponds to harvest the run-off from the respective catchment. Based on the nature of catchment area delineated by GIS, three ponds in one and two ponds in second series are considered. The three fold rectangular pond being the best geometry among square and 2-fold rectangular pond is considered for the design. The regression model is developed for optimal design of the pond. Based on catchment harvest and geometry of the pond, the final dimensions and the storage capacities of 5 ponds are designed.

Key words: water harvesting: optimization model: pond geometry: storage capacity.

Introduction

Water is the most precious natural resource and a universal asset. Its proper development, management and utilization is of paramount importance for socio-ecological development of different regions of the world inhabited by human, plant and animal beings Samra et al. (2002). Most areas with low rainfall and/or with high rainfall but erratic distribution suffer from low and unstable crop yields. Generally, storage of rainfall in the soil profile is cheaper and more efficient than storage of run-off in excavated ponds. However, the major limitation of storage in the soil profile is its limited capacity to hold for a long period of time. Thus, use of water harvesting ponds for a life saving irrigation to rain-fed crops is an alternative option. Water harvesting is an ancient method of obtaining water that has received renewed interest in recent years as a viable water supply method for many regions of the world Frasier and Myers (1983). Even though water harvesting is as old as human civilization itself, the use of optimization techniques for design of the pond irrigation system is a recent area of interest to scientists and engineers.

Studies in the past have addressed to the problem of tank and reservoir irrigation systems. Sharma and Helweg (1982) developed a non-linear optimization model to minimize the excavated volume of a tank under the constraints that earthwork is equal to embankment. Helweg and Sharma (1983) designed tank using non-linear optimization model taking the same constraint as that of Sharma and Helweg (1982). Verma and Sarma (1990) developed a procedure to design the storage tanks considering different probability levels (0.10 to 0.9). Arnold and Stockle (1991) used simulation model to determine optimum pond size. Srivastava (1996) developed a methodology to optimize the design of tank irrigation system considering a series of tanks

These studies do not link the catchment harvest with the pond design and the relationship between different de-

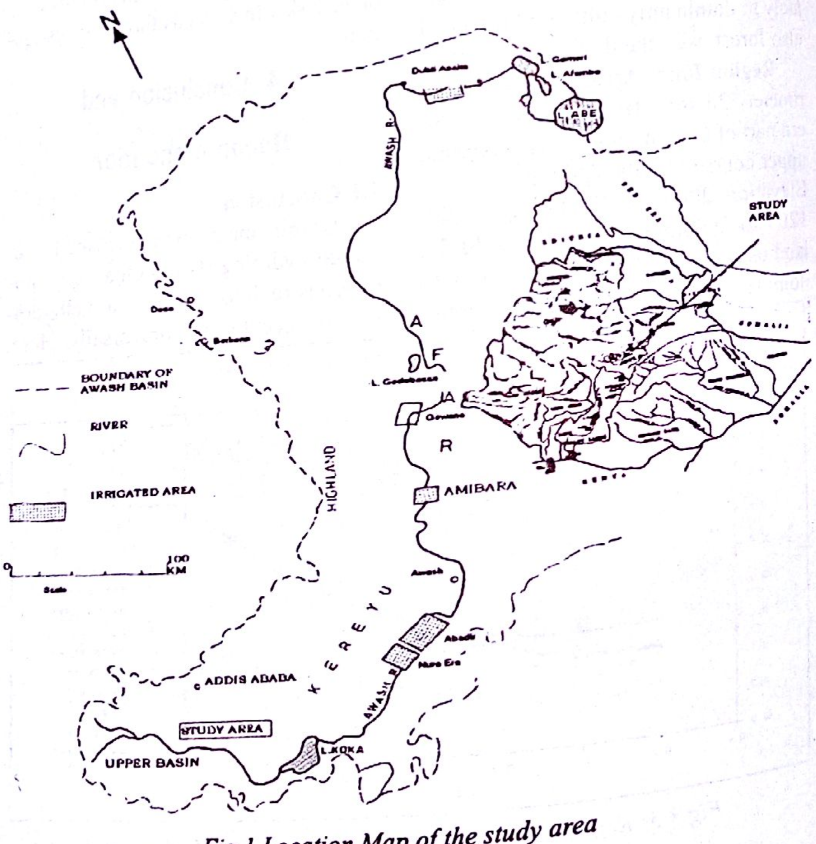

Fig.1 Location Map of the study area

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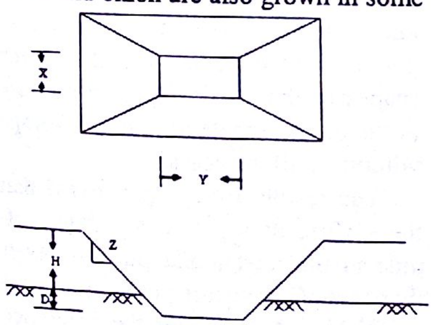
sign parameters, which could be utilized for optimal design of ponds, has not been reported.

Therefore, the present study is taken up to evaluate different geometries of the water harvesting ponds using optimization techniques and to develop regression models for optimal design of ponds corresponding to a catchment harvest. The upper basin of Awash River in Ethiopia is selected for the study.

Study area

Awash River is one of the most important rivers and is a lifeline of Ethiopia from irrigation as well as hydroelectric generation point of view. The large-scale irrigation schemes are widely practiced especially in the upper, middle and lower portions of this river valley. However, the available water resource flowing in small tributaries in the upper basin of Awash River is not yet fully developed for irrigation purposes. As shown in Fig1, the area lies between the headwaters and Koka hydropower reservoir. The geographical area of the upper basin is 11,500 Km^2 and lies between 8°40'N and 8°45'N latitude and 38°36'E and 38°44'E longitude with the altitude ranging from 3000 to 1800 m above M.S.L.

The average annual rainfall in the area ranges from 835 to 1216 mm. The maximum temperature reaches up to 29°C during May and minimum goes up to 9.6°C during December. The average wind speed at 2m heights is recorded as 1.36m/s. The maximum and minimum relative humidity is recorded as 80% and 45% during August and November respectively. The soils of the study area are generally classified as Eutric vertisol and its texture is clay. The major crops grown in the area are teff, wheat, chickpea and lentil, whereas potato, tomato and onion are also grown in some places.



Geometry of water harvesting ponds

The study mainly focuses on selecting appropriate geometry of the pond and designing the dimensions of the pond and its optimal storage capacity. A series of water harvesting ponds has been proposed in which catchment area of the first pond remains un irrigated and the catchment area of the following pond is the command area of the preceding pond. The pond design under partial excavation and partial embankment is considered (Fig.2). The trapezoidal shape of the ponds, because of its stability for the earthen structures has been considered Steuart (1961). The value of the top width of the embankment (T) is taken as 2m for all sides of the embankment. The geometrical formulae used for determination of the design components were derived based on the principle of solid geometry as frustum pyramid.

Optimization model

The classical optimization model using Lagrange multiplier has been used to obtain the optimal design of the pond. The storage capacity of the pond as an objective function is maximized subject to the constraint that the volume of earthwork is equal to the volume of embankment.

Mathematically the model may be expressed as

Maximize Z = Vsc ...(1)

Subject to:

$$V_{dug} = V_{emb} \quad ...(2)$$

Where,

$$V_{sc} = \left(\frac{D+H}{3}\right)\left[CX^2(C+2) + 2Z(D+H)\left(2CX + X + 2Z(D+H)\right)\right] \quad ...(3)$$

$$V_{dug} = \frac{D}{3}\left[CX^2(C+2) + 2DZ(2CX + X + 2DZ)\right] \quad ...(4)$$

$$V_{emb} = 2\{(T+2Z)H\}\left[\{X(C+1) + 2Z(D+H)\}\right] + \left[4T^2H + 4THZ + \frac{4}{3}H^3Z^2\right] \quad ...(5)$$

where,

X = bottom width (m)

Y = bottom length (m)

D = excavated depth (m)

H = height of embankment above ground surface (m)

Z = side slopes (Z: 1)

V_{sc} = Storage capacity (m^3)

V_d - dug volume (m^3)

V_{emb} - Volume of embankment (m^3)

A_w = Wetted surface area (m^2)

A_s = Surface area (m^2)

$$C = \frac{Y}{X}$$

The augmented Lagrange function is obtained as:

$$L(H,\lambda) = V_{sc} - \lambda\left(V_{dug} - V_{emb}\right) \quad ...(6)$$

Where, l is Lagrange multiplier.

$$L(H\lambda) = [\frac{1}{3}C^2DX^2 + \frac{1}{3}C^2X^2H + \frac{2}{3}CDX^2 + \frac{2}{3}CX^2H + \frac{4}{3}CD^2XZ + \frac{8}{3}CDXZH + \frac{2}{3}D^2XZ + \frac{4}{3}DXZH + \frac{4}{3}D^3Z^2 + \frac{12}{3}D^2Z^2H + \frac{12}{3}DZ^2H^2 + \frac{4}{3}CXZH^2 + \frac{2}{3}XZH^2 + \frac{4}{3}Z^2H^3] - \lambda[(\frac{1}{3}C^2DX^2 + \frac{2}{3}CDX^2 + \frac{4}{3}CD^2XZ + \frac{2}{3}D^2XZ + \frac{4}{3}D^3Z^2) - (4CXH + 4XH + 16DZH + 24ZH^2 + 2CXZH^2 + 2XZH^2 + 8DZ^2H^2 + 16H + \frac{25}{3}Z^2H^3)] \quad ...(7)$$

Differentiating equation (7) with respect to H and l, the necessary conditions for optimization problem is given as equation (8) and (9) respectively:

$$\frac{\partial L}{\partial H} = \frac{1}{3}C^2X^2 + \frac{2}{3}CX^2 + \frac{8}{3}CDXZ + \frac{4}{3}DXZ + \frac{12}{3}D^2Z^2 + \frac{24}{3}DZ^2H + \frac{8}{3}CXZH + \frac{4}{3}XZH + \frac{12}{3}Z^2H^2 + 4CX\lambda + 4X\lambda + 16DZ\lambda + 48Z\lambda H + 4CXZ\lambda H + 4XZ\lambda H + 16DZ^2\lambda H + 16\lambda + 25Z^2\lambda H^2 = 0 \quad ...(8)$$

$$\frac{\partial L}{\partial \lambda} = -\frac{1}{3}C^2DX^2 - \frac{2}{3}CDX^2 - \frac{4}{3}CD^2XZ - \frac{2}{3}D^2XZ - \frac{4}{3}D^3Z^2 + 4CXH + 4XH + 16DZH + 24ZH^2 + 2CXZH^2 + 2XZH^2 + 8DZ^2H^2 + 16H + \frac{25}{3}Z^2H^3 = 0 \quad ...(9)$$

Solving the differential equation (9) and rearranging the parameters yields equation (10) in terms of H.

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$$AH^3 + PH^2 + QH + R = 0 \quad \text{...(10)}$$

where,

$$A = \frac{25}{3} Z^2 \quad \text{...(11)}$$

$$P = 24Z + 2CXZ + 2XZ + 8DZ^2 \quad \text{...(12)}$$

$$Q = 4CX + 4X + 16DZ + 16 \quad \text{...(13)}$$

$$R = -\left(\frac{1}{3}C^2DX^2 + \frac{2}{3}CDX^2 + \frac{4}{3}CD^2XZ + \frac{2}{3}D^2XZ + \frac{4}{3}D^3Z^2\right) \quad \text{...(14)}$$

To get the value of coefficients, A, P, Q and R of equation (10), the initial values of the design variables X, D, C, and Z are assumed arbitrarily. The value of 'X' is taken as 1, 2, 4, 6, 8, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, and 100. The values for side slope, Z is taken as 1:1 for the soil type of the area which is heavy soil. The bed length and width ratio (Y/X) is taken as C = 1, 2, 3 corresponding to square, 2-fold and 3-fold rectangular pond. The value of D within practical range is taken as 1, 2, 3, 4 and 5m. Thus, 360 combinations were compiled and solved using Newton- Raphson iteration algorithm for cubic function using Visual FORTRAN 6.5 program to arrive the value of the decision variable, H. After getting the value of H, all the 360 combinations were classified based on their respective geometries as square, 2-fold and 3-fold rectangular. The storage capacity as per equation (3) was calculated. The wetted surface area and surface area were calculated from their respective geometrical equations based on the design parameters of the pond. The excavated volume as per equation (4) was computed and construction cost of the pond was determined for all the geometries and excavated depths based on the excavated volume and locally available unit cost data. The optimum pond geometry was evaluated based on the evaluation criteria considered for the design.

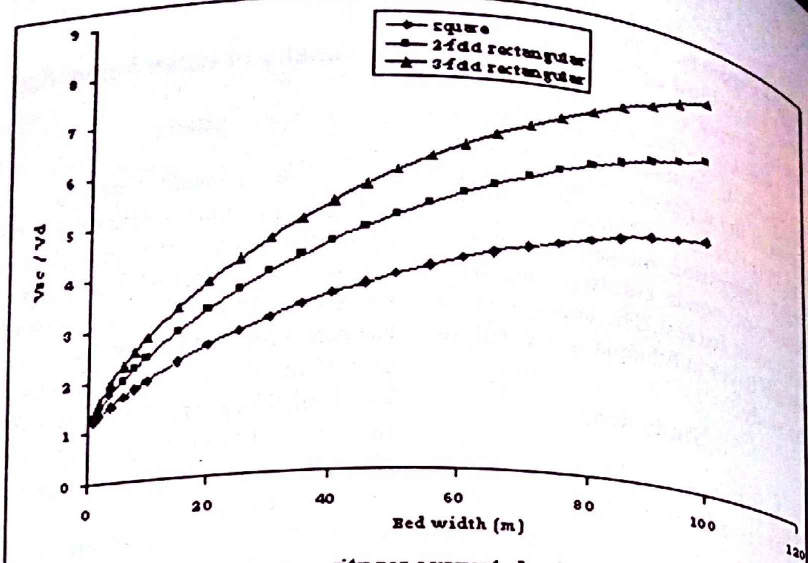

Fig. 3 : Storage capacity per excavated soil of different pond geometries at 1 m excavated depth for heavy soil

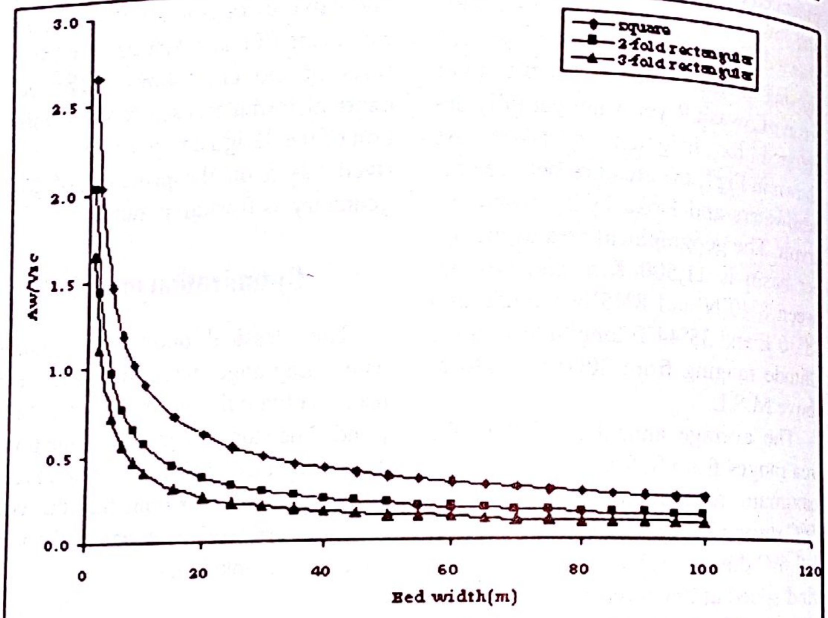

Fig. 4 : Wetted surface area per storage capacity of different pond geometries at 1 m excavated depth for heavy soil

Optimum pond geometry

The optimum pond geometry out of square, 2 and 3-fold rectangular ponds, was selected based on the criteria of maximum storage capacity per unit-excavated soil; minimum wetted surface area per unit storage capacity (minimum seepage loss), minimum surface area per unit storage capacity (minimum evaporation loss) and minimum construction cost (USD) per unit volume of stored water.

The storage volume per unit volume of excavated earth in the 3 fold rectangular pond as shown in Fig.3, is found higher than that of square and 2 fold rectangular pond for all the depths of 1-5m.

The wetted surface area per unit storage volume is less in case of rectangular pond as compared to the square pond for all bottom widths and 1m excavated depth (Fig.4). The wetted surface area per unit storage volume in 3 fold rectangular pond is less than that of the 2 fold rectangular pond. Similar results were obtained for other excavated depths. In general, as the bed width of the pond increases, the difference in the value of wetted surface area per unit storage volume for all the three shapes of the ponds diminish because of the proportionate increase in storage volume in all the cases.

The results from Fig.5 reveal that the surface area per unit storage volume in the rectangular pond is lower than that of the square pond for 1 m excavated depth. However, the difference in surface area per unit storage volume

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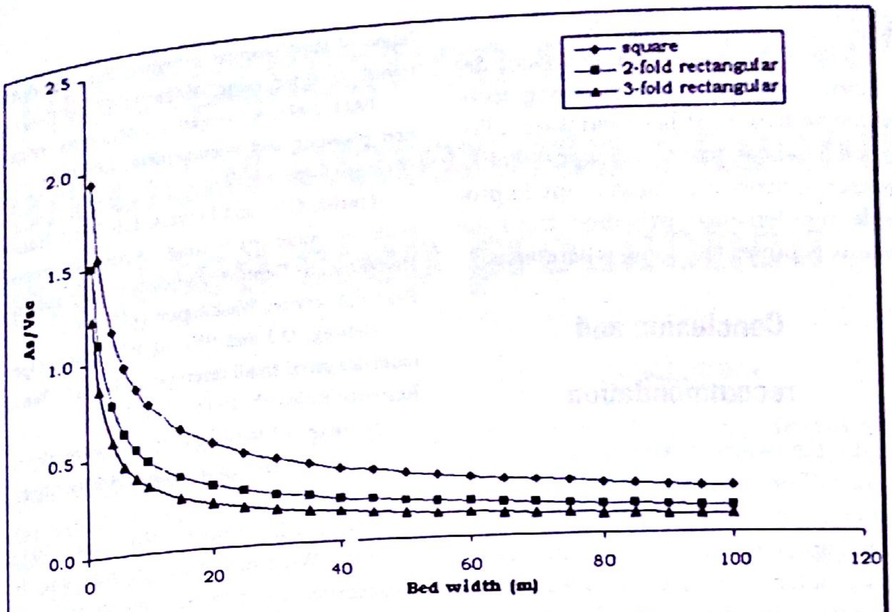

Fig. 5 : Surface area per storage capacity of different pond geometries at 1m excavated depth for heavy soil

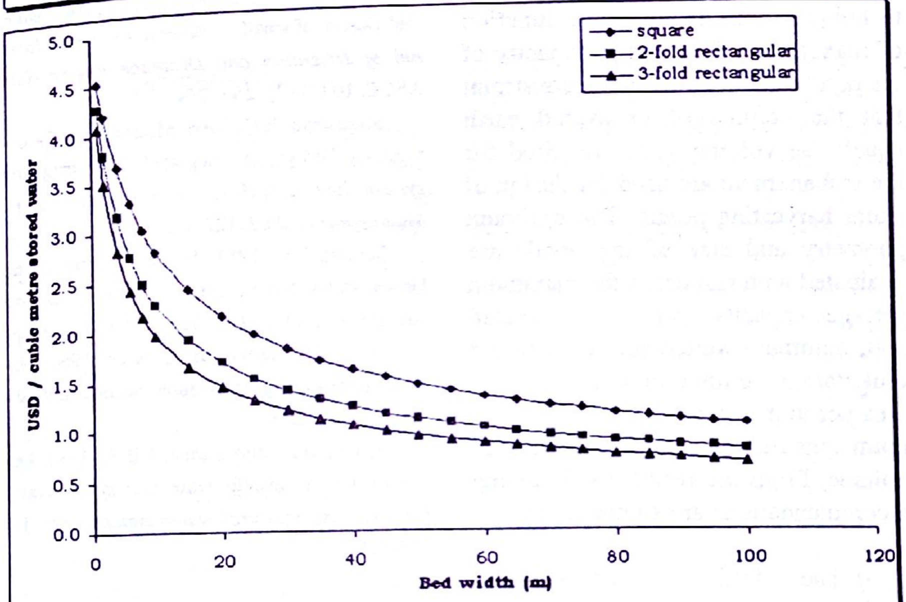

Fig. 6 : Cost of construction per storage capacity of different pond geometries at 1 m excavated depth for heavy soil

between the two rectangular ponds is less. Hence, evaporation per unit storage volume would be minimum. The trend in surface area per unit storage volume is the same for other excavated depths of 2-5m.

The cost of construction of rectangular pond per cubic meter stored water is less than that of the square pond for 1m and other excavated depths. For 1m excavated depths and 1 to 100m-bed width, the cost of construction per cubic meter stored water of a 2-fold, 3-fold rectangular and square pond ranges from USD 4.276 to 0.797, 4.063 to 0.676 and 4.521 to 1.048 respectively (Fig.6).

Thus, it can be concluded that 3 fold rectangular pond is the best geometry amongst the considered shapes and could be selected for its maximum storage capacity per unit excavated volume, minimum wetted surface area per unit storage, minimum surface area per unit storage and minimum cost of construction per unit storage for excavated depths of 1-5m.

Delineation of catchment area

A topographic map prepared on the scale of 1:50,000 by the Survey and Mapping Department of Ministry of land reform and Administration (1999) was used for the analysis of slope area classification and watershed delineation. The Slope - area classification was performed using ILWIS (GIS packages) to identify the topographic nature of the catchment and command areas. Delineation of small watersheds was done using GeoMedia professional GIS packages for identifying catchment and command areas of different ponds for preparation of the water harvesting and utilization plan.

Slope, %	Area, m^2	Area, km^2	Area, ha
0-2	179995006.9	179.995	17999.50
2-4	6563090.9	6.56	656.31
4-6	2970083.8	2.97	297.01
6-8	1705081.4	1.71	170.51
8-10	768150.1	0.768	76.82

Based on this, from the total delineated area of 19295 ha, water harvesting pond design was made for 3253ha (Fig.7). The area falling under different range of slope is given in the following table.

Estimation of surface run-off

The surface run-off from the delineated catchment area was determined using curve number (CN) method (USSCS, 1964) taking into consideration of 5 days Antecedent Moisture Condition (AMC) from eleven years (1991-2001) daily rainfall data recorded at the near by station and for hydrologic soil group of 'D' and locally available land use/land cover data. Using Weibull plotting position method, the annual run-off was calculated at 20 % probability of exceedence level. The surface run-off on volumetric basis is obtained by multiplying it with the respective catchment area. It is used as catchment harvest for the design of respective water harvesting ponds.

Regression models

After deciding the geometry of the pond i.e. three fold rectangular, the relationships of bed width (X), Vs storage capacity (V_{sc}) and bed width Vs height of embankment (H), are established fitting to polynomial and Weibull equations respectively. Models are developed for different excavation depths (1-5m) of 3 fold rectangular

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pond with side slope, Z = 1:1 corresponding to heavy soil.

Application of model

For three-fold rectangular pond out of the five excavated depths, 1 m depth is selected for its minimum cost of construction as compared to the other depths. Two series comprising 3 and 2 ponds are considered for the design. The regression models are used for optimal design of the pond with 1m excavated depth and side slopes (1:1) at 20% probability of exceedence level i.e. wet year condition FAO (1991). Moreover, the regression models for optimal design of the 3-fold rectangular pond with 1 to 5 m excavated depth under wet year condition are shown in Table 1.

$$V_{sc} = 77.789 - 23.1441X + 2.5038X^{2} + 0.184X^{3} \quad ..(15$$

$$H = 19.264 - 19.442\,EXP(-0.018X^{0.691}) \quad ...(16)$$

The value of bed width (X) of the pond is obtained using equation (15) for the catchment harvests of 1256664, 1157377, 988995, and 588869, 533225m^3 for pond I, II, III, IV, and V respectively. Using these values of bed width the height of embankment, H is determined using equation (16). The storage capacity of the pond is again tested using the geometrical equation (3). This storage is then compared with maximum monthly inflow (surface runoff + direct rainfall to the pond+ spillage in the case of downstream ponds) to the respective ponds. The maximum between the two is selected as the final storage capacity of a pond.

Thus, the optimum storage capacity of pond I, II, III, IV and V is obtained as to be 1202244, 1109124, 954495, 579798 and 531588m^3 respectively. The respective dimensions of the five ponds for 1 m excavated depth, (bed width X length X embankment height) are155 X 465 X 8.46m, 150 X 450 X8.31m, 141 X 423 X 8.05m, 115 X 345 X 7.21m and 111 X 333 X 7.07m respectively. The cost of excavation per unit storage of the respective ponds is USD 0.55, 0.56, 0.58 0.63 and 0.64 (Table 2).

The water use planning model developed by linear programming technique with optimal land and water allocated to wheat, maize, chickpea, lentils, potato, tomato and onion crops to provide supplemental irrigation from the ponds is presented some where else.

Conclusion and recommendation

In the water scarce areas, which have sufficient rainfall to meet the crop water demand, water harvesting is a rational approach to mitigate water scarcity problem by collection of water during rainy season and utilizing it during other periods. The geometrical relationships and classical optimization techniques with an objective function of maximizing the storage capacity of the pond satisfying the given constraint that the volume of excavated earth equals the volume of fill required for the embankment are used for design of water harvesting ponds. The optimum geometry and size of the ponds are evaluated with respect to the maximum storage capacity per unit-excavated soil; minimum wetted surface area per unit storage volume, minimum surface area per unit storage volume and minimum construction cost per unit storage volume. From the result the following recommendations are summarized.

i) The 3-fold rectangular shape is the best geometry of pond from among 2-fold rectangular and square ponds with 1-5 m excavated depths.

ii) Under the most practical range of 1-5 excavated depth, the above polynomial and Weibull equations could be used for design of optimal geometry and size of water harvesting pond under the condition that the volume of excavated soil is equal to the volume of embankment.

iii) The optimum storage capacity of pond I, II, III, IV and V is designed as 1202244, 1109124, 954495, 579798 and 531588m^3 respectively under wet year condition.

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The Application of forecasted rainfall for efficient water use and management of irrigated crop production

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Abstract

The increase in food production primarily depends on the judicious utilization of water resources. The effective use of water both for irrigation and rainfed agriculture will be one of the main conditions to meet increasing food demands and to sustain growing competition for clean water. Defining effective strategies in planning and management of water for rainfed and irrigated agriculture is a national and global priority.

The soil water balance is the primary factor determining agricultural production in either rainfed or irrigated agriculture. Methodologies developed by FAO to estimate crop water requirements and to assess yield response to water under various water supply conditions are used in this study.

The results indicate that forecasted rainfall amount could successfully be used in water balance computation for irrigation management.

Introduction

The purpose of utilization of forecasted rainfall amount in crop production is to make a good assessment of the forthcoming harvest at a very early stage in relation to what have been sown. This desire has also been at the base of all crop-breeding programs and has guided the farmer in his estimate of the food requirement of his family. This will allow to predict critical situations, which could lead to food crises, and to take adequate measures well in advance. Too often, crop monitoring is limited to rainfall monitoring where rainfall amounts are cumulated over the season for assessing crop performance. This approach does not take into account (i) how rainfall is distributed over the season and (ii) what the crop actually needs. Agrometeorological monitoring of crops requires thus not only knowledge of what the crop receives through rainfall, but also what the crop needs for inhibited growth. These water needs are called crop water requirements. Crop water needs are different at different growth stages of the crop and that water stress will result in production losses depending on the plant's development phase.

The great challenge for the coming decades will be the task of increasing food production and ensuring food security growing world population, particularly in countries with limited water and land resources. While on global scale water resources are still ample, serious water scarcities are developing at national and regional levels and an increasing number of countries face serious water shortages as existing water resources are fully exploited. Since agriculture and economic development depend on adequate water supplies, water scarcities slow down developments, threaten food supplies and aggravate rural poverty. The dependency on water for future development has become a critical constraint for development.

As a result of some extreme periods of drought over the last decades, it has become increasingly necessary to early monitor crop and to forecast size and quality of harvest, particularly for the cereal crops, which remain the basic source of food. The tool available for agrometeorological crop monitoring will follow the distribution of the rainfall, which directly influences the crop during the growing season and compare it with the water requirements of the crop at each phenological phase. An agrometeorological model was designed by FAO (Frere & Popov, 1979) for crop monitoring and forecasting, based on a cumulative weekly or ten daily crop water balance, which at a given moment of crop growing cycle gives an index expressing the degree of satisfaction of the crop water requirements. The index is strongly correlated with the yield and gives a very good idea of the yield to be expected. The method proposed is intended mainly for utilization in areas where inadequate availability of water to the crop, as regards both amount and distribution, is the main constraint in irrigated agriculture. The methodology for monitoring crops uses simultaneously soil, meteorological and agronomic information for the calculation of the water requirements of the crops. The proposed technique is more precise than a single assessment of actual rainfall alone and its comparison with normal rainfall, but it remains simple enough to be easily operated without sophisticated equipment.

To introduce an effective crop water supply system adequate information is required on the crop water requirements as determined by crop and weather conditions. Is the following examples are provided how to evaluate, plan and manage field water supply conditions based on crop and forecasted rainfall conditions for various irrigation management systems.

Materials And Methods

The cumulative water balance model is used established over the whole growing season for the given crop and for successive periods of ten days or weeks for the management of irrigation. The water balance is the dif-

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Table 1. Standard dekads

Standard Dekad	Date	Standard Dekad	Date	Standard Dekad	Date
1	1-10 January	13	1-10 May	25	1-10 Sep
2	11-20 "	14	11-20 "	26	11-20 "
3	21-31 "	15	21-31 "	27	21-30 "
4	1-10 Feb	16	1-10 June	28	1-10 Octr
5	11-20 "	17	11-20 "	29	11-20 "
6	21-28/29 "	18	21-30 "	30	21-31 "
7	1-10 March	19	1-10 July	31	1-10 Nov
8	11-20 "	20	11-20 "	32	11-20 "
9	21-31 "	21	21-31 "	33	21-30 "
10	1-10 April	22	1-10 Aug	34	1-10 Dec
11	11-20 "	23	11-20 "	35	11-20 "
12	21-30 "	24	21-31 "	36	21-31 "

ference between rainfall received by the crop and the water lost by the crop and the soil. Water retained by the soil should also be taken into account in the calculation (FAO, 1986).

The input data used in the crop water balance model are weather, soil and crop data. The weather data required are on ten-day intervals and include rainfall (actual, average (normal) or dependable, forecasted rainfall amount) and PET. The Soil data required for the model are the soil moisture or the water holding capacity (AWC) in the root zone if the soil moisture data is not available. The crop data includes type of crop, planting dekad in standard dekads (Table 1), length of growth cycle in dekads and crop coefficients.

The basic principle laid over the water balance model is the computation of the balance between moisture added through rainfall or irrigation to that lost through evapotranspiration, surface runoff and deep drainage. Moreover, the calculations follow a procedure known as the "accounting" or the "bookkeeping" method of soil water budgeting. This is expressed as:

$$dSM_i = R_i - (AE_i + (Ro + D)_i)$$

Where: - $dSM_i = SM_i - SM_{i-1}$, soil moisture change in a given time interval (in this case a ten day period or dekad);

SM_i - soil moisture reserve at the end of a given time i, mm

SM_{i-1} - soil moisture reserve at the end of a given time i-1, mm

R_i - Rainfall or irrigation received in a given time i, mm

AE_i - Actual evapotranspiration which has taken place in a given time i, mm

Ro_i - Surface runoff which has taken place in a given time i, mm

D_i - Deep drainage which has taken place in a given time i, mm

i - Standard dekad i = 1...36

Based on the above principles Frere and Popov (1979) have introduced a procedure for the estimation of the water requirement satisfaction index using the FAO model. The calculation of the water balance is carried out on special forms for successive periods.

The different steps involved in the computation of the cumulative water balance are detailed here under with an example for maize crop in Melkassa (East Shoa) (Table 4)

Step 1. Fill column 2 with standard dekads. The first dekad is the planting dekads. The first dekad is the planting dekad and the last one is the maturity dekad.

Step 2. Column 3 refers to the actual rainfall for the corresponding dekad in mm. Actual rainfall is the rainfall amount on real time basis.

Step 3. Columns 4 refer to the normal PET computed from the normal climatic values respectively. PET is defined as the maximum quantity of water, which may be lost by a uniform cover of dense short grass when the water supply to the soil is not limited as defined by Penman (1948).

Step 4. Column 5 refers to the crop coefficient (Kc), which refers to the evapotranspiration of a disease free crop grown in large fields under optimum soil water and fertility conditions and achieving full production potential in the given growing environment (FAO, 1986). The crop coefficient is the ratio between maximum crop evapotranspiration (ETc) and the reference crop potential evapotranspiration (PET) estimated from the Penman formula (Frere & Popov, 1979):

$$Kc = \frac{ETc}{PET}$$

The crop coefficient integrates all effects that distinguish a typical field crop in the different growth stages from the standard grass reference, which has a constant appearance and a complete ground cover. Different crops will have different K_c, while the changing coverage and characteristics of the crop canopy over the growing season also affect the K_c.

Step 5.Column 7 represent the crop water requirement, WR_i is estimated as:

$$WR_i = PET_i \times Kc_i$$

Crop water requirements (WR) are defined as "the amount of water needed to meet the water loss through evapotranspiration of a disease free crop, growing under non-restricting soil conditions including soil water and fertility (Doorenbos et al 1975; 1977). Once crop water requirements are known, water needs can be compared with available water (rainfall and conserved soil moisture) by using a water balance model.

The total water requirement (TWR) of a given crop from planting to harvest is given as:

$$TWR_i = \sum_{PD}^{i}(PETy_i \times Kc_i) + \sum_{i+1}^{HD}(PETn_i \times Kc_i)$$

Where: PD is planting dekad and HD is harvest dekad

Step 6. Column 8 refers to the difference between actual water received either throught rainfall or irrigationand the water requirements. It expresses the quantity of water available to crops, without taking into account the water stored in the soil. From this it can be seen that the effect of a given rainfall amount may vary according to the crop development stage. This value is usually referred as rainfall surplus or deficit (S/D) and is expressed as:

$$S/D = RY_i - WR_i$$

That is if the water supply exceeds

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the water requirements at a given dekad i, it is said to be surplus (and goes to the soil moisture reserve or the runoff). If the water requirement exceeds the rainfall amount of that dekad the deficit is covered from the conserved soil moisture if available.

Step 7. Column 9 refers to the soil moisture (SM) reserve at the end of a given dekad i. This term expresses the quantity of water present in the root zone, which can readily be utilized by the crop. However, it can only be utilized up to a maximum of AWC level and the excess water will go as runoff. It is estimated as:

$SM'_i = SM_{i-1} + S/D$
If $SM'_i < 0$ then $A_i = SM'i$ and $SMi = 0$
if $0 <$ SM'<AWC then $A_i = 0$ and $SMi = SM'_i$
If $SM'i > AWC$ then $A_i = SM'_i - AWC$ and $SMi = AWC$

The amount of water usefully stored in the soil will depend on the depth of the soil exploited by the roots of the crop and the phyto-chemical characteristics of the soil.

Step 8. Column 10 refers to deficit (D_i) or surplus (S_i)

If $A_i <= 0$ then $S_i = A_i$ else $Di = A_i$ that is, under this column when the value is positive then it is S_i or if it is negative then it is D_i

Step 9. Column 11 refers to the extent to which the water requirements of the crop have been satisfied in a cumulative way up to any given stage. This is termed as "water requirement satisfaction index (I)". On the planting dekad, the index is assumed as 100 %, and refers to no stress.

The index is calculated as follows. It is assumed that at the beginning of the growing cycle sowing takes place when ample water is available in the soil. The index is thus assumed to be 100 and will remain at 100 for the successive dekads until a deficit appears. The index at the end of the growing season will reflect the cumulative stress endured by the crop and will usually be closely linked with the final yield of the crop unless some other harmful factors (pests and diseases) have significant effects. i.e.

If deficit ($A_i <= 0$) then $Ii = I_{i-1} - \frac{(A_i \times 100)}{TWR}$

However, if the surplus water has exceeded the AWC, it has also a negative effect on the final yield. In order to determine the effect of this excess water Reddy (1991) has suggested a reduction factor based on the amount of excess water. Hence, if surplus (A_i 0)then $Ii = I_{i-1} - 3xP$

where $P = 0$ if 0, $A_i < 100$
$P = 1$ if 100, $A_i < 200$
$P = 2$ if 200, $A_i < 300$

The correction under surplus condition is valid only if proper soil management was not used.

Step 10. Estimation of the present crop condition

The following procedures are proposed by Reddy (1989) for the estimation of the crop condition. For the purpose of discussion of the crop condition the index is divided into six ranges as indicated in Table 3.

Hence, the final index value 54% in our case indicates that there is moderate to severe drought condition and therefore the crop condition ranges from fair to poor.

Step 11. Estimation of the future crop condition

The future crop condition in terms of I is expected to be reduced or maintained at the same level is expressed by future water requirement (FWR) relative to future water available (FWA).

The FWR for i+1 dekad is estimated as: FWR i+1 = [PETn * Kc] i +1

The FWA for i+1 dekad is estimated as: FWA i+1 = SM i +Rf i +1

Table 2. The crop and drought conditions as determined by the index, I.

I %	Crop condition	Drought situation
? 25	Very Poor	Very Severe
25 - 50	Poor	Severe
50 - 70	Fair - Poor	Moderate - Severe
70 - 80	Fair	Moderate
80 - 90	Good - Fair	Low
> 90	Good	Very low

Where: - i - the current dekad; PETn – normal PET; SM i – Soil moisture at the end of dekad i; Rf i +1 – forecasted rainfall for the coming dekad

Step 12. Estimation of yield

For the quantitative estimates of yields, a direct relationship between the water requirement satisfaction index (I) and the crop yield is used. This yield can be expressed either in absolute figures (Kg/ha) or in relative figures (percentage of optimal crop yield). From experience accumulated in field projects and research institutions, it appears that this cannot be straightforward linear relation. In fact a crop receiving only 50% of its water requirements will see its growth and development severely slowed down. In most cases it will reach some advanced stage in the form of straw, with a negligible yield or no yield at all. In order to assess a relative yield it is first necessary to define the maximum yield possible for a given crop and location.

In light of FAO's experience, it appears advisable to consider the maximum yield as the average of three best yields in a series of say 10 years. This avoids taking as a maximum a yield, which might be exceptionally high for different reasons. On the basis of this "weighted" maximum yield, one can establish the scale, representing the correspondence between the percentage of water requirement satisfaction index (I) and the percentage of maximum yield foreseeable.

% of yield in relation to the average of 3 best yields	Yield condition	Index I,%
? 100	Very Good	100
90 - 100	Good	95 - 99
50 - 90	Average	80 - 94
20 - 50	Moderate	60 - 79
10 - 20	Poor	50 - 59
? 10	Complete failure	< 50

Table 3. Correspondence between the index and percentage of maximum yield.

Results and Discussion

The results of the cumulative water balance are shown in table 2. As indicated in the table a 180 day maize crop

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Table 4. Cumulative water balance worksheet for Melkassa during the 2001cropping season on Maize crop with 75 mm water holding capacity and observed rainfall amount.

No.	Dekad	Observed rainfall amount	PETn	Kc	WR	RR-WR	SM	S/D	I,%
1	13	68.6	52	0.3	15.6	53	53	0	100
2	14	34.2	52	0.3	15.6	19	72	0	100
3	15	34.8	59	0.3	17.7	17.1	75	14	100
4	16	32	50	0.3	16.0	17	75	17	100
5	17	63.2	48	0.39	18.7	44.5	75	45	100
6	18	78	49	0.56	27.4	-19.6	55	0	100
7	19	104.9	45	0.73	32.9	72	75	52	100
8	20	64.5	39	0.9	35.1	29.4	75	29	100
9	21	52.0	47	1.07	50.3	1.7	75	2	100
10	22	64.4	42	1.15	48.3	16.1	75	16	100
11	23	41.9	40	1.15	46.0	-4.1	71	0	100
12	24	53.1	45	1.15	51.8	1.3	72	0	100
13	25	31.3	43	1.15	49.5	-18.2	54	0	100
14	26	19.5	45	1.15	51.8	-32.3	22	0	100
15	27	0.0	42	1.08	45.4	-45.4	0	-23.4	96
16	28	1.4	49	0.94	46.1	-44.7	0	-44.7	89
17	29	0.0	50	0.81	40.5	-40.5	0	-40.5	83
18	30	0.0	54	0.67	36.2	-36.2	0	-36.2	77

TWR = 643.9 mm

Tablele 5. Irrigation needs determination for Melkassa using forecasted rainfall data

Dekad	FWR	FWA			FWA-FWR	Irrigation need
		SM	Forecasted rainfall (Rf)			
27	45.4	0.0	N/AN	19.3	-26.1	26
28	46.1	0.0	N	9.6	-36.5	37
29	40.5	0.0	N	5.4	-35.1	35
30	36.2	0.0	BN	10.5	-25.4	25

over Melkassa does not suffer from water shortage from planting (May) up to the second dekad of September. However, after this period the rainfall failed to satisfy the water requirement of the crop. As a result, the final index dropped to 77%. This index indicates that there is a moderate end season drought, which reduced the percentage of maximum yield in relation to the average of 3 best yields to drop as low as 47%.

However, to avert this condition we need to determine irrigation need based on the forecasted rainfall amount. The computation is shown in table 5. In the table the future water requirement (FWR) is the water requirement of the crop determined as indicated in step 11 above. Future water available (FWA) is computed from the soil moisture reserve and the forecasted rainfall amount. The difference between FWA and FWR in positive sign is irrigation requirement. Therefore, this amount is required through irrigation.

Based on this value, the cumulative water balance is further computed with adjustments. The observed rainfall amount and the water supply through irrigation together constitute the water supply to satisfy the crop water requirement. It is indicated at the end of the season that the index has raised to 93%. This indicated that we have minimized the drought risk to negligible level and the maximum yield to be obtained rose to 87%.By using the forecasted rainfall amount for determining the irrigation need we have lifted the index from 77% to 93 % and correspondingly the expected yield for 47% to 87%.

Table 6. Computation of water requirement satisfaction index based on forecasted rainfall for Melkassa

Dekad	Water available			WR	Total-WR	SM	S/D	I,%
	Observed rainfall amount	Irrigated	Total					
27	0.0	26	26	45.4	-19.4	0	-19.4	97
28	1.4	37	38.4	46.1	-7.7	0	-7.7	96
29	0.0	35	35	40.5	-5.5	0	-5.5	95
30	0.0	25	25	36.2	-11.2	0	-11.2	93

Conclusions And Recommendations

The soil water balance is the primary factor determining agricultural production in either rainfed or irrigated agriculture. In water balance studies climate and soils are linked to determine the length and characteristics of the growing season and potential yields of a given region. As a result of this, it has become necessary to forecast the size and quality of harvest particularly for cereal crops - which remain the basic sources of food in most parts of the world. However, the method presented here does not claim to replace the other forms of crop assessment based mainly on statistical sampling. Instead, it constitutes a useful complement, allowing an early assessment of the crop situation based on the causes of possible modifications in crop behavior leading to crop production loses.

The cumulative water balance method demonstrates the utility of calculating the water requirement of crops for short period of 7 or 10 days to show yield losses due to water stresses in the plant during its growing cycle. It is evident that other factors could contribute to yield reduction. These elements may be physical such as strong winds, floods causing water logging, or biological such as locusts, birds, fungi or insects.

For this reason, the establishment of a final forecast of the yields will depend in many cases on the water status of the plant, but should also take in to account all the other causes. This is why information as complete as possible on all aspects of crop development is important for the establishment of a good crop monitoring and forecast-

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ing system in the country.

In general, factors affecting yield are so numerous and variable, both in time and space, that any attempt to cover all these aspects will inevitably complicate any model, to such a degree that it will no longer be possible to utilize it for any practical operation, since the time factor is the most important of all. Our own aim is to find a model, which operates with the maximum of simplicity, which takes in to account all the agricultural and other characteristics of the country and is able to provide yield variation tendencies on time.

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Analysis of Rainfall Climate and Evapotranspiration in Arid and Semiarid Regions of Ethiopia using Data over the last half a Century

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I. Characterization of Rainfall of the Region

Abstract

Although it is one of the most drought-hit countries in the world, almost no study has ever been conducted in characterizing the rainfall pattern of the arid and semiarid regions of Ethiopia. In this study, rainfall data of the past 50 years was used to study the basic statistical characteristics of the rainfall of this region. Probability of rainfall expected in wet, normal, and a dry year was determined using RAINBOW software. Frequency histogram of the rainfall distribution of the stations was prepared. Probability of wet days and dry periods of different durations was determined. It has been found that the rainfall distribution is positively skewed. Heavier rainfall events are infrequent but they make up a significant percentage of the total rainfall. There is high variation of rainfall pattern among the stations.

Introduction

Generally only few studies have been conducted of rainfall characteristics of arid and semiarid of the tropics (Rowntree, 1988). A review of research on tropical rainfall reveals that most detailed studies have been concerned with the more humid areas, a reflection of the distribution of both population and rainfall stations (Jackson, 1977; Oguntoyinbo and Akintola, 1983). The few published studies available from semiarid areas tend to be from outside of the tropics (Sharon and Kutel, 1986) and the results are not necessarily representative of tropical areas. Ethiopian arid and semiarid region is not an exception with almost no study on the climatic pattern of this area. With the current high population growth rate of about 3%, the present and future pressure on marginal lands seems to be greater than ever. In this area rainfall is undoubtedly the main environmental factor limiting the development.

The present study tries to characterize the rainfall in the arid and semiarid region of Ethiopia. Distribution of daily rainfall totals by frequency and amount, rainfall variability, monthly rainfall distribution, frequency of dry and wet years, annual rain-days and monthly evapotranspiration distribution were considered. The study provides essential information for several local research programs, rehabilitation projects, irrigation scheduling, and hydrological studies in the area.

Materials and Methods

The study area encompasses the arid and semiarid region of Ethiopia found in the southern, southern-eastern, eastern, and north-eastern part of the country. The altitude, latitude, and longitude of the meteorological stations are presented in Table 1. Daily weather data, including rainfall, was obtained from the National Meteorological Services Agency (NAMSA) of Ethiopia. The length of data record for all the stations was greater than the 30 years of climatic data needed to do accurate climatic analyses in the tropics (Stewart, 1988; Aldabadh et a., 1982). Traditional summary statistics were used to characterize the rainfall data.

Monthly reference evapotranspiration was calculated using the FAO Penman-Monteith equation (Allen et al., 1998) given as

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\left[900/(T+273)\right]u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where ET_o is the reference evapotranspiration (mm/day), R_n is the net radiation at the crop surface (MJ/m²/day), G is the soil heat flux density (MJ/m²/day), T is the air temperature (°C), u_2 is the wind speed at 2 m height (m/s), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), (e_s-e_a) is the saturation vapor pressure deficit (kPa), " is the slope of vapor pressure curve (kPa/°C), and g is the psychrometric constant (kPa/°C).

The monthly reference evapotranspiration frequency analysis was done

Table 1. Range of rainfall data and geographical location of the meteorological stations

Station	Rainfall data range	Altitude (m asl)	Latitude	Longitude
Assaita	1964-2002	420	11°20'N	41°16'E
Assebe Teferi	1962-2002	1900	9°02'N	40°31'E
Dire Dawa	1953-2002	1260	9°22'N	41°30'E
Gode	1967-2002	295	5°32'N	43°21'E
Jijiga	1953-2002	1775	9°12'N	42°28'E
Mekele	1960-2002	2070	13°18'N	39°17'E
Nazareth	1954-2002	1622	8°20'N	39°10'E
Negele Borena	1953-2002	1544	5°12'N	39°20'E
Zeway	1970-2002	1640	7°34'N	38°26'E

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using RAINBOW software (Raes et al., 1996). The program is designed to execute a frequency analysis of rainfall and evapotranspiration data. It is especially suitable for predicting the probability of occurrence of either low or high rainfall amounts.

The agro-climatic zonation of the meteorological stations was determined using UNESCO aridity index (AI) given in Rodier (1985) as

$$AI = \frac{P}{ET_o} \qquad (2)$$

where P is the mean annual rainfall and ETo is the mean annual reference evapotranspiration.

In order to determine the probability of a wet day P_{wet}, the number of days (n_i) that were wet were counted and expressed as a fraction of the total number of days (N_s) on record for the station as

$$P_{wet} = \frac{n_i}{N_s} \qquad (3)$$

Since the climatic records for the stations are all greater than the minimum recommended length of data record (i.e., 30 years), the sample estimate is assumed to be reasonably closer to the population's probability of wet days. A day was considered to be wet when there was more than 1 mm of rainfall and dry when rainfall was 1 mm or less. The probability of wet day vs. time was plotted to show the time when the station is likely to be dry or wet.

Table 3. Exceedence probability and return period for annual rainfall of different

Exeedence probability	90%	80%	50%	20%
Return period (years)	1.11	1.25	2	5
Assebe Teferi	606	694	863	1031
Negele Borena	417	523	726	928
Zeway	494	578	738	897
Jijiga	372	480	685	891
Dire Dawa	395	473	622	771
Mekele	436	500	623	747
Gode	36	108	247	385
Assaita	59	92	157	221

magnitudes

The probability of a dry spell of a given duration was estimated by using a conditional probability as follows. From the daily rainfall data, the number of rainy days and dry days were counted. The event "day *i* is rainy" is denoted as R_i while the event "day *i* is dry" is denoted as D_i. The notation $P(D_i/D_{i-1})$ is the probability that two consecutive days are dry and $P(D_i/D_{i-1} \cap D_{i-2})$ is the probability that three consecutive days are dry. Similarly $P(W_i/W_{i-1})$ is the probability that two consecutive days are wet. In this way, dry periods of lengths of upto one month were determined. A major application of dry spell analysis is to predict extended drought durations during the growing season, which forms a basis for planning the crop production strategies (Sharma, 1996).

Monthly and annual dependable (20%, 50%, and 80% exceedence) rainfall was calculated using RAINBOW. The 20% dependable rainfall is expected on average to be exceeded in 1 out of 5 years, 50% in 1 out of 2 years, and 80% in 4 out of 5 years. The frequency of dry, normal, and wet years was estimated after calculating the 20% and 80% dependable rainfall. Each year with annual rainfall above the 20% dependable rainfall was taken to be a wet year, each year with annual rainfall less than the 80% dependable rainfall was taken to be a dry year. Each year with annual rainfall in between 20% and 80% dependable rainfall was taken to be a normal year. The number of dry, normal, and wet years were then counted and expressed as a percentage of the total number of years on record for the station. This gives estimates for the frequency (probability of occurrence) of dry, normal, and wet years.

The distribution of daily rainfall totals by amount and frequency was obtained using a frequency analysis of historic daily rainfall. This was achieved by counting the number of times a daily rainfall of specified amount occurred during the recorded period for the station.

Table 2. Agroclimatic zonation

Station	Precipitation (mm)	Evapotranspiration (mm)	Aridity Index	Zonation
Assaita	157	1842	0.09	Arid
Assebe Teferi	863	1651	0.50	Semiarid
Zeway	737	1554	0.47	Semiarid
Mekele	627	1742	0.36	Semiarid
Gode	266	2156	0.12	Arid
Jijiga	672	1634	0.41	Semiarid
Negele Borena	727	1505	0.48	Semiarid
Dire Dawa	628	1970	0.32	Semiarid

Results and Discussion

Agroclimatic zonation

The aridity index (AI value) calculated using Eq. (2) is presented in Table 2. Included in the table is also the corresponding agroclimatic classification of the stations based on the UNESCO classification criteria. Two areas, Assaita and Gode, are relatively arid as can be seen from the low rainfall and high evapotranpiration in these areas. In some stations such as Dire Dawa, although the evapotranspiration is high, due to the relatively high rainfall, it is described as semiarid.

Amount of rainfall expected in dry, normal, and wet periods

Exceedence probability and return periods of annual rainfalls of different magnitudes is shown in Table 3. Some areas such as Gode and Assaita, even if the rainfall at exceedence probability of 20% is considered, it is not possible to produce crops without irrigation. Monthly dependable rainfall for Dire Dawa, Mekele, Gode and Negele

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Table 4. Dry, normal, and wet year probabilities

Station	Dry		Normal		Wet	
	Rainfall, P (mm)	Probab-ility (%)	Rainfall, P (mm)	Probab-ility (%)	Rainfall, P (mm)	Probab-ility (%)
Assebe Teferi	P<694	15	694<P<1031	65	P>1031	20
Negele Borena	P<523	20	523<P<928	60	P>928	20
Zeway	P<578	24	578<P<897	52	P>897	24
Jijiga	P<480	12	480<P<891	72	P>891	16
Dire Dawa	P<473	22	473<P<771	62	P>771	16
Mekele	P<500	19	500<P<747	65	P>747	16
Gode	P<108	14	108<P<385	69	P>385	17
Assaita	P<92	23	92<P<221	56	P>221	21

Table 5. Monthly rainfall of some meteorological stations at different exceedence probability levels)

Month	Monthly dependable rainfall (mm)											
	Dire Dawa			Mekele			Gode			Negele Borena		
	80%	50%	20%	80%	50%	20%	80%	50%	20%	80%	50%	20%
Jan	0	0.0	47.5	0	0	6.2	0	0	0	0	0	8.8
Feb	0	3.9	45.4	0	1.8	11.7	0	0	0	0	2.3	29.5
Mar	18.1	59.3	118	2.6	23.0	51.0	0	3.0	24.3	3.7	44.7	113.9
Apr	33.1	83.1	151	7.3	27.8	59.1	20.8	62.0	125.3	123	197.7	270.9
May	7.4	37.3	80.1	5.3	25.4	56.2	12.5	36.0	94.8	75.6	127.9	216.0
Jun	4.8	18.3	38.1	9.3	30.0	59.9	0	0	0.4	0	6.6	20.4
Jul	43.8	82.1	133	143	202.8	273	0	0	0	1.0	4.4	11.4
Aug	84.5	125	173	143	228.7	309	0	0	0	0	3.2	9.6
Sept	37.4	63.8	97.2	13	31.2	55.7	0	0	4.7	13.3	33.1	61.7
Oct	1.8	10.4	41.2	0	0	6.4	10.6	30.8	86.4	86.0	155.2	224.3
Nov	0	2.0	33.2	0	0	8.9	3.8	15.9	50.5	10.3	40.9	86.5
Dec	0	0	9.0	0	0	0	0	0	0	0	4.0	20.1

Borena representing the east, north, south-east, and south of the country determined using RAINBOW is presented in Table 5.

The distribution of dry, normal, and wet years for the stations is shown in Table 4. From the table it can be seen that in almost 60% of the years, the rainfall received is within the normal range, in about 20% of the cases it is in the wet range and the remaining 20% is in the dry range. The accuracy of these estimates will increase as the length of the climatic record increases.

The shape of the rainfall distribution is important in that interpretations of several statistical terms depend on it. The distribution of a set of observations is best characterized by a histogram, a chart which portrays information about the central tendency as well as about the variability of the observations. The frequency of rainfall of different ranges is plotted as shown in Fig. 2. The histograms indicate that small rainfall occurs more frequently than do relatively large amounts. Such a distribution is said to be "positively skewed." This type of skewness is characteristic of the distribution of rainfall in arid and semiarid regions. In particular, the drier the climate, the higher will be the degree of skewness (see also the values of index of skewness in Table 6). Table 6 shows the basic statistical parameters relating to each rainfall station. The coefficient of variation of annual or seasonal point rainfall is, in general, negatively correlated with mean annual rainfall amount indicating the greater variability of annual rainfall with decreasing mean rainfall at a point. The ratio of mean deviation to the standard deviation has been included as an indication of the normality of the distributions. For a normal distribution, this value is about 0.80 with the 95% probability limits of 0.75 and 0.85.

Another characteristic of arid zone rainfall, in addition to its skewness, is its variability. Water development planning and management in arid zones present difficulties which are due less to the limited amount of rainfall than to the inherent degree of variability associated with it. In temperate climates, the standard deviation of annual rainfall is about 10-20%. In arid and semi-arid climates, this value is much higher. The practical implications of rainfall skewness and variability for assessing the impacts of climate on society are that such impact assessments should be based on entire probability distributions rather than on mean values alone.

In comparing the mean and the median, it should be noted that for a positively skewed distribution, the median is smaller than the mean. This contrasts with the normal distribution, for which the mean and the median are identical, except for sampling fluctuations. The mean is extremely sensitive to skewness in that it tends to be inflated by the relatively few cases of large values which cause more than half of the observations to fall below the mean. For example, the number of rainfall data below the mean (%) for some of the stations are: Assaita (56%), Negele Borena (58%), Zeway (55%), Jijiga (62%), Gode (61%), and Mekele (51%). In addition, rainfall observations close to the mean value do not occur often in arid and semiarid regions. For example, the number of observations falling within 10% of the mean are: Assaita (21%), Negele Borena (26%), Jijiga (32%), Gode (19%) for Gode, Dire Dawa (34%), and Mekele (37%). Hence one might conclude that, at least in some sense, the mean is too large and not at all indicative of how much rainfall commonly occurs in this region, making its interpretation unclear.

The median, as a measure of the midpoint of the distribution of rainfall observations, is affected only by the number of extreme observations and not their values. It is, therefore, less

Table 6. Basic statistics of the annual rainfall data at different meteorological stations

Station	Period	Mean	SE*	Median	SD+	CV⁻	Kurtoisis	Skewness	Minimum	Maximum	Range	95% CB⁼	|d|°	|d|/SD
Assaita	1964-2002	157	12	148	72	0.45	-0.36	0.36	14	311	297	23	57	0.79
Assebe T.	1962-2002	863	30	864	189	0.22	0.41	-0.09	404	1286	882	60	144	0.76
Dire D.	1953-2002	628	22	641	157	0.25	-0.57	-0.08	313	948	635	45	123	0.79
Gode	1967-2002	266	27	244	159	0.59	2.15	1.23	39	754	715	54	115	0.72
Jijiga	1953-2002	672	31	619	222	0.32	1.66	1.44	398	1295	897	63	156	0.70
Mekele	1960-2002	627	23	624	148	0.24	1.76	0.70	317	1106	788	46	110	0.74
Negele B.	1953-2002	727	33	695	223	0.31	0.55	0.68	292	1381	1089	65	181	0.81
Nazareth	1954-2002	821	25	830	171	0.21	0.71	-0.13	366	1217	851	49	124	0.72
Zeway	1970-2002	738	31	684	178	0.24	-1.09	0.21	442	1095	654	63	154	0.86

SE* = standard error, SD⁺ = standard deviation, CV⁻ = coefficient of variation, CB⁼ = confidence band, |d|° = mean deviation

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sensitive to skewnes than is the mean. In addition, and more important, the presence of skewness does not change its interpretation. The median still marks the amount of precipitation which is exceeded one-half of the time. The difference between these two measures of central tendency raise the question: which one best represents "normal" with respect to the rainfall in this region? It can be argued that for this region the mean, in reality, is above "normal", while the median can still be interpreted as "normal". Hence it is important to note that, although most analyses of semiarid rainfall assume that the mean is an appropriate measure of central tendency, the median may, depending on the circumstances, be preferable.

The standard deviation is a statistic which only measures the variability well when the observation are normally distributed. Because it is a measure of the degree to which each observation deviates from the mean, the standard deviation is based on a measure of central tendency which, as has been noted for the arid and semiarid Ethiopian rainfall data, is too large. The standard deviation is also overly sensitive to extreme values because they result in large, unrepresentative squared deviations from the mean. Consequently, a few relatively large amounts of precipitation may make an inordinate contribution to the standard deviation. There appears to be two definite advantages of the CV as a measure of rainfall variability: firstly, it is considerably faster and easier to compute from original data; and secondly it is intimately related to a measure which characterizes the frequency distribution of any series of rainfall totals. However, because the coefficient of variation differs from the standard deviation only in division by the mean, it has the same deficiencies. The range is a simple measure of variability. It is not particularly sensitive to skewness because it does not depend on the shape of the distribution curve. Its interpretation is, therefore, always clear; it is the difference between the greatest and the smallest amounts of rainfall ever observed.

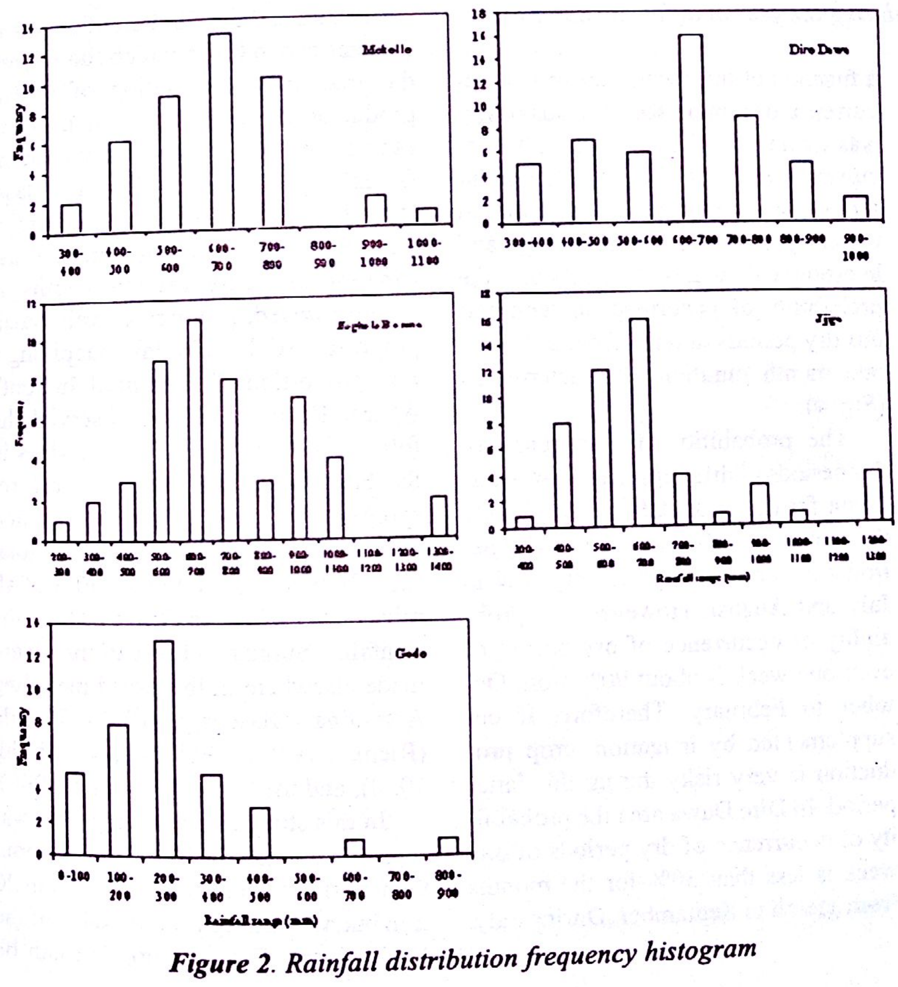

Figure 2. Rainfall distribution frequency histogram

Probability of a wet day

The frequency of rain-days is an important determinant of annual rainfall (Hofmeyr and Gouws, 1964). Knowledge of wet day probability is important in the soil and water conservation planning and to predict the incidence of crop diseases. It should however be noted that higher number of rainy days for arid and semiarid areas do not necessarily imply higher amount of rainfall since in arid areas smaller number of rainy days are more frequent. A daily point rainfall frequency analysis was carried out and the result is presented in Fig. 3. The plotted points on the graph show the frequency of occurrence of daily rainfall of 1 mm or more for each calendar day in the record period. The probability plot clearly shows the rainfall pattern in a year. It can be seen that over a long time period, there is a well-defined daily rainfall probability pattern within the season. The shape of the curve varies from station to station. From the figure, the probability of daily rainfall occurrence throughout the year may be inferred. Thus, for example for Dire Dawa, we would expect about 2 rain-days in January (0.07 x 30), 7 in March (0.24 x 30), and 13 in July and August (0.43 x 30).

The probability of a day being wet throughout the year is 0.75 for Mekele, 0.50 for Dire Dawa, 0.52 for Negele Borena, 0.48 for Jijiga and 0.55 for Zeway. Since the rainfall pattern in Mekele is highly unimodal, 80% of Mekele's annual rainfall occurs from June to September. The Mekele area is almost dry for the rest of the season (October to May). The rainfall intensity is high during this period and runoff and erosion would be very high unless different soil and water conservation structures are implemented. The rainfall pattern in Dire Dawa area is bimodal with two rainfall peaks: one from March to April and the other from July to September. The first peak occurs in the last week of March while the second peak occurs in the beginning of August. About 45% of the annual rainfall occurs in the second peak period. The highest probability is 0.38 during the first peak period and 0.50 during the second peak. Negele Borena also

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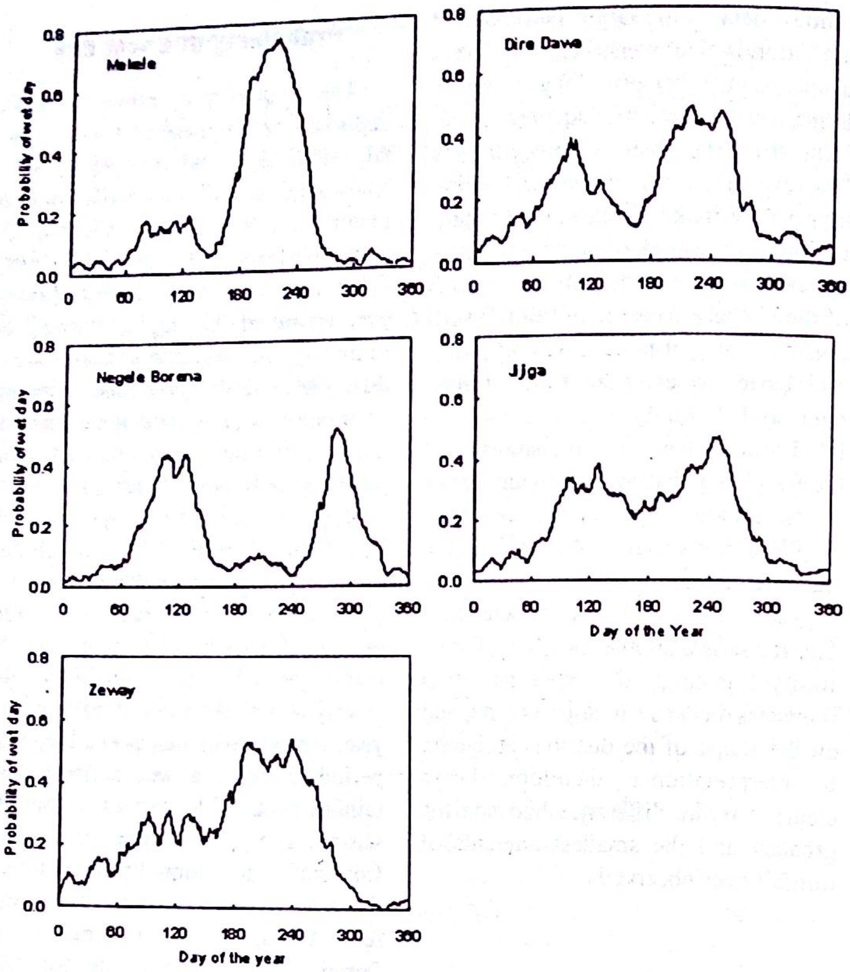

Figure 3. Probability of a wet day during the year at different stations.

exhibits a highly bimodal rainfall pattern. The two peak periods are such that: the first peak is from mid March to mid May and the second peak is from beginning of October to mid November. Unlike other stations, July and August are dry periods. Jijiga area exhibit only slight bimodality in April and May and September with the annual highest number of rainy days occurring in September. Generally, the rainfall is distributed from March to September. At Zeway, the number of rainy day starts increasing in March and peaks in August and decreases then after. At a probability level of 0.20 of a day being wet, only a period can be identified from June to mid September which is the main growing season.

Probability of dry periods of different durations

Further investigation into the probability of occurrence of daily rainfall as a function of the occurrence or non-occurrence of rain on the previous day(s) was carried out. Knowledge of the occurrence of dry periods of different durations is important in agricultural planning (irrigation scheduling) and hydrological studies. In this study the probability of occurrence of continuous dry periods ranging from 2 days to one month duration was determined (Fig. 4).

The probability of occurrence of dry periods of different lengths was different for different stations. At Mekele the probability of occurrence of dry period of even two days is very low in July and August. However, the probability of occurrence of dry period of even one week is about 90% from October to February. Therefore, if not supplemented by irrigation, crop production is very risky during this latter period. In Dire Dawa area the probability of occurrence of dry periods of one week is less than 50% for the months from March to September. During July, August and September, the probability of dry period of two consecutive days is less than 40%. At Zeway, the probability of dry period of one week is less than 60% for the months from February to October. The probability of occurrence of dry period of 3 days in July and August is the same as that of the probability of dry period of one week in June. In Negele Borena area, the probability of dry period of one month is less than 60% throughout the year while the probability of dry period of two days to one week is more than 60% for the months of June, July and August. In Jijiga area, the probability of dry period of even two days is less than 60% throughout the year. The probability of dry period of one week is less than 20% in July, August and September and the probability of dry period of two weeks is less than 20% for the months from April to September.

Cumulative frequency and cumulative depth of daily rainfall

The annual distribution of storms is summarized in Fig. 5 which shows both the frequency distribution of storms producing various rainfall amounts and estimate of percentage of annual rainfall falling in storms within each class. It can be observed that the lightest rainfall events are more frequent. The distribution of daily rainfall depths is highly skewed, a comparatively small proportion of the rain-days supplying a high proportion of the rainfall. In South Africa, Harrison (1983) observed the following: only 13% of all rain-days in the Eastern Orange Free State are responsible for 50% of the rainfall and only 27% contributed 75% of the total rainfall, whereas the lowest 50% of all rain-days produce as little as 7% of the rainfall. Similar observations were made elsewhere in the world including Argentina (Olascoaga, 1950), Florida (Riehl, 1949), Philippines (Riehl, 1950), and the Sudan (Hammer, 1968).

In this study the following observations were made. In Mekele area about 98% of the storms produce less than 20 mm but accounting for only 60% of the total rainfall. From Figure 5 it can be

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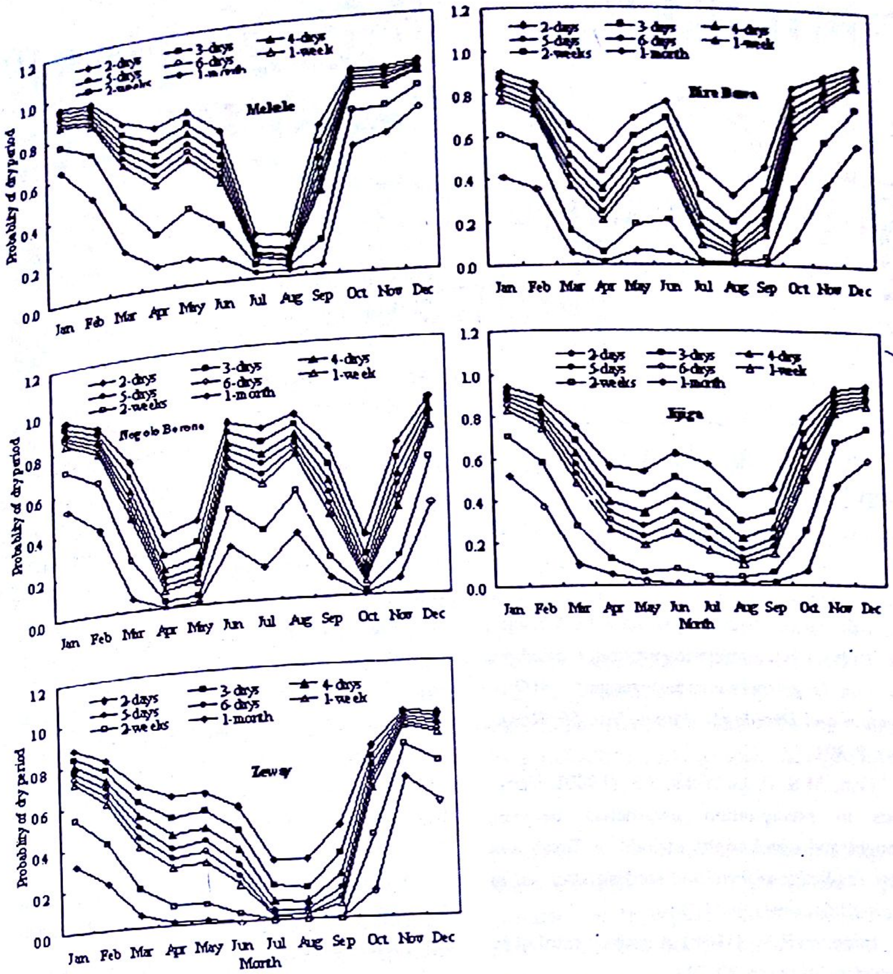

Figure 4. The probability of dry periods of different

seen that 3% of the storms and 53% of the total rainfall amounts equal or exceed the 15 mm required for rainwater harvesting (Roberts, 1985). Although the heavier rainfall events are relatively infrequent, they make up a significant percentage of the total rainfall. At Dire Dawa, about 98% of the storms produce less than 20 mm but accounting for only 53% of the total rainfall. Only 1% of the storms produce 40 mm of rainfall or more, yet they account for 18% of the annual rainfall total. In Negele Borena area, about 97% of the storms produce less than 20 mm but accounting for only 45% of the total rainfall. Five percent of the storms and 67% of the total rainfall amounts equal or exceed the 15 mm. Only 1% of the storms produce 40 mm of rainfall or more, yet they account for 24% of the annual rainfall total. At Jijiga, about 97% of the storms produce less than 20 mm but accounting for only 55% of the total rainfall. From the figure it can be seen that 4% of the storms and 57% of the total rainfall amounts equal or exceed the 15 mm. One percent of the storms produce 40 mm of rainfall or more, yet they account for 17% of the annual rainfall total.

The annual rainfall volume was plotted against annual number of rain-days for Dire Dawa data (Fig. 6). It can be observed that the number of rain-days was positively correlated with total annual rainfall ($r = +0.57$). In most of the years, a decrement in rainfall volume implies a decrease in number of rain-days. But in dry periods the correlation between annual rainfall and annual rain-days cannot be significant, as in the longest dry period, the number of rain-days remained high inspite of the low precipitation as observed also by Lazaro et al. (2001) in Spain.

Rubin (1956) showed that rainfall over South Africa increases with both increasing numbers of rain-days and increasing rain per day. Equivalent results have been obtained elsewhere (Riehl and Schacht, 1947; Smith and Schreiber, 1974). This has an important implication as the mitigation of droughts by cloud seeding may depend on the maintenance of a sufficiently high frequency of light rainfall events during a dry period (Flyn and Griffiths, 1980).

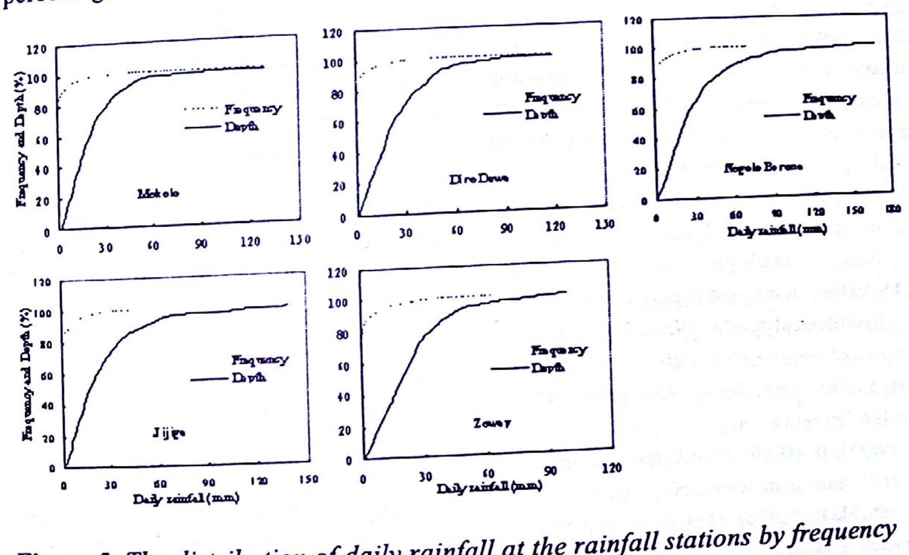

Figure 5. The distribution of daily rainfall at the rainfall stations by frequency and amount

Conclusions

Most of the dry areas of Ethiopia can be classified as semiarid climate rather than arid. The rainfall in this region is positively skewed indicating more number of small rainfalls than big ones, and the median value was smaller than the mean which are characteristics of arid and semiarid regions rainfalls. Although heavier rainfall events are infrequent, they make up a significant percentage of the total rainfall. Consid-

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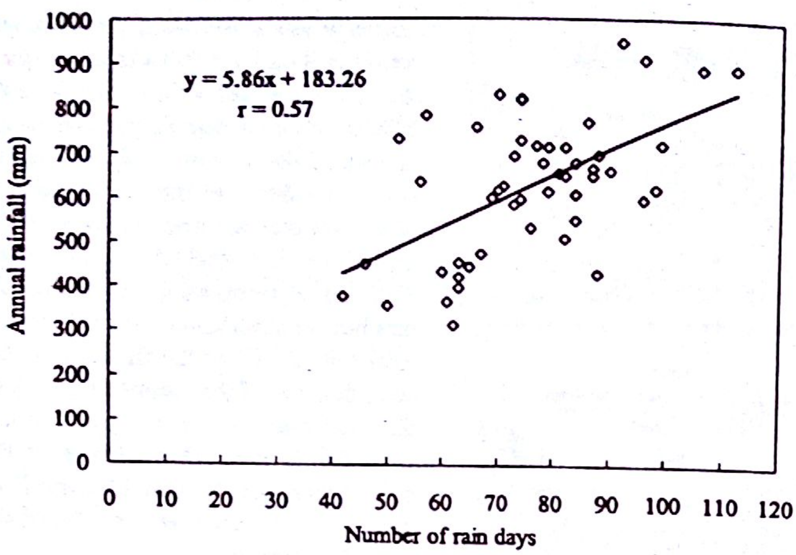

***Figure 6.** The relation between annual rainfall and number of rain-days at Dire Dawa*

ering a rainfall level which is exceeded in 4 out of 5 years, rainfall in most of the arid and semiarid regions of Ethiopia is not sufficient to support rainfed agriculture. Therefore, impact assessment should be based on entire probability distributions rather than on mean value alone. Since the time of occurrence of rainy days varies irrigation and water conservation planning should be designed accordingly.

The probability of getting a day which is wet throughout the year is 0.75 for Mekele, 0.50 for Dire Dawa, 0.52 for Negele Borena, 0.48 for Jijiga, and 0.55 for Zeway. The probability plot of number of wet days follows similar pattern as the rainfall amount distribution in a year. Annual rainfall was positively correlated with the annual number of rain-days.

It is becoming increasingly important to understand the nature of variability of rainfall so as to be able to optimally utilize the low rainfall areas for agricultural purposes. A simple analysis of the frequency distribution of seasonal or annual rainfall amounts is of course of great value giving estimates of probabilities of having more (or less) rainfall than certain specified amounts.

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Analysis of Rainfall Climate and Evapotranspiration in Arid and Semiarid Regions of Ethiopia using Data over the last Half a Century

Dr.Ketema Tilahun, Alemaya University

II. Analysis of Rainfall and Evapotranspiration Pattern

Abstract

Rainfall and evapotranspiration are the two major climatic factors affecting agricultural production. While rainfall can be directly measured, evapotranspiration is estimated from weather data. In this study reference evapotranspiration ETo was estimated using Penman-Monteith, under full data and limited data availability conditions, and Hargraves method. Monthly rainfall and evapotarnspiration data were plotted and compared in order to determine moisture deficit periods for several stations in arid and semiarid parts of the country. Rainfall and reference evapotranspiration at different probability levels were compared. Temporal variation of annual rainfall was analyzed using variability indices: cumulative departure index, standard climate departure index and rainfall anomaly index. It was found that when there is only limited data, it is better to estimate ETo using FAO Penman-Monteith method than using simplified methods such as Hargraves. ETo showed relatively low variation with time while year to year rainfall variability was very high. From these plots information on rainfall pattern over the past 50 years, such as drought years was obtained.

Introduction

In general, soil moisture management in arid and semiarid areas is faced with limited and unreliable rainfall and high evapotranspiration rate. Therefore, it is essential to understand the spatial and temporal variability of the amount of rainfall received in relation to evapotranspiration rate in order to develop effective management strategies. The Horn of Africa has for a long time been an area neglected by climatological studies. However, repeated droughts badly affect the region, each time claiming the lives of several hundred thousands of people, e.g., 1973-1974 and 1982-1985 in Ethiopia (Beltrando and Camberlin, 1993). It is true that long term annual rainfall series in African dryland countries are limited (Ogallo, 1983). However, some authorities (e.g. Dennett et al., 1985) would argue that long term records are not needed, since it is more appropriate to use the last 20 or 30 years of annual rainfall data to plan effective development and rehabilitation strategies.

In order to develop objective techniques for forecasting seasonal and annual rainfall amounts a study of the variability of rainfall based on past records is essential. A presentation of the variation of this basic climatic parameter in this part of the world may also contribute to the understanding of the large scale behavior of the atmosphere. Some earlier studies of the East African rainfall variability have been summarized in Brown and Cocheme (1973). Recently, a major concern has also emerged about an increasing frequency of dry years in many parts of sub-Saharan Africa.

Evapotranspiration is another important climatic factor in the arid and semiarid areas but its accurate estimation is very difficult. However, the evaporation from a free water surface (pan evaporation) and the evapotranspiration of a perfectly irrigated permanent vegetation cover (reference evapotranspiration) are not too difficult to evaluate. Having well-defined conditions, these two kinds of evaporation may provide benchmark characteristics of evaporation for climatic conditions. Both are very useful for practical purposes. In this study reference eavpotranspiration was determined using the FAO Penman-Monteith method (Allen et al., 1998).

The major objectives of this work were to statistically analyze the temporal variation in monthly and annual rainfall and evapotrnspiration in the area, identify drought periods using various indices, and determine the frequency of dry, normal and wet years. The parameters analyzed were rainfall variability, monthly rainfall distribution, frequency of wet years, annual rain-days, and monthly distribution of evapotranspiration.

Material and Methods

The basic data consists of weather data for 9 stations given in Table 1 (Tilahun, this issue). Daily rainfall, maximum and minimum temperature, relative humidity, wind speed and sunshine hours data were obtained from the National Meteorological Services Agency (NAMSA) of Ethiopia from the period as early as 1950s for some of the stations. In order to obtain uninterrupted data series, missing values were synthesized by correlation with neighboring stations. For many agrometeorological purposes the WMO recommended that length of 30 years will be quite adequate. This is especially the case for agricultural planning purposes where most of the decisions are made relative to the immedi-

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ate, rather the most distant past (Todorov, 1985).

Rainfall was used in drought index calculations since it is the most important hydrological variable and generally one of the only meteorological measurements made in arid and semi-arid areas. Rainfall variability indices were used to identify droughts and to establish some arbitrary values for drought identification. These simple indices with rainfall as the only input perform comparatively well compared with more complicated indices in depicting periods and density of droughts (Oladipo, 1985).

One of the rainfall variability indices used was the simple climate departure index (SCDI) or standard score. Variations of the SCDI (z-score) have been used by Ojo (1987) and Suckling (1987) to describe annual rainfall variability. It is calculated as

$$SCDI(Z) = \frac{X - \mu}{\sigma} \qquad (1)$$

where SCDI(Z) represents the simple climate departure index (standard score), X a given annual value, m the arithmetic mean of the distribution, and s the standard deviation of the distribution. For a normal probability distribution, approximately all values are within ± 3s of the mean. Similarly, there is a 68% probability that a value will lye within the interval m±1s, and 95% probability that the value is between m±2s. Another index was the van Rooy (1965) rainfall anomaly index (RAI), which has been modified to account for non-normality, and is calculated as follows for positive anomalies

$$RAI = +3\left[\frac{RF - M_{RF}}{M_{H10} - M_{RF}}\right] \qquad (2)$$

and for negative anomalies

$$RAI = -3\left[\frac{RF - M_{RF}}{M_{L10} - M_{RF}}\right] \qquad (3)$$

where RAI represents the annual rainfall anomaly index, RF the actual rainfall for a given year, M_{RF} mean for the total length of record, M_{H10} the mean of the 10 highest values of rainfall on record, and M_{L10} the mean of the 10 lowest values of rainfall on record. The RAI of van Rooy has been shown to be a very effective index for detecting drought periods, and it compared favorably well with the more complex indices of Palmer and Bholme-Mooley (Oladipo, 1985). While analyzing drought periods, evapotranspiration is another factor which should be considered.

There are several methods to estimate evaporative power of the atmosphere with different data requirements. These range from the simplest Hargarve method which depends only on temperature to the complex FAO Penman-Montheith methnod (Allen et al., 1998). Inorder to see the applicability of Penman-Montieth equation under limited data availability condition, ETo calculated using all data required for Penman-Monteith equation and limited data availability was compared. ETo was also calculated using the Hargrave method and the result of the three methods was compared. In the Penman-Monteith Method, ETo can be determined using temperature data f (T), temperature and relative humidty f(T,H), temperature, relative humidity, and wind speed f(T,H,U) and temperature, relative humidity, wind speed, and sunshine hours f(T,H,U,n).

Results and Discussion

Evapotranspiration estimation

Evapotranspiration was determined as a function of temperature f(T), temperature and relative humidity f(T,H), temperature, relative humidity and wind speed f(T,H,U), and temperature, relative humidity, wind speed, and sunshine hours f(T,H,U,n) using the FAO Penman-Montheith method (Allen et al., 1998). The reference evapotranspiration determined for Gode and Dire Dawa areas is presented in Fig. 1. Reference evapotranspiration ETo calculated using Penman-Monteith method under limited data availability was compared with ETo calculated using complete data set (T,H,U,n) (Table 1). In the table Y is ETo as a function of f(T,H,U,n) and X is ETo as a function of f(T), f(T,H), or f(T,H,U). It can be observed that for most of the stations the approximation is good (high r^2). The maximum difference between f(T) and f(T,H,U,n) is as follows: Assaita (30%), Assebe Teferi (13.4%), Zeway (9.2%), Mekele (8.6%), Gode (5.4%), Jijiga (8.9%), Negele Borena (10.7%), Dire Dawa (2.4%). This difference may be tolerable for planning purposes. Therefore in areas where climatic data to use full Penman-Monthieth equation is not available, the simplified version based on f(T) only can be used under such conditions.

Table 1. Relation between reference evapotranspiration determined by FAO Penman-Montieth method with limited data and full data

Station	Available Data	Equation	r^2
Assaita	T	Y = 0.69X + 15.75	0.922
	T,H	Y = 0.64 X + 39.51	0.917
	T,H,U	Y = 0.68 X + 34.85	0.923
Zeway	T	Y = 0.83 X + 12.20	0.711
	T,H	Y = 0.81 X + 15.84	0.805
	T,H,U	Y = 0.82X + 14.26	0.843
Gode	T	Y = 0.77 X + 48.67	0.543
	T,H	Y = 0.63 X + 63.56	0.431
	T,H,U	Y = 1.06 X - 19.98	0.937
Jijiga	T	Y = 0.12 X + 117.53	0.026
	T,H	Y = 0.29 X + 93.40	0.144
	T,H,U	Y = 0.64X + 41.83	0.376
Mekele	T	Y = 1.14X – 5.52	0.749
	T,H	Y = 1.04 X + 4.72	0.871
Assebe Teferi	T	Y = 1.19X – 47.03	0.993
	T,H	Y = 1.08X – 15.94	0.992
Negele Borena	T	Y = 1.02X – 15.96	0.835
	T,U	Y = 0.97X – 14.97	0.911
Dire Dawa	T	Y = 1.73X – 112.6	0.811
	T,H	Y = 1.48 X – 87.3	0.856
	T,H,U	Y = 0.91 X + 4.29	0.993

Reference evapotranspiration determined using Penman-Monteith method as f(T) and f(T,H,U,n) and Hargraves method is presented in Fig. 2. It can be observed that there is not much difference between these estimates. The highest difference was observed in the month of June as 0.49 and 1.30 mm/day for f(T) and Hargraves method respectively. The evapotranspiration estimated by Penman-Monteith method as f(T) is closer to the Penman-Monteith with full data than the Hargraves method. This shows that it is better to use Penman-Monteith method than Hargraves method when we have only limited data, for example only temperature.

As a follow up to the above observation annual reference evapotranspiration ETo for several stations in arid and semiarid parts of the country was estimated using temperature data (Fig. 3). From the stations shown in the figure, Gode has the highest ETo while Mekele has the lowest. Unlike rainfall,

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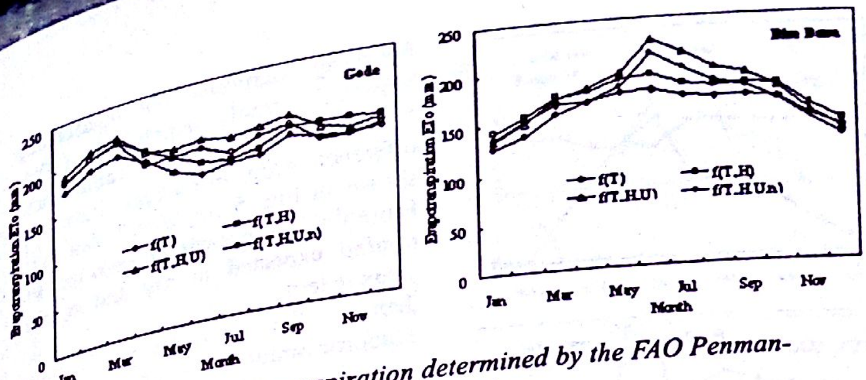

Figure 1. Reference evapotranspiration determined by the FAO Penman-Monteith method under different data availability.

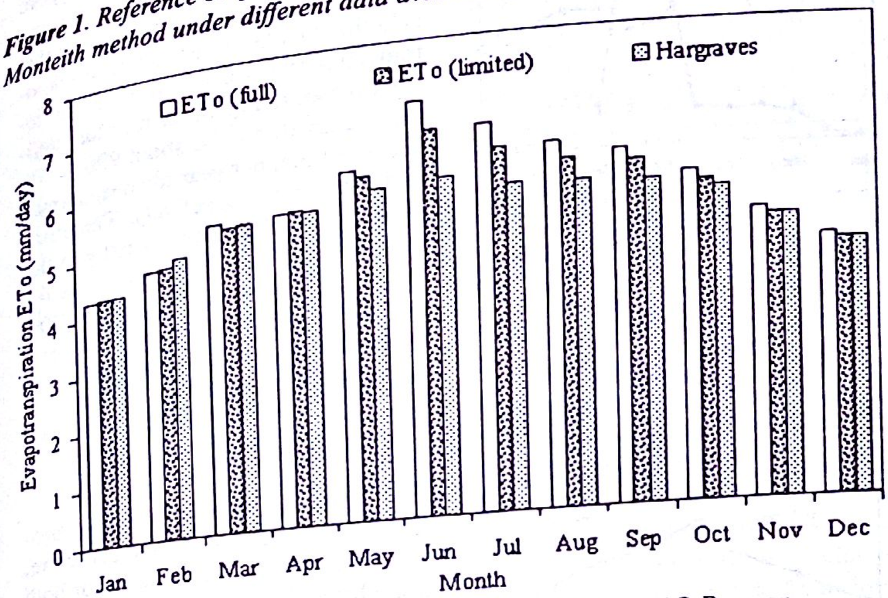

Figure 2. Reference evapotranspiration determined using FAO Penman-Monteith method and Hargraves method.

ETo did not show much variation over the years. The respective range of rainfall and evapotranspiration (P, ETo) values in mm for some stations is Mekele (788, 267), Negele Borena (1089, 307), Dire Dawa (635, 336), Gode (715, 325) and Jijiga (897, 226). The range of rainfall is much higher than that of evapotranspiration. This shows that rainfall is a highly variable climatic factor and success in rainfed agriculture largely depends on rainfall than evapotranspiration. Therefore, it is better to invest in establishing rainfall measurement than evapotranspiration estimation.

Monthly variation of rainfall and evapotranspiration

Monthly evapotranspiration was estimated and compared with the monthly rainfall (Fig. 4). This is helpful in determining the moisture deficit and the periods when the need for irrigation is high. From Fig. 4 the following observations were made. Assiata and Gode are the areas where the difference between ETo and rainfall is high throughout the season. Mekele, Negele Borena, and Zeway are the three stations where the rainfall amount exceeds evapotranspiration at least for certain period in a year. At Negele Borena, there are three months where monthly rainfall exceeds ETo; April, May and October. During the rest of the season, ETo exceeds rainfall by about 104 mm. In Jijiga and Dire Dawa areas, rainfall and evapotranspiration are relatively closer throughout the season. In Jijiga area, from October to March there is a high difference (about 104 mm) between ETo and rainfall. At Dire Dawa in April, July, and August the two values are closer (with an average difference of 77 mm) than in the rest of the season. The highest difference is in June (about 190 mm) as this is the month with the highest ETo and the second lowest rainfall. At Assebe Teferi, the difference between ETo and rainfall is maximum in the months from November to February and in July and August. There is no time where rainfall is higher than ETo. In Zeway area, the difference between ETo and rainfall is high from October to March. During the months of July and August rainfall is higher than ETo. At Mekele, ETo is much higher than rainfall for most of the year, the average difference being 130 mm. However, rainfall is higher than ETo in July and August by an average of about 100 mm. This excess rainfall during this two rainy months need to be stored for use during the rest of the season. In Gode area, there is a huge gap between rainfall and ETo in almost all the months. The average yearly difference being about 158 mm. In the months of April, May and October the difference gets smaller with the average difference of about 131 mm.

Land management programs must be designed in such a way as to cope with the probability of drought being an aperiodic, as well as a recurring phenomenon (Glantz and Katz, 1985). Therefore, utilization of probability curves for monthly rainfall is important

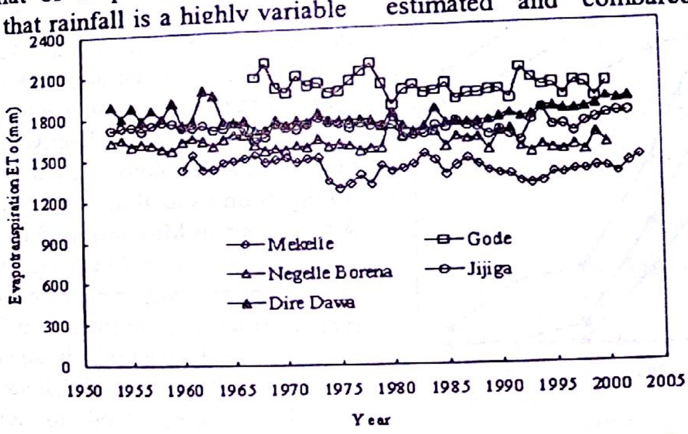

Figure 3. Time series of reference evappotranspiration at selected stations in arid and semiarid parts of Ethiopia.

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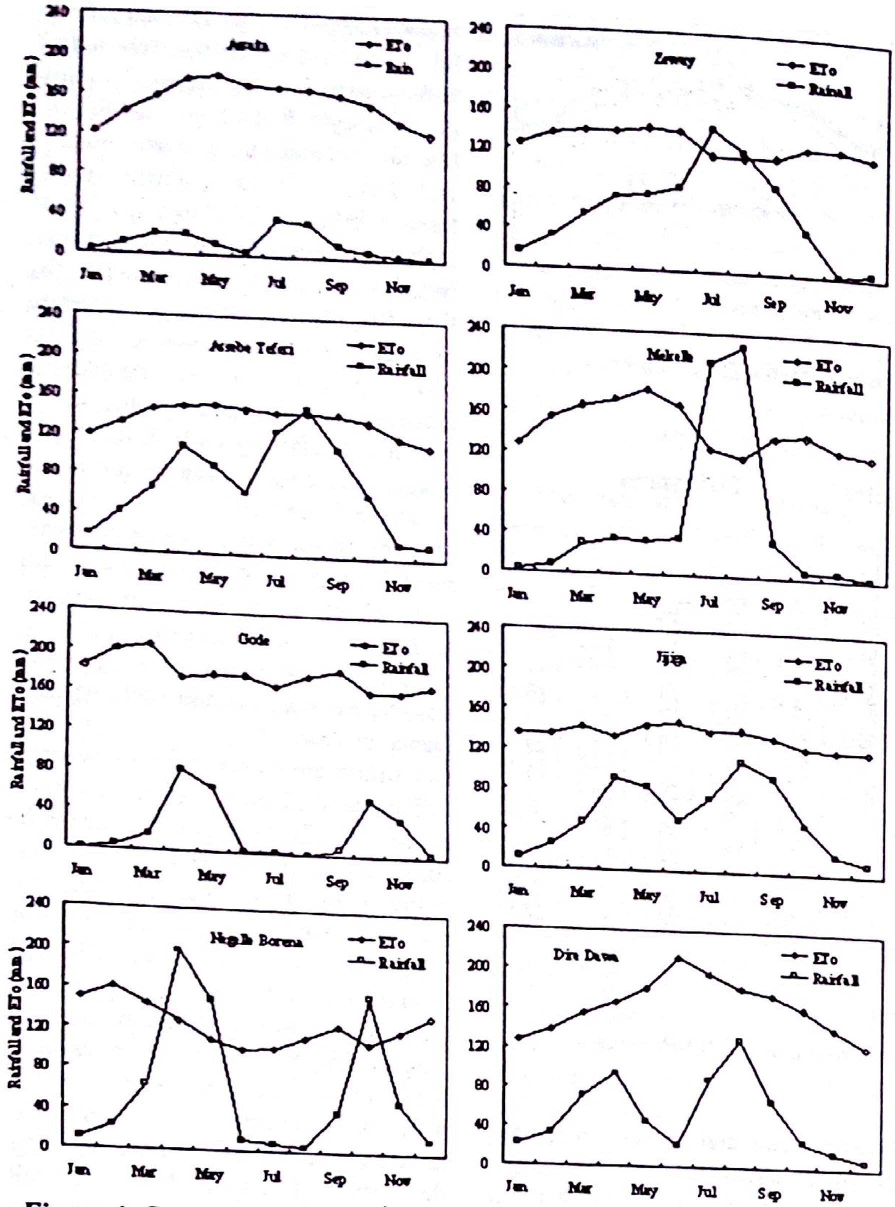

Figure 4. Comparison of monthly rainfall and reference evapotranspiration.

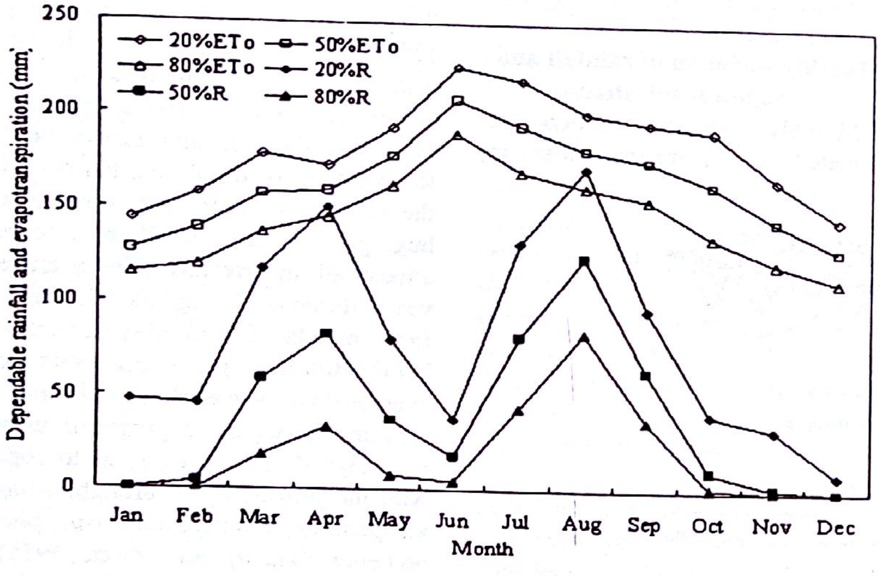

Figure 5. Monthly rainfall and evapotranspiration at three exceedence probability levels for Dire Dawa.

for design purposes. The relationship between monthly dependable (20%, 50%, and 80%) levels of rainfall and reference crop evapotranspiration is shown in Fig. 5 for Dire Dawa area. From the figure it can be seen that the rainfall expected in dry and normal years is less than the reference crop evapotrnspiration throughout the year. In a wet year (20%R) only the months of April and August expect rainfall that is higher than the reference crop evapotranspiration at 80% ETo. From the results shown in Fig. 5, the moisture deficit is estimated to be about 998, 1478, and 1732 mm per year for wet, normal, and dry years respectively. Therefore, rainfed agriculture is very risky in this area. Furthermore, using the same figure it is found that the monthly 20% and 80% dependable reference crop evapotrnaspiration is in the range ± 19 mm of the monthly mean value.

Rainfall variability

In comparison with other meteorological parameters such as temperature, rainfall is a highly variable factor both spatially and temporally. In a relative sense, this variability increases, the drier the location or the smaller the area over which the value is averaged. Besides its marked variability through time, annual rainfall in arid zones is also highly variable in space as a result of the inherently local nature of convective storms. After a storm, it is not uncommon for appreciable amounts of rain to be observed at a single gauge site while all neighboring gauges record little or even no rain. Although over the years these effects tend to balance out, it is nevertheless true that annual rainfall recorded at gauge sites a short distance apart can vary significantly. Moreover the effectiveness of rainfall depends almost as much on its timing as on its total during the season. A false start in May followed by a dry spell in June can be disastrous. Degefu (1987), for example, demonstrated that recent droughts in northeastern Ethiopia were mainly due to the failure of the spring rains. Different rainfall variability indices were used to identify drought and establish some arbitrary values for drought identification.

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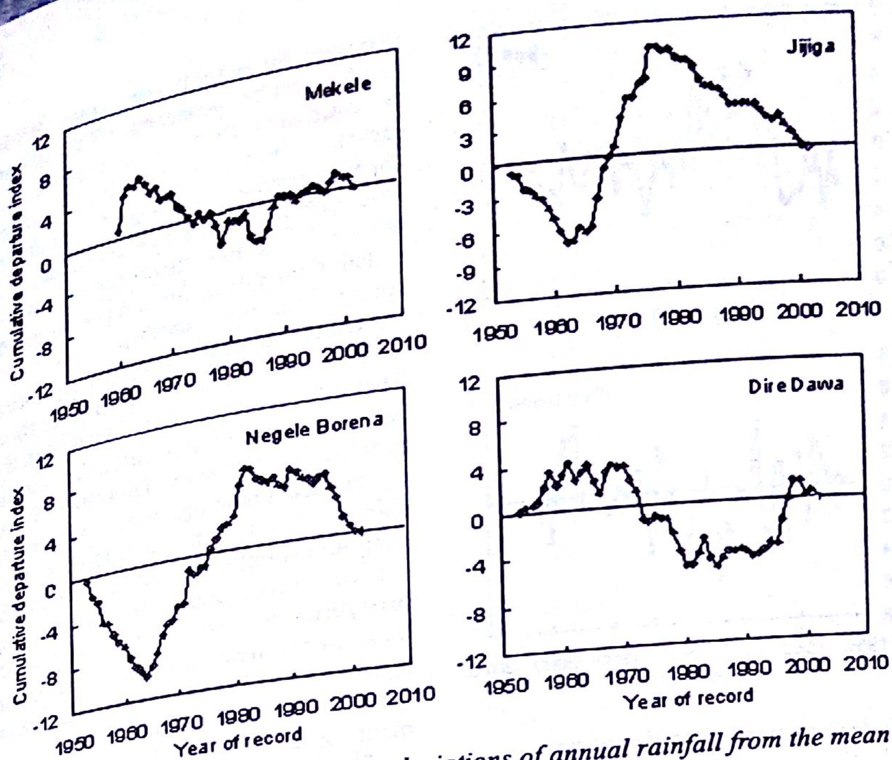

Figure 6. Time series of cumulative deviations of annual rainfall from the mean at some selected arid and semiarid stations in Ethiopia.

Cumulative departure index

A measure of annual variability and long-term trends is achieved by plotting the cumulative departure from the arithmetic mean for the period of record. On the plot of cumulative departure, the long term periods of upward and downward movement of the graph correspond respectively with those of above and below average rainfall. Data indicate that in Mekele, starting from mid-1960s to 1980s there was a decreasing trend of rainfall. After this period, the rainfall seems to be close to the long-term average (Fig. 6). In Jijiga and Negele Borena areas, the rainfall amount was increasing from 1960s to late 1970s and decrease thereafter.

Simple climate departure index

The rainfall at Mekele did not show any long term persistence above or below a z-score of zero (Fig. 7). Approximately 77% of all rainfall years fall within ±1s of the mean for Mekele. This value is 76% for Jijiga, 72% for Negele Borena, 64% for Dire Dawa. Approximately 95% of all rainfall years fall within ±2s of the mean for Mekele. This value is 92% for Jijiga, 96% for Negele Borena, 96% for Dire Dawa. Hulme (1989) used the z-score statistics for central Sudan (1900-1986) and found a significant persistence of drought since the late 1960s. A similar conclusion was reached for West Africa by Ojo (1987) who found that since 1967 droughts have been relatively persistent. However, no such persistence was recorded for the annual rainfall data from Perkerra in Kenya (Sutherland et al., 1991). From Fig. 7 it can be observed that in Dire Dawa area, 1973 was the worst drought year followed by 1984. In Negele Borena area, the lowest rainfall record was in the year 2000. In the Northern part of the country, as can be seen from Mekele data, 1984 is the driest year on record. Generally in the past 5 years the rainfall was below the long term normal.

Rainfall anomaly index

The RAI for Mekele ranges from +4.7 in 1968 to -5.2 in 1984 (Fig. 8). This value ranges from +4.46 in 1996 to -5.38 in 1973 for Dire Dawa. For Jijiga it is +5.02 in 1976 and -3.76 in 1984. The rainfall varied a lot around the mean. In the Jijiga area, the rainfall was below the mean for the past two decades and it was above the long term mean in the two earlier decades. In Negele Borena area also the rainfall was below the long term mean in the last 6 years. There is no evidence of drought persistence in the region. Values of the SCDI < -1s and RAI < -3 normally correlate with drought. The most devastating drought in Ethiopia occurred in 1984. The 1984 drought was also experienced in other areas of Africa, such as Kenya (Homewood & Lewis, 1987), the Sahel (Dennett et al., 1985), Sudan (Walsh et al., 1988; Hulme, 1989), and in West Africa (Ojo, 1987). The rainfall regime in the Sahel has changed considerably during the last three decades. The devastating

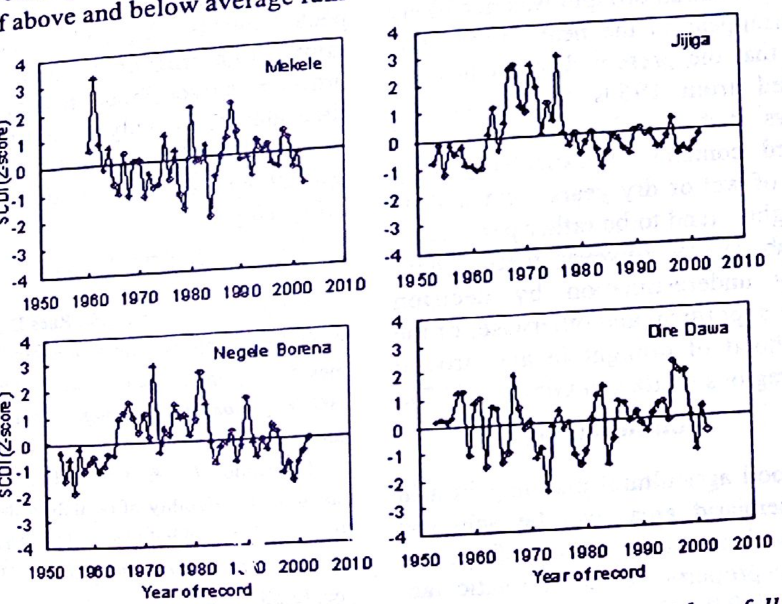

Figure 7. Time series of simple climate departure index for annual ranfall at some selected arid and semi arid stations in Ethiopia.

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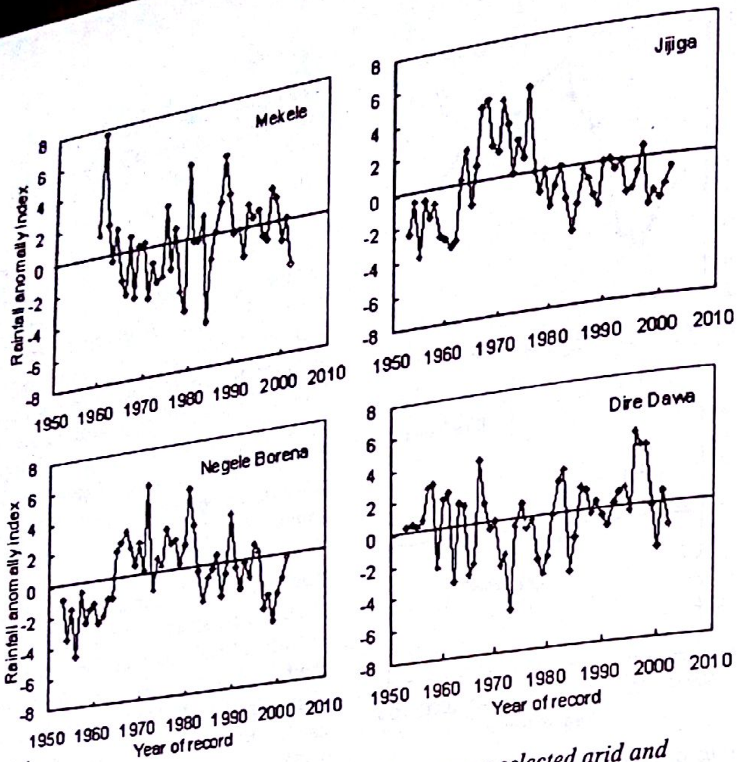

Figure 8. Time series of rainfall anomaly index at some selected arid and semiarid stations in Ethiopia.

drought in 1972-73 was followed by an even more devastating drought in 1984.

Different parts of the region experienced different rainfall pattern before the 1984 drought. In some of the areas 3 to 4 years before 1984, there was a decreasing trend of rainfall. In some of the areas such as Dire Dawa, the year immediately before 1984 was a year with very much above normal rainfall. As was observed from monthly data (not shown here), the primary reason for drought in the area was the failure of March-April rain. These rainfall periods are crucial to agriculture and forage productivity in the area.

The evidence available does not appear to be conclusive on the issue of permanent changes in climate on a historical time-scale. However, it is now widely recognized that significant variations do occur in the "average" climatic conditions locally experienced in successive periods of thirty to fifty years duration. For example, considering the Sahelian rainfall over the past few decades, there has been the persistence of drought. Starting from the late 1960s there has been a continuing pattern of sub-average rainfall witnessed by all regional rainfall series generated for the Sahel. This strong persistence of Sahelian rainfall anomalies is consistent with the notions of the degradation-induced drought hypothesis and the regional differences. An initial perturbation in the annual rainfall series is amplified by the feedback mechanism leading to continuation of the anomaly. Although rainfall increased progressively from the especially severe 1973 drought year, this recovery did not last long and again in 1984 there was drought.

The foregoing results show that the Subsaharan drought was not likely to disappear in the near future. The fact that the present drought has extended from 1960s to the present shows that the Subsaharan rainfall record contains "unexpectedly long runs of wet or dry years" and that its droughts "tend to be rather persistent" (Lamb, 1982). However, there is generally underestimation by decision makers, political and otherwise, of the likelihood of drought in and around arid regions (Katz and Glantz, 1977).

Conclusions

Good agricultural planning in arid and semiarid areas can be achieved only with an understanding of the statistical properties of the climatic factors; rainfall being the major climatic parameter. Other parameters can be aggregated by evapotranspiration. While rainfall can be measured, ETo can only be estimated from other climatic parameters. When long term data required for ETo estimation using FAO Penman-Monteith method is not available, it is advisable to use this same equation rather than going for simple methods such as Hargraves method.

Unlike rainfall, evapotranspiration do not show much variation with time. This is the results of low variation in the weather factors used to calculate this parameter over the years. Therefore during agricultural planning, rainfall variability should be given much attention than evapotranspiration. From the comparison of rainfall and evapotranspiration time series, it has been observed that almost all the areas in the arid and semi-arid region of Ethiopia experience moisture deficit and irrigation should supplement the rainfed agriculture.

Time series plot of rainfall data revealed that the occurrence of drought varies among the stations in the region. For some areas such as Mekele and Jijiga, 1984 was the driest year while in Negele Borena the year 2000 was the worst drought-hit year. In Dire Dawa area, 1973 was the driest year. Generally, the rainfall amount in recent years was below the long term normal. In these regions where interannaul rainfall variability is relatively high, recurrent droughts are in fact a part of climate and not apart from it and are, therefore, not to be viewed as unexpected events. The coming up of the rainfall to normal do not imply that the problem is over. Since this study is the first attempt to analyze the time series of rainfall in this part of the world, the normal used should be updated at most every 10 years.

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Application of Geostatistical Techniques and Remotely Sensed Data to Estimate Grid-Bases Rainfall Of Pangani Basin (Tanzania)

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Abstract

The purpose of this study is to estimate the spatial rainfall in Pangani River using techniques called geostatistics. Three geostatistical techniques were applied in the estimation of rainfall: Simple Kriging (SM), Ordinary Kriging (OK) and Kriging with trend model or external drift (KT).

Estimation results show that Ordinary Kriging produced reasonably better estimation than others single variable kriging methods (taking rainfall alone) with R^2 value 58 % for annual rainfall. An encouraging improvement was observed by including CCD and DEM data as secondary variable in the kriging with external drift (KT) model. The R^2 between the observed and estimated rainfall was improved from 58.0 to 73% when CCD is used as a secondary variable and 76% for DEM for annual data. On monthly basis, the estimation performance is even better than the annual case during the wet seasons from April to June. This technique can be applied in Ethiopia to estimate rainfall in remote areas and filling data gaps.

Key words: CCD, DEM, Geostatistics, kriging, variogram

1.Introduction:

Variations of some physical and hydrological properties tend to be correlated spatially up to a reasonable distance of separation in space. Such quantities may include elevation, rainfall, temperature etc i.e. two values taken close together tend to be more alike than two samples far apart. Geostatistics offers the method for quantification of the spatial continuity of the variable (s) under study and enables in estimating a property in unsampled location from the measured close variable (s) by using spatial correlation modelling and different interpolation algorithms. The primary paradigm of geostatistics is to estimate a weight to be associated with each neighbouring station based on statistical distance (such as variance, covariance, etc.) rather than Euclidean distance (h) between the point to be estimated and the neighbouring station.

This technique derives the weights to be associated to the neighbouring station by solving the objective functions such that the expected value of the error i.e., estimated minus the observed, $E[Z^*(u) - Z(u)]$, is equal to zero and the error variance, $Var[Z^*(u) - Z(u)]$, should be minimum using least squares technique and eventually estimating the unsampled z(u) value

The purpose of this paper is to model the spatial variation of rainfall and estimate grid based rainfall surface for Pangani Basin using these techniques of characterising the spatial variation.

2.Theoretical Background of Geostatistics - KRIGING

As briefly described in the introduction section, kriging finds the weights to be associated with the each neighbouring station such that the first condition requires that;

$$E\left[Z^*(u_o) - Z(u_o)\right] = 0.0 \text{ and,} \qquad (1)$$

and the second condition requires that the varuiance between the estimated and observed quantity should be minimum

$$Var\left[Z^*(u_o) - Z(u_o)\right] \text{ is minimum} \qquad (2)$$

Where;

$$Z^*(u_o) = \sum_{j=1}^{n} \gamma_j \cdot Z(u_j) \qquad (3)$$

λ_j is the weight to be associated

$Z^*(u_o)$ is the estimated variable

$Z(u_o)$ is the observed variable

If equation (3) is substituted in equation (1), that is the first condition produces a constrain that the sum of all the weights of the neighbouring stations should be equal to unity (Equation 4)

$$\sum_{j=1}^{n} \lambda_j = 1.0 \qquad (4)$$

and when the variance equation (3) is partially differentiated with respect to each weights, and Langrangian constant is introduced, it produces the general linear regression model (equation 5)

$$\sum_{j=1}^{n} \gamma_j \cdot \gamma_{i,j} + \mu = \gamma_{0i} \qquad i = 1,\ldots,n \qquad (5)$$

Where: l_j's are the weights, $g_{i,j}$ are the average inter-station variogram values (correlation or variance, etc) and m is the Langrangian constant and $g_{0,i}$'s are the variogram values between the point to be estimated and station i.

The weights to be used at each station are estimated using the least square solution technique and eventually applied in equation (3) to obtain estimated sample value $Z^*(u_o)$. The above

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Table 1. Summary of Types of Kriging Used in the Analysis

Type of Kriging	The Linear Regression Estimator	Conditions
Simple Kriging (SK)	$Z^*_{SK}(u) = \sum_{j=1}^{n} \lambda_j(u) \cdot Z(u_j) + [1-\sum_{\alpha=1}^{n} \lambda_\alpha(u)] \cdot m$	$\sum_{j=1}^{n} \lambda_j(u) \cdot \gamma_{ij} = \gamma_{iu}, i = 1,\ldots,n$
Ordinary Kriging (OK)	$Z^*_{ok}(u) = \sum_{\alpha=1}^{n} \lambda_\alpha(u) \cdot Z(u_\alpha)$.	1. $\sum_{j=1}^{n} \lambda_j(u) \cdot \gamma_{ij} + \mu(u) = \gamma_{iu}, i = 1,\ldots,n$ 2. $\sum_{j=1}^{n} \lambda_j(u) = 1.0$
Kriging with External Drift (KT)	$Z^*_{kt}(u) = \sum_{\alpha=1}^{n} \lambda_\alpha(u) \cdot Z(u_\alpha)$	1. $\sum_{j=1}^{n} \lambda_j(u) \cdot \gamma_{ij} + \mu_0(u) + \mu_1(u)\, y(u_i) = \gamma_{iu}$ $i = 1,2,\ldots,n$ 2. $\sum_{j=1}^{n} \lambda_j(u) = 1$

basic theory can also be extended to include secondary variable in estimation of the unsampled data of different nature. This study used the cold cloud cover (CCD) and Digital Elevation Model (DEM) data as secondary variable to improve the spatial rainfall estimates. The following Table..provides the geostatistical techniques applied in this study

Simple kriging and ordinary kriging are similar except the earlier depends on stationary mean throughout out the area and the weights are not constrained to unity where as the later requires the sum of the kriging weight to be constrained to unity and it amounts to re-estimating the mean as used in SK at each new location u using moving search neighborhoods [1].

Kriging with external drift is similar to a trend model which assumes that the underlying variable can be separated into the trend component (T) and a residual component (R) of the original variable. The trend model can be modeled as a function of coordinate vector u and the parameters of the trend model are estimated. The random component is modeled as stationary random function zero mean and covariance g_R. In Kriging with external Drift, the trend component model is further divided into the trend of the original variable and the component of a secondary variable [1].

3.The Data

Average monthly and annual rainfall data from 170 station were used in this study. The station distribution is shown in figure 1. The record length for most of the stations extends up to 1995. The available dekadal CCD value ranges from 1989 to 1996. So concurrent data of 1989 to 1995 was aggregated to annual and monthly average and used in the analysis. The aggregated CCD image is shown in Figure 2.

Africa DEM data originally downloaded from GTOPO30, obtained from the public domain of US Geological Survey (USGS, 1996) is used to extract the elevation data for Pangani basin. It is a raster data of a resolution of approximately 1km by 1km or 30 arc seconds.

4.Results

Spatial Variability (Variogram Model) Results

Variogram modelling for the monthly, annual and for the secondary variables were done using VARIOWIN (Pannatier, 1996). The best variogram fit parameters for the mean annual and for the monthly average data and secondary variables were derived. . A typical variogram model fitted to a spherical function to the Mean Annual Rainfall (MAR) is shown below (Figure 1)

Table 2. The Performance of Different Kriging Type for the Model Variogram Parameters for Pangani Basin

Estimator	Parameters					(R^2)
	Model	Nuget	Sill	Range H_{km}	Search Radius	
Simple kriging	Sph	0.51	0.50	0.235	0.50	49.1
Ordinary kriging	Sph	0.51	0.50	0.235	0.50	59.7
Kriging with Drift	Sph	0.51	0.50	0.235	0.50	47.0

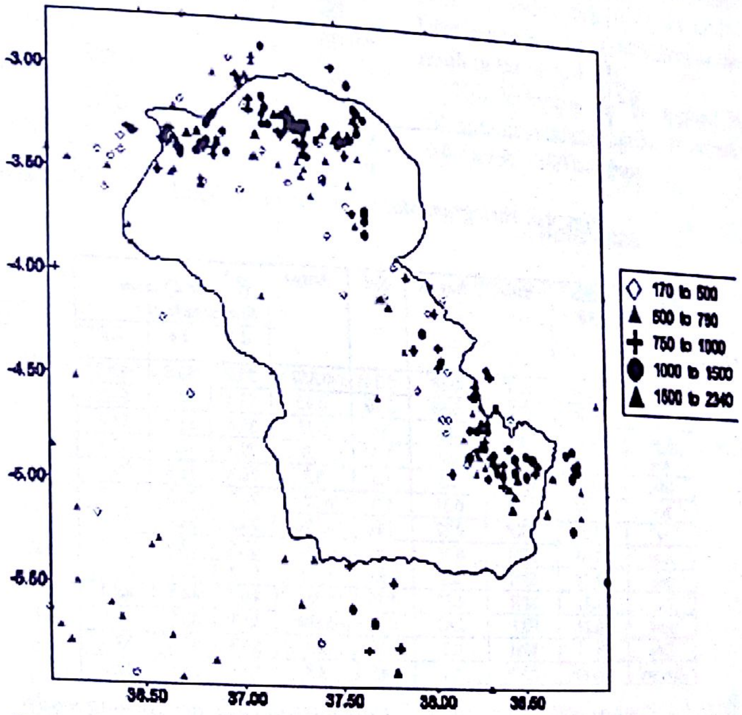

Figure1. Observed Mean Annual Rainfall Distribution (mm) in Pangani Basin

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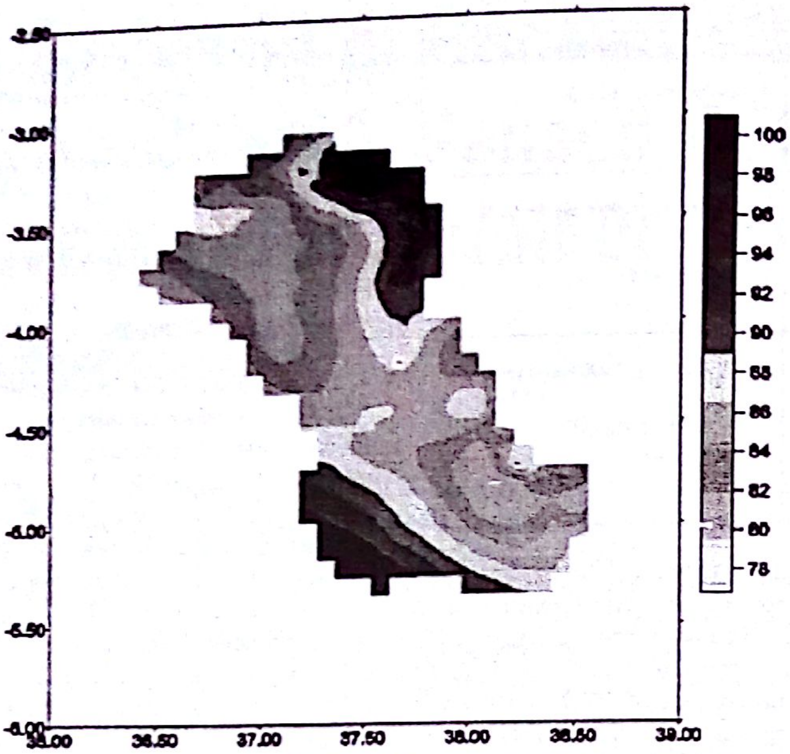

Figure E3: Average Annual Cold Cloud Duration (CCD) Image Over Pangani Basin(aggregated from dekadal CCD image)

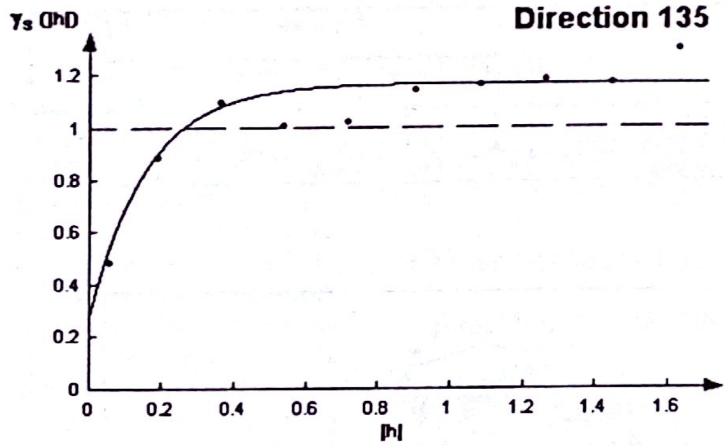

Figure 3. Variogram Model for Annual Rainfall

Month	Mean RF	Model	Nugget	Sill	Range	R^2 (for different Search radius) 0.5	1.0	2.0
Jan	71.14	EXP	0.50	0.34	0.357	53.2	53.0	53.0
Feb	66.51	EXP	0.66	0.70	0.45	53.4	53.4	53.3
Mar	112.65	SPH	0.6	0.6	0.25	51.6	51.4	51.4
Apr	209.74	SPH	0.2	1.0	1.0	70.2	70.1	70.1
May	145.79	EXP	0.3	1.0	0.3	76.8	76.8	76.7
Jun	37.34	EXP	0.31	1.0	0.227	76.9	76.9	76.7
Jul	24.63	EXP	0.22	1.0	0.176	76.5	76.1	76.4
Aug	20.95	SPH	0.36	1.0	0.317	67.6	67.4	67.4
Sep	22.28	SPH	0.3	0.85	0.51	57.2	57.1	57.2
Oct	41.81	SPH	0.57	0.56	0.765	44.3	44.3	44.4
Nov	96.23	EXP	0.63	0.4	0.374	45.3	45.3	45.3
Dec	98.11	SPH	0.7	0.34	0.51	53.7	53.5	53.6
Annual	***936.89***	***EXP***	***0.3***	***0.85***	***0.3***	***59.9***	***59.6***	***59.7***

Table 3. Variogram parameters and the Performance of Ordinary Kriging model on monthly basis.

Kriging Results

Applicability of different kinds of kriging types has been investigated. These include, simple kriging (SK), ordinary kriging (OK), kriging with external drift (KT) and cok-kriging (COK). Nash and Sutcliffe efficiency criterion (R^2) was used to validate the performance of the model and select the overall robust estimator for the basin. As shown in table 2.The ordinary kriging was selected as robust method and further analysis including the secondary variable was done using ordinary kriging method.

On monthly basis, the model performed better than the annual case in the wet months of April to June and poorly for short rain season from October to November and dry season of December, January and March.

Using CCD and DEM Data to improve Estimation

Estimates of Kriging with external drift are given in Table 4. Using CCD data as a secondary variable for annual

Secondary variable	Parameters: Model	Nugget	Sill	Range	Search Radius	No. of stations	(R^2)
CCD	EXP	0.43	0.85	0.53	0.5	1-20	58.7
DEM	EXP	0.32	0.85	0.60	0.5	1-20	65.1
MAR/CCD	SPH	0.45	0.98	1.0	1.0	1-20	63.3
MAR/DEM	SPH	0.47	0.80	1.0	1.0	1-20	76.7

Table 4 Performance of Ratio Kriging

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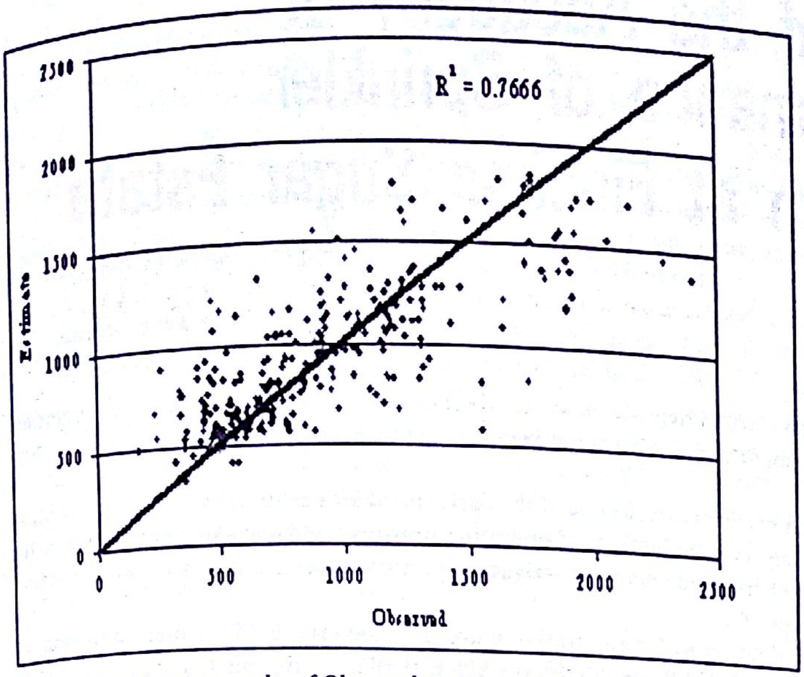

Figure 4. Calibration results of Observed vs. Estimated mean annual rainfall at the recorded location

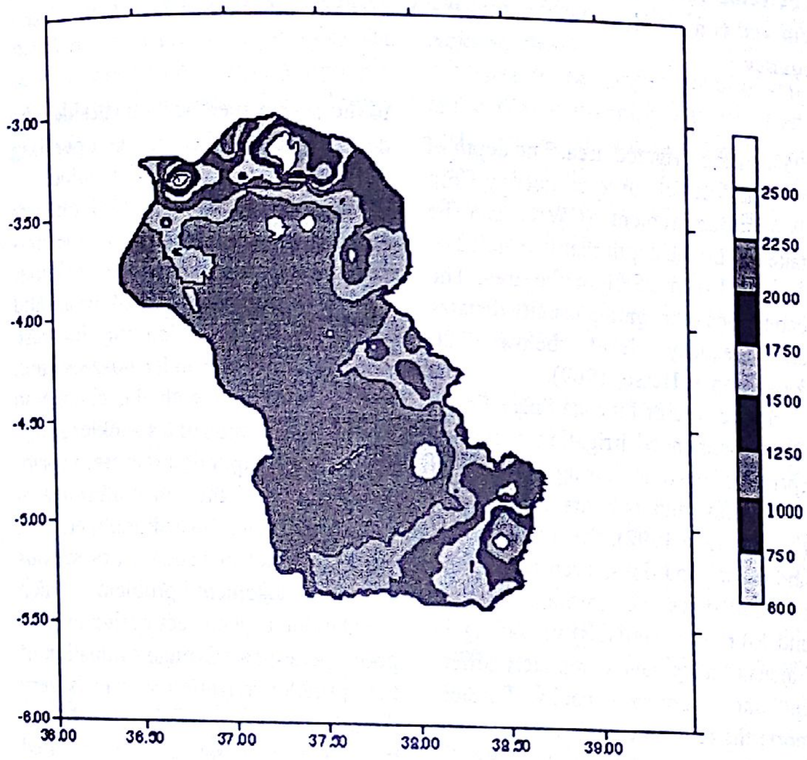

Figure 4.1 Mean Annual Rainfall Image of Pangani Basin as estimated from the observed mean annual rainfall and DEM as secondary variable

case hasn't improved the results of the estimate. Though not significant, the DEM data was found to have better correlation and produced a better result of 65 % compared to inclusion of CCD or earlier estimate by OK. It is interesting to note that improvements of the results were observed for both cases when the CCD and DEM data was used as a background image. The techniques was creating of the ratio map of the observed rainfall to the corresponding CCD and DEM extracted values and then estimate the ratio surface using OK method. The estimated surface was used as a secondary variable in estimating with the drift model. The estimated results corresponding to the observed data are extracted and compared. The results of the performance index (R^2) are significantly improved to 63.5 and 76.7% for CCD and DEM cases respectively. The estimated and observed scatter diagram is shown in Figure 4.

The best annual estimated surface using DEM as a secondary variable for the annual case is shown in Figure 5.

5.Conclusion

Investigation of varied kriging algorithms revealed that, ordinary kriging system is found to be a robust estimator on the basis of Nash and Sutcliffe efficiency criteria (R^2). When the method was applied to annual rainfall, the performance index was about 60%, where as applied to average monthly values, the performance results are in the range of 70 to 76 % for wet seasons from April to June and less than 50 for dry months from January to March. Kriging with External drift using CCD and DEM has shown a better estimation in annual basis.

It was also learnt that as long as the variogram parameters are in the allowable range, (nugget effect, sill or range, and other parameters), the spatial rainfall variation is less sensitive. The R^2 variation was less than 5%.

The selection of the robust geostatistical model is much more important in rainfall estimation than the type of variogram model or its parameters. Secondly, identifying the correlated secondary variable improves the result in the annual case.

This technique can be applied in Ethiopia to estimate rainfall in remote areas and filling data gaps

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Determination of the Adequacy of Irrigation Performance of Sprinkler Irrigation System at Finchaa Sugar Estate

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Abstract

The success of Sprinkler Irrigation System largely depends on its actual performance at field condition. The evaluation of this performance level is, therefore, very important not only for irrigation water managers, but also for irrigation policy makers, irrigators, and researchers.

Accordingly, the adequacy of irrigation performance, as one of the basic sprinkler performance indices, was measured actually at field condition considering six combinations of operating pressures and sprinkler nozzle sizes with main objective to determine the level of current adequacy of irrigation performance in relation to the expected/ predicted performance during the design period.

The study result indicates the excess irrigation water application more than the crop net irrigation requirement and Soil Moisture Deficit (SMD), especially the 2.4*4.8 mm nozzles sprinkler, at all pressure ranges considered. Inline to this, tremendous losses in terms of deep percolation (about 40 %) have been observed the consequence of which is loss of valuable water resources and in extreme cases rise of Ground Water Table (GWT) which in turn may need construction of expensive drainage system and can also lead to the overall salinization and alkalization of the area.

Key Words: Performance Indices, adequacy

Introduction & Background

An ***adequate*** and ***dependable*** water supply is needed in order to make possible and facilitate irrigation application in accordance with the biological needs of plants (FAO/UNESCO, 1973). That means the irrigation water requirements and irrigation frequency should be fully satisfied during the irrigation. This requires an understanding of the soil-water-plant-climate interactions. Unless the adequate & timely supply of irrigation water is assured, the physiological activities taking place within the plants are adversely affected, which results in reduced yield of crops (Duggal and Soni, 1996).

The adequacy of irrigation performance indicates the ability of an irrigation system to deliver the required amount of water that can be stored in the effective root zone and meet the crop water requirement. It is generally agreed that a CU value of 0.80 is 'adequate' or 'acceptable', this value is difficult to interpret in a physical sense since it does not indicate whether the fields are adequately irrigated or not (Seginer & Kosteinsky, 1975).An adequate irrigation is defined as one which replenishes the root zone over 95% of the irrigated area. The depth of water effectively used in meeting Crop Water Requirement (CWR) can be taken to be the depth that is equaled or exceeded over 95 % of the area. The economics of irrigation usually dictates an adequacy level below 100 %(Allison & Hesse, 1969).

In the case of Finchaa Sugar Estate the recommended irrigation cycle and sprinkler set-time during the design was 15 days and 24 hours, respectively (Tate & Lyle 1992), for all soil types and plant conditions, even though the two soil types (i.e. chromic Luvisols and Eutrophic Vertisols) prevailing in Finchaa Valley have completely different water holding capacity. Furthermore, the recommended sprinklers are brass impact type (Ura-riego VYR 35 or Ura Costa Rc) with two nozzles(2.4 * 4.8 mm diameter) designed to give a gross discharge of 0.5 l/s(5.6 mm/hr) at 3.17 bar sprinkler pressure, i.e., 4.5 bar hydrant pressure(BookerTate,1998). However, during the field assessment a deviation from the recommended design condition was observed in both operating pressure and sprinkler – nozzle combinations. In general, the estate is currently irrigating using the sprinklers nozzles that do not conform to the design specification (besides the design nozzle sizes) at an operating pressure less than the design value.

Every sprinkler with nozzles has its own hydraulic and hydrodynamic performance. In addition, the sprinkler nozzles have a problem of wear and tear through time which may increase diameter of the sprinkler nozzles, and, hence, associated with the change in drop size condition of a sprinkler spray, increased precipitation rate from sprinkler nozzles, change in uniformity of water application/ distribution, etc.

The estate, in general, has serious water management problem, which may be due to incorrect design and/ or poor operational. Critical evaluation of the sprinkler irrigation system is very important in order to identify whether the system is operating at the required performance level and then suggest improvements to the operation of the system (Jensen, 1983). Reliable measures of the system performance are extremely important for irrigation policy making and management decisions(Shaul & Jorge, 1991).

The bottleneck in irrigation water management of the estate has got special attention by Irrigation professionals. All attempts made so far to alleviate the water management problems of the

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estate were based on the normal hydraulic design condition (Nurzefa, 2001; Habib, 2001). The soil, crop and climatic factors were more or less evaluated in those studies. But, no critical/scientific research based on the recommended standard procedures has been conducted regarding the actual performance of sprinkler irrigation system at FSE, except the preliminary in-field irrigation assessment done (as overview) by Girma Teferi (1996) and recently by the Soils & Agricultural Engineering Department Staff (Habib D., Megersa O., and Abiy F.). Without the knowledge and information of the actual field performance of the sprinkler irrigation system, all attempts made to alleviate the water management problems of the estate remains incomplete and fruitless.

Therefore, due to the aforementioned and other problems, this study has been initiated to investigate the level of current adequacy performance of the system in relation to the design adequacy performance expected.

The specific objectives of the study are:

To determine the particular combination of operating pressure and sprinkler nozzle sizes that can adequately perform under the prevailing field condition.

To identify design and management problems , if any , and then suggest improvements to be made to the operation of the system.

To provide an information for the future system improvement studies

2. Methodology

2.1 Description Of The Study Area

Finchaa Sugar Estate is located in Western Oromiyaa at a distance of about 340-km from the capital city. It is situated within 9°30' to 10° 00 ' North and 37 ° 30' East with an average altitude of 1350 – 1600 m.a.s.l . The Long Years Average (LYA) mean annual rainfall recorded for 23 years was about 1300 mm, which is high enough or rain fed cane agriculture. But, about 77 % of the stated rain amounts fall within four months (June – September) consecutively. The peak LYA monthly rainfall recorded was about 340 mm, which occurs in the month of July. The other eight months (Oct- May) are termed as 'dry season' and hence requires supplemental irrigation. Sometimes, there is an appreciable amount of rain falling in the month of October & May and also an occasional heavy rainfall during the month of April.

The LYA mean maximum and minimum monthly temperature in the Finchaa Catchment are 29.8 ° C and 14.6 ° C, respectively, with the mean annual temperature value of about 23 ° C. Maximum temperature occurs in March and the minimum in December. Its LYA mean daily wind speed is about 3.5 km/hr at 2m heights, which is low and therefore desirable for sprinkler irrigation system. Generally, Finchaa Sugar estate can be characterized by a moist sub-humid with large Winter water deficiency and megathermic temperature efficiency regime (Ademe Adinew, 2001).

There are two major groups of soils are available in Finchaa valley: Reddish Brown (Chromic, Hepallic & Gleyic) Luvisols and Black Clay Eutric Vertisols (i.e., 27 % Vertisols and 73% Luvisols). Most of them were developed from alluvial and culluvial deposits of the surrounding escarpment (Girma Teferi, 1995).

2.2 Data Collection And Analysis

The sprinkler adequacy performances (adequacy of water delivery, adequacy of water infiltration and adequacy of water storage) were determined from the measurements of the two important basic sprinkler performance parameters (i.e. discharge and uniformity). The performance parameters were measured at six combinations of operating hydrant pressure and sprinkler nozzle sizes (i.e., 4.0, 4.5 & 5.0 bars operating hydrant pressures and 2.4*4.4 mm and 2.4*4.8 mm diameter nozzle sizes). The pressures considered for the tests are within the recommended pressure variation (± 20 %) from the mean value (4.5 bar).

2.2.1 Discharge Measurement

The discharge rate from individual sprinkler was measured on two fields, namely: GO266 & PS316 having a lateral length of 540 m and 340 m, respectively. The fields are selected, as they are harvested fields just at the inception of irrigation for the next ratooning(cane cycle) which makes the work easier and also represents most of the estates field & lateral condition.The discharge was measured across the lateral at selected three (first, middle & end) riser positions with two replicates by connecting a flexible hose & tube to the range (larger) & spreader (smaller) nozzle, respectively, and allowing the water to fill a known volume of barrel (208 lit) for a measured period of time.

The discharge from individual sprinkler was calculated by:

$$Discharge(q) = \frac{Volume\ of\ water\ collected(Lit)}{Test\ Period(Sec.)}$$

(1)

Then, the following relation can compute the application rate from the measured discharge & sprinkler spacing:

$$Application\ Rate(Ra) = \frac{Sprinkler\ Discharge(l/hr)}{S_l * S_m} = 11.11\ q$$

for Finchaa case..................................(2)

where,

Ra = application rate (mm/hr)

S_l = sp. spacing across the lateral (m) = 18 m S_m = sp. spacing on the main line (m) = 18

q = sprinkler discharge(l/s)

2.2.2 Uniformity Measurements

The uniformity of water application/distribution of sprinkler irrigation system was measured on four fields considering the two soil types i.e., Eutric Verisol & Chromic Luvisol, prevailing at Finchaa valley. The uniformity measurement was done on Fields: GO266, PS370, and GO115& PS316 by using four sprinklers. In addition, the surface uniformity was conducted using single sprinkler on field PS 316.

Thirty-six plastic pegs were installed between the squares bound by four sprinklers in square grid patterns of 3m intervals for the uniformity measurement using four sprinkler methods. In the case of uniformity measurement using single sprinkler 108 plastic pegs were installed around the centrally located sprinkler with 3m square grid

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pattern (see Figures below). Then soil samples were collected at selected peg positions for the determination of the initial (pre – irrigation) volumetric water content. The sprinkler is then allowed to simulate water through sprinkler nozzles continuously for a period of about 22 hours. During the continuous water application, surface uniformity was measured (with three replicates) by positioning graduated catch cans a top of each peg for a period of 2 hours in average. Finally the final (post-irrigation) volumetric moisture content was determined by collecting the soil samples just after the sprinkler shut off and then certain times (12 hrs for Luvisols and 24 hrs for vertisols) after the sprinkler shut-off time.

In the case off uniformity measurement using single sprinkler, the performance of the sprinkler according to the overlap pattern by four sprinklers in the actual field operation was evaluated, approximately, by superimposing the individual observations one upon the other and summing together from different positions based on the geometric similarities and wind effects.

The soil samplings were done by probing the soil using the soil auger up to the depth of 60 cm with 30 cm increment. The samples were collected using the moisture can for the moisture content determination on mass basis and using core for the bulk density determination.

The ***coefficient of uniformity (CU)*** was evaluated using the Christiansen (1942) CU formula as:

$$CU = 100\left[1 - \frac{\sum X}{n * m}\right] \qquad (3)$$

Where,

X = |z- m| = absolute deviation from catch observations (mm)

m = mean observation

n = number of observations

Distribution uniformity (DU) was determined as:

$$DU = \frac{average Low Quarter catch infiltrated depth}{av\ catch\ infiltrated\ depth}$$

(4)

Finally, the adequacies of irrigation and application ratio performances were determined based on the methods adopted by Chaudry (1976). Also, certain correlation analysis has been adopted between the performance parameters and operating pressure-nozzle combination.

3. Results And Discussions

3. Adequacy

3.1 Adequacy of Water Delivery Performance

The adequacy performance of water to be delivered by sprinkler was determined from the expected or predicted (5.6 mm/hr) and actually obtained flow rate from sprinkler nozzles. Those areas receiving the depth of irrigation greater than or equal to the expected depth are considered to be adequately irrigated. The mean application ratio, which is the ratio of the average depth of water actually obtained to that of the expected one, was also determined.

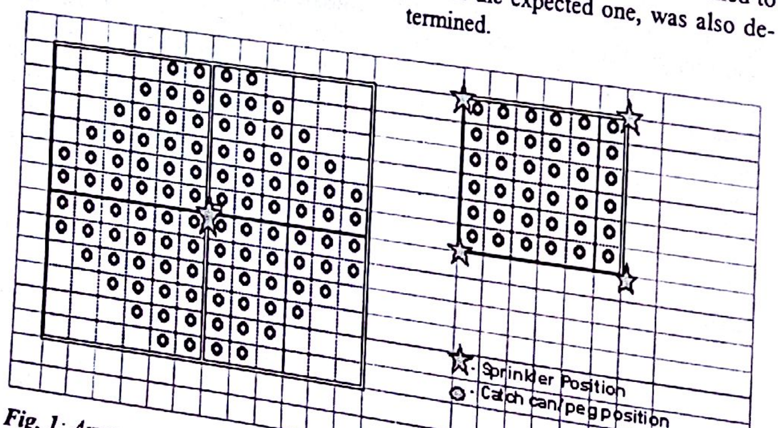

*Fig. 1: Arrangement of catch can pattern in the single sprinkler (**Left**) and four sprinklers (**Right**) uniformity test*

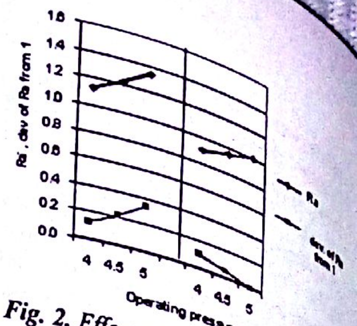

Fig. 2. Effect of Operating Pressure & sprinkler Nozzle sizes Combinations on the adequacy of water delivery (Mean application ratio) performance (Left: 2.4*4.8; Right: 2.4*4.4).

The obtained mean application ratio (Ra) ranges between 0.9 - 1.0 for the 2.4*4.4 mm nozzles, and 1.13 - 1.34 for the 2.4*4.8 mm nozzles at the respective hydrant pressures of 4.0, 4.5 and 5.0 bars. The result indicates a strong direct correlation between Ra and operating pressures and also between Ra and nozzle sizes (Fig.2).

It is important to note that the highest Ra value do not indicate the better adequacy performance. The adequacy performance level is indicated based on the deviation of Ra from unity. The increased in operating pressure will result in an increased deviation of Ra from unity for the 2.4*4.8 mm nozzle, while the opposite is true for the 2.4*4.4 mm nozzles (Fig.1).

3.2 Adequacy of Water Infiltration Performance

The mean application ratio and adequacy of water application was determined assuming that the mean depth of water in the catch can observed is infiltrated into the soil profile and considering the expected net depth of application (4.2 mm/hr).

The obtainable adequacy of irrigation for the 2.4*4.4 mm nozzle sprinkler are 6%, 81%, & 86% , respectively, at the hydrant pressures of 4.0 bar,4.5bar & 5.0 bar(Fig.3). The 6% adequacy of irrigation indicates that more than 90% of the field receives an application depth of water less than the net irrigation requirement. This shows the highest degree of crop stress due to under irrigation when the 2.4*4.4 mm nozzle sprinkler operates at 4.0 bar hydrant pressure. However, the adequacy level increases to 47 % considering

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lower application efficiency, for-example 70 %. Again, reducing the application efficiency to 60%, the adequacy of irrigation at 4.0 bars hydrant pressure increases to > 100 %. For the 65 % application efficiency the adequacy level becomes about 90 %, which is acceptable value.

At the extreme condition, the 2.4*4.8 mm nozzle sprinkler operating at 5.0- bar hydrant pressure has the adequacy level of 134 %, which indicates the excess water application more than the crop net irrigation requirement. That means energy is being wasted since the cost of irrigation water application increases with the increment of operating hydrant pressure. The 4.0 & 4.5 bar hydrant pressures have acceptable level of adequacy greater than 80%. Even though the 4.5 bar hydrant pressure has better adequacy than that of 4.0 bars for the 2.4*4.8 mm nozzle sprinkler the economics of water exploitation and the yield reduction associated with the water stress dictates the choice of the particular combination of operating pressure and sprinkler nozzle sizes.

The 2.4*4.8 mm nozzle has greater adequacy of water application value than the 2.4*4.4 mm nozzle at each & every operating hydrant pressures considered. This may be due to the greater discharge and higher drop size of sprinkler spray from the larger nozzle. However, the greater adequacy level does not indicate the better adequacy performance as discussed in the preceding session. Furthermore, the adequacy of irrigation increases as the operating hydrant pressure increases for both the sprinkler nozzle combinations. In general, adequacy of irrigation water infiltration increase as the operating pressure and sprinkler nozzle diameter increases.The relationship between the Coefficient of uniformity and adequacy of water application can be clearly seen from Fig .3. The higher adequacy performance is associated with the lower uniformity performance, except for 2.4*4.8 mm nozzles at 4.5 bars, at the five combinations of operating pressure and nozzle sizes.

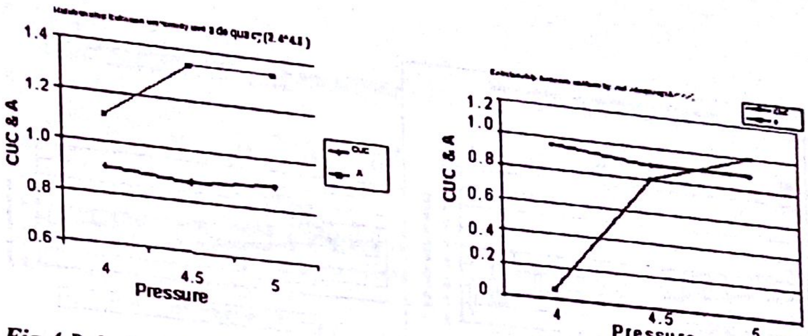

Fig.4 Relationship between Christiansen's Uniformity Coefficient (CUC) and Adequacy (A) of water infiltration performance **(Left: 2.4*4.8; Right: 2.4*4.4)**

3.3 Adequacy of Water Storage Performance

The adequacy of water storage performance was determined from the measurements of sub-surface uniformity test. It was determined from the mean application ratio, which is the ratio of the depth of water actually stored to the net depth of irrigation water expected (4.2 mm/hr) at 75 % application efficiency and the results are presented as in Table 1. The sub-surface moisture distribution and adequacy of water storage performance were presented in Fig .4 for the two soil types and two-sprinkler nozzle combination.

The 2.4*4.4 mm nozzle has an adequacy level varying from 33 – 115 % for Luvisols and 44 - 116 % for Vertisols. As in the case of the adequacy of water infiltration performance, the adequacy of water storage is very low at 4.0 bar hydrant pressure for both soil types even though its storage efficiency is greater than 77 %. This condition indicates that storage efficiency don't indicate the level of adequacy of water application.

For the 2.4*4.8 mm nozzles the adequacy of water storage level varies from 75 to 142 % (Luvisols) and 119 to 152 % (vertisols). The minimum adequacy level is at 4.0 bars in both soil types and sprinkler-nozzle combinations (Table 10). There is higher adequacy level (A>1.0) for both soil types, which indicates also the higher application depth.

3.4 Deep Percolation Loss and Relative Production

The net depth of application (I_{ad}) , deep percolation loss (L_d), and the relative production(Ya/Yp) are indicated in Table 9. The net application depth and deep percolation losses were determined from distribution coefficient (H) and Storage Coefficient (E) values presented in Table 7.1 of Cuenca(1992) at the different Coefficients of Uniformity(CU) and adequacy(A) levels determined during the surface uniformity test.

Here, it is noted that the adequacy levels greater than 100 % was considered to be equal to 100 % and Adequacy below 60 % as 60 %. For intermediate values interpolation techniques have been adopted. Furthermore, the relative production (Ya/Yp) at the obtained adequacy and uniformity coefficient level was estimated from Table 6.3 of Keller & Bliesn(1990) assuming that over irrigation do not bring yield reduction.

As observed from the Table 2 the higher application depths don't indicate the higher net application depth in-

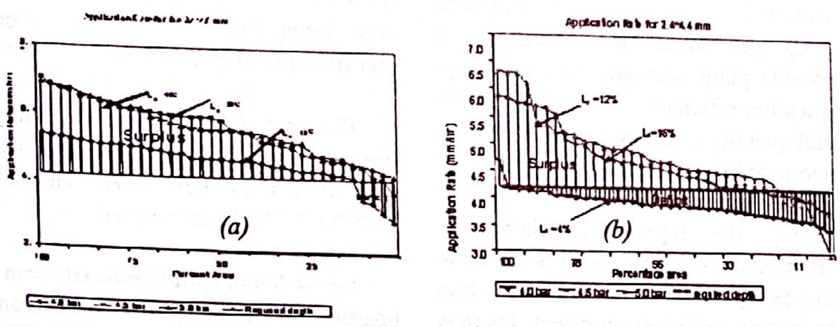

*Fig. 3 Distribution pattern for the individual catch depth (average of the three replicates) in relation to the required net depth of irrigation at 75 % application efficiency: (a) 2.4*4.4; (b) 2.4*4.8*

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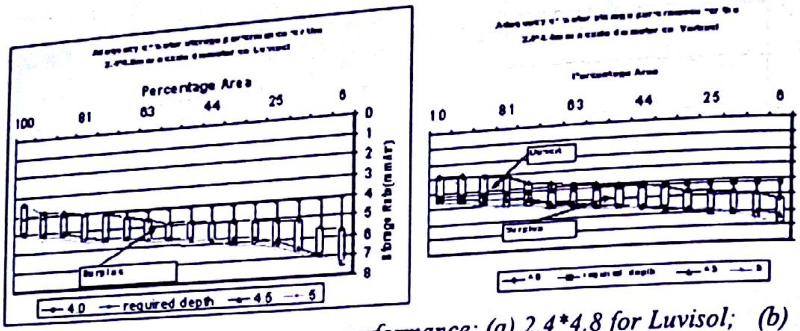

*Fig. 5. Adequacy of water storage performance: (a) 2.4*4.8 for Luvisol; (b) 2.4*4.4 for Vertisol*

Nozzle size	pressure	Adequacy			
		A_d	A_i	A_s	
				L	V
2.4*4.4	4.0 4.5 5.0	90 95 100	6 81 100	33 44 89	75 119 138
2.4*4.8	4.0 4.5 4.5	113 122 134	111 134 134	75 115 116	140 142 152

A_d - adequacy of water delivery L - Luvisol
A_i – adequacy of water infiltration V - Vertisol
A_s – adequacy of water storage

Table 1: Summary of the three adequacy performances

filtrated and stored in the effective root depth. The obtained net application depth increases as the adequacy of water application (up to 100 %) and uniformity increases; whereas it decreases as uniformity decreases and adequacy increases.

The deep percolation determined also increased with the increase of adequacy level. The deep percolation loss obtained varies from 4- 16 % and 13 - 40 %, respectively for the 2.4*4.4 mm and 2.4*4.8 mm sprinkler nozzles. The effect of adequacy level on the deep percolation loss is greater than that of the uniformity. There is a significant increase in deep percolation loss as the percentage of area receiving adequate irrigation increased (Fig 10).

Summary and Conclusion

The obtained uniformity performance level (Table 1) is greater than the minimum acceptable value for sprinkler irrigation at the six combinations of operating pressure and sprinkler-nozzle sizes. However, the uniformity level does not give any physical meaning about the adequacy of irrigation water application (Chaudry, 1976). The three adequacy performances determined confirm the stated argument. In general, the higher adequacy performance is associated with the lower uniformity performance (see Fig.10).

The higher adequacy values in the case of 2.4*4.8 mm nozzles sprinkler (Table 1) indicate the excess water delivery beyond the need of crops irrigation requirement and the Soil Moisture Deficit (SMD). This lead to increased deep percolation loss, leaching of soluble plant nutrients, low water application efficiency, reduced in quality and quantity of crops, and also a drainage problem). The situation is specifically dangerous for Eutric Vertisols having the highest capillary rise (Hansen et.al. 1980). Deep percolation loss as high as 40 % and yield reduction as high as 13 % was observed. There is a significant increase in deep percolation as the percentage of area receiving adequate irrigation increased (On-farm Irrigation Committee, 1978). The effect of adequacy level on the irrigation water performance and yield reduction is greater than that of uniformity. It is possible to conclude that a good uniformity performance level may not be an indicator of the good adequate irrigation performance level.

The economics of irrigation system usually dictates less than 100 % (but the acceptable value should be greater than or equal to 90 %) of the area to be adequately irrigated. Therefore, based on the recommended adequacy level, the 2.4*4.4 mm nozzle sizes of sprinkler has by far better and acceptable adequacy of irrigation performance than that of the 2.4*4.8 mm nozzle sizes sprinkler at all operating pressures considered. For the 2.4*4.4 mm nozzles the adequacy performance level is good & acceptable at all operating hydrant pressures, while it is poor and unacceptable for the 2.4*4.8 mm nozzles, except at 4.0 bar operating pressure.

Nozzle Sizes mm	P bars	CU %	A %	$\bar{z}$ mm/hr	H	E	L_{ad} mm/hr	L_d %	Ya/Yp %
2.4*4.4	4.0 4.5 5.0	95.6 89.6 89.0	6 81 86	3.89 4.66 4.78	1.000 0.894 0.853	0.960 0.880 0.842	3.89 4.17 4.08	4 12 16	87 98 98
2.4*4.8	4.0 4.5 5.0	90.3 87.8 89.9	83 98 134	4.67 5.62 5.63	0.886 0.620 0.600	0.873 0.610 0.600	4.14 3.48 3.38	13 39 40	98 100 100

$\bar{z}$ - mean catch can depth
H - distribution coefficient
E - storage coefficient
A - adequacy
L_{ad} - Net applied Depth
L_d - Deep percolation
P - pressure
Ya - actual yield
Yp - Potential Yield
Y_a/Y_p - relative production

Table 2: Estimated deep percolation, net applied depth (L_{ad}) and Relative Production (Ya/Yp)

4. Recommendations and/ or Suggestions

Based on the aforementioned discussed results, the following recommendations/ suggestions are forwarded:

The Estate should use the best combination of operating pressure, sprinkler nozzle sizes, set time, and soil type. A compromise should be made for the adoption of the stated combinations considering the economics of irrigation and field practicability.

The best combination of operating pressure and sprinkler nozzle sizes: 4.0 bars for 2.4*4.8 mm nozzles and 4.5 bars for 2.4*4.4 mm nozzles.

2.4 *4.4-mm sprinkler-nozzle combination has better performance than the 2.4*4.8 mm sprinkler nozzles. Therefore, the estate is highly encouraged to purchase 2.4*4.4 mm nozzle

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diameter for future use.

The 2.4*4.8 mm nozzle discharge has been increased tremendously from the expected one probably due to the wear and tear of sprinkler nozzles and poor maintenance of sprinklers. Therefore, periodic maintenance of the sprinklers and periodic replacement of sprinkler nozzles, if possible, is suggested.

Immediate replacement of the 4.8 mm nozzle diameter is highly recommended.

Further critical revision of the dragline sprinkler irrigation systems is extremely important to understand the interactions between the wind condition (speed & direction) and the distribution pattern of sprinkler spray.

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Design of a Micro Hydel Scheme for Seka River Stream with two Options

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Abstract

Considering the vast, economical, untapped mini- and micro-hydro power potential of Ethiopia, this paper envisages the design of a micro hydel scheme encompassing two options, namely one with dam and another without dam. The first option(with dam) comprises two Kaplan turbines, each with a power output of 750kW and the second involves a Cross flow turbine with a power output of 35kW, and both have been designed.. The second option(without dam) has been considered to utilize the perennial discharge in the Seka river stream and this design is based on the flow duration curves obtained after taking in to account the rain fall data for this region from three rain gauge stations situated at Shebe, Dedo and Seka. The entire range of accessories have been designed, and the cost estimation for cross flow turbine along with the local manufacturing strategy has been discussed.

Key Words: Micro Hydel Design, Cross flow turbine, Kaplan Turbine,Seka Water fall, Ethiopia

Introduction

Ethiopia's per capita consumption of modern energy is 20kgoe (kgs of oil equivalent) which is about 2% of the world average. Per capita consumption of electricity was estimated to be 28kWh [1] equivalent to about 1% of the world average. The extent of electrification across the country is depicted in Table 1.Per capita GDP also stands at about US$100, thereby presenting a major financing challenge for the provision of modern energy to the rural majority. Only 13% of the population has access to electricity But Ethiopia is blessed with enormous hydro energy resources, the gross theoretical potential (650Twh/year) being the second largest in Africa. Technically feasible potential is stated to be 260Twh/year, of which 10% represents the potential for small scale hydro installation, refer Table 2. Hydro output in 1999 was about 1.6TWh, a minute fraction of the assessed potential. Ethiopia needs affordable energy to increase agricultural productivity and food distribution, deliver basic educational and medical services, establish adequate water supply and sanitation facilities as well as to build and power new job creating industries.

The standard of living is reflected by the per capita power consumption and as such Ethiopia ranks 174 in Human Development Index. Most of its energy consumption is met from biomass related products. Traditional sources of energy can not supply the increasing and diversified demand of the community. Therefore a means must be established for the substitution of these traditional sources of energy. From many possible sources of energy, hydro is the best substitute for that it has such advantages like no pollution, renewable nature as well as low operating and maintenance costs. Sustainable development implies that man can prosper and survive with a wise stewardship of technology, natural resources and the earth's eco system This availability in Ethiopia of rich water resources makes it possible to combine hydro power development with general economic development. In this aspect, there is great scope for integration and secondary benefits. Firstly, the exploitation of hydro power represents a never ending source income which the country needs badly. Secondly, hydro power development can serve as a valuable input for rural development in the areas where projects are located. Such inputs should be recognized as worthy objects for investment themselves [2]. But the important thing is that this type of integrated development requires a different approach and new attitudes both in planning and implementation.

When an isolated community needs power either for house hold and community use, for driving small agricultural processing plants or other small industries, one of the now frequently used energy sources is a small hydro-electric plant [3]. It can be part of an overall rural development plan [2] The significant positive social and economic benefits include i)promotion of local industry ii)use of indigenous labor and materials iii)reduction of fire-wood consumption iv)raising income level of rural population v)saving in transmission line costs to remote rural areas vi)low operating cost and less skilled labor requirement vii)mitigation of population drift towards urban areas, and viii)development of potential for tourism. Local manufacturing and innovations have the potential to greatly reduce the capitol costs involved in small hydro power generation.

Impediments for broader application of small hydro may vary from country to country, but generally include cost, lack of inventory of potential sites and hydrological data, lack of local technical expertise and management skills, lack of long term government support because of bias towards large projects, and lack of finances. Opportunities for cost reductions may involve: to standardize equipment, to manufacture equipment locally, to control cost of civil works, to limit scope of pre-feasibility studies, to implement a large number of projects together, and to train local personnel in all phases of planning, design, construction, operation and maintenance, as well as management.

In Ethiopia, one of the energy policy objectives is to ensure a reliable supply of energy at the right time and at

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Table 1:Electrification at national and Regional levels (for major region in Ethiopia ,1999) [1]

Indicator	National	Regions					
		Tigray	Afar	Amhara	Oromia	SNNP	Somalia
1).population in millions	61.7	3.6	1.2	15.1	21.1	12.1	3.7
2).RegionalPopulation as % of national total	100	5.8	1.9	258.7	35	19.6	6
3).Urban population as % of regional total	14.6	16.7	7.6	10.1	11.5	7.4	13.9
4).Population in Electrified town (in million).	8	0.47	0.05	1.13	1.82	0.53	0.24
5).Percent population with accesses to electricity	13	13	4.2	7.5	8.6	4.4	9.5

Table 2: Hydro potential in Ethiopia

Blue Nile basin -280Twh/year	Omo river basin-100Twh/year
Wabisheble basin - 25Twh/year	Awash basin - 22Twh/year
Tekeze basin - 36TWh/year	Genale basin – 50TWh/year

Table 3: Raw data of monthly rain fall(mm) at Seka

Month / year	Jan.	Feb.	Mar.	Apr	May	Jun	July	Aug.	Sep	Oct.	Nov	Dec
1985	32.6	28.56	49.91	174.3	211.73	227.1	267.84	259.16	149.4	91.74	69.3	32.24
1986	3.1	91.28	94.24	95.4	169.57	360.9	187.24	216.38	153.9	49.91	29.1	1.8
1987	27.59	68.88	182.9	115.2	168.95	278.9	107.26	273.38	146.4	94.24	11.1	17.76
1988	37.51	97.44	67.27	90.6	159.03	235.8	168.33	241.49	244.8	162.44	0.0	4.34
1989	36.89	57.12	182.9	220.2	70.99	118.8	246.45	139.19	121.2	149.42	33.9	153.45
1990	31	75.6	110.98	187.4	132.37	168.9	223.2	305.35	248.1	46.19	41.1	34.1
1991	104.78	105.84	44.64	167.1	147.29	145.2	137.95	250.17	168.9	79.67	702	106.98
1992	33.79	150.08	64.48	86.7	219.17	208.5	291.09	298.22	321	267.22	103.2	38.4
1993	34.72	81.2	84.94	258.3	302.25	295	198.09	215.14	150.9	204.91	30.6	19.84
1994	16.12	32.76	115.63	69.9	206.77	247.8	213.9	147.25	214.8	19.84	88.2	3.1
1995	10.54	32.2	91.14	202.5	143.22	123.9	129.27	244.59	142.2	106.95	53.4	128.96
1996	56.11	39.48	226.3	272.7	256.99	250.2	199.95	293.88	447.3	106.33	110.4	44.02
1997	17.05	71.4	218.86	261.9	196.85	188.4	92.07	221.65	295.5	321.78	458.4	44.32
1998	153.76	7.84	210.8	102.9	153.45	193.8	363.01	387.81	438	468.41	12.3	54.56
1999	0.00	24.36	0.0	9.3	252.03	373.8	325.81	234.67	416.4	298.84	0.0	0.93
2000	0.93	22.4	72.85	209.1	496	455.1	205.22	243.04	274.2	244.59	168.3	13.02

affordable price, particularly to support the Country's agricultural and industrial development strategies. Enhancing and expanding the development and utilization of hydro power is one of the priorities of the energy policy. Hydro Power, a renewable energy, features high in Ethiopia's power sector. It's continued development is perceived as essential given the extremely low level of current electricity generation, demand forecasts at hand, and the abundance of hydro power resources [1].The supply of power for remote rural areas is not an easy task by large scale hydro power station, since transmission cost is high due to topographic and socioeconomic problems; however small scale hydropower (mini and micro hydel scheme) is the ultimate choice to supply power to remote areas where the national grid does not extend, since it can be used for domestic and communication purposes or directly coupled with driven machinery like Grain Mills or other process industries.

In this background, considering the vast, economical, untapped mini and micro hydel power potential, this paper envisages the design of a micro hydel scheme for *Seka river* stream encompassing two options one with dam and another without dam, namely

*1. Two **Kaplan*** turbines with the power out put each of 750Kw

2.The second option involving the ***cross flow*** turbine with power out put of 35.Kw to utilize perennial discharge in the Seka river stream, based on flow duration curves obtained taking into account the rain fall data available.

One of these options can be selected depending on the availability of financial resources with private sector parties / individuals/ power sector companies.

Description of project area (Seka River)

The Seka water fall is found in Jimma zone, Oromia region 366 km south west of Addis Ababa. The Seka River is part of Gilgel Gibe drainage basin. The catchment area of the river up to Seka fall is 220km^2, the elevation is between 1800 & 2600m. The selected dam site is about 1.5km west of Seka town. In the Seka basin, the rainy season normally begins in mid May and continues through the early October. The heavy and mostly constant rain fall is from July to September. The annual lean flow period is from December to June. Mean annual rain fall of the area is 1820mm. Local centers of population are towns of Seka, Dedo, Shebe and other small towns. From the total population of Seka Chekorsa Woreda, 96.63% is living in rural areas with scattered individual homes through out.

Option I – With Dam Using Kaplan Turbines

The rainfall data had been collected previously from the three rain gauge stations namely Seka, Dedo and Shebe which are found in Seka Chekorsa Woreda The rain fall data for Seka is presented in Table 3. Based on the rainfall data , a suitable concrete gravity dam and its associated parts have been

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Table 4: General information for proposed dam and its associated parts

Results of hydrological analysis Inflow design flood $=522m^3/s$ Safe yield(Reservoir yield) $=3.4m^3/s$	***Dam*** Type: Concrete gravity dam Foundation: Basaltic
Reservoirs Total capacity=17 88Mm^3., Live storage=14.88Mm^3. Dead storage=3Mm^3	***Dimension*** Hydraulic height=24.2m, Top width=4m Maximum base width=22m, Crest length=125m
Spill Way: Location and type: Uncontrolled over flow (ogee) type with stilling basin at the gravity dam. Creest length=30m, Maximum discharge=257.5m^3/s Stilling basin: Reinforced concrete 30m Wx 22m long	***Out let works*** Penstock 1.64m diameter and 1.64cm thick with length of 125m
Power house dimension Length=60m Width=12m Height=10m	The power house is located close to the natural river way so that the tail water is diverted back to it with a simple tail race channel.

designed. The dam ensures availability of water at a rate of 6.8m^3/s and at a head of 33.6m The installed capacity of the project is fixed at about 1.5MWe which is going to be produced by two Kaplan turbine units, each of 750kw capacity. The essential features of the dam designed are listed in Table 4.

Design of Kaplan turbine

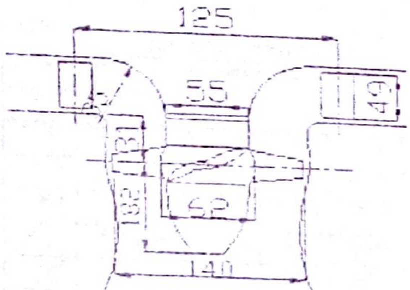
Kaplan turbine is an axial flow turbine, suitable for low heads and high discharges. In this turbine, water first enters in a radial direction through guide vanes which act like nozzles and then flows through the runner in an axial direction. Based on the available data i.e. discharge and head Kaplan turbine and its associated auxiliaries are designed. The overall generation efficiency has been taken as 67% [4].

Power delivery =P= $\eta_o * H * Q * g * \rho$ =

0.67*33.6*(2*3.4)*9.81*1000=1.5*10^6 watt=<u>1.5MWe</u>

I. Determination of size and hydraulic design of Kaplan turbine.

From the design charts [4], for a head of 33.6m the specific speed is obtained as 132 and corresponding to the head and discharge available, the speed of the turbine is estimated as 1000rpm. For this specific speed of 132, the



Scale = 1:5

Fig. 1 Partial cut view of kaplan

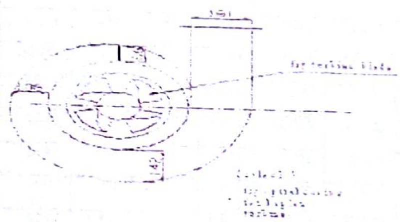


Fig.2 Aschematic of the volute casing with runner

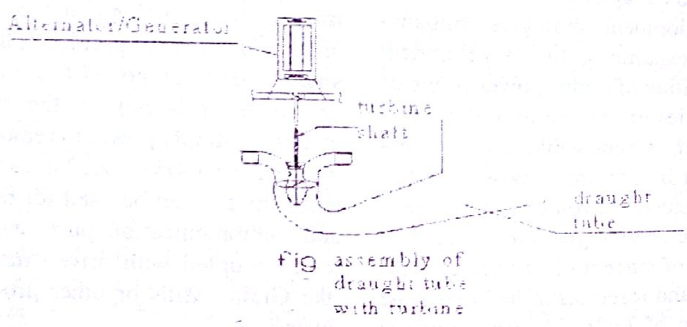


Fig.3 Assembly of draught tube with turbine

speed coefficient turns out to be 1.42 and this directly determines the diameter of the rotor as 0.7m. The energy coefficient and flow coefficient are estimated to be 0.491 and 0.241 respectively while the unit speed and unit discharge are calculated to be 120.87 and 1.19 respectively. The different dimensions of the Kaplan turbine can be estimated based on the previously obtained rotor diameter [5], and are depicted in Fig.1 The twist profile for the blade arrived at by applying free vortex design is highlighted in Table 5.and the blade chord, pitch and number are listed in Table 6. The profile of volute casing is also shown in Table 5. and is sketched in Fig.2. The particulars of the draught tube designed with an efficiency of 91.8% are included in Table 6.

<u>II. Mechanical Design</u>

The tangential force on each blade is estimated to be 7.96kN . There are three types of stresses at the root of the blade namely stress due to bending moment arising from hydraulic pressure and weight of blade, stress due to centrifugal force and torsional stress due to transmitted torque. After considering all these the resultant stress at blade root is found to be 31MPa. To transmit the power output from the turbine, the shaft diameter is designed to be 90mm after making all the design checks. The details of the coupling for direct connection with generator and other auxiliaries for an integrated safe design are given in Table 6. A custom built generator is proposed considering that there is no danger of winding failure at over speed, which is specified as 180% on a continuous basis. The overall arrangement is depicted in Fig.3.

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Option II - Cross Flow Turbine

This option has been proposed without a dam, but to utilize the perennial discharge in the Seka river stream. The rain fall data that has been gathered from three rain gauge stations mentioned earlier, has been processed on an average basis and flow duration curves have been constructed. The flow duration curve thus obtained along with the one showing the power output per unit head are depicted in Figs. 4(a)& (b). Considering an average 86% flow duration and taking the discharge available at $0.55m^3/s$ and using the available head of the water fall at the project site as 10m, a Cross flow turbine with an indirect coupling(to the generator using a belt drive) has been proposed, based on the nomogram available [6] and also considering the suitability of Cross flow turbine for the specific speed (m.kW) range of 55 - 200 [4] The actual specific speed, n_s of the cross flow turbine designed in this study turns out to be 159

A cross flow turbine is basically an impulse turbine, which comprises a drum shaped runner consisting of two parallel discs connected together near their rims by series of curved blades. A cross flow turbine has its runner shaft horizontal to the ground in all cases. In operation, a rectangular nozzle directs the jet to the full length of the runner. The water strikes the upstream blade and imparts most of (72-75%) its kinetic energy. It then passes through the runner and strikes the down stream blade on exit imparting a smaller amount of energy about (25-28) % of the total energy before leaving the turbine. Its working is akin to that of a two stage velocity compounded impulse Two major attractions of cross flow turbine have led to a considerable interest in this turbine. Firstly it is a design suitable for a wide range of heads and power ratings. Secondly it lends it self easily to simple fabrication techniques, a feature which is of primary interest in developing countries like Ethiopia [6]. For instance, the runner blade can be fabricated by cutting a pipe, length wise, in strips. The efficiency of cross flow turbine depends on the sophistication of its design. A feature such as vacuum enhancement by using a draught tube is necessarily expensive as it requires the use of air seals around the runner shaft. In this case, an air valve is installed to control the pressure in the casing to keep the runner from being submerged. Sophisticated machine can attain an efficiency as high as 85%. Simpler ones range typically between 60-75% [7, 8].

Design Of Cross Flow Turbine

To exploit maximum performance, turbine hydraulic efficiency is estimated as η_H =92% and this has been used to design an optimum configuration for tne Cross flow turbine.

Power out put= Q*H*g* η_H *Á =

0.92*0.55*10*9.81*1000=50kW

The above power calculation is used, just to fix parameters of turbine (flow angle, fluid angle, absolute and relative velocity etc). But to get the actual power out put, efficiency is conservatively taken as 65% because the efficiency of locally made cross flow turbines usually ranges between (60 to75percent). Hence the realistic power output of the turbine would be at least 35kW. With this data, the speed of the turbine has been fixed as 400 rpm, from the Nomogram [6] available for Cross flow turbine.

I. Determination of the size of cross flow turbine

A Photograph of the water flow through the cross flow turbine runner is

Table 5 Variation of flow parameters from hub to tip and Volute casing profile

D(m)	U_2(m/s)	C_{r2} (m/s)	α_2 (deg)	β_2 (deg)	β_3 (deg)	ω_2(m/s)	ω_3(m/s)
0.308	16.13	15.32	54.44	4.24	55.83	10.98	19.49
0.355	18.59	13.29	50.51	25.85	59.51	12.16	21.58
0.402	21.06	11.73	46.98	40.41	62.53	14.38	23.73
0.425	22.29	11.08	45.36	45.66	63.84	15.66	24.83
0.456	23.93	10.32	43.32	51.18	65.41	17.46	26.32
0.480	25.16	9.82	41.89	54.49	66.48	18.85	27.44
0.504	26.40	9.36	40.53	57.27	67.47	20.25	28.58
0.535	28.04	8.81	38.83	60.34	68.67	22.12	30.10
0.558	29.27	8.44	37.63	62.27	69.49	23.53	31.25
0.582	30.50	8.10	36.50	63.95	70.25	24.93	32.41
0.605	31.74	7.78	35.42	65.43	70.96	26.33	33.57
0.629	32.97	7.49	34.39	66.74	71.62	27.72	34.74
0.652	34.20	7.22	33.42	67.90	72.24	29.11	35.91
0.676	35.43	6.97	32.50	68.95	72.82	30.49	37.08
0.700	36.66	6.74	31.62	69.90	73.37	31.86	38.26

Volute Casing profile with θ	
θ(Radians)	Radius, r (m)
0	0
0.7857	0.2190
1.5714	0.3365
2.3571	0.4386
3.1428	0.5333
3.9285	0.6234
4.7123	0.7102
5.4977	0.7951
6.2831	0.8783

Table 6 - Kaplan Turbine auxiliaries

Turbine Shaft Diameter = 90mm	Key for the shaft 22.2X22.2X82mm Material – SAE/AISI 1020
Blade parameters: Axial chord= 0.188m Pitch = 0.242m Number = 4	Coupling: Size 9 Pin&Bush type coupling Generator: Custom built type generator (Direct coupling to turbine)
Draught tube: Inlet dia-0.6825m Outlet dia.- 1.365m, Angle – 14^0	Cavitation check: to be submerged 1.757m or more below the tail water surface level

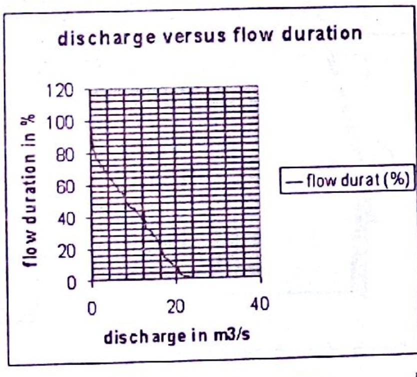

Fig.4 (a) Flow duration curve

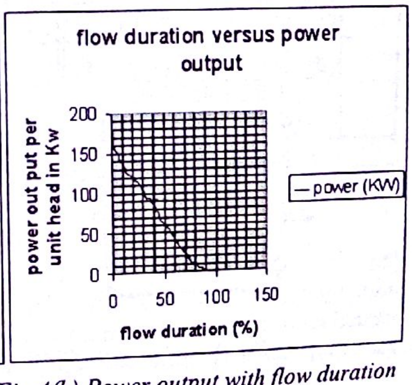

Fig.4(b) Power output with flow duration

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reproduced here in Fig. 5 from Osberger layout [9]. Treating this turbine as a 2 stage velocity compounded impulse turbine, the velocity triangles for flow in the successive 2 blade passes in the runner are depicted in Fig.6 for optimum performance. Larger diameter for the runner results in a smaller length of the runner. The advantage that can be obtained from a larger diameter is that, the mechanical stress by water pressure would be reduced. But it will cost more to build mainly due to heavier drive component required because of the slower speed and greater torque, when compared to a smaller machine of same power. However, using a larger diameter runner results in a machine having much higher durability and a much greater potential for increasing the efficiency beyond the apparent fixed limit 87%. The biggest concern with a runner, this larger in diameter, is the loss in head due to the bigger inlet. So an attempt has been made to reduce the diameter of the runner by increasing its length. The design methodology adopted and the different dimensions of the cross flow runner obtained are incorporated in Table 7. The number of blades, the blade radius and the dimensions of the jet are presented in Table 8.

Fig. 5 flow through the runner

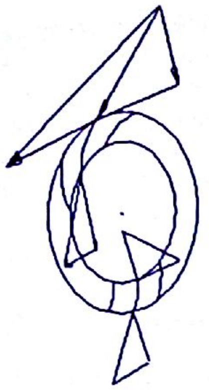

Fig. 6 velocity triangle

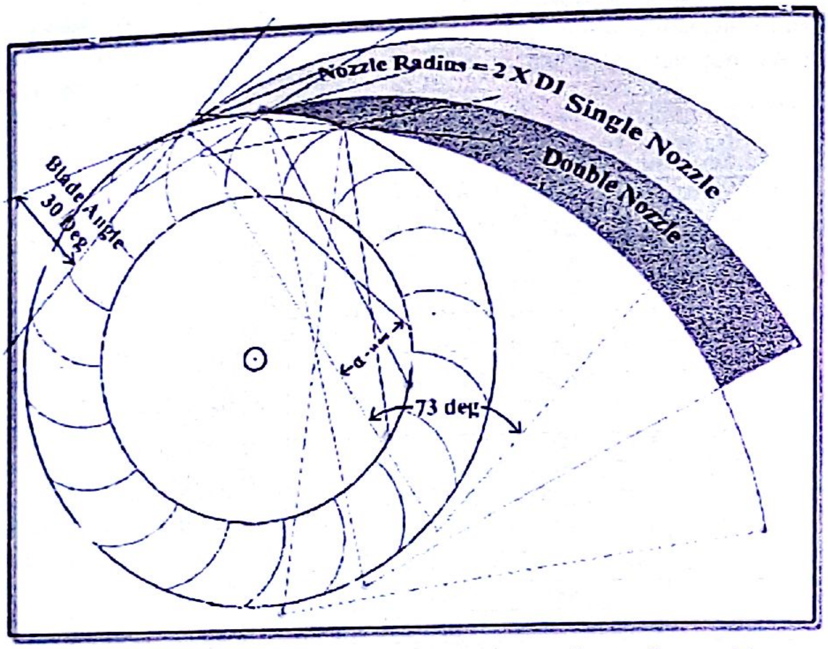

Fig. 7 disposition of nozzle with respect to runner of cross flow turbine

II. Design of nozzle

For maximum efficiency, the runner is designed for a single blade operation [9]. The nozzle curvature is selected as two times the runner diameter, to give a nice long gentle sweep on the blade Considering mechanical clearances and a long gentle sweep, arc of nozzle is taken as 73° as shown in Fig7. The important parameter is the angle (a) which the water hits the blade; it is calculated as 16° in the previous calculations of blade angles. This angle is measured relative to the blade angle b(30°) which it self, is relative to the periphery of the runner. There are several nozzle arrangements that may be used but the simpler arrangement is to use a flow control valve as nozzle, to adjust the angle of attack. The nozzle parameters are listed in Table 8.

III. Over all dimension of Cross flow turbine

A schematic of the turbine arrangement in two different views is presented in Fig.8. The actual dimensions

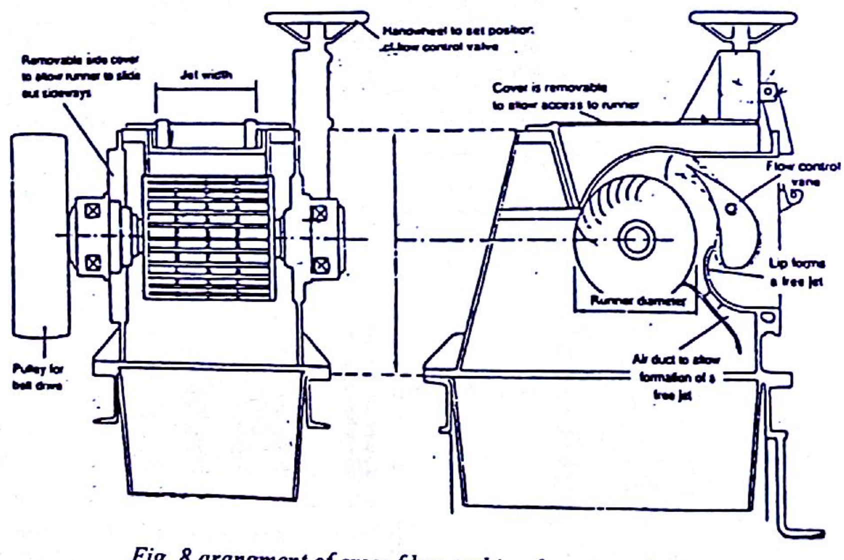

Fig. 8 arangment of cross f low turbine from two views

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Discharge, $Q=0.55m^3/s$	Head, $H=10m$ and Speed, $N=400rpm$
$D_{runner}=\frac{41\sqrt{H_{net}}}{rpm}=\frac{41\sqrt{10}}{400}=0.324m$	$t_{jet}=1/5\, D_{runner}=\frac{0.324}{5}=0.0648\ m$
$Q=C_4 * 4.43\sqrt{H} * b_o * t_{jet}=0.55m^3/s$	$U_1=U_4=\frac{\Pi D_1 N}{60}=\frac{\Pi(0.324)*400}{60}=6.78m/s$
$b_o=\frac{0.55}{1*4.43\sqrt{10}*0.0648}=0.606m$	$\alpha_2=\alpha_3, C_2=C_3, \beta_2=\beta_3$ $\Rightarrow \omega_2=\omega_3$
$C_1=C_4\sqrt{2gH}=\sqrt{2*9.81*10}=14m/s$	$W_{1st\ stage}=6U^2$ & $W_{2nd\ stage}=2U^2$.
Power out put(max)= $Q*H*g*\eta_H*\rho$ = $0.55*10*9.81*0.92*1000$ =50kW Power out put(actual)=35.1kW	$W_{total}=\frac{P_{total}}{\dot{m}}=\frac{50*10^3 w}{550kg/sec}=90.91J/kg$ $W_{1st\ stage}=68J/kg$, $W_{2nd\ stage}=22.70J/kg$
$W_2=U_3C_{y3}-U_4C_{y4}=U_3C_{y3}=U_2^2=22.7$	$U_2=4.765m/s=\frac{\pi D_2 N}{60}$, $D_2=0.227m$
$\omega_1=7.77m/s$ and $\beta_1=31.43°$ $\alpha_1=16.80°$	C_{x1} =4.05m/s, $\omega_2=C_{x2}=4.05$-
$C_2=\sqrt{(4.765)^2+(4.05)^2}=6.25m/s$	$\alpha_2=40.3°$, $\beta_2=\beta_3=90$
$\omega_3=C_{x3}=C_{x4}=4.05\ m/s=C_4$ $\alpha_4=90°$	$\omega_4=\sqrt{4.05^2+6.78^2}=7.9\ m/s$, $\beta_4=30.88°$
Blade radius = $0.326*D_1/2$=52.8mm	Area of the Jet= $Q/C_1=0.039m^2$
Jet Thickness, $S_o=A/L$ = 64.4mm	Number of blades, $n=(\pi*D_1)/(t+S_o)=15$ t=Thickness of blade=0.237"=6mm (made from 4"steel pipe)
Nozzle radius= $2*D_1$= 0.648m	Arc of Nozzle = 73^0

Table 7: Parameters of the designed Cross flow turbine

Table 8: Other constructional parameters obtained for the cross f low turbine

Blade radius= $0.326*D_1/2$=52.8mm	Area of the jet = $Q/C_1=0.039m^2$
Jet thickness, $S_0=A/b_0$=64.4mm	Number of blades, $n=(\pi*D_1)/(t+S_0)=15$ T=thickness of blade=0.237 "=6mm (made from 4" steel pipe
Nozzle radius= $2*D_1$=0.648m	Arc of Nozzle = 73^0

Table 9: Cross flow turbine auxiliaries

Shaft sizes Turbine shaft dia. = 55m Driven shaft dia. =35mm	**Belt Drive**Speed ratio=2.5, Center diatance = 2.6m, No. of V belts = 4, Smaller pulley dia. = 440mm, Larger pulley dia. = 1100mm
Coupling Size 3 Pin-Bush type coupling Pin - 0.25 to 0.6% Carbon steel 220-230BHN	Key- Material SAE/AISI 1020 Smaller pulley 9.52X9.53X30.7mm Larger pulley-12.7X12.7X24.4mm
Bearings-Deep grove radial ball bearing with 2 seals, Smaller bearing life-26yeras	Larger bearing life -44 years

Table 10 : Common pipe sizes which can be used to make cross flow turbine blades

Common size	OD	ID	Wall Thk	Radius	Runner Diameter
4	4.500	3.998	.237	2.000	12.27
6	6.250	8.625	.280	3.125	19.17
8	8.625	7.943	.322	4.312	28.53
10	10.750	9.976	.365	5.375	33.00

of the turbine and associated components designed are highlighted in Fig..9. The runner can even be partitioned into two parts, so that 1/3, 2/3 or the full length may be used at a time depending on the load condition. The performance characteristics of the turbine are such that efficiencies of 83-84% have already been reported over a wide flow range of 25-100%, see Figs 10(a) and (b).

Manufacturing of Cross flow turbine blade.

Options

Using the rolling die, it is possible to form the blade from flat stick and finally cut to the required length and later machining to the required accuracy. Or else, the blade can be fabricated by cutting a 4 inch pipe length wise, in strips and machining to the required accuracy and radius.

Details

In the first case, once the value of blade radius, central angle and length are known, it is possible to take these figures to a machine shop and have them form the blade from flat stock. To conform to the blade radius, we need to machine the blade section to form the 73.46° using rolling die and finally cut the blades to their final length. There is another alternative which is much simpler to arrive at near the same result. The dimension and the angles in the design represent the near optimum dimension angles to satisfy mechanical advantages & unrestricted passage of the water. These dimensions are fairly fixed, there fore can't be arbitrary changed with some decrease in efficiency. As a result, there are definite dimensional relation ships between the various components of the runner. We can use this to a great advantage because a supply stock is all around us and readily available in the form of steel pipe. For the manufacturing of cross flow turbine, runner diameters usually range between 305mm to 813mm in the length and usually most of them are made from 4 inch steel pipe, how ever there is no hard and fast rule to fabricate always from 4" steel pipe [9]. Some relevant dimensions using other size steel pipes are given in Table 10.

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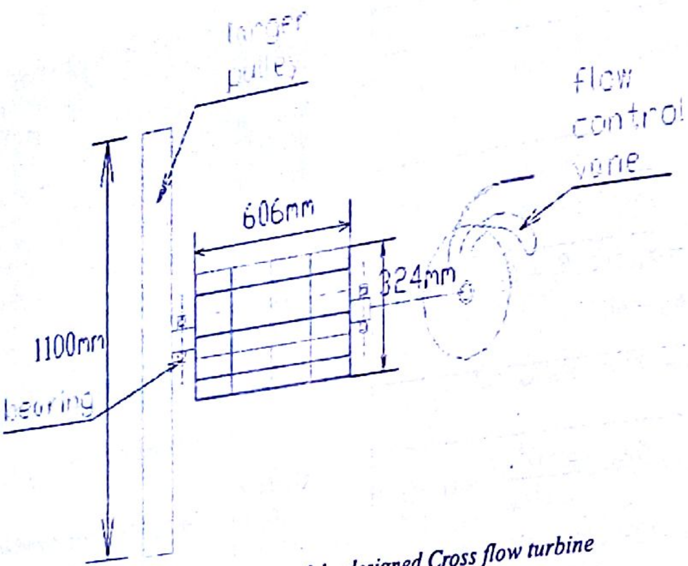

Fig. 9 Over all dimenssion of the designed Cross flow turbine

Cost estimation

Total cost including manufacturing for locally made cross flow turbine and all of its associated parts with locally available material is estimated as 15,000 birr. The cost of Cross flow turbine depends on its sophistication For example if it is associated with draught tube it costs much. The same capacity Cross flow turbine, if it purchased from foreign country would cost as much as 80,000birr.

Conclusion

One of the proposals outlined here can be feasibly implemented depending on the availability of financial resources with private sector parties / individuals/ power sector companies. The design of the systems and associated components has been carried out to minimize both hydraulic and mechanical losses. The salient feature of this project is that it can be implemented easily; especially the second option of the design i.e. the cross flow turbine. This turbine and its associated parts can be made with locally available material in local workshops. It is known that Ethiopia has so much hydro potential resource for generation of power both in micro, mini and large. Since the design is affordable with minimum cost, both the private sector and the government have the chance to implement this project to improve the supply and lessen the shortage of power generation in rural areas of this region. The capacity of this project with second option is such that it can serve on an average 175 families. Other special feature of this cross flow turbine is that it is particularly relevant in the Ethiopian context and need to be widely publicized, manufacturing strategies firmed up and standardized to reduce the overall cost associated with its fabrication.

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Nomenclature

b_o	Runner length,m	C	Absolute velocity of the fluid, m/s
C_d	Coefficient of discharge of nozzle	C_a	Component of C in flow direction, m/s
C_y	Tangential component of C, m/s	H	Head of water available, m
D	Diameter of rotor, m	N	Rotational speed, rpm
P	Power output, W	Q	Discharge, m3/s
S_o	Thickness of water jet, m	U	Blade velocity, m/s
g	Acceleration due to gravity, m/s^2	W	Work output, J/kg
ω	Relative velocity of fluid, m/s	η_H	Hydraulic efficiency of turbine
ρ	Density of fluid, kg/m^3	α	Fixed blade angle, °
β	Rotor blade angle, °	A	Cross sectional area of jet, m^2
n_s	Specific speed (N*0.001* P^0.5)/(H ^1.25)		

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Gis Based Irrigation Suitability Analysis (A Case Study of Abaya-Chamo basin, Southern Rift Valley of Ethiopia)

Negash Wagesho[1] and Dr.Seleshi Bekele[2]. A MU,
Arba Minch, P.O. Box 21

Abstract

Existing data on topography, climate, soil, land use pattern, water availability, agricultural practices, investment costs and socioeconomic practices are investigated and the irrigation suitability criteria is defined based on these variables. Digital Elevation Models (DEMs) is developed to investigate the terrain feature of the basin from the digitized Contour map of the basin and the variation in elevation as well as slope is evaluated.

Stream net work characterization, mapping soil and land use units using GIS environment and defining their suitability for irrigation as well as crop development with respect to the prevailing conditions has been made.

Super-imposing all these attributes in the GIS environment and identifying potentially suitable areas for crop development, suggesting appropriate method of irrigation, compiling georeferenced suitability data base (slope, soil, land use, water) for irrigation are among the main treatments undertaken during the study.

Large portion of Gelana and the lower delta of Hare, Kulifo and Bilate are characterized with suitable soil units having good inherent fertility and high moisture holding capacity. Besides, these areas are with very flat land slope as observed from the DEMs, which falls below 10 %, and are suitable for surface irrigation.

The capacity of low flow as well as 80%, 90% and 95 percentage time of exceedence flow of the available surface water in the respective sub basins is estimated and the area that can be irrigated with this flow is computed for the selected cropping pattern. To maximize the extent of irrigable land storage requirement with respect to different flow reliability level is estimated.

In all the basins the potentially irrigable land exceeds the available surface water capacity during the low flow periods. This does not mean that the total annual flow capacity is less than the irrigation water demand. There is large amount of river flow as well as run off during the peak flow periods, which can able to satisfy the demand of irrigated area and even for some other energy generating options with provision of storage requirement.

I. Introduction

Population of Ethiopia is largely rural and dependent on agriculture for their livelihoods. But agricultural production has not kept pace with population growth, leading to sever chronic malnutrition and hunger, and periodic crises induced by drought. Despite irrigation potential estimated about 3.7 million hectare, only about 190, 000 ha (5.3% of the potential) is currently under irrigation, which plays insignificant role in the country's agricultural production. Thus to bring food security in the national as well as in house hold level, improvement and expansion of irrigated agriculture must be resorted.

Appropriate management and selection of best-fit irrigation method is a prerequisite for wise utilization of scarce physical resources, land and water. To ensure adequate management and design of a particular irrigation system, well-developed and suitable database related to spatially and temporally varying factors affecting the system is quite important.

FAO (1987) conducted the first GIS based study to assess the land and water resources potential for irrigation for Africa. Limited number of reports and investigation were made to asses the irrigation potential of Ethiopia based on the physical land and water resources. Some of them are reports made by World Bank (1973), IFAD (1987), MoA (1986), WAPCOS (1995) and WSDP (2003). Focusing on the present study Area – Abaya Chamo Basin, Development prospects in the southern Rift valley organized by Land Resources Division, the Rift Valley Lakes Basin study (Halcrow), Study on Rift valley Lakes and Investigation of water Resources potential in ACB (Seleshi,2001) are among the major investigations and reports so far.

The present study concentrates on qualitative as well as quantitative assessment of the existing physical resources – land and water with respect to its suitability for irrigation and to develop a suitability database that would help for further investigation on the area. The soil, terrain features (DEM and its derivatives) and land use classification criteria are the basis used to define the suitability. With this respect, the Geographic Information System (GIS) facilities were extensively used.

1.2 Objective of the study

The main objective of the study is to provide GIS based irrigation suitability criteria and to assess the natural physical resources land and surface water for irrigation with specific objective of:

1. Providing an integrated, geo-referenced irrigation suitability data base that can be used for identifying potential irrigation investment opportunity with the aid of GIS.

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2.To map existing and potential identified irrigable areas based on the soil, terrain feature and surface water availability in the basin.

3.To estimate potentially usable available physical resources; land and water for irrigation and suggest techniques to be used to compromise between the two.

4.To point out appropriate irrigation methods (surface, overhead, pumped irrigation or semi-gravity) that suit particular condition based on the data obtained.

The study area tries to cover major perennial rivers in Abaya- Chamo sub basin basin. Geographically the basin is situated between 5°5'& 7°00' North latitude and 37°16' & 38°39' East longitude. ETo as well as CWR estimation is made for selected climatic stations and agricultural farms. Run off & low flow potential of the streams is computed for major rivers in the basin. Dominant soil and land use/ cover units are considered for the present study.

2. Data Analysis and Methodology

2.1 Input data and Materials used

The following input data have been collected from the respective sources and further analysis is made.

Topographical map:

About 6 topographical maps of scale 1:250,000 defining the basin have been collected from Ethiopian mapping Authority. Out of which the catchment boundary and other spatial as well as grid data is developed for the present study.

Soil map and Land use map:

Soil and land use/cover condition maps on the scale 1: 1,000,000 including the legend describing the features were collected from Ministry of Agriculture and mapped using GIS environment..

Climatic Data: Relevant climatic data such as rain fall, temperature, relative humidity; wind velocity and sun shine hours for six stations were collected from NMSA as well as from AWTI, RPD. The climatic stations considered for ETo as well as crop water requirement are AWTI, Mirab abaya, Bilate, Alaba kulito, Sille, Chencha and Arbaminch Farm. The Alaba Kulito, Arbaminch, Mirab Abaya and Sille stations have a rainfall data from 1971-2000 and the Bilate station covers from the year 1989-2003.

Hydrological Data: The monthly run off and discharge data for Hare, Bilate, Gelana, Gidabo, Basso, Bedessa are collected from MOWR and AWTI with varying length of record periods.

In addition to this, other relevant data on investment cost of small-scale irrigation projects, socioeconomic aspect, infrastructure etc is also collected and interpreted accordingly.

Materials used: Soft wares: GIS Software, CROPWAT4.3, AUTOCAD 2002; Hard copies of topographical, soil, and land use maps, personal computers, scanner and tracing papers.

2.2. Methodology

2.2.1 Estimation of ETo, Crop water requirement and Available low flow

Estimation of ETo

Different methods have been developed and being in use over the last half dozen of decades to estimate reference crop evapotranspiration with respect to the available data. Each of them were subjected to local calibration and limited to global validity. But the penman Monteith method that combines the energy balance and mass transfer equation is commonly recommended and hence used.

The estimation of ETo for selected climatic stations is made available by using the CROPWATW4.3 version. In some cases where the available climatic data is limited to temperature only, the Haregreaves method is used.

Crop water requirement

A crop water requirement for selected crops is estimated using CROPWAT4.3 for windows. It uses monthly data to estimate evapotranspiration. Monthly rainfall magnitude is converted in to daily values in each month through interpolation.

In addition to climatic data, crop and soil data of the area under consideration is provided as input data. The cropping pattern is so selected to fit with the local cropping calendar and the respective crop coefficient for the initial, mid and let seasons is identified

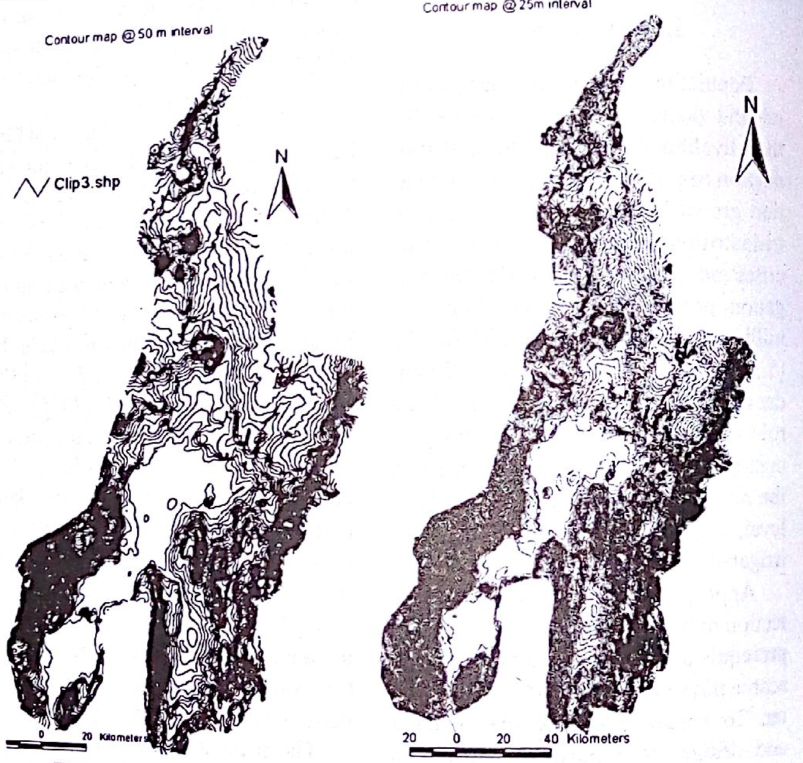

Figure 2.1: contour map of ACB @ 50m and 25 m contour interval

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based on the FAO guidelines. The intermediate Kc values were linearly interpolated between the pre-identified Kc values for different stages.

Thus the crop evapotranspiration demand is calculated as:

ETc = ETo *Kc , mm/month

The crop water requirement is estimated taking care of the rainy seasons. Effective rain fall is determined with the aid of SCS method option in the program and deducted from the ETc value.

$CWR = ETc - P_{eff}$, and $NIWR = CWR * A_{crop}$, mm/month

2.2.2 Developing DEMs and Derivatives

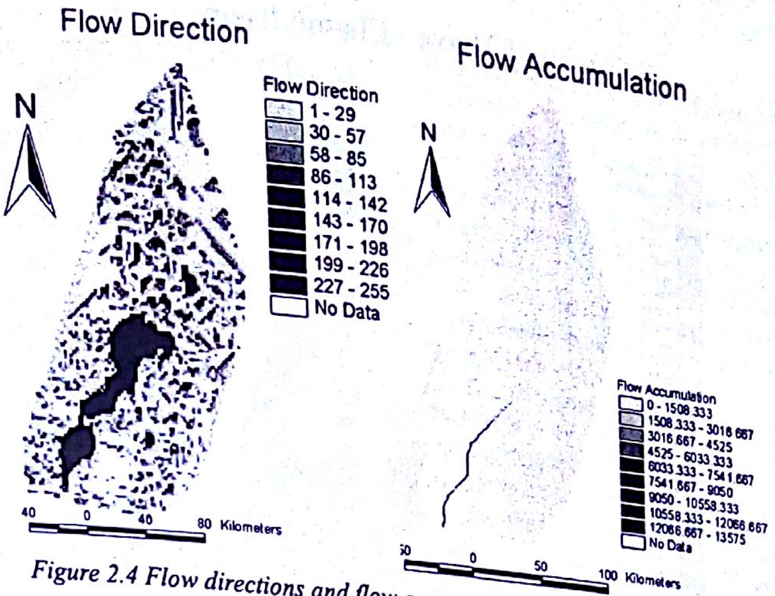

Figure 2.4 Flow directions and flow accumulation characterizing the basin

The Digital Elevation Models (DEMs) are point elevation data stored in digital computer files. These data consists of x, y grid locations and point elevation data or z variables. They are generated in a variety of ways for a variety of map resolutions or scales. The point elevation data are very useful as an input to the GIS. The data can further be processed to yield important derivative products such as slope, aspect, flow accumulation, flow direction, curvature etc.

The study area covers much area and digitizing the contour map with 25 m interval is some thing that takes a long journey with respect to the very limited time. Thus, a digitized map of the whole Ethiopia with 200m resolution is considered and the Digital Elevation Models (DEMs) and its derivatives were worked out for the basin. Out of which the terrain feature, the variability of slopes and their respective classification has been made.

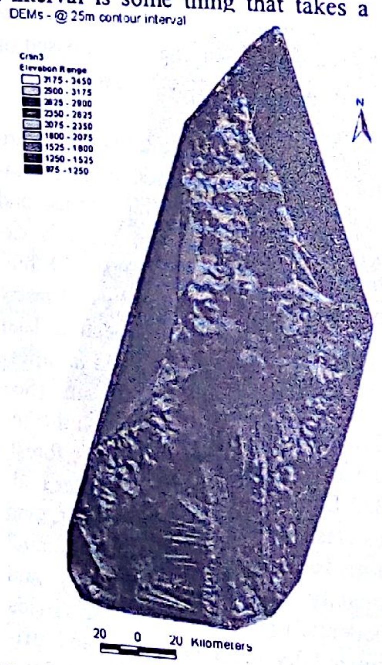

Figure 2.2 DEMs of ACB @ 25m contour interval.

Slope:

Slope is defined by a plane tangent to the surface as modeled by the DEM for all grid cells. The slope gradient can be understood as the maximum rate of change of altitude. The calculation of slopes from DEMs is particularly important for derivation of flow direction, flow accumulation, slope length, terrain units and estimation of potential gravitational energy etc.

This helps in identifying the slope, or maximum rate of change, from each cell to its neighbours. The output slope grid theme represents the degree of slope for each cell location. Data on slope is provided as floating data. The main significance of developing slope map of the basin is to observe how flat, mild and steep the slope is. In addition to this, it describes the variation in slope relative to the adjacent lands and energy generating power of the run off. Observing the derived slope of the basin different methods of irrigation; surface, overhead as per the suitable soil can be suggested.

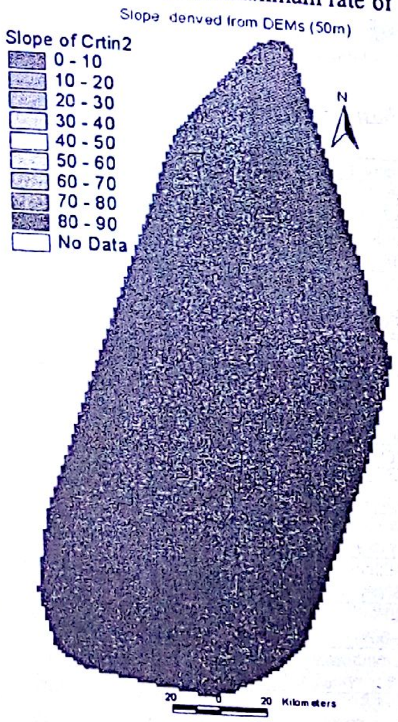

Figure 2.3: Slope map of Abaya – Chamo basin derived from the DEMs

Flow Direction:

The flow direction function calculates the flow direction of each cell in the surface to its neighbors. Data on flow direction are provided as integers. This attributes defines the potential flow direction and its accumulation. The dark line in the figure indicates the point where the flow is get accumulated and to which way the flow takes place. It gives a clear view of the run off direction and further helps to confirm the actual flow direction so that the derived digital elevation models from the contour map actually represents the basin characteristics.

2.2.3 Mapping soil and Land use

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Soil map of Abaya - Chamo Basin

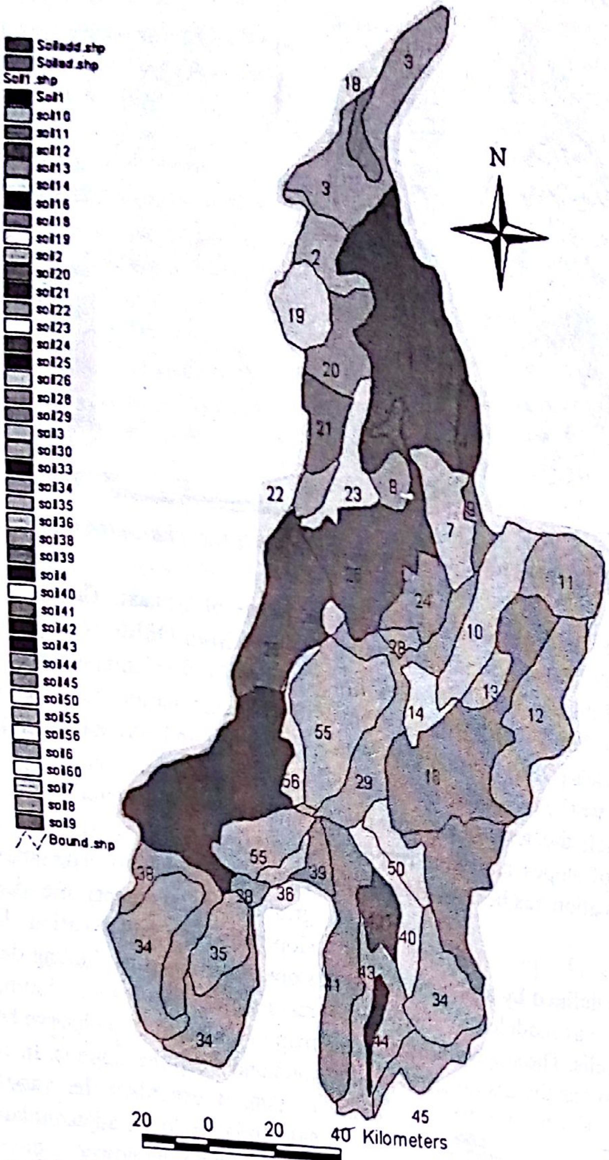

Figure 2.5: Soil map of Abaya- Chamo basin, mapped using Arc View/GIS

River	Area irrigated(ha) with — percent reliability level of flow			
	80%	90%	95%	100%
Gidabo	809	560	435.5	365
Gelana	1818	1125	996	11
Bilate	152	95	87	76
Hare	177	135.5	127	77
Kulifo	13	8	4.0	2.0
Sille	4.5	2.6	2.5	1.0

Table2.2: Area irrigated with different percentage exceedence flow

Criteria for appraisal	condition	Range of the criteria
Topography: slope	optimum	< 10%
Drainage	optimum	Well drained (W)
	Marginal	Moderately well drained
Texture	optimum range	Loam, silty clay, clay loam Silty loam
Soil depth	Optimum	> 100cm
	Marginal	< 50cm
Calcium carbonate	Optimum	< 30%
	marginal	30-60%
Salinity	Optimum	< 8 mmhos/cm
	marginal	8-16 mmhos/cm
Alkalinity	Optimum	< 15 ESP*
	marginal	15-30 ESP

*ESP = exchangeable sodium percentage

Table 2.3: Soil suitability criteria set for the present study

units of the basin.

The basin is characterized with diversified geomorphology and soil patterns. However, the identification of representative soil textures and there physical as well as chemical properties is based on the FAO/ UNDP's classification. To this end, a soil map to the scale 1:1,000,000 is reviewed and mapped.

3.3 Identification of potential irrigable sites

Qualitative land evaluation for irrigation is generally based on interpretation of physical characteristics of which slope, soil, land use and the available water resources and its quality are among the most important parameters.

In evaluating the soil suitability, the criteria identified are soil drainage class, soil texture, soil depth, and salinity /alkalinity hazard of the soil and presence of important minerals such as phosphorus. Slope classification is assumed to be suitable for surface irrigation if it is less than 10% and in other areas where the soil is suitable and water is available in growing seasons or can be trapped by means of storage mechanisms, slopes up to 20 -30% can be irrigated with sprinkler or drip system with the aid of pumped irrigation. Hence these areas are also considered to be suitable for irrigation; in fact the selection between the two is based on the soil texture and other factors.

Different land use units are identified and criteria are set for their suitability for irrigation. The land use and cover condition for the basin is extracted from the land use map of Ethiopia, which was developed by Ministry of Agriculture. The respective land cover conditions are mapped in different sub basins of the study area (See figure 2.6 and table 2.2). With this respect, areas covered with dense forest, Bad Lands, swampy areas, water bodies, restricted / controlled areas, and stony lands are excluded from potential capacity estimation. Intensively and moderately cultivated areas, farm fields covered by perennial crops and irrigated agriculture practiced by medium scale estate farms are supposed to be

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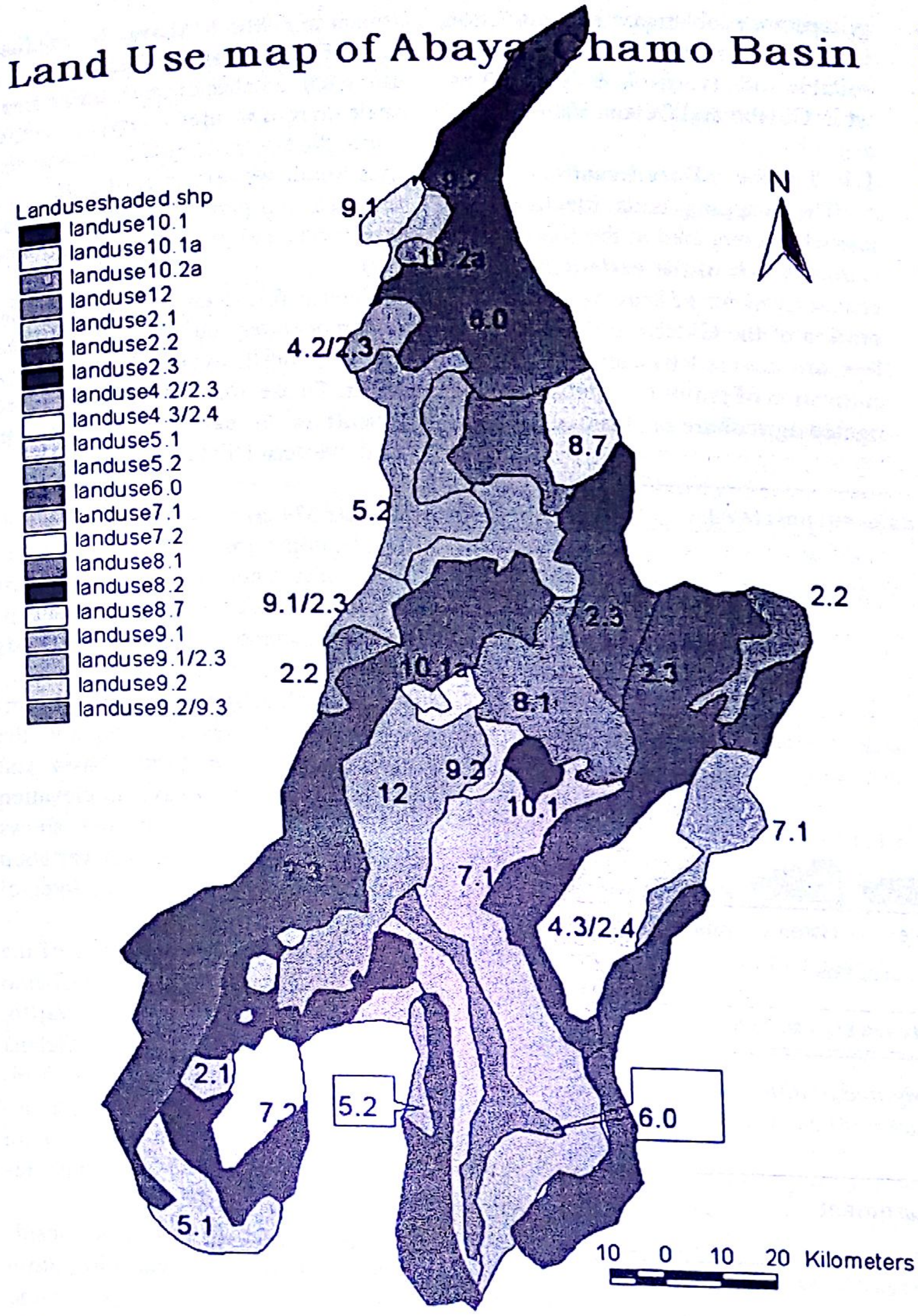

Figure 2.6: Land use/cover condition map of Abaya- Chamo basin, mapped using Arc View/GIS (see table 2.2 for details)

lection criteria to identify between surface and other methods of irrigation. Of course other limiting factors such as type of common crops grown, socio economic status are also investigated. Based on these criteria a low land area near the west and east banks of main river are under less than 10% slope classification characterized by sandy loam to clay loam soil type. In this area surface irrigation, which can be set with relatively low initial investment and available technology, is of paramount importance.

On the other hand, a lot of cultivable lands are observed at high land as well as at small portion in lower banks of the riverside. These areas can be irrigated only if slope adjustment or power supply to pump the water up hills to some distance has to be resorted. (See figure 2.7)

3. Results and Discussions

1.1 Soil data Results

Nitosols, which are fertile and good for agricultural purposes, is observed in alluvial fans and deltas of Lake Abaya and Chamo, in the immediate northern part of Lake Abaya and in the southern summit of Bilate basin. The lower Hare as well as Kulifo basins are taken as good for agricultural production provided that other factors affecting irrigation kept constant.

2.4. Water resources availability and Scenario Development under Existing water Resources Condition

Estimated Potentially irrigable area is divided in to the respective sub basins and compared to the available minimum flow and different level of percentage exceedence minimum flow of the river. The storage requirement needed to meet the crop water demand on the identified area is also computed.

3.4 Suggested irrigation methods on identified areas

The available technology, slope of the terrain, people's socio economic status, etc are also among the limiting factors in selecting appropriate method of irrigation. The present study considers the terrain feature (slope, topography) and the soil characteristics as se-

Fig.2.7 Potential irrigable land sugested for semi gravity (pumped) system

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also covered by patches of nitosols (soil number 24, 33,34, 38, 56). The southern tip of Gelana valley is characterized with fluvisols, still good for cultivation.

Luvisols with clay loam texture covers the southern tip of Lake Chamo. The Gelana valley is dominantly covered by cambic luvisols and lithosols of clay texture (soil 16, 40, 44, and 14 , see soil map in figure 2.5). Cambic Vertisols, with effective depth greater than 150mm, clay to clay loam is observed in Alaba kulito area. These soil groups are problematic for cultivation, unless treatment is done. Moderately suitable soils (vertisols & luvisols) exist in Gidabo and Gelana Valleys.

1.2 Land use Data Results:

The mapping units identified are less when compared to the soil classification. Much of the eastern and western escarpments of lakes area and great portion of the Gidabo and Gelana valleys are covered by rain fed peasant cultivation of grains (Land use 2.3). Irrigated agriculture is observed in Arba minch and Mirab Abaya- by Medium scale Estate farms (see land use 2.1). But small patches of lands under small scale irrigation are observed in other areas than already given in land use map.South western part of Bilate and north eastern part of Gidabo basin are intensively cultivated areas (land use 2.2).

Dense forest and open grass land with moderately cultivated land is observed in north western Bilate escarpments. Dense wood lands with mixed agriculture in patches were seen in south western Bilate area.

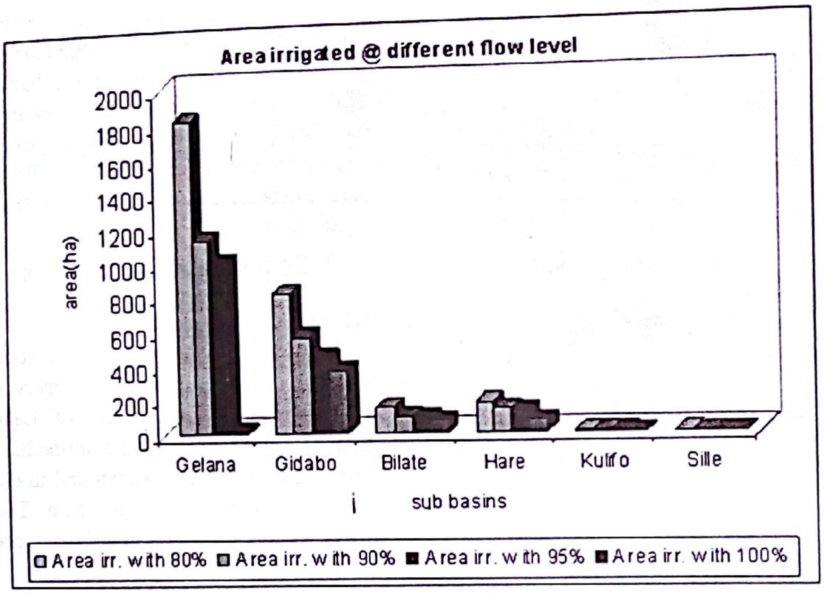

Figure 3.1: Area that can be irrigated at different flow levels

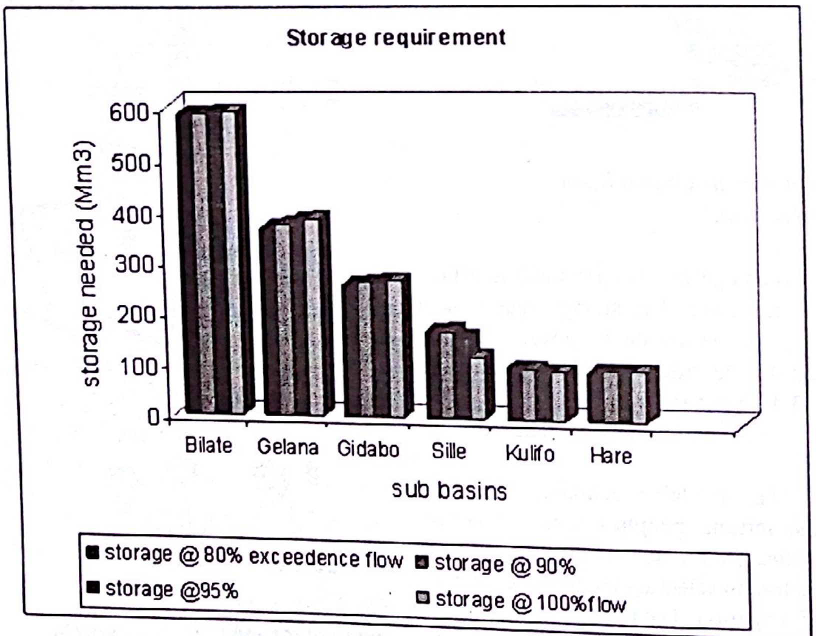

Figure 3.2 storage requirements under different scenario of flow reliability

1.3 DEMs and Terrain feature

The upper areas of Hare river catchment (near Chencha), the South west hills of lake Chamo, Eastern escarpments of Gidabo and Gelana high lands are characterized with rugged topography and elevation range of 2150m-3440m a.m.s. level. Typically the Chencha, northern Bilate basin and east of Lake Chamo have an elevation range of 2900m-3200m and shows variation in elevation so that variation in slope with in short distance interval appears.

On the contrary, much parts of the alluvial fans of lake Abaya and Chamo (Arba minch, Mirab Abaya, Wajifo, Sille) and the lower valleys of Gelana and Gidabo are characterized with elevation range below 1700 and characterized with flat slope (< 10%). So are suitable for surface irrigation with respect to topography.

Slope of less than 10% is considered to be suitable for surface irrigation with minor adjustment to negotiate the natural slope. And slope ranges between 10-20 %, with suitable soil type and limited constraints found to irrigate with pumped-gravity surface method. Irrigable lands with rugged topographic feature and with moderate slope range are considered to irrigated by sprinkler and micro irrigation based on the specific soil type.

1.4 Crop water Requirement:

Crop water demand for common crops during the growing season is estimated using the available climatic, soil and cropping pattern data. The crop water demand over the entire identified potentially irrigable area is calculated

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and compared with the existing flow. Both the monthly low flow as well as the percent time of exceedence low flow is calculated and compared to the total water requirement of the crops over the irrigable area.

1.5 Storage requirement

Storage requirement to meet the demand of crop water requirement at critical month is estimated at different exccedence available flow level for each sub basin. It is observed that much storage is required in Bilate basin than others. This storage is not only due to the river water but can be provided in the form of small-scale water harvesting mechanisms too when storage reservoir with respect to the river discharge is not possible.

4. Conclusions and Recommendations

Approximately 0.1Mha of land, which is nearly equal to 5.5% of the basin area, is identified as potentially irrigable both in surface-gravity as well as semi- gravity over head methods of irrigation with limited constraints. These constraints can be improved with appropriate water management, soil amendments, provisions of pumped system to irrigate moderately slopping up lands.

Large portion of Gelana and the lower delta of Hare, Kulifo and Bilate are characterized with suitable soil units having good inherent fertility and high moisture holding capacity. Besides, these areas are with very flat land slope as observed from the DEMs, which falls below 10 %, and are suitable for surface irrigation.

In all the basins the potentially irrigable land exceeds the available surface water capacity during the low flow periods. This does not mean that the total annual flow capacity is less than the irrigation water demand. There is large amount of river flow as well as run off during the peak flow periods which can able to satisfy the demand of irrigated area and even for some other energy generating options.

Due to seasonal variation of stream flow, provision of storage reservoirs has to be implemented in all the basins. This is because the distribution of available water is not even both in space and time domain.

A detailed investigation and estimation of the potential capacity of physical resources: land and water can be made by considering soil samples from the respective areas and performing analysis in the laboratory, including erosion hazard and considering present land use/cover condition. Areal photographs interpretation and Normalized Differentiated Vegetation Index (NDVI) data can be collected and interpreted accordingly to represent the current status of land use and cover condition. In addition to this, Remote sensed data interpretation to identify wetlands and salinity hazardous areas has to be made.

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Preliminary Survey of Groundwater Potential of SNNPR

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1. Abstract

SNNPRS is affected by recurrent drought due to the delay of the seasonal rainfall and this resulted in drying of springs, drying of streams and lowering of the water table in hand dug wells. However, the effect of climate change is minimal on the groundwater resource. Hence, survey of the groundwater potential of the region is crucial and timely to plan mitigation measures to be taken to reduce the effect of drought. The region is endowed with both abundant surface and ground water resources.

Rock suites ranging in age from Archean to recent characterize the geology of SNNPRS. The geological units in Southern regions fall in to one of the following three major categories; the Precambrian basement, the Cainozoic volcanic rocks & Quaternary sediments. The major aquifer in volcanic terrains is fractured volcanic rocks. Ground-water in the volcanic rocks of the rift valley basin is generally fault controlled and of moderate to high potential in low relief areas; depth to groundwater in these units varies from around 100 meters to more than 300 m. However, the Quaternary sediments situated at physiographically low relief areas and around lakes possess high groundwater potential; and depth to groundwater varies from a few meters near lakes to 50 meters. On the other hand in the hard rock terrains the availability of groundwater is restricted to fracturing or weathering and recent sediment depositions along stream channels. Generally these rocks possess low to moderate groundwater potential and depth to groundwater is from a few tens of meters near stream channels to more than 60 meters.

As far water quality is concerned, generally the groundwater is of good quality for drinking but high concentration of fluoride is observed in the groundwater of the rift valley drainage basin in waters which are characterized by high temperature and low calcium content. In the highland areas covered by volcanic rocks concentration of iron in both surface and ground water is higher.

In general considering replenishable groundwater potential of the region much remains to be done in utilization of the water resource for irrigation, human and animal consumption and industrial purposes.

Introduction

Man and living nature can neither develop nor survive without water. Man has been concerned with water from the beginning of his existence. In addition to water's being essential to his diet, it is also the means by which he can banish hunger, develop energy, drive industry, promote trade and transport, enjoy recreation and finally remove and dispose of the impurities and by products produced by his cultural activities.

At first glance there appears to be excess of water on earth. On a global scale, total water abundance is not a problem; the problem is water availability in the right place, at the right time in the right form. More than 99 % of the earth's water is unavailable or unsuitable for beneficial human use because of its salinity (ocean water) or form and location (ice caps and glaciers). Thus the amount of water for which all the people on earth compete is much less than 1% of total (Botkin & Keller, 1987).

The economic progress and social well-being of human population greatly depends on the appropriate development of surface and ground water resources. Ethiopia is endowed with both abundant surface and ground water resources. In any country especially

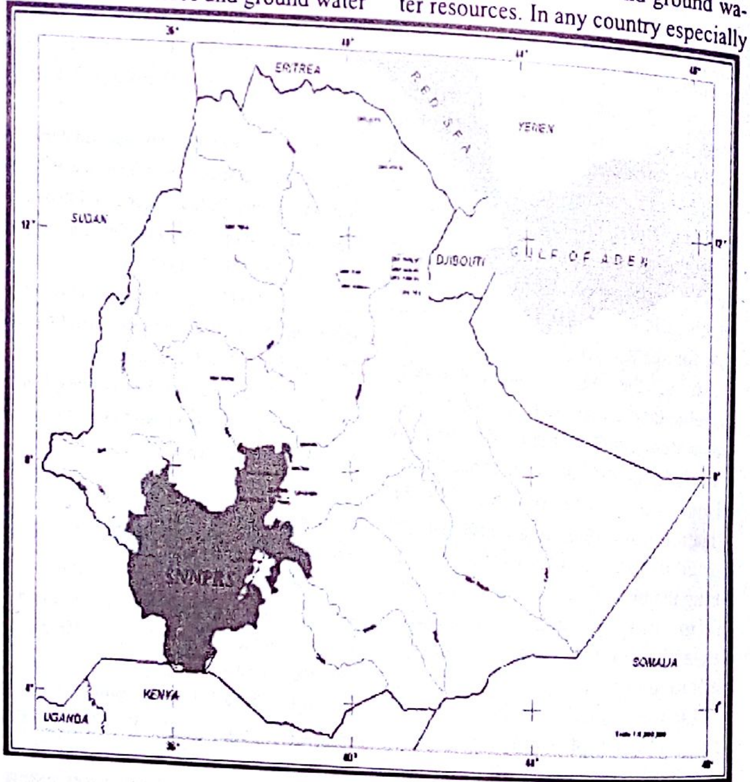

Figure 1 Location map of SNNPR

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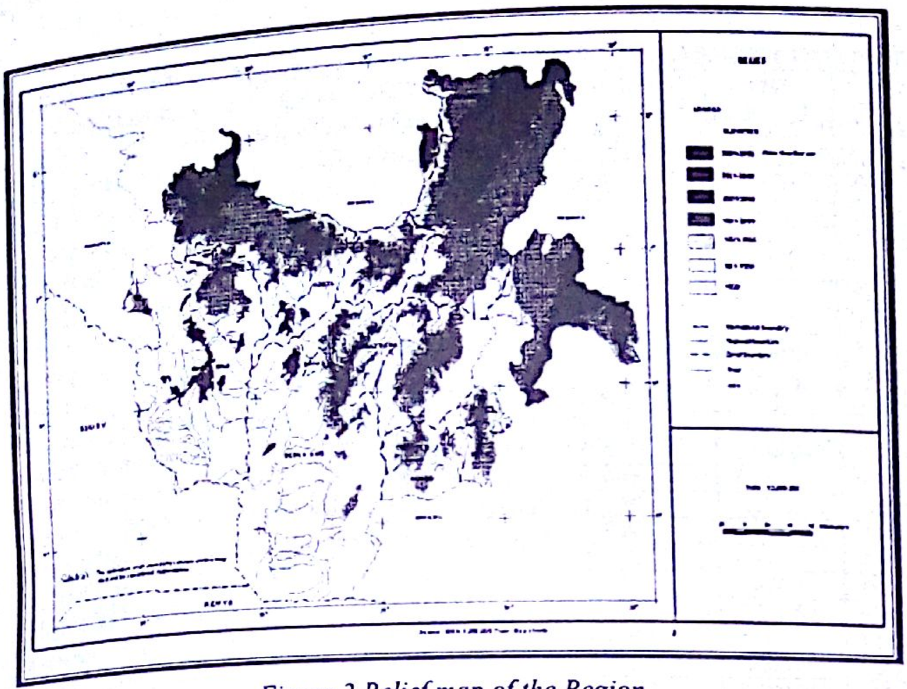

Figure 2 Relief map of the Region

drought prone like Ethiopia, intensive water resource planning, development and management can have a deceive role in the economic and social growth of the country and in reducing the recurrent drought problems.

Southern Nations, Nationalities and People's Region covering an area of 110,932 sq. km is located between 4° 27' – 8° 30' N latitude and 34° 21' – 39° 11' E longitude. The region is bordered with Kenya in the south, Sudan in south west, Gambela Region in the north-west, and Oromiya Region in the north and east (Figure 1). The region is organized in to 104 woredas with a total population of around 14 million.

Physiography

The physiography of the region varies from dissected fault-block and bordering escarpments to low lands and rift valley basins. All the landforms in the region are oriented NE-SW. Generally the elevation declines from north to south and this gradual sloping surface is modified by two ways; through erosion and late Tertiary Rifting activity. There is a great elevation difference in the region varying between over 3500 m.a.s.l. at Gurage mountains and the water divide of Rift Valley and Genale basins in the north and north-west respectively to less than 500 m.a.s.l. around lake Rudolf in the south. The high relief areas are located at the water divides of

1. Omo-Ghibe and Rift valley basins in the north at Gurage and the central part around Arbaminch and Gidole;
2. Rift valley and Genale basins in the east and
3. At Amaro horst

Population & Water Supply Situation

In the region there are climatic conditions not only governing the areas suitable for human occupation but also the type of culture that can develop. The region is organised in to 104 woredas in 13 zones and 8 special woredas.

The region has a total population of 13,685,996 (projection for 1995 EC, Statistics and population office) with a population density of 123.4 people per square kilometre area. The population density varies from 1020.4 in Wonago woreda of Gedeo zone to 3.9 in Selamago woreda of South Omo zone.

The following table (table 1) gives summary of population and population density data by zone and special woreda.

Table 1 Population and population density in the region

WOREDA	Scheme No.	Total pop^{n} Served	Water supply coverage (%)		
			Rural	Urban	Average
Gedeo Zone	350	363,951	47.01	57.83	48.48
Gurage Zone	658	524,872	32.45	76.94	35.28
Hadiya Zone	336	235,685	15.82	56.97	18.70
Keffa Zone	275	141,126	15.80	46.73	18.35
KT Zone	407	274,903	36.68	79.70	40.04
Sheka Zone	96	47,514	24.54	39.81	26.97
Debub Omo zone	364	135,405	30.30	41.22	31.17
Welayta Zone	618	657,097	41.38	57.93	42.73
Bench maji Zone	345	210,768	48.87	42.66	48.29
Sidama zone	1278	1,233,385	44.59	58.29	45.73
Silti zone	99	263,809	33.49	57.33	34.94
Dawuro Zone	110	64,850	17.79	27.87	18.14
Gamugofa Zone	411	348,469	21.34	55.24	24.43
Konso	58	31,081	13.31	55.45	15.06
Alaba	20	106,239	49.23	85.61	53.55
Amaro	17	23,423	15.60	85.60	18.20
Basketo	18	8,058	14.24	74.47	19.14
Burji	25	18,392	27.90	85.62	35.67
Derashe	26	55,109	48.75	25.74	46.28
Konta	35	20,793	22.57	85.61	26.00
Yem	48	44,962	52.49	85.04	53.13
Region	5594	4,809,891	33.09	58.43	35.14

Generally in the region the settlement is sedentary, however in South Omo and parts of Benchi-Maji zones the population is nomadic or semi-nomadic.

The water supply coverage of the region at the end of 1995 EFY is estimated to be 35.14% (33.09 % rural and 58.43% urban). Table 2 gives the water supply coverage by zones/Sp. woreda. A total of 5594 water supply schemes are constructed in the region. When the proportion of the different water supply schemes is evaluated almost all of the sources for the water supply is groundwater (Hand dug well, shallow well, Deep borehole and springs). The contribution of surface water sources as potable water supply is small or negligible (table 3 and figure 3)

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Table 2 Water supply coverage of the region by zone/sp. woreda

No	Zone/Sp. woreda	Pop[a] (1995 EC)	Area (sq. km)	Population density
1	Dawro zone	359,025	4,436.7	80.9
2	Wolayta zone	1,544,361	4,471.3	345.4
3	Gamo Gofa zone	1,432,509	12,581.4	113.9
4	Sidama zone	2,708,667	6,972.1	388.5
5	Gurage zone	1,493,831	5,932.0	251.8
6	Silti zone	758,422	2,537.5	298.9
7	Hadiya zone	1,265,813	3,850.2	328.8
8	Kembata-Tembaro zone	689,121	1,523.6	452.3
9	Kefa zone	767,615	10,602.7	72.4
10	Sheka zone	177,022	2,134.3	82.9
11	Gedeo zone	754,200	1,347.0	559.9
12	South Omo zone	434,049	23,535.0	18.4
13	Bench-Maji zone	395,567	19,965.8	19.8
14	Konso sp. woreda	207,230	2,354.3	88.0
15	Derashe sp. woreda	119,593	1,532.4	78.0
16	Amaro sp. woreda	129,188	1,597.2	80.9
17	Yem sp. woreda	84,956	724.5	117.3
18	Burji sp. woreda	51,793	1,374.6	37.7
19	Konta sp. woreda	69,068	2,196.8	31.4
20	Basketo sp. woreda	44,557	407.5	109.3
21	Alaba sp. woreda	199,407	855.0	233.2
	Region	13,685,996	110,931.9	123.4

5. Objective & Methodology

The main objective of this paper is to give a preliminary survey on the distribution and condition of groundwater in the region. The methodology adopted was as follows

- Collection and analysis of hydrometeorological data
- Collection and analysis of previous geological, hydrological and hydrogeological investigations done in the region and surrounding areas
- Collection and critical evaluation of hydrochemical data in the region
- Field survey and
- Reports of water supply feasibility studies done in the region.

Data Analysis & Results

Hydrometeorology

In the region rainfall varies from 2200 mm in the northwestern highlands to around 400mm in the lowlands of Omo River. The seasonal variability of rainfall is related to the direction of moisture bearing seasonal air current. The inter-annual oscillation of the surface position of the Inter-Tropical Convergence Zone (ITCZ) causes a variation in wind flow patters in Ethiopia. In its oscillation to the North and South of Equator, the ITCZ passes over Ethiopia twice a year and this migration alternatively causes the onset and withdrawal of winds from North and South (National Atlas of Ethiopia, 1988). Accordingly areas located south of 6°30' N possess bi-modal rainfall with a dry period in between and those areas in the northwest get rainfall almost all the year. Areas of high elevation cause the prevailing atmospheric flow to rise and cool; with accompanying condensation. Thus in general the highland areas are relatively moist and cool.

Figure 4 gives the isoheytal map of the region on a mean annual rainfall base. The map indicate that the highlands and northwestern parts of the region get the highest precipitation. The mean annual rainfall over the region is computed to be 1260mm.

The availability of water is governed largely by the prevailing climatic condition. Thus the existence of a long dry period and the decrease in the amount of rainfall and spatial and temporal variation of rainfall have an effect on the availability of both surface and subsurface (ground) water resource. The region is affected by recurrent drought due to the delay of the seasonal rainfall. One of the immediate effects

Table 3 Summary of scheme type (1995 EC)

No	Zone/Sp. Woreda	Scheme type HDW	SW	DBH	PSS	PMS	PLS	RI	DAM	Total
1	Gedeo	4	148	11	168	9	9	1		350
2	Gurage	138	204	75	227	10	4		1	658
3	Hadiya	52	57	37	178	13				336
4	Kefa	14	51	9	193	8				275
5	Kembata-Tembaro	294	39	9	43	16	6			407
6	Sheka		31	3	60	2				96
7	Sidama	192	292	54	659	70	9	2		1278
8	Silty	12	15	41	21	6	4			99
9	South Omo	166	145	4	49					364
10	Wolayta	151	93	57	253	47	17			618
11	Bench-Maji	26	14	6	290	6	3			345
12	Dawuro	21		5	82	1	1			110
13	Gamugofa	103	87	27	181	11	2			411
14	Konso		38	6	14					58
15	Alaba			18			2			20
16	Amaro		9		5	3				17
17	Basketo				18					18
18	Burji	2	11	5	7					25
19	Derashe		1	6	17	2				26
20	Konta		3	2	30					35
21	Yem	8	7	1	28	4				48
	Region	1183	1245	376	2521	208	57	3	1	5594
	% of total	21.15	22.26	6.72	45.07	3.72	1.02	0.05	0.02	100

Where: DBH- Deep boreholes; PMS- Protected medium spring; PLS- Protected large spring; PSS- Protected small spring; DAM- Earth dam; RI- River intake

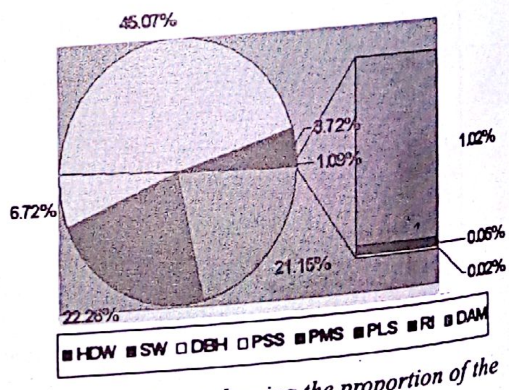

Figure 3 Pie-Chart showing the proportion of the different water supply schemes

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of drought is the shortage of drinking water supplies due to lowering of the groundwater table and drying of streams. For instance the spatial and seasonal variation in distribution and amount of rainfall, i.e., the decrease in amount of rainfall and unseasonal rainfall has caused the following consequences in the water resource (Kedir Yasin, 2003)

Ø Decrease of spring discharge as in springs found in Jirer PA

Ø Drying of springs as in Ladishe and Kilicho PA's

Ø Drying of rivers and streams for example Wardie stream, Bila stream and the stream near Soyama town

Temperature is generally altitude dependent and the mean annual temperature is above 27°C in the lowlands and around 10°C in the Gurage and Hagereselam highlands (Figure 5).

Based on the annual and monthly mean of temperature and rainfall and also on seasonal changes of rainfall, type of natural vegetation associated and altitude the climate of the region varies between cool temperate and warm temperate traditionally called "Dega" and "Kola" respectively (National Atlas of Ethiopia, 1988).

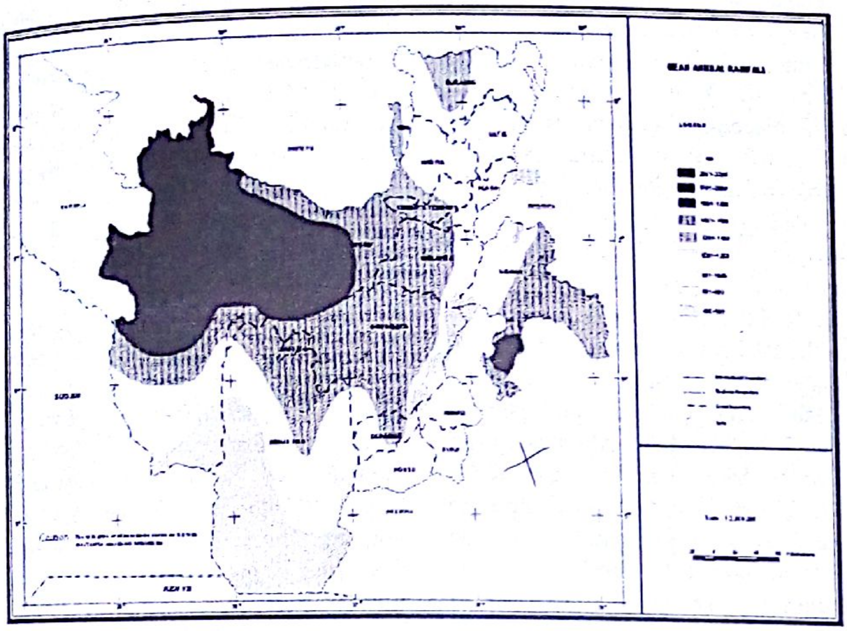

Figure 4 Isoheytal map of the region

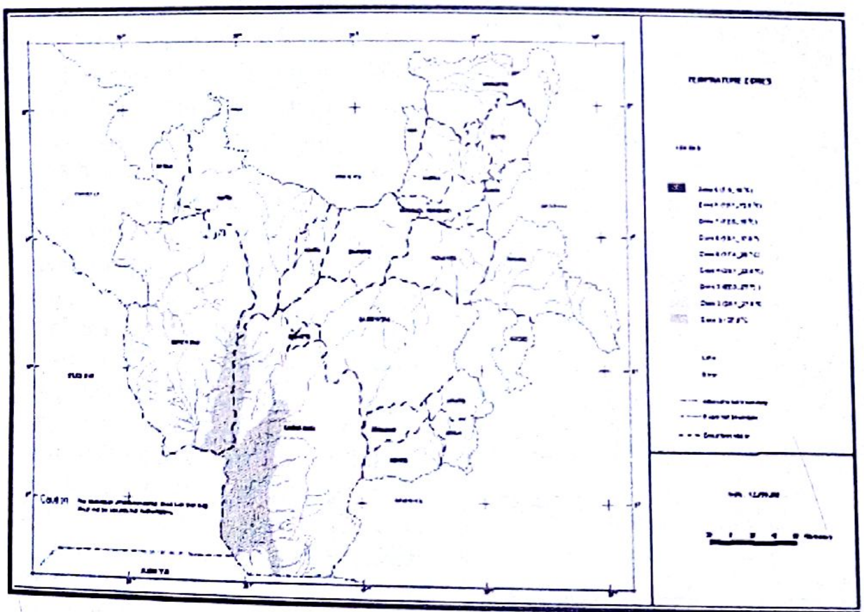

Figure 5 Temperature map of the Region

No	River Basin	Area (Sq. km)	% of total
1	Awash	188.58	0.17
2	Rift Valley Lakes	31,360.45	28.27
3	Omo-Ghibe	57,329.61	51.68
4	Baro-Akobo	19,679.32	17.74
5	Genale Dawa	2,373.94	2.14
	Total	110,931.9	100

Table 4 River basins and catchment area in the region

In the region there are 5 drainage basins (table 4 and figure 6). Omo-Gibe River basin and Rift Valley Lakes basin are the largest basins in the region covering almost 80% of the total area of the region.

When compared to the total catchment area of the basins in Ethiopia with the proportion of the region it can be seen that the area contribution of the Awash and Genale-Dawa river catchments is negligible. Hence the major river basins in the region are the Omo-Ghibe (containing almost 75% of the total catchment area), Rift valley Lakes (containing some 60 % of the total basin area) and Baro-Akobo River basin (having a proportion of about 25% of the total catchment area) (Table 5).

As far as the drainage density is concerned the density is higher in the mountainous areas and lower in the valley floors. And this is mainly four two reasos the rock type and slope conditions.

The rift lakes of Ethiopia are situated between 4° to 14° N latitudes and 36° to 44° E longitudes. Presently they occupy an enclave of internal drainage basin separating the tributaries of the Nile and Wabi Shebele basin, and are lying between the Eastern and Western escarpments of the Main Rift Valley. The Main Rift starts in the neighborhood of lake Abbe and extends some 1000 km SSW wards into Northern Kenya (Gasse et. al., 1980).

The Main Ethiopian Rift Lakes are presently represented by three closed basins (of course they are four) but assumed three for simplicity

1. The Ziway - Shalla Lake System
2. The Awassa - Shallo Lake System
3. The Abaya - Chamo - Chew Bahir Lake System

Parts of Gurage zone (Sodo, Maskan and Mareko woredas) and most of Silty zone are included in the Ziway – Shalla Lake system. The

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Ziway - Shalla lake system is a closed basin having a total catchement area of 13,000 km² of which 1443 km² is covered with water bodies. The lakes in the basin are volcano-tectonic in origin fed by surface waters (rivers) and groundwater in addition to precipitation on the lake surface. The basin lies near the highest part of the Main Ethiopian Rift floor and contains the volcano-tectonic lakes Ziway, Langano, Abiyata and Shalla and the crater lake Chitu.

The Awassa - Shallo lake system is a closed sub-basin found in the middle of the Main Ethiopian Rift and mainly contains Sidama zone. The sub-basin contains the lake Awassa and the Shallo swamp. Lake Awassa is a small lake interms of surface area, lying in the cen ter of a caldera named Awassa caldera totally enclosed by faulting having a total catchement area of 1400 km². The major source of surface water to the lake is Tikur Wuha river which connects the lake with Shallo swamp (having an area of 12 km² at an elevation of about 4 m high from the elevation of lake Awassa) and springs in the vicinity of the lake like Loke spring in addition to direct precipitation on the lake surface. The lake has an average annual direct surface inflow amounting 145 mcm, direct precipitation on the lake surface amounting 88 mcm giving the total input to be 233 mcm and a loss of water from the lake surface by evaporation being 151 mcm (Zeménu, 2000).

No	River Basin	Total Catchment area (Sq. km)	Area in the region(Sq. km)	% of total Catchment area
1	Awash	112,700	188.58	0.001
2	Rift Valley Lakes	52,740	31,360.45	59.5
3	Omo-Ghibe	78,200	57,329.61	73.3
4	Baro-Akobo	74,102	19,679.32	26.6
5	Genale Dawa	171,050	2,373.94	1.39

Table 5 Comparison of total catchment area of basins with the contribution of SNNPR

The Abaya - Chamo - Chew Bahir lake system is in the Southern end of the Main Ethiopian Rift. The sub-basin is more extensive than others having a drainage area of 37,500 km² and contains Sidama, Gedeo, Hadiya, Gurage, Silty, Wolayta, Gamogofa and South Omo zones and Konso, Burji, Amaro, Derashe and Alaba special woredas. The system contains three lakes Abaya, Chamo and Chew Bahir. Even if the lakes look separate at present, in the past discontinues river flows have linked lakes Abaya, Chamo and Chew Bahir (Stefanie) (Beadle, 1981 as cited in Tudorancea et. al., 1989). Lake Abaya is the largest lake in the Rift Valley Lakes. The main surface water inputs to the lake are direct precipitation on the lake surface, run off from rivers Bilate, Uraye, Shope, Hare Kola, Gidabo and Gellana, and springs around the lake shore. At times it overflows to lake Chamo through Kulfo river. The main surface water inputs to lake Chamo are precipitation and run off from rivers Sille and Kulfo. It discharges to lake Chew Bahir through Metenafesha stream (HALCROW, 1992). The source of Segan river, which flows to lake Stefanie, lie East of the Southern end of lake Abaya and there is a broad water channel connecting lake Chamo with the Segan river. When the water rise in lake Chamo for about 5 inches, which will probably take place every year at the beginning of the rainy season a large river will flow from lake Chamo to Segan river. Lake Chew Bahir situated at the Southern end of the Ethiopian Rift occupies a shallow depression fed by the rivers Weyto, Segan and Gayoharo. It is a small ephemeral lake presently isolated from the lakes Abaya and Chamo.

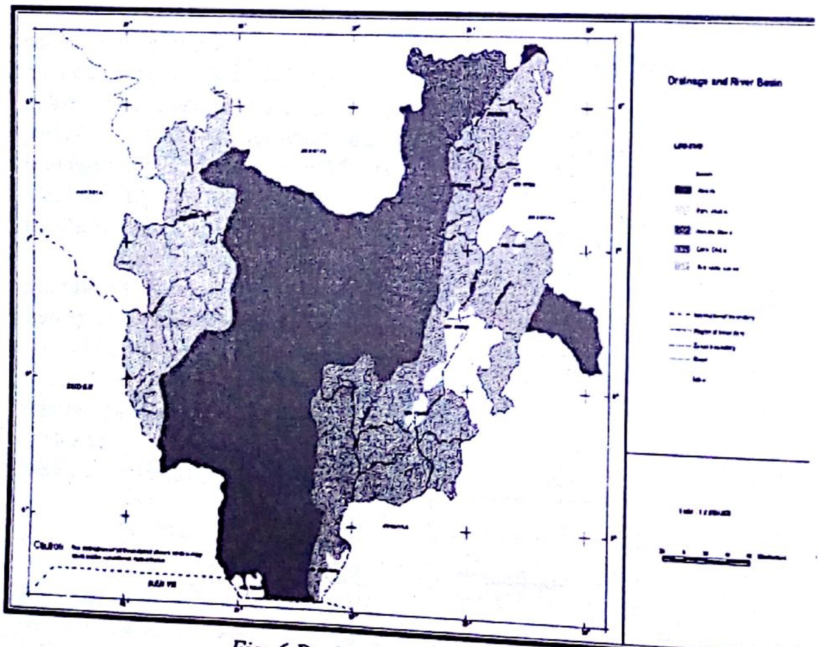

Fig. 6 Drainage map of the region

The Omo-Gibe Basin is about 78 000 km² in area, occupying the south-west of Ethiopia, between 4° 30' and 9° 30' N; and 35° and 38° E and includes Gurage, Hadiya, Dawuro, Kembata-Tembaro, Wolayta, Gamogofa and South Omo zones and Yem, Basketo and Konta special woredas.. The southern extremity coincides with Lake Turkana. Its defining drainage consists of the Omo river, flowing into Lake Turkana, and its main tributaries the Gibe draining the north of the Basin and the Gojeb draining the west of the Basin. The Omo-Ghibe river basin is the second drainage basin in the country next to Abay (Blue Nile) interms of annual runoff (amounting 17.96 billion m³ and average flow (having an average flow of 300 m³/sec). A key characteristic of the Basin is its topography. The Basin divides sharply, and almost exactly, into highlands in the northern half and lowlands in the southern half. The northern highlands are deeply dissected, and drained by the Gibe and Gojeb systems; these merge to form the Omo in a deeply entrenched gorge which slices north into the highlands. The highlands are characterised by steep slopes; and the area is favoured by a climate of moderate temperatures and rainfall.

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The lowlands, by contrast, are characterised by low altitude, relatively gentle slopes, and a harsh climate of high temperature and low to medium-low rainfall. The annual rainfall varies from a minimum of 400 mm in the extreme south of the Basin to maxima around the Basin watershed. The mean annual rainfall over the Basin as a whole is 1140 mm. In the west of the Basin, over 1500 mm of average annual rainfall has been recorded in the area around Maji and 1900 mm north of Bonga. The north-eastern edge has similarly high rainfall - over 1700 mm east of Welkite. However, rainfall decreases towards the north - to 1200 mm near Bako - and to the south and south-east - to 1000 mm near Sodo, increasing to 1500 mm near Sawla, before dropping to the minimum in the south.

Baro-Akobo drainage basin which has the highest annual precipitation covers parts of the Benchi-Maji, Kafa and Sheka zones and Genale-Dawa basin covers parts of Sidama zone.

6.2 Geology

A. Geological Setting

The Main Ethiopian Rift (MER) is roughly a NE oriented segment of the East African Rift system which extends from the Afar depression southward to a broad zone of basin and ranges near the Ethiopian boarder with Kenya. It has a length of about 1000 km and divides the uplifted Ethiopian volcanic province in to the Northwestern and Southeastern plateau. The Main Rift is essentially linear as far as 6 ° 30' N, where it bifurcates in to the Gunguli (Chamo) and Gelana Grabens, separated by the Amaro Horst.

The MER is characterized by active extensional tectonics. Two main fault systems have been distinguished in the MER: a N 30 ° E - N 40 ° E trending fault which characterizes mainly the rift margins and a N-S to N 20 ° E trending fault system, the Wonji Fault Belt (WFB), which exhibits a number of sigmoidal, overlapping right-stepping en-echelon fault zones obliquely cutting the rift floor (Boccaletti et al, 1998). Tertiary volcanic rocks dominate most of the geologic sections exposed along the rift margins. The rift floor of the Central sector of the MER consists of three caldera related basins occupied by lakes: Ziway-Langano-Abiata, Shala and Awassa and the Bilate River basin. The volcano-tectonically active Wonji Fault Belt (WFB) connects these basins. In the Northern Central sector (Ziway-Langano-Abiata basin) the rift axis consists of two en-echelon Quaternary volcano-tectonic zones, as narrow grabens along each margin of the rift floor. Elsewhere in the MER, the rift axis forms a single median zone.

On the Ziway-Langano-Abiata rift floor adjacent to the Gurage escarpment, in which the project area is situated, the active marginal graben is termed Silti-Debre Zeit Fault Zone (SDFZ). The project area in the SDFZ is bordered by the Dugda horst in the east and the western Main Ethiopian Rift escarpment in the west. The graben contains lacustrine sediments and welded tuff on which several interspersed coalescing nested scoria cones aligned parallel to the Gurage escarpment. In Sodo woreda and eastern parts of the project area basalts, scoria and gravel are the dominant lithologic formations.

The plateau areas overlooking the rifts probably originate during the Oligo-Miocene when an immense volume of Trap basalts and minor ignimbrites were out poured on top of an updomed Mesozoic and Precambrian basements. Volcanism, plateau uplift and development of the Main Ethiopian Rift have been attributed to a mantle hot spot beneath the Ethiopian plateau (Ebinger *et al*, 1993).

According to Giday WoldeGebriel *et al* (1990), the MER is believed to develop in to a symmetrical rift in two stages of evolution. In an early tectonic phase (pre- Pliocene) there were four high angle boarder faults bounding alternating and opposing half grabens in the central and adjacent northern and southern sectors of the MER. Proceeding south these alternating and opposed scarps are the eastern margin in the Arba Gugu mountain region, the Gurage western rift margin, the Agere Selam eastern rift margin and the Chencha western escarpment.

From dating and spatial and temporal relationship of volcanism it has been deduced that the transition from opposing and alternating high angle border faults of the early phase of rifting of the MER to the more symmetrical rift of today probably took place in late Miocene or early Pliocene time by fault controlled accommodation zones of volcanic centres linking the alternating opposed high angle border faults. The northern margin of the Main Ethiopian Rift is formed at about 10 Ma and recent K-Ar dating confirmed age limits of 8.3 Ma and 9.7 Ma for the Gurage and Agere Selam scarps respectively. The tectonic framework of the Ethiopian rift thus appears to have been already established in the late Miocene (Boccaletti *et al*, 1998).

As previously said the MER ex-

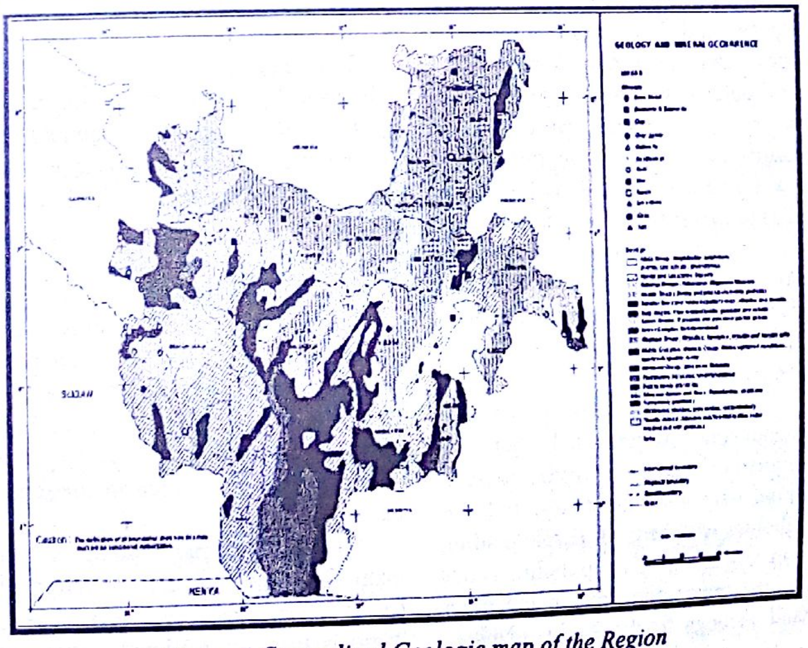

Figure 7 Generalised Geologic map of the Region

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tending southward from the Afar triangle is not continuous with the Gregory Rift in Kenya, here the Stefanie and Lake Rudolf (Omo Rift) dominate and connect directly with the Kenya rift system (Moore & Davidson, 1977)

B. Lithology

Rock suites ranging in age from Archean to recent characterize the geology of SNNPRS (figure 7). The geological units in Southern regions fall in to one of the following three major categories; the Precambrian basement, the Cenozoic volcanic rocks & Quaternary sediments. The Main Ethiopian Rift is a major structural feature in the region. The Ethiopian Rift is the northern segment of the East African Rift System separating the Somalian and Nubian blocks. It extends south-southwest from Lake Abbe triple junction, in the Afar, to Lake Turkana region. For simplicity the rock units covering the region area grouped in to four:

1. The basement rocks
2. Trap Series volcanic rocks
3. Post Rift volcanic rocks
4. Quaternary sediments and lacustrine deposits

1. The basement rocks

The Precambrian rocks out crop in four major areas in the Southern Peoples region, where the younger cover rocks have been eroded away. These areas are the peripheral & remote Southern & Western parts of the region including Bench-Maji, South Omo, Konso-Amaro-Burji Special Woredas and Eastern part of Sidama zone i.e Bansa-Aroressa Woredas and a small outcrop is observed in the western rift escarpment west of the Butajira-Bui road. These outcropped rock formations consist of low grade Volcano-Sedimentary assemblages with associated mafic to felsic intrusives and high grade gneisses and schists that belongs to the Precambrian upper and lower stratigraphic complexes respectively.

The Lower complex is part of Mozambique orogenic belt that predominantly consist of orthogneisses, paragneisses and migmatites, and amphibolites with beds of marble grading from amphibolites to granulite facies and the upper complex on the other hand belongs to the Arabian-Nubian Shield of which both complexes are major lithotectonic assemblages recognized in the precambrian crystalline basement rocks of Ethiopia. þ5□In the region the basement rocks are overlain by trap series rocks except for the western rift escarpment where the basement is overlain by Mesozoic sedimentary rocks.

2. The Trap Series

The Trap Series includes Mekonen basalt, Surma basalt, Fejeji basalt, Oligo-Miocene highland pyroclastics, ignimbrites and trachytes bordering the MER. The North central parts of the Southern Peoples region, including Guraghe, Hadiya, KT, Kaficho, Shekicho, Gamugofa, Wolayta, Sidama, South Omo & Gedeo which exceeds two-third part of the region, is dominantly comprised and covered by volcanics.

The highland volcanic terrain of Southern Region is product of eruption of voluminous basalitic magma that form Trap series including Ashangie and Maqdala groups, erupted from fissures during the early and middle Tertiary of Cenozoic era.

The Ashangie formation is the earliest fissural flood basalts consists predominatly mildly alkaline basalts with interbedded pyroclastics and rare rahyolites. The Akobo basalts in Southwestern Ethiopia are considered to be analogues with this formation.

The Maqdala volcanic group predominate by acidic rocks including acid tuffs, mostly ignimbrites panteleritic rhyolite and trachyte with subordinate intermediate and basic rocks.

3. Post Rift Volcanics

The rift floor is dominantly comprised of Aden Series constituted by siliceous domes & flows alternate layers of ignimbrite, tuffs & ashes as well as Basalitic flows and related spatter cones at the base of which are predominantly basaltic lavas.

All the Quaternary basalts in the main Ethiopian Rift are composed of basalt flows, scoriaceous and basaltic hyaloclastites, transitional types of both fissural and central successive stages and concentrated at the Rift floor along the WFB. The other younger analogous units outside the rift in the southwestern Ethiopia are fresh Tepi and Mursi basalts produced by central type eruption of a Holocene age (Davidson, 1983). The basalitic flows and spatter cones of the Quaternary Volcanics in Cenozoic era are typically developed in small areas of East Guraghe, South Maji, North & South of lake Abaya.

4. Quaternary Sediments and Lacustrine Deposits

On the other hand the lowlands of Southern & South western borders of Ethiopia and a variety of central basins and Depression, surrounding the rift valley lakes, which were developed during rifting processes are filled by undivided lacustrine and fluvial sediments of Pleistocene-Holocene age. Among them the Omo group sediments that cover most parts of Kibish, Omo and Usno branches of the Turkana rift is comprised of four formations i.e Mursi, Nkalabong, Usno and Shungura formation (Davidson 1983). In the main Southern Ethiopian rift the quaternary sediments are commonly of lacustrine origin. The Quaternary sediments are not uncommon in the lowland areas bordering highlands as in the Gelana river valley bordering the Amaro horst.

6.3 Groundwater Resource

The Roman architect Vitruvius, has explained the now accepted infiltration theory that the mountains receive large amounts of rain water which percolates through the rock strata and emerge at their base to form streams (Todd, 1980). This was an important step forward to explain the origin and movement of groundwater. Here it can be seen that the movement of groundwater in the geological formations is related to the presence of some sort of conduits in the formations. It is a well-known fact that the factors geology, topography and climate play a significant role in determining the distribution, quality and quantity of surface and ground water.

A. Hydrogeology of Rock Units

1. The basement rocks

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These rock units are considered as hard rocks. Generally rocks that have very low primary porosity will not have the capacity to allow the movement of water, their capacity to allow movement of groundwater is greatly dependent on the presence of secondary structures. Gustafsson, 1993 (cited in IAH, personal collection) termed all rocks, which have no sufficient primary porosity and conductivity for feasible groundwater extraction as "hard rocks". Weathering and fracturing enhance the water storage and circulation capacity of hard rocks. Generally ground water occurrence in unweathered hard rocks is not a regional type it is localized to the areas that have interconnected open fractures.

The metamorphic rock units in the region posses secondary porosity related to weathering and fracturing. Several shallow wells are drilled in these formations (South Omo zone, Guraferda Woreda and Aroresa woreda), most of the wells are located along streams which are structurally controlled and act as groundwater conduit. Generally depth to groundwater in these formation is below 60 meters. The basement rocks in the region posses moderate potential at fractured and weathered zones.

2. The Trap Series

The Trap Series is mainly composed of tracytes, rhyolites, basalts and ignimbrites. Volcanic rocks differ in their mineralogy, texture and structure; therefore, the water bearing potential of these rocks vary accordingly. The water circulation and storage capacity of volcanic rocks depend on the nature of the porosity and permeability of the aquifer.

Volcanic rocks show high range of permeability variations: from highly permeable basalts to tuffs with high porosity but low permeability or dikes with both low porosity and permeability. The porosity of unfractured fresh volcanic rocks varies from less than 1 % in massive basalts to 85 % in pumice or scoria. Although porosity may be high the permeability is largely a function of other primary and secondary structures in the rock mass.

The primary porosities are results of volcanic textures and structures, which include vesicles, lava tubes and shrinkage cracks; while the secondary porosities are results of fracturing and weathering. Hence the important characteristic features governing the groundwater movement and accumulation in volcanic rocks are

– Vertical permeabilities due to fracturing

- Horizontal permeability in horizons

- Occurrence of impervious horizons

Of course all fractured and porous rocks may not contain water, the main controlling factors are

- The type, frequency, orientation and aperture of fractures

- Nature of fracture filling material

- The degree of interconnection of fractures

- The thickness of the flow

- Presence of cementing material and their hydraulic character

- Nature of the cover soil and

- Climatic and topographic conditions

Generally the trap series rocks occupy highland areas and the rift escarpment, and they are generally fractured related to the rifting. Groundwater occurrence and movement is related to fractures and depth to groundwater varies from 100 meters to more than 250 meters. There are large springs emerging from these rocks at fault breaks (to mention some: Bojobar spring in Gurage zone with a discharge of over 100l/s, springs in Silty zone with a discharge of about 80 l/s located at the western rift escarpment).

Since the units are out cropped at the highland areas they get high rainfall and are generally considered as recharge areas and posses from moderate to good potential.

3. Post Rift volcanics

The post rift volcanics found in the rift floor along the WFB and SDFZ in the northern part; are highly fractured and the lava flows have vesicular texture. The streams in these zones generally follow the faults and stream losses are great, indicating good recharge conditions. The faults with varying deep orientations form local horst and graben structures and accordingly the faults are acting as barriers for groundwater movement in the horst area. This indicates that the groundwater movement in the post rift volcanics is fault controlled. As a result in horst areas as for example the Dugda-Koshe-Tora horst and the Midrekebid horst depth to groundwater is generally over 200 meters. On the other hand in the graben areas (west of Tora, around Butajira, around Arba Minchi area and east of Boricha ridge in Sidama zone depth to groundwater varies from 0 to 60 meters. As to the groundwater condition along the Bilate river depth to groundwater increases as one moves away from the river along the asphalt road to Shashemene and Wolayta Sodo towns. There are a number of hot and cold springs emanating from these post rift volcanic rocks. To following are some of the cold and hot springs emanating from these formations: Gidabo hot spring, hot springs north of Lake Abaya, Arsho hot spring, Awada spring (Q~160l/s), Arbaminchi springs (Q~180l/s). Generally in low relief areas the groundwater potential in the post rift volcanics is good and in the horst areas the potential is moderate.

On the other hand the post rift volcanics in the Omo-Ghibe drainage basin is represented with Mursi basalt in South Omo zone and Tepi basalt extending from Aman to Masha town. These basalts are generally massive and porphyritic and generally considered as hard rocks. Groundwater generally occurs in the weathered zone of Tepi basalt, which has a thickness of about 30 meters (Aman well). The lower part Mursi basalt having a thickness of some 50 meters at the fringe zone is observed to be vesicular and posses moderate groundwater potential.

4. Quaternary Sediments and Lacustrine deposits

The hydrogeological condition of the lacustrine deposits and quiaternary sediments is governed by grain size of materials, sorting and degree of cementation.

The quaternary sediments and lacustrine deposits occur at low relief areas; generally around Awassa, Abaya and Chamo lakes, Boyo lake area bor-

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dering mountainous areas as in Meskan, Sodo and Mareko woredas of Gurage zone, at lower reaches of rivers like Bilate, Gelana, Gidabo, Omo and others streams. Their physiographic position favour good accumulation of groundwater. Generally depth to ground water varies from a few meters to around 50 meters. These rock units are the potential aquifers in the region.

B. Groundwater recharge

A recharge area can be defined as that portion of the drainage basin in which the net saturated flow of groundwater is directed away from the surface and the water table is usually lies at some depth where as discharge area can be defined as the movement of the net saturated flow of groundwater is directed toward the surface and the water table usually lies at or very close to the surface (Freeze and Cherry, 1979). There are many sources of recharge to groundwater systems; these include recharge from precipitation, rivers, irrigation losses and inter aquifer flows (Tenalem Ayenew, 1998). Determination of recharge rates for aquifers is one of the most important aspects of ground water resource evaluation. However, when dealing with a large catchment area, representative direct field measurements of recharge would be impractical. Several other methods are available to estimate recharge, and although the results produced are liable to show very high variations, indirect approaches such as water balance methods, baseflow separation method, recharge area estimation method and well level fluctuation could be employed to obtain acceptable recharge rates.

However, the estimated recharge is not evenly distributed, with the low land areas have an annual water balance in deficit, while the highland areas have a surplus, making water available for recharge. When we see the recharge of some of the sub-catchments within the region the mean annual recharge is about 15% of mean annual rainfall (Desse Nedaw, 1997, Kedir Yasin, 2002, AG Consult, 2004). On the other hand from the recharge-discharge condition given in the Hydrogeological map of Ethiopia (Tesfaye Cherinet, 1993), in the northwestrn part of the region the recharge is about 40% of mean annual rainfall and the recharge in the low land areas is negligible or about 5 % of the mean annual rainfall (figure 8).

Observing the above factors, the stream loses along stream channels and at the quaternary sediments and lacustrine deposits (surface-ground water relations) taking 10% of the mean annual rainfall of the region as replenishable recharge, will be a good initial estimation. Accordingly, considering this the mean annual replenishable recharge to groundwater in the region can be computed to be about 14,000 MCM.

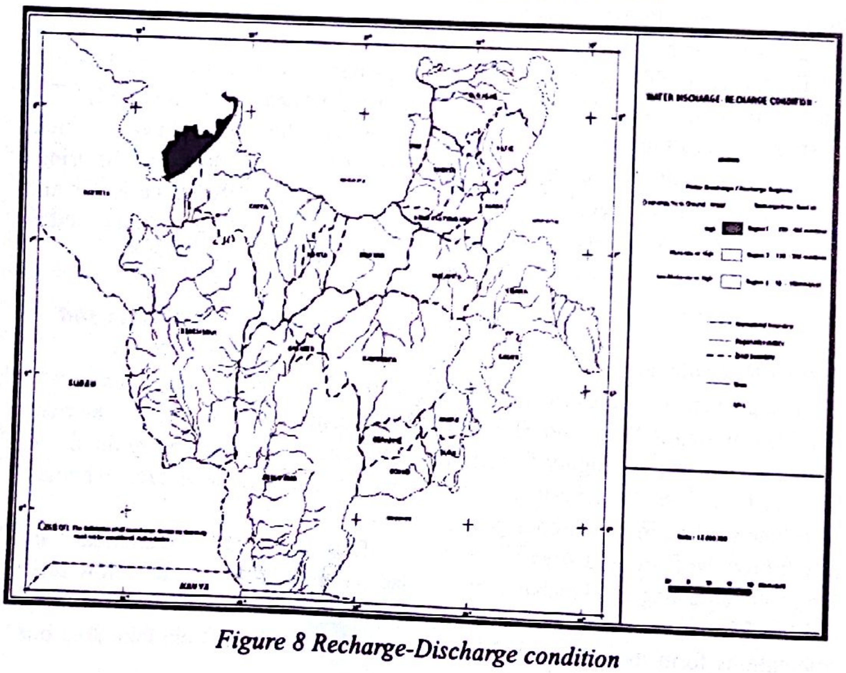

Figure 8 Recharge-Discharge condition

C. Groundwater Quality

Atmospheric precipitation, which is the principal source of water on earth, is by no means distilled water when it lands on the earth's surface. Volcanic eruptions, emission of gases and sublimation of solids from the earth's crust, dust and other wind-born solids in the atmosphere, gaseous and other metabolic products excreted by the earth's biota in to the atmosphere, reactions caused by cosmic rays and gaseous emissions of industrial and other pollutants are examples of the many ways in which chemicals enter the atmosphere. From there they can return to the earth dissolved in rainfall and snow or as dry fallout which subsequently can be dissolved by rain after it has landed on the earth's surface. Because of its molecular structure and its electrical properties of a very high dielectric constant and a low conductivity, water is capable of dissolving many substances, so that the chemistry of natural water is so complex. All natural water contains varying amounts of other materials in concentrations ranging from minute traces at mg/l level of trace chemicals in rainwater to around 35,000 mg/l in seawater. The quality of water depends on the salinity, temperature and other chemical contents of the water, the physical and chemical properties of the surrounding rocks, the volume and velocity of water in movement, human factors (industrial activity, changing agricultural practices and increasing urbanization) and biological processes (Tebbutt, 1998).

$$HCO_3^- \rightarrow HCO_3^- + SO_4^{2-} \rightarrow SO_4^{2-} + HCO_3^- \rightarrow SO_4^{2-} + Cl^- \rightarrow Cl^- + SO_4^{2-} \rightarrow Cl^-$$

Travel along flow path →
Increasing age →

The quality of water as determined by its physical, chemical and biological characteristics is of great importance in determining the suitability of a particular water for certain use. The quality of water is resultant of all processes and reactions that have acted on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring.

Water Type

Generally as groundwater moves along its flow paths in the saturated zone, increase of total dissolved solids

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and most of the major ions normally occur. Groundwater evolve chemically toward the composition of sea water and the generalization of anion evolution of groundwater flow along its path is as follows

Generally the water type of groundwater system in the region varies from Ca-HCO, type in the highland area and recharge zones to Na-Cl type around lake Chew Bahir and Lake Rudolf.

Fluoride & Iron Problems

Conceptually water quality refers to the characteristics of water supply that will influence its suitability for specific use; i.e., how well the quality meets the need of the user. In this regard the groundwater quality in the region have problems of iron and fluoride.

Fluoride

Fluoride is present in trace amounts in soils and rocks, but most prevalent in volcanic regions. High ambient temperature, alkaline medium and low calcium concentration favor the concentration of fluoride in water (Tamiru Alemayehu, 2000). Because of its beneficial effects on dental health and its use as municipal water-supply additive in many cities fluoride is a constituent that has received much attention in recent decades. Concentrations recommended for optimum dental health are close to 1 mg/l, but also vary slightly depending on the temperature of the region (Freeze & Cherry, 1979). At higher concentrations, however, mottling of the teeth (fluorosis) and other skeletal abnormalities are caused.

Sources of fluoride in groundwater are minerals like calcium fluoride (fluorite), apatite, certain amphiboles, cryolite (in igneous rocks), and fluorspar (in sedimentary rocks). The weathering of alkaline and siliceous igneous rocks and sedimentary rocks supplies fluoride to the aquatic environment and groundwater usually contain higher concentrations than surface waters. In general, the contribution is primarily from natural sources rather than from man derived sources (UNESCO, 1984).

Groundwater with more than 1mg/l of fluoride are often found. Sometimes, F concentrations exceed 10 mg/l and can reach more than 30 mg/l. These high concentrations tend to be associated with a high pH (Freeze and Cherry, 1979). There are several potential solubility controls that can limit the dissolved-fluoride concentration in water. It appears evident that high fluoride concentrations are more likely to occur in water that has low calcium concentration (Hem, 1985).

The rift valley waters are characterized by exceptionally high fluoride concentration (Tenalem Ayenew, 1998). With in the re gionthe fluoride concentration varies from non-detectable to 8.85 mg/l (table 6). The high fluoride concentration in the borehole and hot springs is due to low Ca content and higher temperature, which favors the solubility of fluoride. High fluoride is generally concentrated in the rift floor.

Nº	Zone	Woreda	Site Name	Source Type	Fluoride (mg/l)
1	Sidama	Awassa Zuria	Dorebafana	SW	2.49
2	Gurage	Mareko	Koshe	BH	2.46
3	Wolayita	Damot Woyide	Bilate Tobacco farm	Hot Spring	8.85
4	Gamogofa	Mirab Abaya	Alge	SW	2.05
5	Silti	Sankura	Alem Gebeya	BH	2.47
6	South Omo	Hamer	Boria/Turmi	SW	5.8
7	Alaba Sp.	Alaba	Teffo	BH	1.97
8	Konso Sp.	Konso	Orombia	Spring	4.15
9	Silti	Silti	M.Eyekoche	Hot Spring	5.6

Table 6 Maximum records of fluoride of groundwater sources in the region

(Source: Water quality control team, 2004)

Iron

Iron is widely distributed in the earths crust. It occurs in minerals like pyroxenes, amphiboles, biotite, magnetite and olivine. The common form of iron in water is the soluble ferrous ion Fe^{2+}. Concentrations of iron in waters are in the 1 to 10 mg/l range. When exposed to the atmosphere, Fe^{2+} is oxidized to the ferric state, Fe^{3+}, which is insoluble and precipitates as ferric hydroxide.

Iron is essential element in the metabolism of animals and plants. If present in water in excessive amounts, however, it forms red oxyhydroxide precipitates that stain laundry and plumbing fixtures and, therefore, is an objectionable impurity in domestic and industrial water supplies. Recommended upper limit for iron in public water supplies is 0.3 mg/l (Hem, 1985).

Table 7 Records of Iron of groundwater sources in the region

(Source: Water quality control team, 2004)

Nº	Location	Scheme Type	Iron (mg/l)
1	Aleta Wondo	BH	1
2	Masha	BH	3.05
3	Masha Toba	HDW	0.4
4	Masha Shimbo	HDW	0.31
5	Chuko Lemela	HDW	1.67
6	Santeriya	HDW	1.05
7	Belle	Spring	1.47
8	Hana Selamago	4 SW	2.4 – 2.6
9	Kure	SW	1.2
10	Kulalta/Konso	SW	0.7
11	Tebele Eyana/Konso	SW	1.2
12	Nabule/Konso	SW	3.4
13	Gure/A.Wondo	SW	2.4
14	Gure Jebeto	SW	2.6
15	Gure Ellalicho	SW	2.4
16	Oddo/A.Wondo	Spring	2.2
17	Dilla	Spring	0.8
18	Ashewalicho/Sodo zuria	SW	3

Iron is present in organic wastes and in plant debris in soils, and the activities in the biosphere may have a strong influence on the occurrence of iron in water. Microorganisms such as thiobasilus ferroxidans are commonly involved in processes of oxidation and reduction of iron, and some species may use these reactions as energy sources. Corrosion of well casings and other pipe may also contribute iron to groundwater.

As far as the concentration of iron in the waters of Upper Gidabo River catchment are concerned it reaches up to 3.4mg/l. When its range of concentrations in the different water bodies (table 7) is evaluated the concentration is generally high in the shallow aquifer system (which is tapped by hand dug wells). Observing its distribution the concentration is higher in basaltic terrains (Mursi and Tepi basalts) in Selamago woreda, Masha and Tepi and in the weathered zones of acidic volcanic rocks around Aleta Wondo, Awassa, Wolayita, Durame and Konso.

7. Conclusion

The water resources of the region are large and, to a very great extent, are

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under-utilised, for which there are a number of reasons: physical, temporal, spatial and economic. An accurate assessment of this resource in terms of its quantity, quality and variability in time and space is essential so that its use can be most effectively planned, developed and implemented.

Generally to improve the proportion of surface water sources for water supply purpose at least in the highland areas and where the human impact is minimum by constructing filtration system and simple chlorination the small streams can be considered.

Water in which the constituents are higher than the permissible concentrations relative to the limiting values that are laid down in national or international guidelines for a given purpose is termed anthropogenically polluted water. Industrial wastes are one of the water pollutants. And to assess the impact of industries on the environment the condition of the environment before the intervention has to be clearly known. Because natural waters unaffected by man may contain constituents that exceed the limits as defined; the pollutions in these cases can be defined by the values that exceed the natural variation of the constituents concerned in a specified water. From this context it follows that the natural quality of water bodies in a region must be known beforehand, as so it can occasionally happen that supposed human factors are infact the result of natural conditions. Presently 19 urban centres have been selected to have industrial zones. With this point the quality of the water in the industrial area has to be known before the intervention of the proposed industries in the water systems of the area.

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(Footnotes)

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Geophysical exploration for Ground water in a Sedimentary Environment: A case study of buried Channel streams as potential sources of Ground water In Wukro, Eastern Zone of Tigray Regional State

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Abstract

The main objective of the geophysical survey was to locate well sites with good ground water potential of the surrounding areas of the Wukro Tannery site.

The geophysical method used was electrical resistivity (Vertical electrical sounding and profiling). A total area of 600m*600m (0.36km²) was covered by the method. A base line of 0.6 km long is laid out parallel to the burried channel, 3 lines each 600m long are cut perpendicular to the base line, with 300m profile interval and readings were taken every 20m.

A total of 9 VES measurements were taken and a geoelectric section was produced from the VES's with a horizontal scale of 1:1,250. Based on the geophysical results, drilling was conducted on the area. The three drill holes intersected the buried channel streams and the wells in the area are yielding 10-13 litres/sec. Since buried stream channels usually contains water saturated sand and/or gravel which are good aquifers and potential sources of ground water which acts as conduits for water flow. The depth to the water table is about 10m.

The geophysical results were well correlated with drill holes and the local geology of the area. Low values of apparent resistivity correlated with high yielding of the well and high values of resitivity correspond to the sandstone unit. As we go from Line 3N to Line 1N the pattern of the buried channel stream shifts towards South West and its width decreases.

The use of the electrical resistivity method can be taken for ground water development program in the future to help and locate more appropriate locations for drilling. Because of the presence of similar geological conditions the electrical resistivity method is successfully used to locate buried channel aquifers as potential sources of ground water.

Introduction

Ground water is the earth's largest accessible store of freshwater that sustains stream flow during period of dry season and is a major source of water in semi-arid and arid areas. It forms an integral part of the hydrological cycle and is the only viable source of water supply to human use and development.

Wukro area is covered by sedimentary rocks and unconsolidated materials ranging in age from Mesozoic to recent. Sandstone, limestone and shale are found dominantly covering the area in different proportions. Sandstone and limestone are the main source of ground water in the area and the search for ground water starts with an investigation of unconsolidated sediments. The unconsolidated deposits of high ground water resource potential exist located mainly on a narrow and long ancient river channel. Buried river channels usually contain sand and/or gravel which are good aquifers. However as the buried channels have no surface expression, techniques that would assist to locate and delineate them are of utmost importance in the sitting of high yielding, more successful boreholes and also in better understanding of the hydrogeology of buried channel streams.

A number of geophysical exploration techniques are available which enables an insight to be obtained rapidly in the nature of water bearing layers. These include: Electrical method, Electromagnetic, Seismic, Gravity, Magnetic, Gravity, Soil temperature and geophysical borehole Logging. Of the several Geophysical techniques, electrical resistivity method are useful in providing supplemental information for location of burial sites (e.g., buried channel streams, trenches, their depths and boundaries) and Hydrogeologic conditions (e.g., depth to water table or water bearing zones, depth to bedrock, and thickness of soil, etc). The resistivities of rocks are primarily a function of porosity, salinity, and temperature of the pore fluid because the conducting medium is mainly water. The importance of electrical method is more because of complexity of the buried channel stream. The method has been found to be cost effective, time saving and simple.

In this regard, electrical method was conducted in Wukro tannery, located about 5km south West of Wukro town, in the eastern zone of Tigray regional state to delineate the extent and trend of a buried channel stream and also to evaluate the usefulness of the method in such geological situations. Accordingly, the field data was acquired during the period 10 March to 8

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April 1996.

Geology of the Area

The study area, Wukro, is located in the eastern zone of Tigray Regional state. Geographically, it is located between longitude 39^0 30' and 39^0 45' E and latitude 13^0 47' to 14^0N. It has an area of about 0.36Km^2 (Figure 1).

The study area is a flat lying sedimentary environment. The main lithological units are limestone, sandstone and shale.

The limestone is outcropping all the survey area and which is mostly covered by transported/residual soil. It is apparently jointed and fractured on the surface. It has variegated layers in terms of texture and composition, but big cavities and karst holes were not observed. It is dissected by Genfel River. The sandstone covers the northern and north western parts of Wukro town. Especially it forms a big hill at the western part. The shale is usually found intercalated with limestone on the survey area.

In one of the river cut, buried river mouths were observed where stream channels cut during an earlier time were drowned or buried by latter sediments. The geophysical survey was aimed to follow and delineate the pattern and extent of the buried channel stream so as to recommend bore holes sites on the channel. Because buried stream channels usually contains water saturated sand and/or gravel which are good aquifers and potential sources of ground water which provide as conduits for water flow in the area.

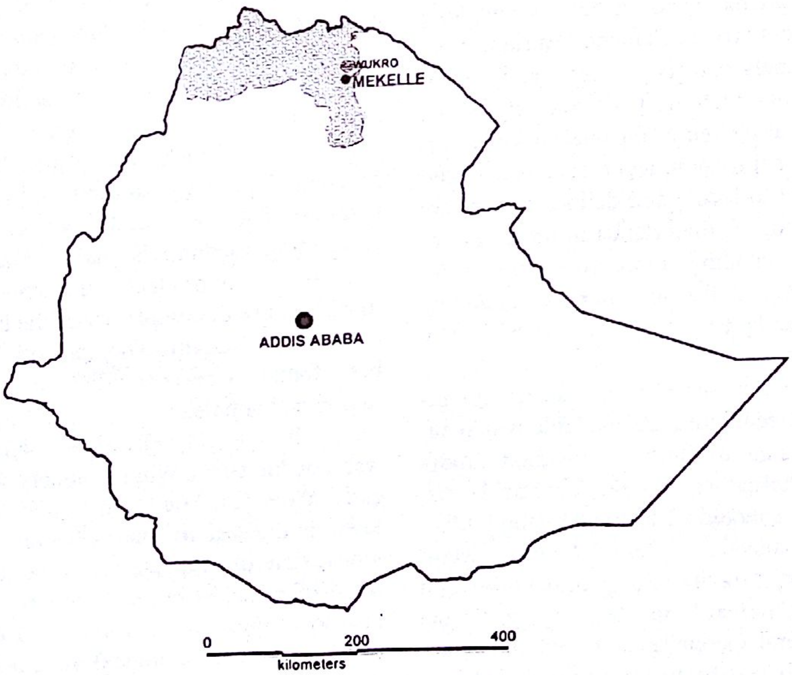

Fig 1 Location Map of Wukro area

Application of Geophysical Methods for Ground Water Investigation

General

Geophysics, in the past few years, has reached a place of vital importance to the scientific development and protection of the world's precious ground water supply. Geophysical investigations of the buried strata can be made either from the land surface or in a drilled hole in the formation. The most commonly geophysical Techniques applied for ground water investigations are:

- Electrical Resistivity
- Magnetic
- Electromagnetic
- Seismic
- Gravity
- Soil Temperature
- Borehole logging

Application of Electrical Resistivity Methods for Ground water Investigation

The choice of a particular method is governed by the nature of the terrain, time and cost consideration. The superiority of the Electrical resistivity method over others in the ground water research is confirmed by the work of Pulawski and Kurth (1977), Zohdy (1973) and Zohdy et al (1974) reported on the ability of the resistivity method to furnish information on the subsurface geology unobtainable by other methods al□in ground water studies. It is found the greatest application to ground water because of its high-resolution power in respect of particular problems encountered for ground water. The resistivities of rocks are primarily a function of porosity, salinity, and temperature of the pore fluids because the conducting medium is mainly water.

Some of the geophysical investigations that can be done by the electrical resistivity method for ground water studies are:

- Correlating lithology and drawing geophysical sections.
- Bed rock profile for subsurface studies
- Contact of geological formations
- Delineating buried channel streams
- Fresh water-salt water interface by constant separation profiling
- Water quality in shallow aquifers and ground water pollution as in oil field brine pollution, pollution by irrigation waters and pollution by sea water intrusion, which cause change in electrical conductivity.

Two methods of investigation are generally employed in the electrical resistivity method of traversing.

Vertical electrical sounding (VES)

Vertical Electrical Sounding is used for mapping of the horizontal or low dipping boundaries; the practice is to use a system of expanding electrodes. Increase in the current electrode separation necessarily increases the depth of current penetration; therefore the variations in resistivity correspond to the change in sub-surface characteristics in a vertical plane.

Profiling method

The electrode separation is kept constant for different values and the

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center of the electrode spread is moved from one station to another station to have the same constant electrode separations. The method helps in mapping vertical or steeply dipping beds, lithological contacts, faults, etc. Profiling can be carried out along a series of parallel lines and a resistivity contour map of the area showing isoresistivity lines can be prepared. This will indicate areas of high/low resistivity and will be useful in identifying aquifer formations.

Vertical Electrical Sounding

Survey Procedures

Ground water survey starts from data collection, interpretation of geomorphic and geologic features on available maps, aerial photographs and land sat imagery followed by field reconnaissance and further map interpretation. The survey plan of Vertical Electrical Sounding is going to be decided after the hydrogeological conditions of the investigated area. In any field study, before setting up sounding apparatus, the following points were considered to minimize common interpretation errors.

- Relatively flat topography
- Spreading performed along the inferred/interpreted geological structure to the direction of sloping
- Checking of survey apparatus
- Avoiding of buried surface materials such as cables, pipes, and high voltage electric lines.

Data Processing and Presentation

For the resistivity profiling, the current "I" of the transmitter and the voltage V_p of the receiver together with an appropriate geometric factor are used for calculating the apparent resistivity of each station. Then the data are entered into the computer and processed in our case using Excel to produce the apparent resistivity profiling curves.

For the VES survey, the apparent resistivities are calculated and plotted on a log-log paper at the spot for the purpose of controlling the measurements, and then these data are entered into the computer for calculating the resistivity and thickness of each layer, using the RESIST software package. Then, interpretation of the results is made.

The VES points are located in the following Coordinates: Line 1N/00, Line 1N/300E,

Line 1N/600E, Line 2N/00, Line 2N/300E, Line 2N/600E, Line 3N/00, Line3N/300E and Line 3N /600E (Figure 2)

Vertical Electrical Sounding

For the Vertical Electrical Sounding (VES) survey the Schlumberger array was used with a maximum electrode separation AB/2 of 500m. 9 VES sites were surveyed by this array

The method is based on the injection of an electric current into the earth by means of two current electrodes. The potential differences, which are created between these electrodes, are measured at another pair of intermediate electrodes. By knowing the injected current to the ground, potential differences at the measuring electrodes and a display point determined by the arrangement of electrodes enable us to determine rock resistivities. These resistivities can be related to subsurface rock types, water table, extent of aquifer zone and outlining the bedrock topography. It is obvious that the depth of penetration increases with increasing electrode spacing. Among a few types of variable electrode distance techniques, the schulumberger layout was used in the survey area. The maximum current electrode separation used was 500m.

Based on the interpretation of VES data, a geoelectric sections were produced along Line 1N, 2N, 3N and along VES 2, VES 5 and VES 8 traverses. Quantitative interpretations were done on the VES data, yield a geoelectric sections. The geoelectric sections, the profiling curves and VES results are interpreted and well correlated with each other. Since the geoelectric section made along Line 1N, 2N and 3N have no significant contribution for the mapping of the buried channel stream, the sections neither are nor prepared for presentation.

Based on the interpretations, the geoelectric section made along VES 2, VES 5 and VES 8 (Figure 3) traverses shows five lithological units. The first unit which is mapped as dry top soil has a thickness of 0-3m with a resistivity range of 145 to 223 Ohm-m. The second unit, which is characterized by relatively low resistivity of 100 to 153 Ohm-m and ranging in thickness from 3 to 8m, is due to water saturated clay soil. The third unit, which is characterized by 153 to 400 Ohm-m and ranging in thickness from 8 to 20m is due to the response of the limestone unit. The fourth unit, which is characterized by low resistivity value of 20 to 90 Ohm-m and ranging in thickness from □20 to 23m on VES 2, 18 to 24m on VES 5 and 17 to 27 m on VES 8, is due to bur-

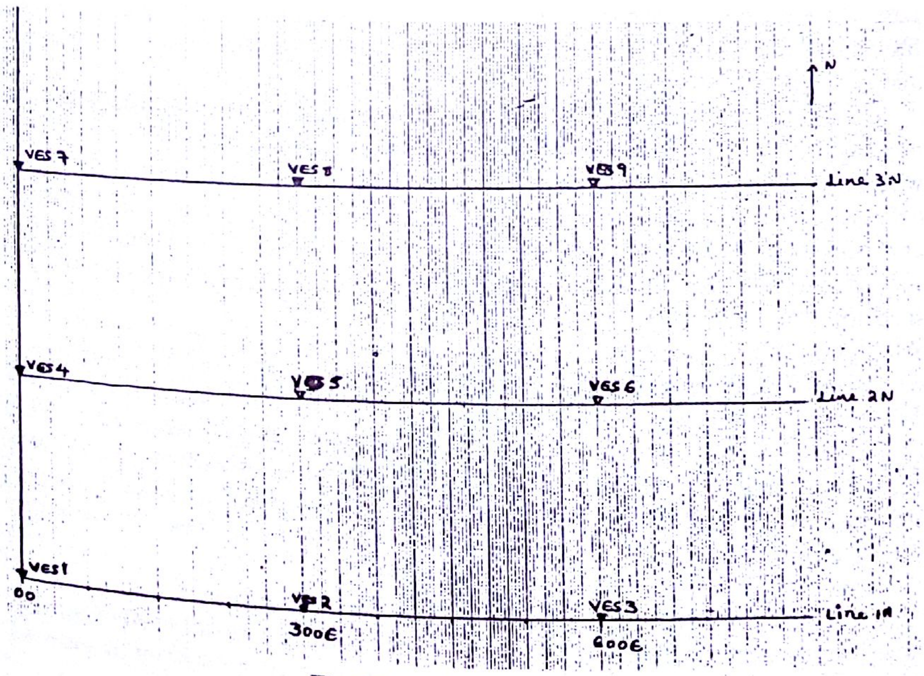

Fig.2 Location of VES sites

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ied channel stream. This unit, being composed of medium to coarse sand and fine gravel, forms the most important water bearing unit in the area. The bottom unit, which a resistivity value ranges from 400 to 670 Ohm-m and infinite thickness is due to sandstone formation.

Resistivity Profiling

The depth at which current enters a formation of higher or lower resistivity is signaled by a change in the resistivities recorded at the ground surface. By proper interpretation of the resistivity data from the field and compared with VES result, it is possible to identify the water bearing formations and accordingly limit the depth of well drilling.

For the resistivity profiling survey a three pole array with electrode separations of a=40m, 80m and 120m was used and readings were taken every 20m interval. The three electrode separations were conducted on three lines corresponding to three depth levels chosen to show responses at near-surface, intermediate and deeper depths of investigation for the selected array.

The resistivity profiling curves of figure 4, 5 and 6 show that, the low resistivity zone is found between 300E to 340E on Line 3N, 300E to 320E on Line 2N and 280E to 300E on Line 1N. This zone is the response of the buried channel stream. The resistivity values caused by the buried channel stream appear to be lower than the common resistivity of rocks. This condition indicates that, buried river channel usually contains water saturated sand and/or gravel which are good aquifers and potential sources of ground water which provides conduit for water flow. Most of the area that is characterized by intermediate value of resistivity that ranges from 100-300 Ohm-m is the response of the combined effect of the thinly intercalated shale with limestone and high values of resistivity corresponds to the sandstone unit.

Based on geophysical survey, three drill sites were recommended and a fourth one was also allocated in case if the three wells give less yields than required. Accordingly, drilling was conducted on the area; the three drill holes intersected the buried channel streams. The aquifers are found to be confined and the wells in the area are yielding 10 to 13 litres/sec.

The geophysical results are well correlated with drill holes and the local geology of the area. Low values of apparent resistivity correlated with high yielding of the well and high values of resistivity correspond to the sandstone unit. The pattern of the buried channel stream shifts towards south west, as we go from line 3N to 1N and its width also decreases.

The geophysical results obtained from the VES and profiling survey have showed the effectiveness of the method to map the different lithologies, the buried channel stream and depth of the bed rock.

Conclusion and Recommendation

It is important that well sites are chosen principally on hydrological grounds. One of the most essential steps for ground water investigation is collection of available data that expresses the surrounding ground water conditions, but in most cases of our country acquision of well data is not adopted. The electrical resistivity method and the corresponding well data should be related so as to produce a model that can best explain the situation. The geophysical results obtained from the VES and profiling survey have showed the effectiveness of the method to map the different lithologies, the buried channel stream and depth of the bed rock.

Of the several Geophysical Techniques, Electrical resistivity method which provides valuable information necessary for the selection of appropriate drill sites. The resistivity method was delineated the limestone/shale, sandstone formations and the extent, and pattern of the buried stream channel. Based on the geophysical results, three drill sites were recommended and a fourth one was also allocated in case if the three wells give less yields than required. Accordingly, drilling was conducted on the area, the three drill holes intersected the buried channel streams and Artesian wells were produced during drilling. The aquifers are found to be confined and the wells in the area are yielding 10-13 litres/sec.

This study has provided information on the depth to the ground water and thickness of the aquiferous buried stream channel in sedimentary environment, Wukro, Tigray region. This information is going to be relevant to the development of an effective water scheme for the area and possibly beyond other areas with the same environment. The method can be taken for ground water development program in the future to help and locate more appropriate locations for drilling. Because of the presence of similar geological conditions the electrical method is successfully used to locate buried channel aquifers as potential sources of ground water. It is of course could not be taken as an exhausted work and should be developed by further study on other geophysical methods so as to take as a model in other parts of our country.

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Determination Of Biological Oxygen Demand Rate Constant and Ultimate Biological Oxygen Demand for Liquid Waste Generated from Student Cafeteria At Jimma University: A Tool For Development Of Scientific Criteria To Protect Aquatic Health In The Region

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Abstract

BACKGROUND: Except Addis Ababa, all towns of Ethiopia discharge every form of liquid waste anywhere. This wastewater ultimately enters to streams and rivers. Deficiencies of sanitary services and absence of regulation and scientific criteria for enforcement has presented an increasing environmental and public health hazards in major towns of Ethiopia. The aim of this study was to determine the strength of Jimma University cafeteria waste and propose the need for scientific criteria and treatment options before discharging into water bodies.

METHODS: Liquid waste generated from student cafeteria at Jimma University was sampled from December - March 2003 to determine Biological Oxygen Demand rate constant (k) and ultimate biological oxygen demand by incubating samples at three different temperatures. Rate constant was determined following Thomas Method and the potential impact of the waste on streams was evaluated.

RESULTS: The rate constant (k) determined at 3 three temperatures was of similar magnitude and the Ultimate Biological Oxygen Demand was found to be under the category of a strong waste (1047.33 mg/L) capable of destroying the self-purifying capacities of receiving water bodies. The rate constant (k) generated based on local samples and environmental conditions can serve as feasible and reliable scientific criterion to optimize treatment facilities such as oxidation ponds in the region.

CONCLUSION: Liquid wastes generated from Jimma University student cafeteria is found to be under the category of strong waste that can degrade the quality of the Awetu-Gilgel Gibe river system and thereby limit its actual and potential use. Determination of Biological Oxygen Demand and rate constant (k) for other sources and consequent provision of wastewater treatment option is necessary to protect water resources downstream.

Keywords: Biological oxygen demand, rate constant, disolved oxygen, liquid waste.

Introduction

The disposal of wastes always constituted a serious problem in the world. With the development of urban areas, it became necessary, from public health and aesthetic considerations, to provide drainage or sewer systems to carry such wastes away from the area (1). On disposal of wastes surface water is obviously highly susceptible to contamination. One particular category of pollutants, oxygen-demanding wastes, has been such pervasive surface-water problem, affecting both running and still water demanding special attention (2).

The 5-day Biological Oxygen Demand (BOD) is the best single strength measure of wastewater or polluted water containing biodegradable wastes and it is the best indicator of organic water pollution. When organic waste is discharged into water bodies with out being stabilized, leads to depletion of dissolved oxygen (DO) in the water and limit water bodies' ability to support desirable aquatic life (3,4).

The worst condition of pollution of receiving water body occurs in dry season when stream flows low and water temperature is high (5). This is because when temperature increases solubility of oxygen decrease and low flow rate of stream reduce its capacity to dilute the waste. Without considering the effect municipal and Industrial wastewaters are largely being discharged with out treatment in to the surface of receiving water body through out developing world (6). The problem of wastewater is expected to be of great concern in Ethiopia where adverse impacts have been reported for rivers and streams flowing through big towns (7,8). Determination of a single 5-day BOD alone does not permit calculation of ultimate Biological Oxygen Demand (BOD¥) and rate constant (k) as described in Tebutt, 1992. Therefore, the advantage of determination of BOD strength and rate constant is apparent: It helps to optimize wastewater treatment facilities such as oxidation pond and also serves as scientific criteria to ensure compliance.

imma University generates large quantity of waste from various sources mainly from student cafeteria kitchen and it is the one, which needs strict liq-

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uid waste management. The Cafeteria waste is discharged into *Kochi* stream without any form of treatment and enters to *Awetu* stream and ultimately to Gilgel Gibe river, which is the main tributary of the River Gibe. Such waste discharge without any form of treatment not only becomes a potential health hazard to the nearby communities, the waste may also upset the ecological integrity of the River *Awetu* by reducing the Dissolved Oxygen (DO) downstream.

Materials And Methods

Study area: Jimma town has an altitude of 1760 m above sea level. The average annual rainfall is 1749 mm with a mean temperature ranging from 11.4°C to 26.7°C. The main campus of Jimma University is located 3 Kms away from the center of the Jimma town on the road to Aba Jiffar Palace. Routine sampling of waster water from the main campus cafeteria that provides food service for a total of 8000 students was taken from December 2003 to March 2004.

Study design: A cross sectional study was conducted by taking samples from the liquid waste generated by the main campus cafeteria. Measurement was taken during the dry period to assess the maximum effect of pollutant due to low flow rate of stream and less solubility of oxygen in dry period.

Samples were collected using tightly covered plastic bottle. To avoid addition of oxygen from atmosphere, sampling bottles were filled with the sample with out leaving air space.

From cafeteria waste each sample was collected at the first manhole, which receives all, wastes those coming in different line from the cafeteria. Each sample was collected at different time for each experiment carried out at 25°C, 30 °C and 35 °C. Several pre tests were carried out to estimate appropriate dilution factor for the waste sample to avoid total consumption oxygen before test period. Trials were done at, 5%, 4%, 3%, 1%... 0.17%. Finally successful dilution factors were obtained as 0.33% at 25°C and 0.17% at 30°C and 35°C. In all cases, laboratory analysis was made in less than 3hours after samples were collected as described in the standard methods (1).

The Standard Methods for the Examination of Water and wastewater (1) was followed in this study except modifications made at incubation temperatures. DO was determined by azide modification of the Winkler method. BOD determination was carried out using ordinary incubators. In the procedure BOD_5 at 20°C was determined indirectly due to lack of special BOD incubator, which maintains the temperature at 20°C. The testes ware carried out at 25°C, 30°C and 35°C using an ordinary incubator. Water bath incubator was employed to run the test at 25°C since room temperature exceeded the minimum temperature that can be thermostatically controlled by the incubators during the test period. BOD_5 at 20°C was measured indirectly by computing from the three test temperatures.

The determination of k and Ultimate BOD at 25°C 30°C and 35°C was carried out using Thomas method of graphical determination of rate constant and Ultimate Biological Oxygen Demand (BOD¥) described in Tebutt (9). Finally, statistical comparison between slopes was made following the method given in Zar (14) after simplifying the calculation using a Macro Program written on Excel.

Results

After determination of BOD values over a period of three days at 25°C Thomas fitting technique has been used to determine rate constant and ultimate BOD as shown in Table 1. A similar approach was used to determine the above variable at the remaining test temperatures (30°C and 35°C). The rate constants incubated at three temperatures (k_{25}, k_{30}, k_{35}) were found to be 0.38, 0.34d^{-1}, and 0.28d^{-1} respectively (see table 2) Similarly, the Ultimate Biological Oxygen Demand determined at different temperatures was found to be 1076.55, 1047.33 and 1176.49 in that order and is presented in Table 2. Statistical test between the slopes for the three temperatures showed no significant variation.

Rate constant (k) and ultimate BOD (L) determined using graphical determination method by plotting the graph $(t/BOD_t)^{1/3}$ against time (t) is shown in Fig.1. All the three plots essentially have a similar pattern of increase with time and the difference between slopes is not statistically significant $t_{0.05}(2)_{10}$ $p>0.05$

(Table 2). In order to compare the K values at the three temperatures determined in this study with typical values in literature, conversion was made to k_{20} and is shown in Table 2. Relatively highest value was recorded for incubation temperature at 25°C, the lowest being for incubation temperature at 35°C.

Table 1. Determination of $(t/BOD)^{1/3}$ from liquid waster generated from Jimma University main campus student cafeteria at incubation temperature of 25°C. December 2002- March 2003

Day (x_i)	$(t/BOD_t)^{1/3}$ (y_i)	$(x_i - x_{mean})$	$(x_i - x_{mean})^2$	$(y_i - y_{mean})$	$(y_i - y_{mean})$ * $(x_i - x_{mean})$	BOD (mg/L)
0.5	0.0993927	-1.25	1.5625	-0.0254214	0.0317767	509.22
1.0	0.1141191	-0.75	0.5625	-0.010695	0.0080212	672.86
1.5	0.1225353	-025	0.0625	-0.0022788	0.0005697	815.28
2.0	0.1307834	0.25	0.0625	0.0059693	0.0014923	894.07
2.5	0.1376898	0.75	0.5625	0.0128757	0.0096567	957.71
3.0	0.1443646	1.25	1.5625	0.0195505	0.244381	997.10

Table 2. Determination of slope, rate constant and ultimate BOD for liquid waste generated from Jimma University main campus student cafeteria at three incubation temperatures, December 2002-March 2003

Parameter/temperature	25°C	30°C	35°C
Slope (b)	0.0173611	0.0181485	0.0177526
Standard error	0.0009381	0.00102919	0.00112319
$t_{0.05}(2)_{10}$	p>0.5(p=0.57)	p>0.2(p=0.27)	p>0.2(p=0.26)
Intercept (a)	0.0944320	0.0894672	0.0872865
k (rate constant) d^{-1}	0.38	0.34.	0.28
k_{20} (converted to 20°C)	0.3807691	0.3443745	0.2787159
Ultimate BOD (BOD∞)	1076.55	1112.82	1176.49

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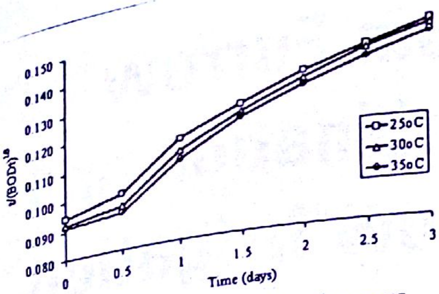

Fig 1. Incubation period (days) versus $(1/BOD)^{1/3}$ to determine rate constant (k) and BOD¥ for cafeteria waste generated from Jimma University main campus student cafeteria, December 2002-March, 2003

Discussion

As presented in the result section of this study, the main campus student cafeteria ultimate BOD is considerably high. Sandy Carencro's stated that raw sewage that has greater than 750mg/L of BOD5 is very strong waste (11). EPA put maximum allowable BOD_5 effluent standard to dispose waste in to water body to be 30mg/L (6). This indicates that Jimma University main campus cafeteria wastewater needs substantial wastewater treatment to reduce BOD if compliance with EPA effluent criteria is a strict requirement.

As stated in the literatures (11, 12) typical k_{20} values of raw sewage ranges from 0.15 to $0.3d^{-1}$. This indicates that k_{20} value of the cafeteria waste measured at 25 and 30°C were somewhat greater than the typical values reported in literature. On the other hand k at 35°C, was observed to fall with in the range reported by other workers. Nevertheless, variation in elevation of the slopes was not statistically supported suggesting that it is possible to obtain comparable BOD data at temperatures other than the standard incubation temperature, i.e. 20°C. The value of BOD reading at 35°C in this study falls within the range reported in literature (13). There are two advantages in using this incubation temperature: Firstly, results are relatively quickly obtained. For instance, incubating samples at 35°C requires only 2 and half days compared with incubation at 20°C, which requires 5 days. Secondly, the provision of special BOD incubators, which are expensive and unavailable in developing countries such as Ethiopia, could be avoided using ordinary incubator. Maintaining incubation temperature at 20°C where room temperature usually exceeds 20°C for most of the year may represent a major setback to determine BOD of water samples if routine national water quality monitoring is initiated.

To our knowledge, no attempt of determination of k and ultimate BOD has been made for liquid waste in Ethiopia making it is difficult to compare our findings with national figures. In literature, typical ultimate BOD values for a strong waste is about 250mg/L (5, 12) suggesting that the cafeteria wastewater generated from Jimma University main campus student cafeteria is a very strong waste prompting to a need for treatment of wastes before discharging to the nearby running watercourses. Postponing taking action may translate to a substantial economic loss for this strong BOD waste may upset the ecological integrity of the *Gilgel Gibe* River, which is much valued as a source of drinking water supply and hydroelectric power generation in the region.

Conclusion and Recommendation

With the present trend of increase in the annual intake of students by Jimma University, the number of accommodation and lounge facilities required to serve the student population is expected to rise and so does liquid waster generation. This preliminary study on liquid waste generated from main campus student cafeteria suggests that the waste is very strong and a treatment system that can achieve about 97% BOD removal efficiency is required to meet EPA effluent standards. Therefore, it is recommended that the amount and strength of all wastewater generated from Jimma University should be determined and treated before discharging in to a water body. Taking cost and climatic conditions as selection criteria, construction of waste stabilisation ponds appears one viable option.

Acknowledgments

The financial assistance provided for this study by Jimma University Research and Publication Office is highly acknowledged.

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Determination of the Optimum Furrow Length and Inflow Rate Combination and Sensitivity Analysis for Furrow Irrigation at Metahara Sugar Estate

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Abstract

This study was conducted at Metahara Sugar Estate on sugarcane crop to determine the best furrow length and inflow rate combination and to analyse the relative sensitivity of performance parameters to furrow length and inflow rate changes.

Non-erosive inflow rates of 2, 3, 4 and 5 l/s were selected as treatments to be applied on 50 and 100 m long furrows. A gross of 134 mm depth of water was applied on all the eight treatment combinations with a pre calculated cut-off time. Each treatment had three furrows. The advance, recession and cut-off times, and inflow rates were measured in situ. Results of the study indicated that the best performance was obtained at a furrow length of 100 m and

3 l/ s inflow rate. In all performance parameters the 100 m long furrows outperformed that of the 50 m long furrows. Thus it is to the advantage of Metahara Sugar Estate to verify the best performing inflow rate and furrow length combinations. The result also indicates the potentials of increasing the furrow length beyond 100 m. With respect to sensitivity, application efficiency and uniformity coefficient were found relatively sensitive to furrow length than that of inflow rate. On the contrary, the storage efficiency was found more sensitive to the inflow rate than the furrow length.

Key wordsSensitivity analysis, Inflow rate, furrow length, performance parameters, cut off time

1. Introduction

Irrigation has played a major role in enhancing agricultural production over the past fifty years. The progress of irrigated agriculture around the world has increased from 8 Mha in 1800 to 275 Mha in 2003 (Jensen et al, 1990; IPTRID, 2003).

Surface irrigation is the most widely used irrigation method in the world, but its irrigation efficiency is usually below 40-60 % (Kruse and Heermann, 1977). However, theoretically designed surface irrigation systems achieve an application efficiency of 70- 85 % (Merriam and Keller, 1978).

The performance of surface irrigation event can fully be evaluated from three different but complementary perspectives: efficiency, adequacy and uniformity. Efficiency measures how efficient an irrigation event is in minimizing unavoidable losses. On the other hand, adequacy of irrigation depends on how much water is stored within the crop root zone, losses percolating below the root zone and losses occurring as surface runoff. Uniformity is a measure of the degree of spatial evenness of the applied water.

The key point in the appraisal and evaluation of existing irrigation schemes is to check for the water application pattern upon which remaining parts of the distribution system depend. Moreover, it is necessary to understand which of the decision parameters play a vital role in affecting the irrigation performance. The decision variables in surface irrigation are the field dimensions (length and width), the flow rate and the cut-off time. Hence the main design consideration in surface irrigation is usually the appropriate combination of field dimensions, flow rate and cut off time (Jurriens et. al., 2001).

Ethiopia has 110 billion m³ of surface water with an irrigation potential of 3-5 M ha. However, a report by Acres International Limited (1995) indicates that, in Ethiopia the share of cereal production through irrigation is only 3 %.

Among the huge irrigated farms in Ethiopia, Metahara sugar Estate is the leading with 10, 000 ha of irrigated sugarcane. Metahara Sugar Estate is located at about 190 km on the Addis Ababa – Asab main road and 10 km to the South of Metahara town. The Estate has an elevation, latitude and longitude of 950 m, 8° 53' North and 39° 52' East, respectively. The mean climatic factors of the region are given in Table 1.1.

Metahara sugarcane plantation has been established in the period since 1966 in 5600 ha sugarcane area with a

Table 1.1: Mean climatic data of Metahara Sugar Estate

MeanT (°C)		RH (%)		Rainfall (mm)	Wind speed (km/hr)		Sunshine (hr)	Pan eva. (mm/day)
Max	Min	Max	Min		Day	Night		
33.5	18.1	88	35.6	615.2	3.7	1.1	8.45	6.3

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total water supply of 7.365 m^3/s or 1.31 l/s/ha. Currently the total furrow irrigated sugarcane area is about 10,000 ha. Because of the dry climate, irrigation is necessary for a period of about 10 months (DHV, 1983). The sources of water for irrigation are two diversion weir sites, the flow of which is regulated from the upstream Koka dam constructed across the Awash River. Gravity irrigation is used for about 85 % of the area and the remaining 15 % area is irrigated using pumps to lift the water to the reservoirs. Irrigation is executed using siphons, which deliver water to a 100 m long furrows, 1.45 m wide furrow spacing and 0.05 % furrow slope.

Though there is no textural soil classification the soils of Metahara were classified for the purpose of irrigation interval determination. Accordingly, six soil classes were identified i.e., Class 1, 2, 3, 4, 5 and 6. Classes 1 and 2 are referred to as light, classes 3 and 4 as medium and classes 5 and 6 as heavy textured soils APECS (1987).

Water application system at Metahara was rarely studied in a comprehensive manner to arrive at better water application practice. As a result soil salinity and rise of water table are progressively becoming one of the bottlenecks of sugarcane cultivation in the Estate. On the other hand, there is a water shortage when the amount of water released from Koka dam is reduced during low flow periods of May and June.

The irrigation performance of some irrigated farms conducted in Ethiopia so far is low (Tessema, 1986; Halcrew 1989; Kassa 2001). Similar inefficient irrigation is true in Metahara Sugar Estate with an average application efficiency of 45 % for a closed furrow irrigation system (Habib, 2004). Moreover, the irrigation water application is subjected to irrigation labourers. Thus the inflow rate, cut-off time, depth of application and in turn the irrigation performance is dependent on the irrigation labourers. In view of the above-mentioned problems a trial was conducted with the following major objectives:

- To determine the most efficient furrow length and inflow rate combination;
- To analyse the relative sensitivity of performance parameters to the changes in furrow length and inflow rate.

2. Methodology

This study was conducted at Metahara Sugar Estate for four months (March through June 2004). First ratoon sugarcane of age 4.5 months grown on clay loam soil was selected as an experimental field. Soil samples were collected for the determination of soil physico - chemical properties at 7 representative locations to a depth of 0-30, 30-60 and 60-90 cm. The allowable management depletion of sugarcane varied from 0.55 (Rao, 1990) to 0.65 (FAO, 1979).

Input parameters such as advance and recession times were measured at every 10 m interval along the furrows. Similarly cut-off time, inflow rate and furrow geometry were recorded in situ. The depth of water required to refill the soil reservoir to its field capacity was worked out from the readily available water content and crop root depth. Infiltration constants of the soil under consideration was a= 2.93 and b= 0.73 (Habib, 2004).

2.1 Determination of Performance Parameters

2.1.1 Application efficiency (E_a) was calculated as the depth added to the target zone (D_s) divided by the applied depth (D_a), Hart et. al (1980) as:

$$E_a = \frac{D_s}{D_a} * 100 \qquad (2.1)$$

2.1.2 Deep percolation ratio (DPR) was calculated as a ratio of the deep percolation loss (D_{dp}) to the applied water (D_a) as:

$$DPR = \frac{D_{dp}}{D_a} * 100 \qquad (2.2)$$

2.1.3 Storage efficiency (E_s), some times known as requirement efficiency was calculated using the formula defined by Hart et al (1980) as the ratio between the storage depth (D_s) and the required depth (D_{req}) as:

$$E_s = \frac{D_s}{D_{req}} * 100 \qquad (2.3)$$

.1.4 Christiansen's uniformity coefficient (UC), it is defined as:

$$UC = 100 - 100 * \sum \frac{|D_i - D_{av}|}{nD_{av}} \qquad (2.4)$$

D_i = Depth of water applied at a given station along a furrow (mm)

D_{av} = Average infiltrated depth (mm)

n = Number of points along a furrow

For n points along the length of the field, uniformity coefficient gives the average of all differences between the infiltrated depths and the average depth.

Furrow lengths of 50 and 100 m were selected for the experiment. Furrow length at Wonji/ Shoa Sugar Estate is 32 m for light, 48 m for medium and 64 m for heavy textured soils. Thus, the 50 m long furrow represents the furrow condition at Wonji/ Shoa Sugar Estate and 100 m represents that at Metahara. Moreover, the two Sugar Estates have the same furrow spacing.

The maximum non-erosive inflow rate (Q, l/s) was determined as a function of furrow slope (S, %) using an empirical formula of the form:

$$Q = \frac{0.63}{S} \qquad (2.5)$$

The cut-off time for each inflow rate and furrow length was calculated using equation 2.6 as:

$$t_{co} = \frac{Z * L * W}{60 * Q} \qquad (2.6)$$

Table 2.1: Treatment combinations for the sensitivity experiment for 50 and 100 m furrow lengths at Metahara Sugar Estate

Furrow Length (m)	Inflow Rate (l/s)	Cut-off time (min)	Furrow Length (m)	Inflow Rate (l/s)	Time of cut-off (min)
50	2	81	100	2	163
50	3	54	100	3	108
50	4	41	100	4	82
50	5	33	100	5	65

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Where

t_{co} = Cutoff Time (min); Z = Depth of Water Applied (mm)

L = Furrow Length (m) ; W = Furrow Spacing (m)

Q = Inflow Rate (l/s)

Irrigation was started by siphoning water to each of the furrows. Stakes were fixed at every 10 m along a furrow to 50 or 100 m depending on the selected furrow length for the measurement of advance and recession times.

2.2 Sensitivity Analysis

A relative sensitivity analysis was carried out to determine whether the furrow length or inflow rate affect the adequacy, uniformity and efficiency of irrigation. This was done by comparing the ratio of change of performance indicators (i.e., application efficiency, uniformity coefficient, and storage efficiency) for the same percentage change of furrow length and inflow rate using equation 2.7. Accordingly, a 100 % increment was made on the furrow length (i.e.,from 50 to 100 m) and inflow rates (i.e.,from 2 to 4 l/s).

$$\text{Sensitivity} = \frac{\text{Change of performance}}{\text{Change of input parameter}} \quad (2.7)$$

The relative change of application efficiency, uniformity coefficient and storage efficiency was worked out for a 100 % increase of furrow length at constant inflow rate. Similar exercise was performed for 100 % increase of inflow rate at a constant furrow length.

3. Results And Discussion

3.1 Performance Parameters

3.1.1 Application Efficiency

For 50 m long furrows the maximum application efficiency of 74.7 % was obtained for an inflow rate of 3 l/s while the minimum was 73 % for 5 l/s inflow rate and the average is 74.1 % (Table 3.1). In general, the application efficiency obtained so far is satisfactory. James (1994) had estimated that the application efficiency at Metahara, which is about 75 %. Roughly the same application efficiency of 73 % was presented in a report by DHV (1983). Results of this study also validated the above efficiency figures.

In the case of 100 m long furrows

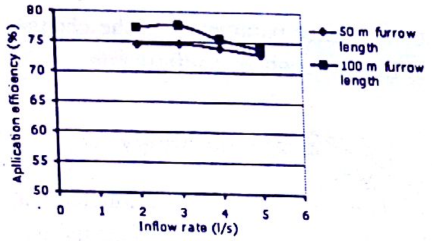

Figure 3.1: Application efficiency of 134 mm application depth as affected by furrow length and inflow rate

Table 3.1: Performance parameters of a 50 m furrow length as affected by different inflow rates at 134 mm application depth

Inflow rate (l/s)	Performance parameters (%)			
	AE	UC	Es	DPR
2	74.5	80	98.4	25.5
3	74.7	81	96.7	25.3
4	74	76	96	26
5	73	70.9	95.7	27

AE= Application efficiency UC= Uniformity coefficient
Es= Storage efficiency DPR= Deep percolation ratio

the highest application efficiency of 77.8 % was obtained for an inflow rate of 3 l/s while the minimum of 74 % was found for 5 l/s inflow rate, with an average of 76.2 % (Table 3.2).

The application efficiency was found better in 100 m (76.2 %) than that in 50 m (74.1 %) long furrow for all inflow rates (Figure 3.1, Tables 3.1 and 3.2). Moreover, for both the furrow lengths the maximum application efficiency occurred at an inflow rate of 3 l/s.

3.1.2 Uniformity Coefficient

Table 3.2: Performance parameters of a 100 m furrow length as affected by different inflow rates at 134 mm application depthA

Inflow rate (l/s)	Performance parameters (%)			
	AE	UC	Es	DPR
2	77.4	84.2	99.2	22.6
3	74.7	84.5	99.5	22.2
4	74	80.2	97.4	24.5
5	73	75.9	97.5	26
Average	76.2	81.2	98.4	23.8

E= Application efficiency UC= Uniformity coefficient
Es= Storage efficiency DPR= Deep percolation ratio

In the case of 50 m long furrows it is the uniformity coefficient, which responded highly to the different inflow rates with the highest C_v value of 5.96 %. The maximum uniformity coefficient of 81 % was found for an inflow rate of 3 l/s while a minimum of 70.9 % was found at an inflow rate of 5 l/s. The average value was 77 % (Table 3.1).

For 100 m long furrows the maximum and minimum uniformity coefficient values of 84.5 and 75.9 % were obtained at inflow rates of 3 and 5 l/s, respectively while the average was 81.2

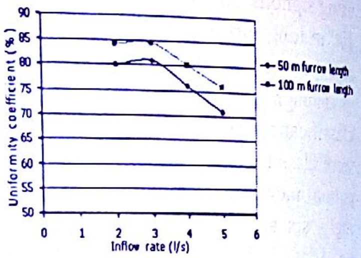

Figure 3.2: Uniformity coefficient of furrow irrigation as affected by furrow length and inflow rate

% (Table 3.2). The uniformity coefficient was found increasing from 84.2 to 84.5 for 2 to 3 l/s changes of inflow rate then decreased linearly with an increased inflow rate from 3 to 5 l/s (Table 3.2 and Figure 3.2).

The average uniformity coefficient was superior in 100 m (81.2 %) than in 50 m (77 %) long furrows (Figure 3.2, Tables 3.1 and 3.2). Similarly, the uniformity coefficient excelled in 100 m than that in 50 m furrow length for each of the inflow rates considered.

3.1.3 Storage Efficiency

For 50 m long furrows satisfactory storage efficiency was achieved for all the inflow rates, with an average value of 96.7 %. The maximum and minimum storage efficiency of 98.4 and 95.7 % was found at inflow rates of 3 and 5 l/s, respectively (Table 3.1). The storage efficiency was decreased linearly by increasing the inflow rate from 2 to 5 l/s (Table 3.1).

No much variation was discovered in the storage efficiency for changes of the inflow rate between 2 to 5 l/s in the case of 100 m long furrows, the result was explained by a low C_v value of 1.12 %. Though the difference was not that considerable it can be learnt from Table 3.2 that a maximum and minimum storage

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efficiencies of 99.5 and 97.4 % were obtained for inflow rates of 3 and 4 l/s, respectively. The average value is 98.4 %.

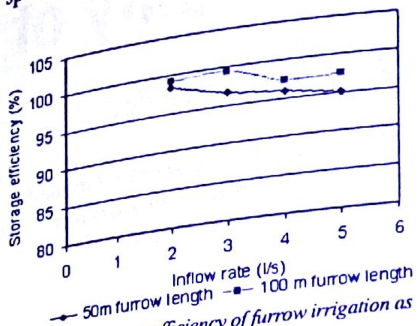

Figure 3.3: Storage efficiency of furrow irrigation as affected by furrow length and inflow rate

Generally, irrigation water is applied to maximize the application efficiency constrained to a storage efficiency of 95 - 100 %. Thus all the inflow rates were successful in delivering a sound storage efficiency of more than 95 %.

It is apparent from Tables 3.1 and 3.2 that for both 50 and 100 m furrow lengths good storage efficiency was achieved. The average storage efficiency was 98.4 % for 100 m and 96.7 % for 50 m. Similar to the other parameters the storage efficiency was found better in 100 m than for 50 m for every

Table 3.3a: Average change of performance parameters in effect of doubling the furrow length and the inflow rate

Para meter	Change of performance (%)		Sensitive to:
	Doubling furrow length at constant Inflow rates	Doubling inflow rate at constant furrow length	
AE	2.9	-1.6	Furrow length
UC	5.1	-4.9	Furrow length
Es	1.1	-2.1	Inflow rate

Table 3.3b: Average sensitivity of performance parameters in effect of doubling the furrow length and the inflow rate

Para meter	Sensitivity of performance (%)	
	Doubling furrow length at constant Inflow rates	Doubling Inflow rate at constant furrow length
AE	0.029	-0.016
UC	0.051	-0.049
Es	0.011	-0.021

inflow rate considered (Figure 3.3, Tables 3.1 and 3.2).

3.2 Sensitivity Analysis

The application efficiency was found to be more sensitive to variations in furrow length than inflow rate. It was increased by 2.9 % by doubling the furrow length from 50 to 100 m while keeping the inflow rate constant (Tables 3.3a and 3.3b). However, for the same 100 % increment in inflow rate (2 to 4 l/s) and keeping the furrow length constant, the average reduction in application efficiency was only 1.6 %.

The uniformity coefficient was found more responsive to the changes of furrow length than the changes of inflow rate. Keeping the inflow rate constant and doubling the furrow length from 50 to 100 m there was a 5.1 % average increase in uniformity coefficient.

However, for the same percent increase of inflow rate the average reduction of uniformity coefficient was 4.9 % (Table 3.3a). The uniformity coefficient showed the same trend as in the application efficiency. It was sensitive to furrow length than inflow rate and the value increased by increasing the furrow length and reduced by increasing inflow rate.

The result also reveals that the effect of doubling furrow length from 50 to 100 m improved the storage efficiency by 1.1 % but doubling the inflow rate from 2 to 4 l/s decreased the same by 2.1 %. Hence, unlike the application efficiency and uniformity coefficient the storage efficiency was more sensitive to the inflow rate than the furrow length. Thus, this study confirms that ,at Metahara Sugar Estate, the furrow length of 100 m should be maintained and further experiments should be conducted to increase the furrow length. Besides, because of some soil and agronomic similarities between Metahara and Wonji Sugar Estates there is a possibility of increasing furrow length also for Wonji Shoa Sugar Estate.

4. Conclusions And Recommendations

1. The best performance was found at 100 m furrow length and 3 l/s inflow rate therefore the Estate may verify the use of 3 l/s inflow rate. 100 m furrow length resulted in better performance than 50 m furrow length; therefore, the Estate is advised to adhere to the present 100 m long furrows.

2. Results of this study imply the possibility of extending furrow length beyond 100 m. In addition, increased furrow lengths are advantageous from the farm mechanical operation point of view.

3. Application efficiency and uniformity coefficient were found more sensitive to furrow length than the inflow rate. On the contrary, the storage efficiency was more sensitive to the inflow rate than the furrow length. All the performance parameters improved by doubling the furrow length but decreased by doubling the inflow rate.

4. Further study need to be conducted to verify the results obtained so far including a furrow length more than 100 m and with a wider range of soil types.

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Effect of Coffee Processing on Physicochemical and Biological Quality of Malawo Stream: *Aleta Wondo, Sidama, Southern Ethiopia*

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Abstract

Sidamo, the major coffee producer region in Ethiopia has a number of small-scale coffee pulping industries; the effluent of which, when discharged in to water body, disturbs the aquatic aerobic life by causing oxygen depletion.

A longitudinal pollution status assessment has been carried out on Malawo stream from January 26 to February 21st 2003 in Aleta Wondo, at seven sampling stations with in total length of 18 km and analyzed in SNNPRS (Southern Nations and Nationalities People's Regional State) Research Laboratory center following standard procedures.

The results of physicochemical parameters indicated station 'D' to be relatively polluted station having the minimum DO of 4.5mg/l and pH of 5.0 and maximum concentration of 15.4mg/L BOD_5, 69.73mg/L NO_3^-, 1.25mg/L NH_3 and 1.925mg/L PO_4^{3-} which attributes the indiscriminate disposal of town wastes. The macroinvertebrate data also show a similar trend with physicochemical parameters in separating site 'D' as the polluted station. However the progressive variation in physicochemical parameters and the diversity indices showed the impact of coffee processing on the stream.

From the results of the study, it is possible to conclude that the stream Malawo is suffering from coffee pulpery effluents and the indiscriminate discharge of town wastes. Therefore appropriate intervention strategies should be done by the owners of the coffee pulpery industries and the municipality to tackle further deterioration of the stream and concerned governmental organizations should monitor and control such industries and devise cleaner processing technologies.

Key words/Phrases: **Sidama, Aleta Wondo, Coffee processing, Macroinvertebrates, Physicochemical parameters.**

Introduction

Water is a commodity with out which life on earth would be impossible. Its availability alone is not sufficient to sustain life; its quality is also of paramount importance. It has been reported that about 80% of all infections in the world are associated with unsafe water *(IRC, 1983)*. In Ethiopia, more than 87% of the total population lives in rural areas. Out of these only 19.9% get accesses to safe water, with the remaining 80.1% drawing their water supplies from unprotected sources such as streams, rivers, ponds, wells etc. (1). Apparently, water from such sources has a large chance of being contaminated with faecal matter, industrial wastes, agricultural chemicals and mismanaged land use.

When biodegradable waste is discharged in to water body, it disturbs the aquatic aerobic life by causing oxygen depletion. Surface water as an aquatic ecosystem contains a wide range of animals, which react differently to different conditions. The presence or absence of specific organisms can be used to detect changes, which are occurring or may have occurred recently in the environment where they live (2).

The basic principle underlying the methodology is that where biotic diversity is high, the river is in a relatively healthy biological and chemical state, integrating and or supplementing physicochemical analysis with such biological study can give best and reliable characteristics of the water body.

Different literatures utilize these physicochemical parameters to evaluate the pollution status of surface waters and found significant correlations to pollution (3, 4, and 5). Therefore, carrying out such similar study in *Malawo stream* using macroinvertebrates and other physicochemical parameters is of great help in assessing *the pollutional effect of coffee effluents* that directly out fall in to streams.

Coffee is the most widely consumed beverage in the world, and is believed being discovered in Abyssinia, now Ethiopia. Sidamo, the major coffee producer region in Ethiopia, has a number of small-scale coffee pulping industries situated along the banks of rivers and/or streams releasing their effluents in the majority of cases without any treatment.

Malawo is one of such streams that receive effluents from six coffee pulping industries in addition to the indiscriminate disposal of solid and liquid wastes from residents of Aleta Wondo town and runoff from agricultural sites. According to a case study conducted in Costa Rica, coffee production has led to different environmental problems, the major problem being river pollution. *"57% of the coffee bean is made up of contaminants which when discarded destroy fauna in streams and rivers and harm people"*. (6)

Bearing this in mind and with an estimated population growth rate of

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about 3% per annum, the anthropogenic pressure on aquatic ecosystem is likely to increase in Ethiopia that has a significant correlation to human health. With so many overriding socio-economic constraints to be resolved, the country cannot afford the luxury of pollute first-clean-later scenario of the developed nations and the government should start to address the far-reaching consequences of polluting the already scarce fresh water ecosystems.

Little research work exists to quantify the nature of man-made disturbances in aquatic systems in Ethiopia. This paper therefore presents a preliminary study on factors influencing the quality of streams crossing coffee pulping industries and can give relevant clues of pollution indicating parameters. It also may help to predict the extent of stream pollution in Sidama as the growing investment on coffee processing increases; therefore it will be possible to take appropriate actions before hand. Besides and above all it may initiate integrated approach to tackle pollution issues and provoke further studies at national level, which may produce useful data.

Methods And Materials

Samples for physical and chemical analysis were collected following standard procedures recommended by 'Standard Methods' (7, 8), and were analyzed in SNNPRS regional laboratory (water laboratory unit) in collaboration with the regional water, mines and energy resource authority water quality laboratory unit. NH_3, NO_3^- and PO_4^{3-} were determined by direct spectrophotometry (HACH-Dr/ 2000 spectrophotometer). A 'check-temp' digital water thermometer and standard pH measuring kit (model NPL LAmotte) were used for onsite determination of temperature and pH

DO was determined by the azide-modification of the Winkler's titration method while BODÿ□$_5$ was analyzed by determining DO content of the sample before and after two and half days incubation at 35°C which gives the same results with BOD_5 measurements incubated for five days at 20°C (9).

Macroinvertebrates were also collected using 153-micron Wagtech field-master plankton net (Cat no 7000-B20) with a diameter of 130mm, based on standard books referenced above. After the invertebrates were sorted from the substrates, they were preserved with 2.5% formalin and transported to Jimma University environmental health laboratory for further identification of organisms in to their respective orders based on the criteria recommended in standard methods (10). A binocular dissecting microscope of 10 and 20-magnification power was used to group the invertebrates in to their orders.

Table I. *Physicochemical parameters collected from Malawo stream. Aleta Wondo (Feb/2003)*

Sampling Stations	Water quality parameters							Speed of flow (cm/sec)
	Temp (°C)	pH	DO	BOD_5	NH_3	NO_3^-	PO_4	
A	22.5	7.0	6.0	4.8	0.17	18.32	0.054	35
B	22.5	6.5	6.0	11.0	0.73	35.51	0.159	32
C	24.0	6.0	6.0	6.0	0.69	28.92	0.122	30
D	22.0	5.0	4.5	15.4	1.25	69.73	1.925	25
E	22.0	6.0	6.0	8.5	0.95	23.55	0.383	40
F	22.3	7.0	6.5	7.0	0.41	15.21	0.625	60
G	22.6	7.0	7.0	0.8	0.28	9.52	0.125	65
CV	2.8%	10.9%	11.8%	56.4%	55.5%	64.8%	127%	

NB. All units except temperature and pH are in mg/l.
CV: Coefficients of variations

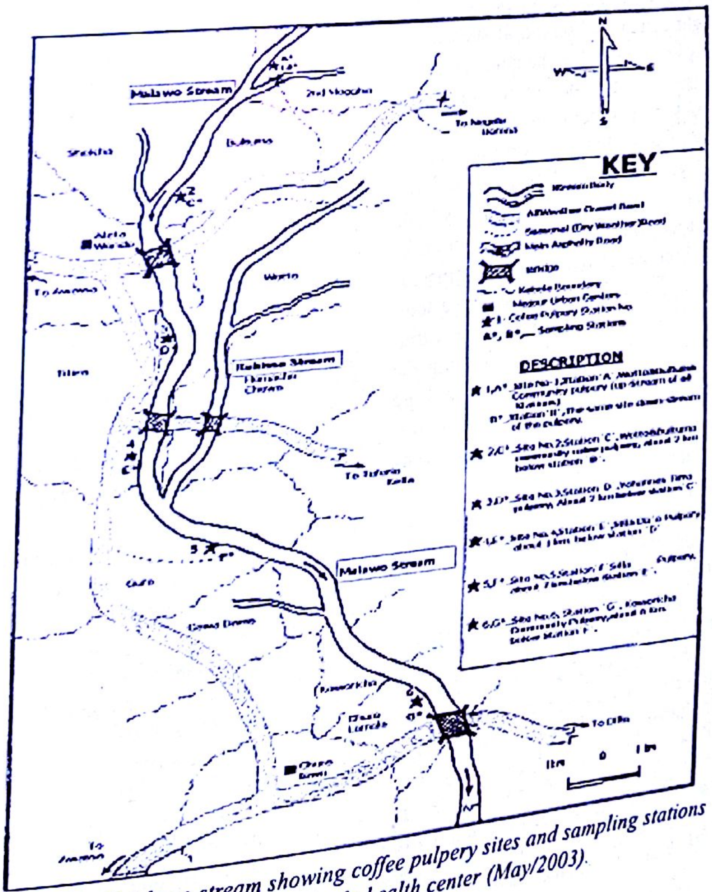

Fig. 1 Map of Malawo stream showing coffee pulpery sites and sampling stations under study; adapted from Aleta Wondo health center (May/2003).

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Finally the diversity indices were computed based on the following formula (10).

Simpson index = $1/D, where, D=\sum\left[\frac{nl(nl)}{N(N-1)}\right]$

n_i = no of individuals in the i^{th} taxon
N = total no of macroinvertebrates collected at the site
Shannon winner index, $H=-\sum\frac{nl}{N}\ln\frac{nl}{N}$

Alpha log series, $\alpha\frac{N(1-x)}{x}$;

where S= total number of species,
N = total number of individuals in the sample, and x is estimated by iteration using the following equation

$$S/N=\left[\left(\frac{1-x}{x}\right)\right]\left[-\ln(1-x)\right]$$

Results And Discussion

Physico- Chemical Parameters

A. Temperature: No significant variation has been observed in temperature; CV 2.8%; i.e. 22°C – 22.6°C; except station 'C' which measures 24°C. This slight increase observed at station 'C' may be attributed to the unique characteristics of the station in which the banks of the stream segment lacks marginal plants that may form a shade to the water body, and also the shallowness of the depth in connection with its relative slow flow could have contributed for the relative rise of the temperature. The difference in daytime temperature due to sampling time variations was minimized by adjusting the sampling organization and as such no significant variation was observed due to this fact through out the sampling stations.

B. pH: The hydrogen ion concentration analysis shows a slight decrement from station 'A' to 'D' and again raised in going further down stream to station 'F' and 'G'. In the former case the highest pH recorded was 7.0 at station 'A' where the site is up stream of all stations in which no point source organic pollutant was observed; while coming down to station 'D' the pH progressively reduced to 5.0 which may be due to the organic waste discharged from the coffee pulpery especially at station 'B' and 'C' and the waste from Aleta Wondo town where up on the stream receives as it crosses the town in particular to station 'D'. This finding agrees with different studies (11, 12, and 3); For example: the study done on Awetu stream, Jimma by Dejene H. and another study done in Kenya on Ruiruaka river, showed low pH at points where the river system received most of the town wastes. The slight decrease in pH value indicates the active decomposition of organic matter. As the organic wastes oxidize, CO_2 is released and increase the acidic characteristics of the water decreasing the pH value below the range of 6.5-8.5; which is WHO standard for any source of water for human use (13, 14).

In the later case the highest pH recorded was at stations, 'F' and 'G'. This shows an increase in pH in which the acidic characteristics of the water reversed back to its neutral state. This may be attributed to: in part as can be noticed going down stream, the amount of the water increases due to tributaries joining the stream, which generally considered relatively unaffected by pollutant sources and thus the assimilative capacity of the stream increases; on the other hand the self-purification capacity of the water body could contribute for the return of pH value to its neutral state (9).

C. Dissolved Oxygen (DO):- The DO content of Malawo stream ranged between 4.5mg/L and 7.0mg/L, the minimum value was at station 'D' indicating the degradation of water quality at this station in relation to other stations. This may be accounted to the organic waste load from the town in addition to the effluent released from the coffee pulpery. The maximum DO level was recorded at station 'G' the implication of which is the re-aeration attained from the increased turbulence observed down stream of station 'D'. Even then, this low level of DO can support a certain tolerant species of aquatic animals though not as diverse as other stations. When compared with the quality standards of drinking waters recommended by WHO, a minimum DO level of 5.0 mg/L, all stations with exception of station 'D' are considered to be satisfactory provided that other water quality parameters should be with in acceptable limits.

D. Biochemical Oxygen Demand (BOD_5): The analytical data for five day BOD recorded a maximum concentration of 15.4 mg/L at station 'D' followed by 11.0 mg/L at station 'B'. This reveals the presence of oxygen demanding pollutants in excess of other stations under study; The amount 11.0mg/L at station 'B' signifies the load of pollutants due to the coffee pulpery as it raised abruptly from 4.8mg/L at station 'A' to 11.0 mg/L at station 'B' with few distance (300m) variation in which the only difference is the effluent discharged to station 'B'. On the other hand, station 'D' also shows the maximum concentration, which may be due to the additional discharge of town wastes.

The minimum five day BOD load recorded was 0.8mg/L at station 'G', May be attributed for the self-purification property of the water body in addition to the confluence of better quality tributaries, and also due to the absence of point source pollutants specifically at station 'G' where the coffee pulpery doesn't release the effluent in to the water body.

Though the BOD_5 level is above the recommended level for drinking water considered fairly pure with a BOD_5 of 3mg/L (8), it generally seems very low when compared with different studies such as in Addis Ababa river systems (3) and in Kenya on Ruiruaka river (11) that crosses the city of Nairobi with BOD_5 as high as 2700 mg/L. However, the rise and fall of all these parameters pinpoints us to consider and anticipate the future fate of such natural water systems likely to be polluted and to design appropriate intervention strategies.

E. Ammonia (NH_3): The results for ammonia (NH_3) in Malawo stream (table 1) indicated the minimum concentration recorded to be 0.17mg/L at station 'A' where there is no possible point source contaminant which after words increases to 0.73 mg/L and 0.69mg/L at stations 'B' and 'C' respectively. This may be due to the discharge of the effluent from the coffee pulpery. The maximum concentration of ammonia was 1.25 mg/L at station 'D' located down stream of Aleta Wondo town, the segment which receives a significant amount of waste

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matter from the indiscriminate disposal by the community; the domestic waste from the town contributes an additional threat to the stream segment over the effluents that directly enter in to water-ways. This increase of Ammonia concentration causes severe DO depletion as its complete oxidation to nitrate imposes high oxygen demand (15).

In general Ammonia will be toxic to aquatic life whenever its concentration exceeds 3mg/L (16); therefore the present study though not as toxic as what literatures agree, the level obtained suggests, the future fate of streams crossing such coffee pulpery industries. Again further down stream analysis indicates a decrease in concentration of ammonia nitrogen. This can be explained by the condition of the stream segment receiving better quality water from tributaries such as from 'Rukissa' stream (fig1), in addition to the self-purification properties of flowing waters, which causes ammonia to be oxidized.

F. Nitrate (NO_3^-): The nitrate concentration in Malawo stream also has a similar trend with all other physico-chemical parameters. Hence; the maximum concentration recorded was 69.73mg/L, at station 'D' in which it exceeds the guideline value (50mg/L) recommended by WHO for drinking purpose. And the minimum concentration of NO_3^-N was recorded at station 'G', 9.25mg/L. Actually except station 'D' all other stations were with in the recommended level and that all stations with exception of the last station 'G' exceeds the maximum contaminant level set by the US environmental protection agency (10mg/L) (17). Starting from the first station 'A', going down stream, the NO_3-N level increases progressively up to station 'D', this implies the effect of effluents discharged from the coffee pulpery in to the water body and the abnormal rise recorded at station 'D' may be due to the additional load from the discharge of town wastes. Finally further down stream; the NO_3^-N level starts to return back to its acceptable levels, indicating the assimilative capacity of the water.

G. Phosphate (PO_4^{3-}): The analytical result with regard to phosphate shows a two-phase trend as described in all above parameters. The minimum concentration recorded was 0.054mg/L at station 'A' where no contaminant sources are supposed to be observed in relation to other sampling stations, and the maximum concentration 1.925 mg/L at station 'D' which is down stream of Aleta Wondo town attributable of the wastes discharged in to the water body. Going down stream further from station 'D', the PO_4^{3-} concentration decreases progressively to 0.125 mg/L at the final station; 'G'. The concentration of PO_4^{3-} in Malawo stream generally is above the maximum allowable concentration (0.01mg/L) (13).

This general increase may be due to runoffs from agricultural sites that the topographical characteristic of the stream has its own role being steepy towards the stream body. But the increase from station 'A' to 'B' and so on is largely due to the effluent from the coffee industry and additionally the waste from the town especially at station 'D'. The self purification capacity of the stream can also explain the decrement in similar fashion with other parameters discussed so far, thus the stream regains its safest concentration, though is relatively.

Macroinvertebrates

The results obtained on the distribution and percentage abundance of macroinvertebrates (Table 2) shows an agreement with the physicochemical parameters and the habitat variables discussed so far. The flow pattern of the stream segment can be classified in to two distinct forms: one as *slow flow*:- those stations with flow rate below 50 cm /sec, stations "A" – "E"; and the other with flow rates greater than 50 cm/sec, considered as *swift flow*, station: "F and "G". For most of it's length the slow flow stations share common characteristics of the stream bed in relation to the siltation pattern, while on the other hand the swift flow segment down stream represents the *gravel*, *boulders* and *large stones* predominate and creates a cascading action that intermixes oxygen and results in a relatively better dissolved oxygen content of the water body, the characteristics of which determines the type of animal forms predominated in such particular environment.

2 From a total of 16 different orders and sub orders of macroinvertebrates collected; *Ephemeroptera* (mayfly groups) represent the most abundant invertebrates collected, this is attributed to the fact that these orders of macroinvertebrates are of two types; viz: *pollution sensitive* groups and *pollution tolerant Baetis rahodani* groups. These groups of *mayfly* have been shown by work worldwide to have resistance to low levels of organic pollution though it is sensitive to inorganic pollution (18). This tolerability can be verified by the fact that; these groups comprises primarily consumers which may be found resting or moving on the bottom or beneath silt for searching food in plant debris (19). They have a capacity to descend more deeply in to the bottom mud and either maintain

Table II. *Density of Macroinvertebrates per square meter and percentage abundance of each group in Malawo stream, Aleta Wondo (Feb/2003)*

Macroinvertebrates (Order)	Sampling Stations A No	A %	B No	B %	C No	C %	D No	D %	E No	E %	F No	F %	G No	G %	Remark Total No	Total %
Coleopteran	85	8.14	-	-	120	22.73	30	4.44	25	3.54	-	-	-	-	260	4.94
Ephemeroptera	380	36.40	200	37.67	235	44.51	10	1.48	-	-	405	43.40	315	38.27	1545	29.34
Orthoptera	53	5.08	32	6.03	-	-	-	-	-	-	-	-	65	7.90	150	2.85
ODOnata	39	3.74	70	13.18	52	9.85	-	-	-	-	74	6.70	55	6.68	290	5.51
Hirudinea	80	7.66	45	8.47	-	-	-	-	15	2.12	-	-	30	3.64	170	3.23
Mollusks	-	-	10	1.88	-	-	-	-	-	-	20	2.10	-	-	30	0.57
Plecoptera	265	25.38	91	17.14	45	8.52	-	-	-	-	169	15.60	185	22.48	755	14.34
Hemiptera	32	3.06	-	-	35	6.63	-	-	-	-	35	4.20	-	-	102	1.94
Chironomids	-	-	-	-	20	3.79	385	56.95	235	33.29	20	2.10	30	3.64	690	13.11
Dipterans	48	4.60	48	9.04	-	-	105	24.41	318	45.04	45	3.60	25	3.04	649	12.33
Eristalis	-	-	-	-	-	-	3	0.44	-	-	-	-	-	-	3	0.06
Polycheats	-	-	-	-	11	2.08	25	3.70	55	7.80	-	-	-	-	91	1.73
Trichoptera	47	4.50	20	3.77	-	-	-	-	15	2.12	115	14.10	-	-	197	3.74
Oligocheata	-	-	-	-	-	-	23	3.40	8	1.13	54	6.10	10	1.22	95	1.80
Decapods	15	1.44	15	2.82	-	-	-	-	15	2.12	20	2.10	48	5.83	113	2.14
Flatworms (Planarian)	-	-	-	-	10	1.89	35	5.18	20	2.83	-	-	60	7.30	125	2.37
Total	1044	19.83	531	10.08	528	10.03	676	12.84	706	13.41	957	18.18	823	15.63	5265	100

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burrows or have extended parts of the body reaching the surface of the mud for breathing.

The second most abundant group of macroinvertebrates is the *plecopteran* group also called stonefly (a type of fly whose larvae live in well oxygenated water). These invertebrate forms are found to be sensitive to pollution as there is a noticeable decrease in number and even absence of these species at the most polluted sites (station 'D' and 'E') where the DO level is relatively poor. The present study strongly agrees with studies done in Peru; which concludes as "*plecoptera species are the indicator group for the most sensitive species, and as such are intolerant of any pollution causing the oxygen concentration to be reduced*" (18).

Family *chironomidae* and other families of the *dipteran* groups are those groups of macroinvertebrates which were found in significant amounts at the most polluted sites 'D' and 'E'. This is attributed due to the fact that species especially tolerant to pollution are those that have adaptations for obtaining oxygen at the water surface (20). Some species of the *dipteran* groups also are deposit feeders such as for example: *sewage fly* and *midge fly* larvae, which depend on the organic matter, deposited on the bottom of the stream body.

Like *Plecoptera* groups; *Orthoptera, Odonata, Hirudinea* and *Mollusks* were not found at the most polluted station so considered, thus can be said that these groups are sensitive to pollution and they lack mechanism of adaptation to aquatic environments with poor DO content (19). *Mollusks* are found predominantly at station 'F' where the DO content is considered to be good and that these groups are associated with increasing $CaCo_3$ and salt levels and also can be associated with the eroding substrates as the flow at station 'F 'is considered to be swift.

The group of *caddis flay* larvae (the *Trichoptean* groups) are also associated with well oxygenated and fast flowing water which supports the results obtained from Peru. The *coleopteran* and *Hemipteran* groups are actively swimming macroinvertebrates, which mostly inhabits the upper surface of water and as such may not significantly affected by pollution of organic matter; thus they can be found in both polluted & unpolluted stations.

The segmented worms such as (*Oligochaets, Polychaets & Hirudinea*) and among the *Dipteran* group, *Eristalis* (the rat-tailed maggot) are the group of macroinvertebrates which are found in considerable number specifically at the most polluted station, station 'D' as literatures agree (20,12). These species therefore can be guarantly taken as pollution indicator species whenever they are predominantly found in polluted sites.

Inspection of the diversity indices presented in fig 2 shows, Simpson index to be separated from Shannon and Alpha log series in describing the pollutional status of the stream. Even though all of them agree in separating site 'D' to be species poor habitat, Alpha & Shannon index are more or less similar. This shows that, Simpson index can significantly be affected by spatial variation and other natural disturbances. This analysis agrees with the explanation given by Dr Worku in his Ph. D thesis (21). He concludes that Simpson index is the most affected index to man made and natural disturbances and thus less effective in describing the pollutional status of streams while the Shannon and Alpha indexes are the least affected by such disturbances. He further noted that, despite the popularity of the Shannon index among ecologists, it appears that Alpha index has a better performance relative to the Shannon in relation to stability to disturbances even when calculated based on EPT (*Ephemeroptera, plecoptera and Trichoptera*) taxa alone. Therefore, from the above explanation, it is evident to observe the agreement of the present study in describing the pollutional status of Malawo stream as the more stable diversity indices showed significant variations from station to station.

The analysis of percentage abundance of all taxa with the % EPT [indicated in fig 3] shows an agreed up on trend in describing the status of the stream segment under study. This study provides a clue on reduction of man power, time and cost constraints on one hand and an additional benefit of a more efficient sample processing and thus improved data quality as an advantage from the entire taxonomic range of organisms collected in the field. The reason of selecting EPT taxa among other taxonomic range of organisms is attributed to their morphological traits and life cycle patterns for quick recovery from natural disturbances, thus environmental 'noise' created due to natural disturbances could be minimized by using these species of macroinvertebrates. Therefore they are considered as good candidates to fulfill water quality criteria and indices calculated based on these species are expected to be more predictable than all taxa combined.

The Bray Curtis similarity cluster analysis for macroinvertebrates shows, station 'A', 'F' & 'G' to have more similar macroinvertebrate compositions as compared to other stations; and station 'D' and 'E' separated from the total sampling stations thus suggesting the pollutional status of stations as de-

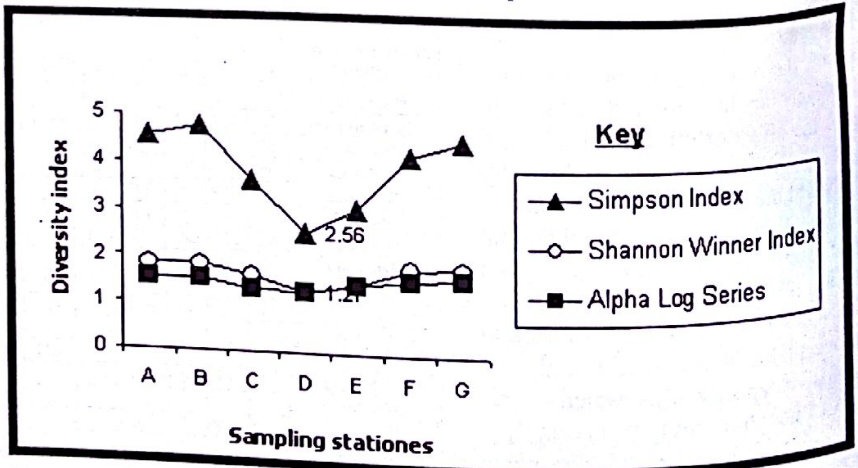

Fig 2.The diversity index of macroinvertebrates between sampling stations, Aleta wondo, Sidama, 2003

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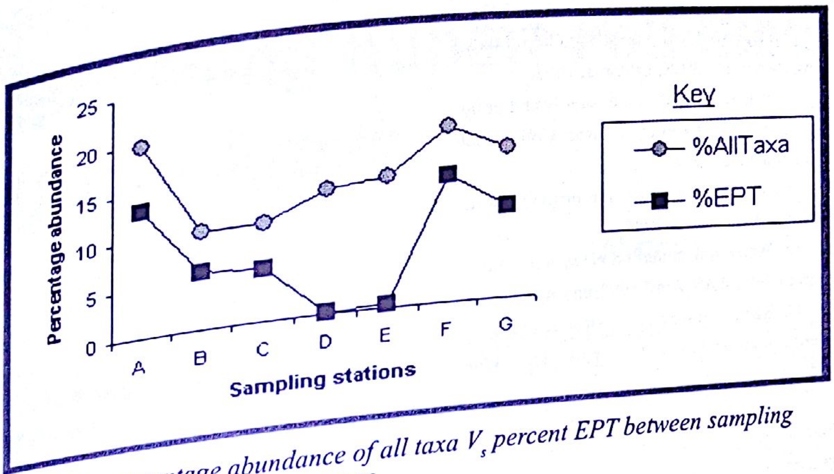

Fig.3, The percentage abundance of all taxa V_s percent EPT between sampling stations, Aleta wondo, Sidama, 2003.

scribed by the diversity indices, the percentage abundance plot and the physicochemical parameters as well (fig.4).

Similarly, the rank abundance plot also shows station 'A', 'B' and 'F' to have more diversified macroinvertebrate communities while station 'D' specifically separated to have less diversified communities. It is also evident to see that stations 'B' and 'C' comprises less abundant but more diversified species while station 'A', 'F' and 'D' posses more abundant species altogether showing the status of the stream segment under study; Fig.5 below.

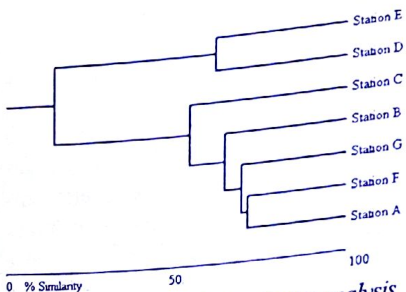

Fig.4. Bray Curtis similarity cluster analysis of macroinvertebrates between sampling stations. Aleta wondo, Sidama, 2003

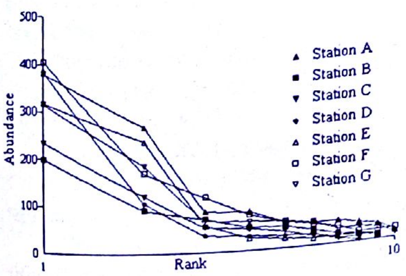

Fig. 5,Rank abundance plot of macroinvertebrates between sampling stations, Aleta wondo, Sidama, 2003.

Generally as literatures indicated (Dejene 1997, and Worku 2001) and from the present study, pollution status assessment on the bases of diversity index is a cost effective, efficient and fast method especially suited to resource poor developing countries with limited skilled manpower such as Ethiopia.

Conclusions And Recommendations

The results of physicochemical parameters discussed so far, though not classify the stream segment under study as septically polluted, the significant variations from station to station indicate the anthropogenic disturbances imposed on the stream body. In this study station 'D' is found to be relatively the most polluted station described by both physicochemical & macro invertebrate data analyzed, actually due to the additional load from the town wastes, however the variations above and below this station clearly shows the impact of coffee processing as there is a remarkable difference from station to station.

It was also found that coffee pulpery stations, spaced well apart (at least 5 km) are less likely to affect the stream environment as it is observed in the cases of station 'E', 'F' and 'G' which is also supported by diversity indices presented in this finding.

Finally it is possible to conclude that from previous studies and the analysis of results of the present study, biotic and diversity indices can successfully be utilized as a cost effective alternative in water quality monitoring programs in Ethiopia.

Coffee is one of the major exportable good that generates foreign currency for the country. In view of this, its production is a must to be encouraged. However, its production and the aforementioned conditions becomes a major hurdle, which pose the most serious environmental issue in Ethiopia. Though it is not possible to come up with one wide-sweeping solution, there seems a need to develop environmental awareness and small-scale eco-technological solutions that involve both the responsible governmental organizations and all citizens at the grass root level. Bearing this in mined, and based on the findings of this study, the following recommendations are forwarded.

1. Creation of environmental awareness among coffee processors and the public in general and technological assistance to promote pollution control should be done by concerned governmental organizations.

2. Environmental Impact Assessment needs to be done before permitting issuance for the establishment of the industry, the presence of which provides technical support in site selection, process modifications and addresses the issues of accountability.

3. Development of Improved and enforceable water quality and industry discharge regulations. One way to address the need for regulations is to establish a partnership agreement between the government and coffee industry establishing the reduction of BOD_5 and other significant parameters as applicable. In line with this policy makers should consider the applicability of the existing environmental laws and regulations with the situation of the country and thus needs to be reinforced extensively.

4. The coffee industry should entertain the cleaner production technology and the issues of reuse and recovery as well as waste treatment options before releasing the effluent directly to water bodies.

5.The municipality of Aleta Wondo town should also be accountable for its polluting action and hence needs to divert design an alternative strategy to divert the drainage system of the town and also should provide treatment facilities.

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6. Further study should be done especially on the cumulative effects of coffee processing on water bodies in different situations (minimizing the limitations there in) and also on the potential applicability of various issues recommended so far.

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Modelling Runoff Pollution Loads in Urban Areas

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Abstract

Pollution of water bodies from urban runoff has become a major issue of concern since three decades ago because of the extensive damages it causes. Urban runoff is characterized by having high levels of sediments, toxic metals and other substances originating from traffic emissions, atmospheric deposition, litter accumulation, and corrosion of metallic materials.

Models play useful roles in the planning and management of urban runoff pollution. This article tries to show the use of a simple urban runoff quality model to estimate the magnitude of pollutant load from different land uses. It also assesses pollutant load reduction obtained by non-structural management practices. Moreover, effort has been exerted to illustrate the applicability of the model in Little Akaki catchment in Addis Ababa.

1. Introduction

Urban runoff pollution has become the major concern of freshwater quality impairment since three decades ago. The need for characterizing and controlling the problem has led to the development of a variety of models whose outcome can be used for screening, planning and design level applications.

Urban runoff quality models can generate information that are useful for accomplishing activities at various stages of the planning process. At the problem formulation stage, by providing information on the magnitudes of pollutant loads contributed by different land uses, they can be used for assessing and ranking of problem source areas. They can also generate information that can be used for screening and selection of mitigation measures. More specifically urban runoff pollution models may be used for objectives such as the following (U.S. EPA, 1991):

· Characterize runoff quantity and quality as to temporal and spatial detail, concentration/load ranges, etc.

· Provide input to a receiving water quality analysis, e.g., drive a receiving water quality model.

· Determine effects, magnitudes, locations, combinations, etc., of control options.

· Perform frequency analysis on quality parameters, e.g., to determine return periods of concentrations/loads.

· Provide input to cost-benefit analyses.

Urban runoff pollution models may support one or more of the following components:

· A hydrology component to estimate surface runoff and/or base flow

· A pollutant loading component to estimate mass of pollutants transported

· A pollutant routing component to obtain pollutant concentrations at any time

· A best management practice (BMP) analysis component to evaluate pollutant removal in control practices

· Optimisation procedure to calibrate model parameters

· Uncertainty analysis to quantify the effect of model parameters that are not known with certainty

The modelling approaches can be statistical, empirical or deterministic (Zoppou, 2001). Statistical models are usually based on regression methods that relate measured quantities with measurable physical parameters. Empirical models involve a functional relationship between a dependent variable and variables that are chosen from the knowledge of the physical process involved and measurements. Deterministic models are based on conservation laws that include conservation of volume, continuity, conservation of energy or conservation of momentum. The empirical modelling approach has been discussed in this paper.

2. Materials and Methods

This article presents an urban runoff quality model that can be used for screening and planning level applications. The model has three interrelated components- Hydrologic, Pollutant load and BMP evaluation components. The flow chart for the model is shown in Fig. 1.

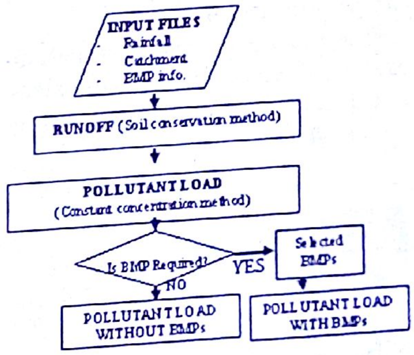

Fig. 1 Flow chart for the model

Input Files

The input files required to run the model are rainfall data and land use/cover data. The rainfall data can be single or continuous historical daily rainfall record. The land use/cover data contains parameters that define the physical characteristics of the catchment. It includes data on area of each land use, percentages of imperviousness and directly connected impervious areas, curve numbers for pervious and impervious surfaces. It also includes information on pollutants' Event Mean Concentrations (EMCs). The input file

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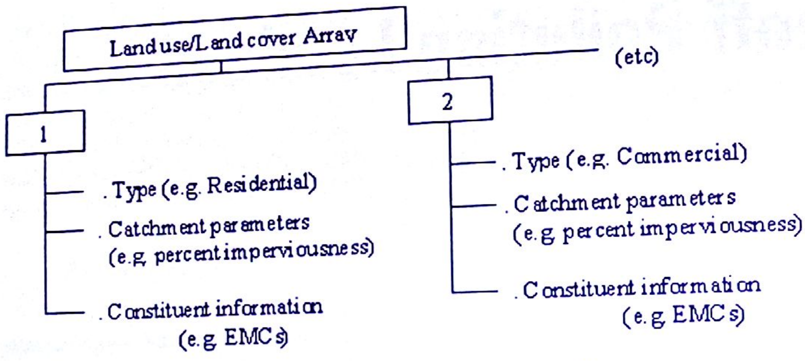

Fig. 2 Data format for land use/cover file

structure format employs the user-definable data structures and structure arrays of MATLAB®. This has the advantage of arranging the land use/cover data in an easy to understand format as indicated in Fig. 2. As many land use types as required by the user can be included in a single land use file.

The hydrologic module

The hydrologic module estimates runoff by the Soil Conservation Service (SCS) runoff curve number method. The simulation time step can be continuous daily, seasonal or annual depending on the input precipitation data time scale. Runoff from a land use can be estimated by first dividing the land use into three parts- pervious areas, unconnected impervious areas, and directly connected impervious areas - as shown in Figure 3.

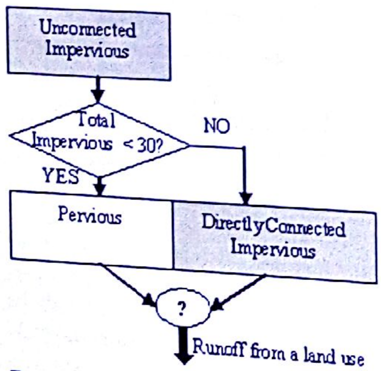

Fig. 3 Representation of a land use for runoff computation

The SCS curve number method estimates runoff based on the equation issued by the USDA-NRCS (1986). The curve number (CN) is a function of land use/cover, hydrologic soil group and antecedent moisture condition.

$$R_i = \begin{cases} \dfrac{\left[P_i - k_{abs}\left(\dfrac{25400}{CN_j} - 254\right)\right]^2}{P_i + (1-k_{abs})\left(\dfrac{25400}{CN_j} - 254\right)} & \text{if } P_i - k_{abs}\left(\dfrac{25400}{CN_j} - 254\right) > 0 \\ 0 & \text{if } P_i - k_{abs}\left(\dfrac{25400}{CN_j} - 254\right) \le 0 \end{cases}$$

The runoff calculated by the above formula should fit observed catchment responses with a minimum error. This can be achieved by calibration which determines optimum model parameters. In this model the constrained non-linear least square optimisation procedure has been adapted to estimate values of optimum curve numbers for each land use. The method concerns with a search for optimum parametric values that minimises the objective function given as:

$$\left[\text{Minimize} X_j = \sum_{i=1}^{n}\left(\sum_{j=1}^{q} 10 \times R_i\left(X_j, P_i\right) \times A_j - VO_i\right)\right]^2$$

$$\text{Subject to}: \quad X_{jl} < X_j < X_{ju}$$

In the above formula 10 is a unit conversion factor

Estimation of pollutant load

The model makes use of the EMC to estimate pollutant loads from different land uses. This method assumes that constituent concentration is constant throughout the simulation. Mathematically, the EMC is expressed as

$$EMC = \frac{\sum_i C_i V_i}{\sum_i V_i}$$

Use of an average EMC in multiple-event computer simulations may lead to estimates that are as accurate as those obtained from more complex models (Charbeneau and Bareeett, 1998). Hence, this simple method is often used for urban water quality modelling due to the complexity of the physical processes involved (Terstriep and Lee 1995). The method is particularly useful for estimating long-term pollutant loads (Pandit and Gopalarishnan, 1997; Chiew and McMahon 1999).

By multiplying the estimated runoff volume from a land use with the corresponding constituents' EMCs, the pollutant loads from a land use can be estimated. Mathematically,

$$L_i = 10^{-2} \times A_j \times R_i \times EMC_{pj}$$

The constant 10^{-2} is a unit conversion factor

Evaluation of best management practices

Best management practice is a technique used for managing runoff volume and quality using combinations of various structural and non-structural controls. This model incorporates non-structural BMPs that include reduction in the percentage of total impervious surfaces, disconnection of some impervious surfaces, and improvement of vegetation/grass cover of a landscape. Such changes on the land surface characteristics affect the curve number (CN) and hence the runoff from a land use.

3. Runoff pollutant load from Little Akaki Basin

Input data

The location of the Little Akaki Basin within Addis Ababa is shown in Figure 4. The basin has a total land area of 3150 hectares. The sizes of different land uses in the basin are indicated in Table 1.

The soil type in Addis Ababa has a high runoff potential. The state of grass cover on pervious surfaces of each land use in the basin could be rated as poor. Based on this information and for normal antecedent moisture condition, the curve number for pervious areas is 89. Most of the impervious surfaces in the

Constituent	Annual wet period load, Kg	Unit load, kg/ha/year
COD	5052670'	1811
TKN	379413	136
Ortho-P	148064	53

Table 1 Catchment characteristics of the Little Akaki Basin

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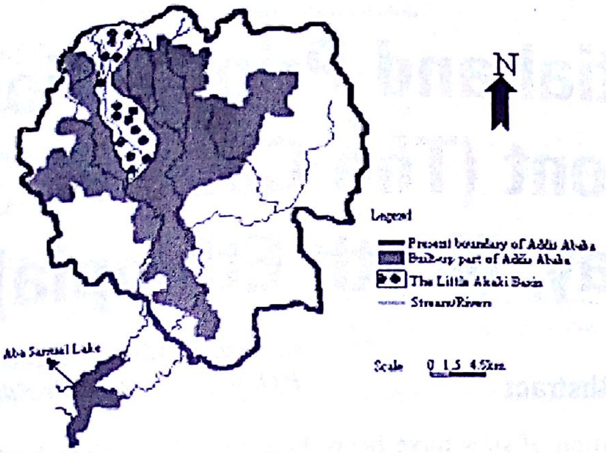

Fig. 4 Location of little Akaki basin

basin are corrugated iron sheets and asphalts. The curve number value for such surfaces and normal antecedent moisture conditions is 98.

Pollutant load has been estimated from daily precipitation data for the average year. After having investigated the daily rainfall records from 1990 to 1999 at Addis Ababa Observatory Station, the 1991 data closely matched the average year data. Addis Ababa Observatory is located at the edge of the central part of the Little Akaki basin.

Estimations of pollutant loads have been made for three constituents, i.e. COD, TKN, and Ortho-P, with mean concentrations calculated from data presented in Table 2.

Table 2 Mean of constituent concentrations of water samples

Constituent	Mean concentrations mg/l
COD	546
TKN	49
Ortho-P	16

[Source: AAWSA et al, 1993]

Results of the simulation

The estimated daily runoff volume using the standard SCS curve number relationship is shown in Figure 5. It represents the runoff volume from Little Akaki Basin (including built-up and woodland area) for the average rainfall year. The estimated total annual runoff volume is 9.4 millions m^3

The estimated annual pollutant loads and unit loads from the built-up area of the Little Akaki Basin are indicated in Table 3.

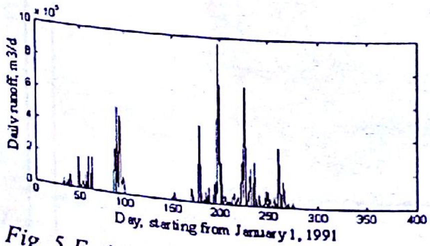

Fig. 5 Estimated daily runoff from the Little Akaki Basin

Table 3 Estimated average annual pollutant load from the built-up area of the Little Akaki Basin

Constituent	Mean concentrations mg/l
COD	546
TKN	49
Ortho-P	16

[Source: AAWSA et al, 1993]

The reduction in the annual pollutant load for *improved vegetation cover* has been evaluated. In this article improving grass cover from poor to fair state on 50-75% of the pervious area has resulted in a decrease in the annual pollutant load of each constituent by 20 %.

4. Conclusion

Urban runoff quality models are extensively used in water quality planning and control activities. This is ascertained by the availability of a large number of non-proprietary and commercial models. Development of accurate physically based runoff quality models remains to be difficult due to the low level of understanding of the processes affecting accumulation and washoff of pollutants on urban watersheds. Besides, complex physically based models are considered to be more of research tools than management tools. Empirical models with few parameters proved to be valuable to decision makers that are faced with watershed management.

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Hydropower Potential and Priorization of Sites for Development (The Case of Ghiba Basin in Tigray, North Ethiopia)

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Abstract

Hydropower potential identification and prioritization of sites have been done for Ghiba river basin in Tigray Regional State, based on various established criteria. Accordingly, eleven storage sites and nine cascades have been identified in the basin.To transfer information from gauged sites to the hydropower sites, which are ungaged; relationships between runoff and rainfall were developed. Thus, the water resources potential at the ungauged sites (hydro sites) have been estimated by applying the relationships developed at the gauged sites. All the hydro sites are assumed to be connected to two near by grid centers at Wukro and Mekelle. Based on limited criteria, topography, hydrology, proximity to load centers, and accessibility by road, the sites were prioritized and the most promising site was selected. Other sites have been ranked in order of priority.Hence, the sites Ghiba and Agulae (close to Mekelle), and Genfel-3 (Gereb Hidar) and Genfel-2 (Close to Wukro) have been raked as superior sites in terms of rank.

1. Introduction

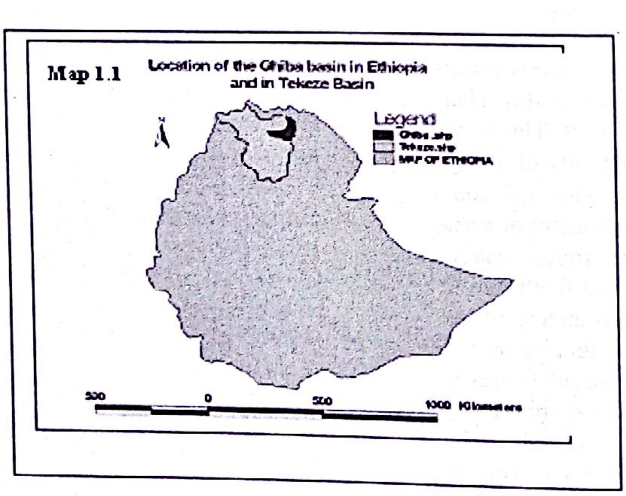
The Ghiba river basin in Tigray regional state, North Ethiopia, has catchment area of 5163km², the length of the main watercourse is 236.4km, with a total fall of 2030m. The basin comprises six tributaries: Suluh, Genfel, Agulae, Illala, Meskila and the Ghiba itself.The average annual rainfall over the basin is 665.5mm and annual runoff volume of 1334milliom m³. There are eleven storage sites and nine cascades planned (identified) in the river based on hydrology and topography. The potential storage sites are: (1) Suluh, (2) Genfel-1, (3) Genfel-2, (4) Genfel-3, (5) Genfel-4, (6) Genfel-5, (7) Agulae, (8) Meskila-1, (9) Meskila-2, (10) Meskila-3 and (11) Ghiba. All the cascades are located on the main river downstream of all the storage sites with the first cascade being a dam scheme. The objective of this study is to estimate hydropower potential at each site of interest as well as the whole basin, and to select the most promising site, which should be implemented first.

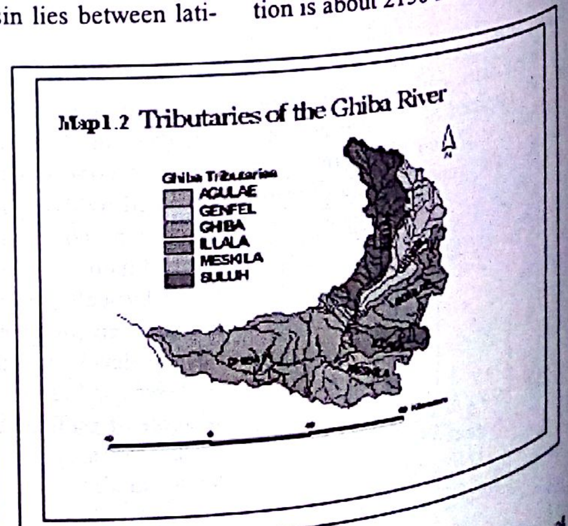
1.1 Description of the Study Area

The study area is located in the regional state of Tigray, in Southern, Eastern and Central zones of the region. The reference town is Mekelle (the capital of the region) found within the watershed (in the southern part of the basin).The basin lies between latitudes 13°17'46" and 14°15'00" N and longitudes 38°37'37"and 39°47'47"E.

This river basin is one of the main tributaries of Tekeze basin located in the northern part of Ethiopia; it joins the Tekeze river 34 kms (along the watercourse) downstream of the Tekeze Hydropower project at an elevation of less than 1000 (about 975)m.a. s.l. The Ghiba river originates at Gasat (Latitude13°38'50"N, Longitude 39°24'42"E and Altitude1762m.a.s.l), and is the junction of Suluh and Genfel, and is 143km long.

The elevation of the study basin varies from about 1000m to 3333 m a.s.l. (Dendera ridge), average elevation is about 2150 m.





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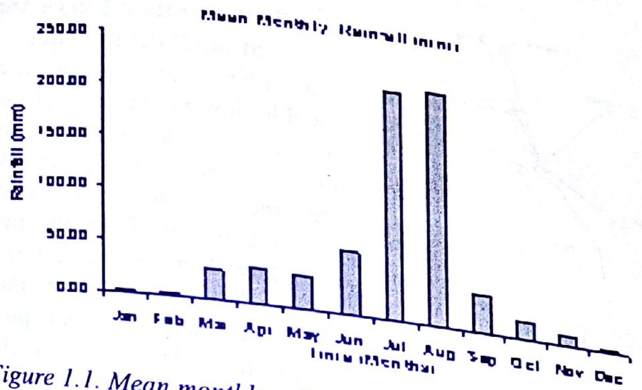

Figure 1.1. Mean monthly rainfall over the Ghiba basin (1992-2002)

The average temperature varies between 16.4°C and 20.2 °C.The rainfall is highly seasonal with an annual rainfall ranging from over 500mm in the northern part to about 700mm in the central and west of the basin. The average over the whole basin is about 665.5mm with more than 60% occurring between July and August, is unimodal pattern. Figure 1.1 shows the temporal variation of rainfall in the basin.

There are seven (7) gauging stations, namely Suluh (121007), Genfel (121010), Agulae (121013), Ghiba1 (121004), Gbiba2 (121008), Illala (121011) and Metere (121012) , in the Ghiba basin and monthly discharge values collected for these stations were used for this study . Limited data were available for all gauging stations in the catchments, with maximum discharges (m^3/s), minimum discharges (m^3/s) and with monthly runoffs volumes (million m^3).

2.2 Existing Hydropower Studies in the Area

According to the Tekeze river basin master plan studies (NEDECO, 1998) , there are several potential sites, which included sites where irrigation is the main purposes. The sites were selected based on the following conditions:

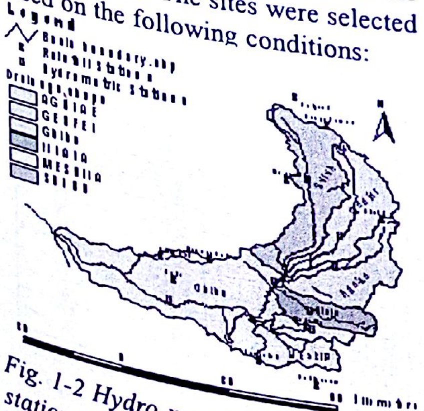

Fig. 1-2 Hydro-metrologic Gauging station in the Ghiba Basin

For the tributaries of the Tekeze river, one site was selected based on earlier studies and on the impression from the reconnaissance flight. More than one site per tributary is considered unattractive, because of the small catchment and hence small runoff of the tributaries.

Of the sites identified by NEDECO (1998) TK23 and TK25 are found with in the Ghiba river basin. TK23 is in the Mesanu (Illala) tributary and TK25 in the Genfel, near the confluence of Genfel and Ghiba itself. TK23 is for irrigation purpose and TK25 for hydropower, which was estimated to produce 6.0 MW of power.

2. Materials and Methods

To estimate the hydropower potential at the area of interest, different materials and various study approaches were used.

Materials

The necessary materials and equipments used in this research work includes: topographical maps with a scale of 1:250,000, scale 1:50,000, ortophotos of scale1:50,000, Tracing Papers, Scanner, Digital camera, GPS receiver and so on.

Methods

The methods and study approaches employed in this research work include: review of existing hydropower development studies in the area and literature review, delineating the boundary of the area and estimating the catchment size, locating possible potential hydro sites.

2.1 Topographic analysis

After identifying the sites on the maps, based on the 20m or 40m interval contour shapes, site verification was the next step.To see the actual conditions, site investigation was carried out with the help of digital camera and GPS receiver. Sample picture of the sites was provided in figure 2.2 below. The GPS receiver was also very helpful in locating the sites and to estimate the available topographic heads for hydropower potential sites, better than the heads collected from the 20m interval counters.

From the available topographic maps, longitudinal profiles of the river along its tributaries, suitable locations for dam sites and reservoir have been identified. Moreover, cross-sectional profiles at some sites (probable dam axis) were prepared and elevation-area-capacity curves of reservoir sites constructed

The reservoir surface area of each site was computed from the 1:50,000 scale topographic maps using the Arc View GIS software, after digitizing the contours. Based on the elevation area curve, the elevation volume was estimated by using the average area method:

$$\Delta S_i = \Delta h_i * \frac{A_i + A_{i+1}}{2} \qquad (2.1)$$

Where,

Dh_i = distance between successive contour lines

DS_i = Storage volume between successive contours

A_i and A_{i+1} = Surface area between successive surfaces

2.2 Hydrologic Analysis

2.2.1 Runoff Data Generation at Potential Sites

To estimate water resources as well as hydropower potentials at the sites , hydrologic study was carried out using existing discharge data recorded at the gauging stations available for the basin and rainfall gauging stations in or nearby the area, rainfall data from 10 stations in or near the area was collected. Due to significant missing data in rainfall and runoff, as well as poor matching of recorded periods, eleven years of monthly rainfall and concurrent runoff data was used. The missing records in rainfall data were filled with established procedures. Filling in gaps in runoff data at gauge stations was car-

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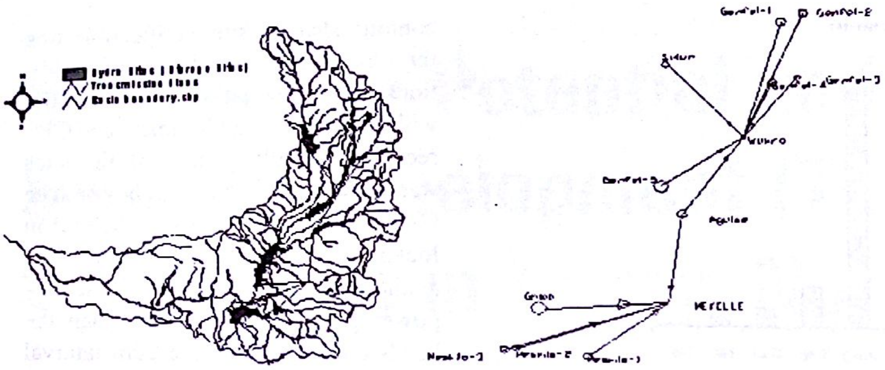

Figure 2.1 Location of hydro sites in Ghiba Basin

Fig.2-2 Picture of Genfel-3 Hydro site (d/s fall)

ried out using various methods such as multiple station regression, rainfall-runoff relation, and runoff coefficients.The average watershed rainfall at the sites of interest was estimated by constructing Thiessen polygon.

In the study area under consideration, all the hydrometric stations are far away from the identified dam locations in the respective rivers (tributaries). To estimate the hydropower potential, runoff data at ungauged sites (hydro sites) were estimated by using the runoff coefficients obtained from simultaneous data of rainfall and runoff at the gauged sites, which is given by:

$$Q_{site} = \left(\frac{A_{site}}{A_{gauge}}\right) Q_{gauge} * \frac{P_{site}}{P_{gauge}} \quad (2.2)$$

Where,

A_{Site} = Drainage area of site of interest (km^2)
Q_{Site} = Discharge at the site of interest (Mm^3)
A_{gauge} = drainage area at the gauge site (km^2)
Q_{gauge} = Discharge at the gauge site (Mm^3)
P_{site} = areal rainfall at the site of interest (mm)
P_{gauge} = areal rainfall at the gauge site (mm)

2.2.2 Flow Duration Curve Analysis at the Potential Sites

In order to see the amount of dependable flow available for power production and the amount of storage required for secondary power development, monthly flow duration curves were constructed, from the monthly stream flow data (see figure 2.4).

From the monthly flow duration curves constructed for each potential site, the dependable flow at 10% to 100% is given in table2.2

2.2.3 Determination of Storage Capacity

Storing water in the high flow season and utilizing it in the low flow period will require a storage reservoir. The first step in evaluating the energy potential of a storage project is to determine the amount of storage available for regulation.

In modeling hydrologic time series for simulation studies of reservoir systems, storage-related statistics may be particularly important. Consider the hydrologic time series y_t, t = 1,..., N and a sub sample $y_1, \ldots y_n$ .Where n d•N. From the sequence of partial sums S_i as (Maidment, 1993):

$$S_i = S_{i-1} + (y_i - \bar{y}_n) \quad (2.3)$$

Where

$S_0 = 0$ and $\bar{y}_n$ is the sample mean.

In the case of stream flow time series, Si represents the cumulative departure from the mean flow $\bar{y}_n$. The plot of Si versus i, i = 1,...,n is the typical mass curve from which the minimum storage capacity D_n of a reservoir to deliver $\bar{y}_n$ through the time period n can be

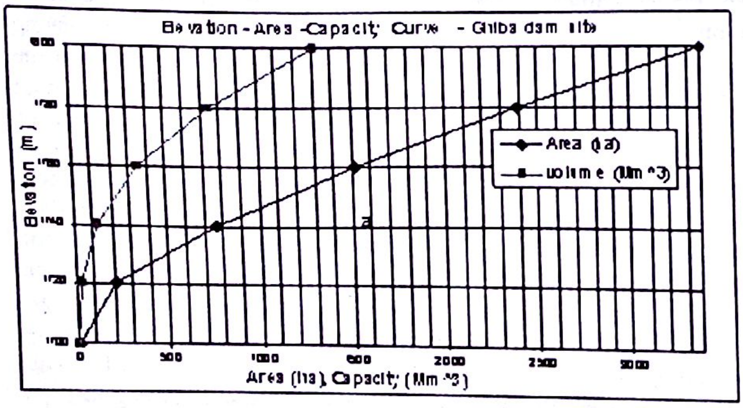

Figure 2.3 Elevation Area Capacity Curve for Ghiba Hydro site

Site Name	Location (UTM)		Catchment area(km^2)	Max.Capacity Mm3	Natural fall (m)
	Latitude	longitude			
Suluh	1535700	555000	617.31	661.35	40
Genfel-1	1543000	570400	173.395	73.50	87
Genfel-2	1544400	573500	21.673	49.57	380
Genfel-3	1433400	572500	133.035	35.354	480
Genfel-4	1532550	569150	420.80	179.80	0.0
Genfel-5	1515200	553600	687.00	422.02	60
Agulae	1510400	556400	493.903	195.425	177
Meskila-1	1486300	543000	160.374	283.85	45
Meskila-2	1487700	533000	508.777	313.764	45
Meskila-3	1487350	531300	134.647	462.40	80
Ghiba	1494350	537300	3112.00	1313.817	94

Table 2.1 Summary of the potential hydro sites and their physical features in the Ghiba Basin

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obtained. Figure 2.5 shows a typical mass curve for which $D_n = Max (D_1 \ldots D_4)$.

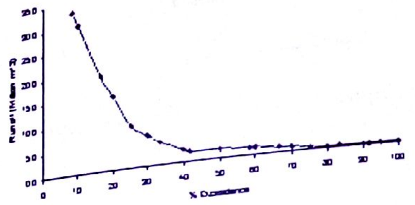

Figure 2.4. Monthly flow duration Curve at Agulae hydro Site

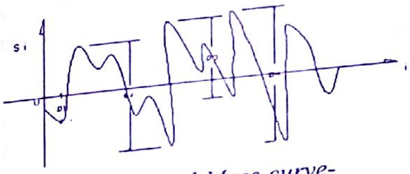

Figure 2.5 Typical Mass curve- showing sequences of deficits

By considering mean monthly flow (average of the mean monthly flows for the length of record) as the constant withdrawal/draft from each reservoir impoundment, the storage capacities at the hydro sites were then estimated, using equation 2.3

3. Prioritization Of Sites Based On Limited Criteria

To select the most promising site for hydropower development, the head and discharge at the identified sites were estimated. Prioritization of sites for development requires quantitative approach that ranked the communities (Fritz, 1994) Based on the important factors described 1- 4 below the potential of the sites were evualuated. The specific criteria and their order used by this study are:

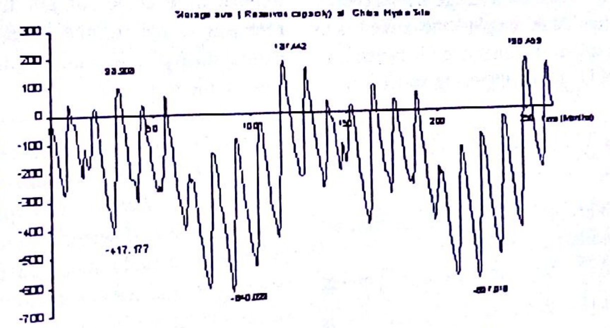

Figure 2.6 Storage sizing at Ghiba hydro site

1. Hydrologic resource (Water resources potential)
2. Topography of the hydrologic resource (Natural fall or available head)
3. Accessibility by road
4. Proximity to existing grid

Each criterion was assigned a value from 1 to 100 with the sum representing the position that the site would occupy in the ranking scheme.

Mathematically, it is simply

$$R = a_1x_1 + a_2x_2 + \ldots + a_nx_n \quad (3.1)$$

Where,
R= ranking number
a_n = assigned value of each criterion
x_n = the score attached to each criterion

The ranking of sites was carried out by giving full value (score) for the site with the highest specific criteria i and score values for other sites were assigned based on the ratio of its criteria to that of the site with the highest criteria. Based on this, the optimal site is the site with highest rank.

Proximity to existing grid center was estimated measuring the areal distances between the power sites and two substations at Wukro and Mekelle. The topographic characteristics considered here is the available natural fall at the proposed site excluding dam height (storage depths).The reader of this paper should be cautious the geologic and cost criteria were not considered due to lack of sufficient data and time

4. Hydropower Potential

To estimate the energy potential of the hydropower sites, two basic approaches were used, the flow duration curve analysis and storage analysis.

4.1 *Energy Potential Using Flow Duration Curve Analysis*

A flow duration curve is converted to a power duration curve through the application of the waterpower equation. From this, an estimate can be made of the sites energy potential (EM 1110-2-1701, 1985, Maidment, 1993). The power potential of the site is given by

$$P = \eta_e Q_t H_{eff} * \gamma_N \quad (4.1)$$

Where,
P = power in Kilowatts (KW)
Q_t = design flow through the turbine
H_{eff} = effective head at a flow of Q_t
η_e = efficiency of the turbine generator

The average annual energy can be obtained by computing the area under the curve multiplying by the number of hours in a year (8760).

$$\text{Annual energy (KWh)} = \frac{(8760.hrs)}{(100 percent)} \int_0^{100} P dp \quad (4.2)$$

Where,
P = power, KW
p = present of time

Table 2.2 Summary of monthly dependable flows at hydro sites

Site Name	Discharge (m^3/s), exceedences											
	10%	20%	30%	40%	50%	60%	70%	75%	80%	90%	95%	100%
Suluh	10.58	7.63	3.06	2.12	1.87	1.54	1.02	0.62	0.58	0.45	0.38	0.28
Genfel-1	7.16	4.52	1.28	0.93	0.85	0.72	0.62	0.50	0.49	0.41	0.37	0.35
Genfel-2	1.05	0.66	0.14	0.11	0.06	0.04	0.04	0.04	0.03	0.03	0.02	0.01
Genfel-3	7.22	4.56	0.99	0.74	0.42	0.29	0.25	0.24	0.22	0.20	0.15	0.09
Genfel-4	18.40	12.31	3.02	2.26	1.18	1.15	1.05	1.02	0.94	0.87	0.86	0.86
Genfel-5	31.18	21.06	4.91	3.43	1.76	1.61	1.53	1.45	1.43	1.30	1.27	1.27
Agulae	22.49	15.08	4.29	1.69	0.80	0.74	0.57	0.54	0.52	0.38	0.25	0.09
Meskila -1	3.07	1.34	0.50	0.15	0.11	0.08	0.04	0.02	0.02	0.01	0.00	0.00
Meskila -2	19.39	9.27	3.77	0.82	0.53	0.35	0.24	0.17	0.12	0.04	0.03	0.02
Meskila -3	19.38	10.67	4.80	0.67	0.53	0.30	0.26	0.21	0.12	0.05	0.04	0.04
Ghiba	324.19	116.35	46.65	31.89	26.47	14.39	12.00	9.49	8.26	6.85	6.01	4.98

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To obtain the average annual energy production of the plant the curve has to be numerically integrated between limits of Q_{min} and Q_{max} using the equation:

$$E = \sum P_i * \frac{\Delta Ti}{100} * 8760 \qquad (4.3)$$

Where E = average annual electricity production, KWh

ΔTi = increment along the percent scale (for this case 10 % and 5% is taken)

Pi = the average power output in the percent increment

8760 = is the number of hour in an average year

In the flow-duration procedure, constant average forebay elevations were assumed for all projects.

Also, as there is no tail water-rating curve constructed or the channel geometry is not surveyed, the head difference between topographic levels of forebay and downstream bed level were considered.

Moreover, for the calculation of the average annual energy potential of the sites, variation in heads was considered negligible and total plant efficiency was taken to be 85 %. Thus, table 4.1 shows the calculation procedures for power potential of sites using the flow duration curve method.

4.2 Energy Potential Using Storage Analysis

At each site proposed for hydroelectric energy production, an average monthly flow and average turbine head was used in the power equation. The head considered here is the reservoir water head plus the available natural fall. The water head is the elevation difference from center of gravity of the reservoir to the turbine level, i.e. the natural drop plus two third of the water head in the reservoir.

4.3 Hydropower Potential by Cascading System

For the comprehensive exploitation and utilization of water resources for hydropower development, cascade development was proposed downstream of the Ghiba hydro site. According to the natural feature of the river and the regulated flow from the hydro sites, Ghiba, Meskila-2 and Meskila-3, the river can be exploited by cascading so as to make best use of the river fall. All the cascades are assumed to be hydraulically mutually connected: the tail water of the upper cascade empties into head pond (reservoir) of the lower cascade and the tail water level of the upper cascade is roughly equal to the upstream water level of the lower cascade. Figure 4.2 shows the cascade connection of diversion schemes.The upper reservoirs are intended to produce hydropower at site and to get a regulated flow for the downstream cascades.

The total power potential of the main river downstream of the confluence of Ghiba and Meskila is the sum of the power out puts obtained from each cascade plant. which is given by: ,

$$P_{total} = \sum_{i-1}^{n} \eta \gamma Q_i H_i \qquad (4.4)$$

Where Q_i = the flow at site i (m^3/s)

$Q_i = Q = Q_1 + Q_2 + Q_3 + \ldots Q_j$

Q_j = regulated release from storage site j

H_i = the head at site i (m)

h= Global efficiency (decimal)

$$P_{total} = \eta \gamma \sum_{i-1}^{9} QH_i \qquad (4.5)$$

Table 4.1 calculation procedures using the flow duration curve method (Suluh hydro site).

	10%	20%	30%	40%	50%	60%	70%	75%	80%	90%	95%	100%
Stream flow (m^3/sec)	4.028	2.903	1.165	0.808	0.712	0.585	0.388	0.234	0.220	0.171	0.137	0.100
Head (m)	40	40	40	40	40	40	40	40	40	40	40	40
Global Efficiency (%)	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Accn. due to gravity (m/sec^2)	9.81	9.81	9.81	9.81	9.81	9.81	9.81	9.81	9.81	9.81	9.81	9.81
Power (MW)	1.343	0.968	0.388	0.270	0.237	0.195	0.129	0.078	0.073	0.057	0.046	0.033
Delta T (ΔT), %		10%	10%	10%	10%	10%	10%	5%	5%	10%	6%	5%
Energy E (GWh)		1.012	0.594	0.288	0.222	0.190	0.142	0.045	0.033	0.057	0.023	0.017
Annual Energy output (GWh)	2.824											

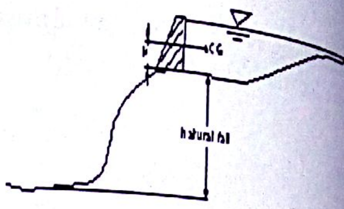

Figure 4.1 Typical reservoir section showing available head

For the series of diversion schemes planned here, an average flow of 26.039m³/sec (23.218m3/sec from the Ghiba plus 1.366m³/s from Meskila-2 and 1.455m³/s from Meskila-3) was considered to estimate the hydropower potential at each site.

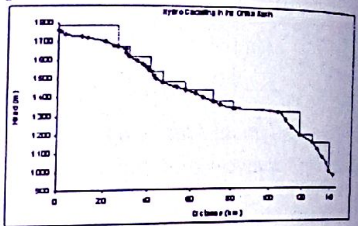

Figure 4.2 Cascading systems in the Ghiba basin

Considering an average natural fall along the river reach, actual head can be obtained by assuming a power canal of length equal to the length of the river reach between successive cascades and providing a permissible bed slope of 1/500. In the estimation of actual driving heads at each site, hydraulic losses were not considered, the head difference between forebay level and turbine level was used. By doing so, the power outs obtained from the sites were summarized in table 4.2

5. Results And Discussions

Reservoir capacity (size) at all the hydro sites is limited by the water resources availability only. That means the capacity of the reservoirs from the topographies (Elevation -area -capacity curves) could provide large storage volumes. Therefore, the hydrologic analysis limits the storage capacities.

The most promising site was found to be the Ghiba hydro site. The second and third potential sites are the Genfel-3 and the Genfel-2. Genfel-1 and Meskila-2 were the least potential sites.

To estimate the energy potential of the hydropower sites two basic methods were used .The Flow Duration

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Curve (FDC) analysis and the storage analysis. Therefore, the total annual energy potential from FDC is170.27GWh and from the storage analysis is 418.126GWh. By combining storage and cascading systems at the main river, 1004GWh of energy could be harnessed

Table 4.2 Power output from each cascade at the Ghiba river (downstream part)

Site No	Distance from Ghiba site (km)	Diversion level	Foreby level (m.a.s.l)	Turbine level (m.a.s.l)	Available head (m)	Discharge (m^3/s)	Power (KW)kw	Energy (GWh)
1	0	1674						
2	5.15	1674	1663.7	1620	43.7	23.218	24.537	214.947
3	15.1	1620	1562.9	1540	22.9	26.039	4.972	43.556
4	20.45	1540	1529.3	1480	49.3	26.039	10.704	93.770
5	31.1	1480	1458.7	1440	18.7	26.039	4.060	35.568
6	44.6	1440	1413	1380	33	26.039	7.165	62.767
7	55.15	1380	1358.9	1341	17.9	26.039	3.887	34.046
8	92.4	1320	1293.8	1200	93.8	26.039	20.366	178.410
9	101.1	1200	1182.6	1160	22.6	26.039	4.907	42.986
10	113.65	1160	1134.9	1000	134.9	20.039	29.290	256.583
Total							109.890	962.633

Table 5.1 Storage Capacity at hydro sites

Site Name	Mean monthly flow (Million m3)	Storage size (million m³)	Max. Capacity (Million. m3)
Suluh	2.988	43.038	661.35
Genfel-1	1.788	25.0482	73.50
Genfel -2	0.225	4.912	49.57
Genfel-3	1.551	33.892	35.354
Genfel-4	4.337	75.159	179.80
Genfel- 5	7.173	128.527	422.022
Agulae	4.841	97.398	195.425
Meskila -1	.550	8.93	263.85
Meskila- 2	3.589	61.338	313.764
Meskila- 3	3.823	61.27	462.40
Ghiba	60.017	827.475	1313.817

Table 5.2 Site Prioritization on the bases of limited criteria (based on a_1=45%, a_2=40% & a_3= 10% & a_4 =5)

Site Name	Criteria , i (1) Mean annual flow (Million m³)	(2) Natural head (m)	(3) Distance from grid (km)	(4) Accessibility by road (km)	Rank
Suluh	35.812	40	15.60	20	1.398
Genfe-1	21.372	87	20.64	0	1.346
Genfel-2	2.697	380	22.71	0	3.628
Genfel-3	18.609	480	12.60	13	5.416
Genfel-4	52.04	-	10.10	13	1.820
Genfel-5	86.074	60	14.00	0	2.150
Agulae	58.097	177	15.30	15	2.934
Meskila-1	6.6002	45	14.60	15	1.468
Meskila-2	43.063	45	22.73	0	1.084
Meskila-3	45.88	80	24.45	0	1.362
Ghiba	732.199	98	17.18	45	5.768

Table 5.3 Energy potential of the Hydro site by FDC and Storage analysis

Site Name	Energy potential (GWh) FDC Analysis	Storage analysis
Suluh	2.624	12.292
Genfe-1	3.278	8.872
Genfel-2	1.736	5.077
Genfel-3	15.133	49.130
Genfel-4	0.000	8.791
Genfel-5	8.875	36.008
Agulae	17.401	57.324
Meskila-1	0.471	1.797
Meskila-2	3.108	18.686
Meskila-3	6.030	22.832
Ghiba	111.614	376.535

Table 5.4 Average Power Potential (MW) of the hydro sites, from FDC & Storage analysis

Site name	P_m (FDC)	P_m (Storage
Suluh	0.379	0.977
Genfel-1	0.492	0.696
Genfel -2	0.271	0.310
Genfel-3	2.362	2.621
Genfel-4	0.00	0.552
Genfel- 5	1.366	2.350
Agulae	2.719	3.323
Meskila -1	0.079	0.134
Meskila- 2	.512	1.262
Meskila- 3	0.970	1.788
Ghiba	18.199	32.281

6. Conclusions And Recommendations

6.1 Conclusion

This study identified 11 hydropower sites in the Ghiba River and its tributaries, based on topographic maps of 1:50, 000 scales. From FDC analysis, it has been observed that dependable flow in the basin with out storage is low. Therefore, runoff river plants are not feasible. Then, storage reservoir sites were selected. Area capacity cures for the reservoirs were constructed. Annual flow at the dam sites was estimated. The longitudinal profile of the river along each tributary showed that there is sufficient head for hydropower.

From the eleven power sites, the total potential capacity that could be harnessed is as high as 27MW, considering mean monthly flows and natural falls only. By considering mean monthly flows, seasonal storage and average heads including reservoir depths and downstream cascades, power capacity is 113 MW.

In order to select the most promising hydro site, which could be implemented first, relative priority of sites has been done considering four basic criteria: hydrology, topograpgy, accessibility and proximity to load centers.Therefore, the study concluded that the Ghiba hydro site, with 94 m natural fall (after 11.3km downstream) and 110m dam height, from the riverbed level at elevation 1674 m.a.s.l, is the most promising site. Approximately 17.8 km of new transmission lines would have to be constructed to connect it with the existing distribution lines from the central grid at Mekelle. The long-term average annual flow at the site, during the study period (1992-2002), is about 732.2million m³ .The site would be capable of generating an average annual energy of 376.54 GWh. On the other hand 1004 GWh of hydro energy can be generated when the storage is accompanied by downstream cascades.

The Tekeze river basin master plan studies (NEDECO, 1998) indicated that only 6MW of power can be obtained from the Ghiba basin. Compar-

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ing the values estimated in the present study and the previous studies there is great difference between the out puts. The main reason for the small value of the previous studies is that detail hydrologic and topographic analyses had not been done. Moreover, exploitation of power potential by cascading schemes was not considered.

6.2 Recommendation

In this study, the estimation has been done may be only for part of the hydropower potential of the basin, many potential sites could be developed. If all these sites could be developed, the hydropower out put might doubled or tripled.

The cascade development aims at an overall benefit to be gained from the whole river rather than from an individual project. Hence, it is recommended that all the cascades be considered together as an integrated project and each separate cascade as just a component of the whole system.

Due to lack of sufficient data and time geology and cost criteria have not been considered for the comparison of the sites. Therefore, detail geological condition and cost benefit analysis have to be done so that the ultimate optimal site could be known.

During this study stream flow losses, seepage and evaporation losses from storage reservoirs were not analyzed in order to know the actual HP potential of the area. Moreover, the cascade development was analyzed with out considering water losses along the river and evaporation, and possible diversions for irrigation and other purposes, which might reduce the estimated power potential significantly. Therefore, geomorphology of the river should be studied.

The scale of topographic map to be used should be larger than the available scales; this will help obtaining accurate reservoir capacities, natural falls and location of sites.

Systems analysis have to be done to know whether the power potential is enhanced by implementing all the site or only some sites by considering the effects of upstream site on the downstream development

Due to the relatively big power out put and large capacity of the reservoir, the Ghiba site has to be implemented first taking in to account downstream developments also.

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Family Approach: Development & Management Option for Shallow Ground Water Resources(A Case In Oromia Region)

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Abstract

Most Parts of Ethiopia is annually getting sufficient rainfall to recharge the shallow ground water aquifers. Deforestation, and environmental degradations have made most of the surface water resources none reliable. The drying out springs and the decreasing base flow and associated reduced yields of rivers are becoming very alarming trends that are felt by all. Although deep well drilling is believed to be most dependable source to develop, the high cost of drilling and construction has made the supply of potable water supply a very difficult task. It is this reality that forced the strategic planning team of The Oromia Water Resources Bureau to go for family approach and use the human resources to develop and manage the water resources the region has. Within a year the rural population of Oromia drilled about 43,772 family hand dug wells and a capped 4,445 springs. In line with this families are undertaking community and family level water resources management activity to protect the sources from dying out. The collective effort of each family will definitely result in sustainable utilization and proper management of the water resources as well as the soil.

1.Introduction

Oromia is the largest regional states in the Federal Government of Ethiopia with respect to population size and area coverage. It is located between 3° N and 12° N latitude and 34° E and 44° E longitude. Total aerial coverage of the region is roughly 357,000km². Almost one third of the region is lowland and is prone to drought.

Oromia hosts about one third of the country's population. According to estimate made based on the 1994 census the population in 2004 is estimated to be 25,098,000. Urban-rural distribution of the population of Oromia Region indicates that about 87.5% of the population resides in the rural areas of the region. The remaining 12.5 % of the population is living in urban areas (CSA, 1998). The current growth rate of the region is 3% i.e. rural is 2.9% and urban is 4.0 %. Based on these assumptions, the population of the Region is estimated to be almost double (46 million) by the year 2030.

The region has an estimated surface water potential of 58 billion m³/year and renewable groundwater potentials of 23.5 billion m³. It is only about 35.1 % of the total population who are accessed to potable water supply at present. Only 17 % of the population has access to sanitation facility (ESP, 2002). The low level of WS coverage in rural areas is mainly due to the low attention given to the sub sector. It was only after the disastrous drought of 1973/74 that RWS programs were carried out (WSDP, 2002). Although there is improved consideration by the government and NGOs the high cost of water supply projects has also hampered the growth in water supply coverage. With such a pace it is totally impossible to attain the millennium development goal.

As agriculture is dominated by small-scale peasant rain-fed farming, the role of irrigation in the sector is quite low. Irrigation practice is far lower than its potential contribution. According to the Baseline Survey done in 1999, only 92,600 hectare (5%) out of the total 1.73 million hectare of irrigable land has been developed.

The low level of development and the alarming future trend are main reasons that forced the planning team to think strategically and plan on maximum use of the region's human resources to develop and manage the water resources of the region. Accordingly, it is planned to dig 445,000 family based and about 3,000 community based hand dug wells and develop 963on spot spring within three years in addition to a number of new schemes that use renewable energy sources and the conventional shallow and deep well drilling.

2. Geology and hydrogeology

Oromia is characterized by the presence of a wide range of lithologic units. These are the Archaen gneiss, Quartzo-feldspathic rock and thin beds of the middle Proterozoic meta - sandstone, marble and mica schist, intruded by amphibolites, and ultra basic rocks, Mesozoic sediments, Tertiary volcanics and Quaternary sediments. The un-metamorphosed carbonate rocks and sandstone unconformably overlie these. In few localities of the area, Tertiary volcanic rock is found uncomformably over laying the basement and Mesozoic rock units. Recent Quaternary deposits are also found mainly along the riverbanks.

Oromia, with various spatial distributions of hydrometeorolgical parameters and geology, reveals various hydrogeological characteristics. In general, the high lands of Oromia that

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receive relatively high annual average rainfall (>1500mm) is the potential groundwater recharge area, whereas the low lands that have comparably small annual average rain fall (<900 mm) is the groundwater discharge area. The least groundwater recharge area is located at eastern and southern lowlands of Hararge, Borena and Bale as well as the rift valley region; these areas receive an annual groundwater recharge of 50-150mm.

In metamorphic areas of the region, fractures and fault zones particularly open faults and intersection of faults are of great interest from hydrogeological point of view. Due to this condition and the shallow nature of weathering depth, ground water potential is minimal in metamorphic terrain of western Oromia in spite of its high annual precipitation. But little amount of subsurface water that can be developed by hand dug and shallow machine drilled wells can be found in the weathered parts and overlying alluvial covers.

The aquifers of Mesozoic formations are important, especially when they occur in the more favorable climatic areas, this is the case for Mesozoic rocks of Blue Nile basin (Vernier, 1993). Mesozoic sedimentary rocks of eastern and southeastern Oromia have insignificant importance hydrogeologically in spite of their great aerial extent. This is mainly due to un favourable climatic conditions and their intercalation with layers of salt and gypsum that make the water particularly unusable. But in some areas of Bale a remarkable deep karstic circulation of ground water has been noticed (Vernier, 1993). In Mesozoic terrains of the high lands thick alluvium covers in valley bottoms and plain areas are best sites to develop shallow ground water resources.

Quaternary sediments in the rift valley as well as close to the rift escarpment deserve great importance for their groundwater potential; good aquifers that are fed mainly by rivers coming from high lands exist in the area. In addition to these the surroundings of those fresh water lakes are best sites for shallow ground water development.

The hydrogeologic, climatic and geomorphologic condition of most part of the region in all direction favors the prevalence of shallow water sources. This is why all districts/weredas in the region are contained in this programme. There is no single district that doesn't have one or two river valley or wet plains that can be dug fro hand dug well.

3. Existing Water Supply Situations and Shallow Groundwater Development and Management Practice

The majority of the current safe water supply schemes (excluding family and community hand dug wells) of the Region are groundwater. It covers about 62% of the sources. The remaining 38 % of the sources is surface water. Out of the surface water source, more than 80% is covered by springs. Rivers intake, dams, ponds and roof catchment share the remaining 20%. Springs cover about 55% and 45% of the water sources for West Wellega and Illuababora, respectively and groundwater covers more than 95 % of the water sources for East Shewa, East Hararge and Borena (OESPO, 1999). From these sources about 35% of the population has got access for potable water at present.

Great effort has been made by Regional Government of Oromia to alleviate potable water supply problem. More than half a billion ETB was channeled to this sector from1987 to 1994 EFY that has benefited more than 2.5 million people, of which about 2.4m are rural beneficiaries. Of the allocated budget 52.5 % went to rural water supply and the remaining to urban water supply. Apart from this effort, about 60 NGOs were involved in water supply and sanitation activities in the Region (OWRB, 2003). Despite all these efforts increasing the water supply coverage status of the region has become difficult task as population growth rate exceeds the water supply coverage growth rate almost by more than two fold. Groundwater depletion due to decreasing precipitation and infiltration and over pumping, decreasing success rate in ground water drilling (as easy to find sources are abstracted), poor drilling method and well design that contributed to increased cost are recurrent problems that are making water supply activities more complicated and costly. Unless paradigm shift is made in the sector, with increasing cost of construction and limited capacity of implementing water supply projects, the gap is expected to increase.

The shallow well concept is not well introduced in Oromia and the country as well. Although there are thousands of wells in many parts of the region there are places with dire need for water and hand dug wells are not known. Even in areas where hand dug wells are available there are thousands of wells that are adequately unprotected or poorly protected and has a tendency to become heavily contaminated due to rain water runoff, and unsafe lifting methods. Many are dangerous due to poor construction workmanship, poorly lined, has little or no protection at well head. They are regarded as a threat to health than benefit. They did not appear on any inventory of RWSS. Hand dug wells were not regarded seriously by government or other organizations.

No material assistance was forthcoming for family based water development either from the government, or by donor or aid organizations. Yet about significant portion of the population use these wells on a daily basis.

Despite the fluoride problem, the rift valley area is well known in this regard. One can see family hand dug wells all along Debrezeit – Modjo road and in West Shewa area, on the way to Jimma. The sanitary condition of most wells is not acceptable. Wells sampled in Modjo-Bushoftu area reveals the poor condition of wells as shown in table below. But with some improvement these family wells can supply potable water like that of Zimbabwe's upgraded family wells (Morgan, 2003), which were in a similar condition like our existing traditional well. For example the mean E. coli/100ml sample of traditional well with bucket, tube well with "bucket pump" and Tube well with hand pump were 475.39, 16.69 and 7.67 in sampled wells in Zembabwe (ibid). This shows that upgrading can bring the water quality in hand dug wells to acceptable standard

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Table Water quality & sanitary conditions of some selected hand dug wells in East Shewa

NO.	Site name	Bacteriological Results (Fecal coliforms)	Physico-chemical characteristics above the max. Permissible limit	Sanitary Condition	Proposed upgrading measures
1	Bushoftu Kebele 15				
	HDW HN 285	500/100ml	Color 44 Pt-Co Turbidity- 15 NTU	- Poorly handled fetching materials - Open during day time	- Well development - Well disinfections - Head work - Improved water lifting
	HDW HN 253	Many to count	Color 31 Pt-Co	- Ditto	- Ditto
	HDW HN 229	5/100 ml		- Ditto	- Ditto
2	Kumbursa Village				
	HDW (prvt)				
3	Lume	Many to count	Color 43 Pt-Co Turbidity- 15 NTU	- Ditto	- Ditto
	Ude Amanuel				
	Ude Kebele	Many to count	Color 40 Pt-Co Turbidity- 14 NTU	- Ditto	- Ditto
	Sirba Village	Many to count	Color 16 Pt-Co Turbidity- 45 NTU	- Ditto	- Ditto
	Bisike Village	Many to count	Color 16 Pt-Co Turbidity- 45 NTU	- Ditto	- Ditto
	Shera	Many to count	Color 50 Pt-Co Turbidity- 13 NTU	- Ditto	- Ditto
	Cheri Sefer	Many to count	Color 73 Pt-Co Turbidity- 23 NTU	- Ditto	- Ditto
	Dibandiba	Many to count	Color 150 Pt-Co Turbidity- 47 NTU	- Ditto	- Ditto
		Many to count	Color 28 Pt-Co	- Ditto	- Ditto

Source: Oromia Water Resources Central Laboratory

The availability of enough rainfall to recharge their wells has made residents of some of the Western Oromia towns users of hand dug wells as security water source for domestic purposes. The recent promotion work by the government has triggered the use of shallow ground water sources, particularly in the rift valley, for commercial irrigation farming. Koka and Meki Zuway areas, and cash crop farmers of Hararge are typical examples. In some parts of the region, where there is/was enough surface water, use of hand dug wells is not well known.

Due to lack of awareness and absence of guidance there is no water management practice that is aimed at ground water resources management. Although not intensified soil and water conservation practices in Hararge and few other places has contributed to ground water recharge.

4.The family approach in action

From years of experience and the limited capacity the country has, it is believed that the conventional development approach is no more a sole means to solve existing water supply problems. Family and community approach in combination with the continuation of existing conventional practices are chosen to be a way out. It is planned each family without potable water supply and located on shallow ground water potential site to have its own well. The foreseen advantages and disadvantages in planning such huge mobilization were the followings:

4.1 Advantages and disadvantages of hand dug wells

Advantages:

1. Are labor intensive and low investment and O& M cost,
2. VLOM
3. Construction materials available in the vicinity
4. No running cost
5. Water close at hand in a backyard
6. Did not depend on government or community sponsorship or manpower

Disadvantages:

1. Non reliable sanitation
2. More time to fetch water
3. Low community acceptance

- Hand dug wells fitted with hand pumps

Advantages:

- Labor intensive and low investment and O& M cost,
- VLOM
- Construction materials available in the vicinity
- Low running cost

Disadvantages:

- Needs skilled/semi skilled person- to maintain hand pumps
- More time to fetch water when compared with motorized ones.
- Require replacement cost
- Needs marginal running cost
- Hand pumps are not locally available

By considering pros and cons of promoting hand dug wells as one of the immediate solutions to access the major part of the society that can't be reached through other type of source development in immediate future is proposed after thorough discussions and arguments. Training manuals were prepared and ToT training was given to all Wereda staffs to be followed by farmers training at PA level. Well digging manuals has been prepared in Oromiffa and distributed to all Genda/ Kebele Administration units to reach selected farmers. The training includes well site identification, well development, wellhead construction, water quality aspects and community and family level water resources management activities.

5.Current status

In every part of the region there was hand dug well digging activity before the start of the rainy season. So far, about 43,000 productive wells are dug. The hesitant attitude and resistance from few individuals is diminishing from time to time as families start to use the water from wells in their backyards in most dry months of the year and when they are in burning needs. Some have gone beyond the use of the water for domestic purposes. Bucket irrigation has started to be practiced in different parts of the Region. In East Hararge and West Hararge zones such practice has longer age. In areas of minimum irrigation practice as West Wellega, Begi Wereda, the author has seen 8 wells used for watering small plots around the wells. Some farmers have started to link ground water with food security. The ultimate goal of this initiative is food self-sufficiency through the use of all available water resources including ground water in a sustainable manner. The exemplary activity in near by villages has triggered farmers to dig their own wells without being told to do so. A farmer in Ha-

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well is a typical example. The well was drilled for 15 meters, of which about 2 meters is through the weathered bedrock, which was strong to be dug by hand. Finding water underneath their feet is a new experience to families in areas where there was no such practice. Such families are happy to find this source that reduced their water fetching distance time and labour and has better ownership right than other sources.

What factors had led to this development?

- River waters are no more save and dependable as times with little population and better environmental conditions in the rural areas.
- Family wells are close at hand and convenient
- Local communities gradually acquired the extra knowledge they needed to improve their own backyard wells
- Hand dug wells take no significant portion of their land.
- No fear of malaria as that of ponds
- Good ideas multiply and within few months, many more families had dug wells.
- The settlement pattern do not encourage isolated families to go and fetch water from distant improved sources

Accompanying water resources management activities that have been told to the farmer to do it to protect his well and springs and rivers from dying out will inevitably contribute to recharge the groundwater resources, hence to sustainable groundwater development. Once farmers understood the use of these wells they will be willing to do anything to protect their wells from deteriorating. The collective effort from each farmer will inevitably lead to better watershade management and hence improved base flow and insure availability of adequate surface and ground water resources.

6. Lessons Learned and Future plans

From this achievement it is learned that the main development resource is our human resource. If it were possible to reach the whole population and bring an attitudinal change at once, digging a family well at backyards is only a week or two activity. With little input from government or other organizations these sources can be easily upgraded to acceptable potable standards. If all dug wells in Oromia are meeting the required standard the water supply coverage is expected to grow by 6.6 % within one year. If according to the plan all families that are located in areas of good potential are going to develop their own wells the water supply coverage is expected to grow as planned. If carefully handled this is a very good opportunity to manage the water resources at a family level.

This year and next year digging similar wells will continue in the same manner. Parallel with this, upgrading program will follow to make the schemes sustainable and sanitarily acceptable. At present there is increasing demand for technical and material assistances. The request for concrete moulds is increasing. Lack of experience in digging wells is a problem in most places. As a result the cost of drilling per meter of depth is soaring high. Training lead farmers, more artisan diggers and extending the training to family level will be undertaken in all parts of the region in the future. Periodic monitoring and supervision will be carried out to decide on future action. The existing better organizational structure of the water sector in the region is very encouraging.

7.Conclusion

With such large population size and alarmingly increasing trend, supplying potable water with only government and few NGOs participation is a difficult task that is not possible to attain. Use of all available resources is a non-negotiable option. In this regard the human resource is the readily available one. If carefully managed use of such abundant resource can bring miracles. The fact that so many families had invested money and time in the construction of family based wells was a good indicator of the potential for future success of this concept. As people start to use and become closely attached and dependant on family hand dug wells upgrading existing hand dug wells to acceptable standard will be possible task with little input. Such approach requires change of attitude huge mobilization of human resources and strong and lasting commitment.

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Progress, Potential & Constraints In Watershed Management: A Special Focus to Dry Land Ethiopia

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Abstract

Basic natural resources including soils, water and vegetation need more attention than ever before. At the international level, many countries in Africa, Asia and South America have designed their rural development programs based on different watersheds and obtained useful results regarding natural resource conservation. While in Ethiopia, watershed management research and development works are at their beginning stage.

Watershed management action aimed at sustainable agricultural production & uses of natural resource in the country particularly in dry land Ethiopia have various progress and problems. The paper tried to review & see the progress in watershed management, its potential and constraint in dry land Ethiopia.

To make the watershed management successful we should begin with characterization of existing potentials and constraints of the watershed then, suitable technologies be demonstrated & popularized to the farmers. Also, this could identify technological gaps for further research. Moreover active participation of farmer from the very begging to implementation and capacity building in area of watershed for farmer (end user) & expertise is another issue.

Key words: watershed, watershed problems

1. Background On Watershed Management

Basic natural resources including soils, water and vegetation need more attention than ever before. Although these resources have been used to the benefits of mankind, they are being over exploited with out assuring their sustainability. This is associated with rapid population growth, inadequate attentions to the resources and the race for maximum production to meet the needs of the growing population. This situation is more serious in poor and backward countries like Ethiopia, where subsistence productions predominate. In Ethiopia smallholder agriculture constitute more than 85% of the population. The small farmland holding with large family size compounded with improper farming practices and institutional and policy constraints have left the bulk of subsistence farmers in state of food insecurity.

Watershed management is the process of formulating and carrying out a course of action involving the manipulation of resources in a watershed to provide goods and services without adversely affecting the soil and water base. Usually, watershed management must consider the social, economic and institutional factors operating within and outside the watershed area.

Watershed management action aimed at sustainable agricultural production & use of natural resource in developing country particularly in dry land Ethiopia have various progress and problems. The objective of this paper is to review & see the progress in watershed management, its potential and constraint in dry land Ethiopia.

2. Why Watershed?

For multidisciplinary approach & its sustainable intervention/development, there should be some sizeable unit. Hence protection, improvement & rehabilitation of a given area can be sustainable attained in a watershed. Moreover for sustainable implementation of multiple objectives, among others: increased crop & livestock production, reduced land degradation & improved household cash income attained in watershed.

By adopting sizeable watershed, the causes and effect relationship of these can be conveniently established. This also implies that, solutions of watershed problems are sought from that watershed area itself. However, it needs strong commitment and enormous inputs.

This emphasizes the need for research and development planning based on a number of small land sizes than distributing ones effort on wider agro ecologies. Experience gained from the past expensive multi-location experimentation indicates that the results are not up to the expectation when judged in terms of the impacts they brought on the livelihood of the farming community. Therefore, the expensive massive experimentation approach largely generates only a few widely adapted modern technologies, which may or may not perform well in other ecology (Girma, unpublished). The modern wave of agronomic thinking advances that, once a package of technologies is generated for a watershed and adopted by farmers, at least the experience gained would help to transfer and extrapolate technologies to any farther radius with less demanding costs.

3. Experience Based Lessons

3.1 Status of watershed management works in the World: Overview

At the international level, many countries in Africa, Asia and South America have designed their rural development programs based on different watersheds and obtained useful results.

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In well managed watersheds of India, return to investments in watershed development was found high, with cost benefit ratios ranging from one to greater than two (Turton et al., 1998; Shriniwassharma and Mishra., 1995). In Srilanka, achievements in afforestation and crop production have been recorded as a result of water collected in earth dams built across 20,000 watersheds (Dharmasena, 1994). Neely *et al.* (1999) reported positive changes in biodiversity conservation, land management, income generation and capacity building as a result of introduction of integrated research and development activities in Manupali watershed (Philippines) and Donsin watershed (Burkina Faso).

In Tanzania semi-arid watershed improved grassed management was identified as the best method for decreasing soil erosion and increasing life of reservoirs. Watershed research also provided information on erosion in watersheds, prognosis of life of reservoirs and use of sand filled reservoirs for ground water storage (Anders Rapp, 1977). Mathias (2001), in his GIS based studies on soil and moisture conservation in Gondar has emphasized the need for developing area specific soil moisture conservation techniques. In China, Wu Faqi (1999) reported on the Nihe Gully watershed (9.48 km ^{2}) through ten years consecutive research that forest grass and vegetation cover has reached 5.8 km ^{2}, accounting for the 61.7 % and land use rate raised to 88%. As a result, food crop yield per mu is stabilized over 200 kg and per capita grain production has risen to 607.6kg/mu.

3.2 Important Issues & Lessons For Sustainable Watershed Programs In Ethiopia

3.2.1 General

- Cost sharing between upland & low land were not properly considered
- Water use right within a watershed system is poor
- There is fragmented institutions with fragmented objectives in one watershed
- Incentive strategies reliant on ford-for-work
- Tenure issues considered not to be important (communal grazing, community forest, federal/regional forest, etc)

A case of project 24881:

The project was implemented from 1980-90 in 44 catchments throughout the country (MoA & WFP). From the evaluation undertaken in 1988, the following were obtained.

¨ To some degree afforested plantation & soil and water conservation (SWC) structures are implemented

¨ There was in appropriateness of SWC structures

¨ Lack of end user's participation: farmers were unaware of about the project activities

¨ Insecure land &/or land tenure: farmer's were unaware of their rights on trees planted on the PA communal lands.

¨ Food aid was used as a pay for maintaining on-farm activities eroding self-initiation and motivation

3.2 .2 Status of Watershed Management Works in Ethiopia: Overview

In Ethiopia, watershed management research and development works are at their beginning stage. Over the last six years, a coordinated watershed research project has been implemented at Ginchi (380 ha) and Chefe Donsa (137 ha) .The project was a collaborative work among the Asian Development Bank, International Crops Research Institute for Semi Arid Tropics (ICRISAT), Vertisol management project and the Ethiopian Agricultural Research organization (EARO). Both watersheds represent the high rainfall areas of the central parts of the country.

From the project, some encouraging results have been achieved, especially in the areas of safe disposal of surplus moisture from the farmland and recovery of vegetation. Particularly at Chefe Donsa, the Broad Bed Furrow (BBF) technology is found useful and farmers have begun using alternate sowing date for wheat varieties and remarkable changes have been witnessed in lentil production in the area. The gap in yields of lentils grown by farmers and the research findings is becoming narrower and farmer's income is increasing.

The experience in watershed management in dry land areas is rather limited. The East Shewa Zone Bureau of Agriculture has limited works in this area, particularly in the areas of soil and moisture conservation techniques on village-based unit of lands. Adama and Dugda Bora weredas have received priority based on the degree of land degradation and their economic importance. A total of 17 sites, each having 600-1000ha were selected. In Adama Wereda, conservation works are being done at Enku, Furfa soloke, Osso, Kechema, Dabe, Qilinto, Boku and Didimtu. At Dugda Bora , similar works are underway, at Dalota Mati, Widoe Hoje, Jura Raqa and Lube in case of Dugda Bora woreda. Although initial gains are yet to be reported the conservation works that largely emphasize terracing, check dams, cut off drains, area closure, plantation on hillsides and trench bunds are already under implementation phase.

Similar work has been done by the GTZ-LUPO project, Oromia Region, (Assefa, 2001) in the corridors of three woredas of northern shewa, from which useful alternate land use and farming system have been drawn. Similar effort is being under way in other regions, as well.

4. Constraint in the past

- Inappropriate use of limited manpower, resources and time.
- Management was not oriented towards achieving main objectives and solving major problem.
- Recommendations were not centered on solving or alleviating these problems, although the overall potential of the watershed should not be neglected.
- Technical/Institutional
- Natural and accelerated soil erosion, causing heavy deposits of sediment in storage reservoirs, irrigation channels and other public installation
- Improper land uses are (slope land farming, shifting cultivation without proper fallow, overgrazing, etc.) resulting in degradation of land and other watershed resources.
- Deforestation, thereby, increasing hazards of seasonal flooding and/or drought downstream.

Resource availabilities and constraints

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- An over-ambitious or unrealistic plan is less likely to be implemented successfully.
- Lack of funds; Insufficient man-power, especially at the professional level;
- Poor coordination among government organization;
- Low mobility and insufficiently equipped field staff;
- Lack of data and research for continuous improvement;
- Poor coordination among multidisciplinary team

These constraints should be developed at the early planning stage. Watershed managers or planners should find out what resources are or will be available to realistically mange the watershed.

5. Technological considerations

The capacity of present technology to cope with the major problems, availability of enough professionals or technicians to handle the work of watershed management, technology transfer from government staff to local farmers, availability of proper extension, education and training activities for farmers in the watershed area are important factor in sustainable watershed management.

Experience in many developing countries has shown that watershed management or soil conservation project can only grow, as trained and experienced persons are available (FAO, 1990). Therefore, the question of how to recruit and train the needed technical personnel for upgrading the capabilities of various agencies must be taken into serious consideration

6. Potentials for watershed management

Availability of labor: Human resource could be utilized if properly managed & utilized

Availability of various local institutions/ associations in a watershed that could help for better communication, extension service, & technology transfer.

7. Recommendations

To make the watershed management successful it is better to begin with characterization of existing potentials and constraints of the watershed that help demonstrate & popularize suitable technologies to the farmers. Also, this could identify technological gaps for further research.

There should be active participation of farmer from the very begging to implementation & evaluation

There should be well coordinated multidisciplinary approach

Because of the undergoing spiral of land degradation and climate changes at a national scale, food shortage is becoming a serious issue, research has to find an entry points through which it can justify the usefulness of its existing improved technologies in the nearby watershed development programs, as well as, plan new research areas for which the gaps are already identified on priority basis for small scale farmers.

To create awareness on the important challenges in watershed among various disciplines

Care should be taken in use of incentive especially for farmer to avoid dependency

Capacity building in area of watershed for farmer (end user) & expertise.

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Water Balance Studies Around Abaya and Chamo Lake Basins

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Abstract

Water balance studies were carried out for three stations of AWTI(Arba Minch University campus),Mirab Abaya and Sille in the lines of Thornthwaite's book-keeping procedure(1948) using the data of temperature and precipitation for over 20 years. Potential evapotranspiration and different indices of aridity, humidity and moisture were worked out to understand the shift of climatic type. Also decennial variation of drought years was worked out for one representative station (Mirab Abaya) to understand the frequency of different categories of drought years. A large water deficit of over 280 mm was estimated in all the three stations without having any water surplus in any month in all the three stations. There is a slight change in climatic type and shift in summer concentration of thermal efficiency (S.C.T.E) period. The frequency of occurrence of different categories of droughts in Mirab Abaya shows that during the period 1972-83, eight moderate and one large drought year and during 1984-95, five moderate, one large and three severe drought years were found.

Key words: Abaya Lake, Water Balance, Thornthwaite's Method.

1. Introduction:

Water is the most important natural resource and is vital for all life on earth. The well being and the development of our society depend on the abundant availability of water. Unfortunately this most precious resource is unevenly distributed on the globe. The availability of fresh water in any region depends on the precipitation of that region. The precipitation of a region mainly depends on precipitable water in the atmosphere, orography, forest cover and proximity to the sea coast and many more other factors. Basing on the precipitation, climate and vegetation types are found. The definition of climate, according to Landsberg (1958) is the composite physical state of the atmosphere at a specific locality for a specific interval of time. The action of climate may not only be on biological organisms like plants and animals which respond primarily to temperature and precipitation but also on inorganic substances like rocks resulting in the evolution of land forms and a variety of soil types that control the agriculture of a place. So there is a need to classify climates. It is also understood that there is a shift in climatic type from time to time even in the same locality. While the Koppen's climatic classification gives basing on vegetation cover in a general way, Thornthwaite's rational climatic classification gives in a finite

Table- 1: Water Balance Of AMU (Region: Snnpre, Zone: Semen Omo)

S.No	Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1.	Temp (T°C)	24	25	26	25	24	23	23	23	24	24	24	24	
2.	P.E	97	101	121	111	100	92	93	92	96	98	94	96	1191
3.	P	25	46	52	144	148	68	51	64	70	105	47	33	853
4.	APWL	295	350	419	-	-	24	66	94	120	113	160	223	-
5.	ΔS	0	0	0	33	48	-24	-42	-15	0	0	0	0	-
6.	S	0	0	0	33	81	57	15	0	0	7	0	0	-
7.	A.E	25	46	52	111	100	92	93	79	70	98	54	33	853
8.	W.S	0	0	0	0	0	0	0	0	0	0	0	0	0
9.	W.D	72	55	69	0	0	0	0	13	26	0	40	63	338

Lat: 06°04'N, Long: 37°36'E, Height (above msl): 1300 m, Region: SNNPRE Field capacity (assumed) : 200 mm, Period: 1987 - 1996. All values are in millimeters I_h = (W.S/P.E)100 = 0, I_a = (W.D/P.E)100 = 28.37%, $I_m = I_h - 0.6I_a$ = -17.23% S.C.T.E :(Mar, Apr , May) = (232/ 1191)100 = 19.47%, Climatic Type : $C_1A'da'$ (Dry sub humid with mega thermal main & sub type and no adequate moisture any time of the year).

Table-2 : Water Balance Of Sille (Region: Snnpre, Zone: Semen Omo)

S.No	Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1.	T(°C)	23	24	25	23	22	22	23	23	23	22	21	21	-
2.	P.E	92	93	105	92	85	83	95	95	91	82	74	75	1062
3	P	37	42	62	128	142	82	35	47	56	75	40	14	760
4	APWL	301	352	395	-	-	1	61	109	144	151	185	246	-
5.	ΔS	0	0	0	36	57	-1	-60	-32	0	0	0	0	-
6.	S	0	0	0	36	93	92	32	0	0	0	0	0	
7.	A.E	37	42	62	92	85	83	95	79	56	75	40	14	760
8.	W.S	0	0	0	0	0	0	0	0	0	0	0	0	0
9.	W.D	55	51	43	0	0	0	0	16	35	7	34	61	302

Lat: 05°58'N, Long : 37°33'E, Height (amsl) : 1190 m, Period : 1979 - 1996 Field capacity (assumed): 200 mm, All values are in millimeters. I_h = 0, I_a = 26.9 %, I_m = - 16.15 %, S.C.T.E (Jan,Feb,Mar) = 27.3 % Climatic Type : $C_1B'da'$ (Dry sub humid meso thermal main and mega thermal sub type and no adequate moisture any time of the year).

Table-3 : Water Balance Of Mirab Abaya (Region: Snnpre; Zone: Semen Omo)

S.No	Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1.	T(°C)	24	24	24	23	22	22	22	23	23	22	22	22	-
2.	P.E	101	94	104	95	93	88	87	91	87	88	84	88	1100
3	P	20	15	54	97	106	76	74	69	69	56	46	16	698
4	APWL	288	367	417	-	-	12	25	47	65	97	135	207	-
5.	ΔS	0	0	0	2	13	-12	-25	-47	0	0	0	0	-
6.	S	0	0	0	2	15	3	0	0	0	0	0	0	-
7.	A.E	20	15	54	95	93	88	77	69	69	56	46	16	698
8.	W.S	0	0	0	0	0	0	0	0	0	0	0	0	0
9.	W.D	81	79	50	0	0	0	10	22	18	32	38	72	402

Lat: 06°18'N, Long : 37°46'E, Height (amsl) : 1260 m, Period : 1972 - 1995 Field capacity (assumed): 200 mm; All values are in millimeters. I_h = 0, I_a = 36.5 %, I_m = - 21.9 %, S.C.T.E (Jan,Feb,Mar) = 27.18 % Climatic Type : $DB'da'$ (Semi arid meso thermal main and mega thermal sub type and no adequate moisture any time of the year).

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Table 5: Yearly Variations At Mirab Abaya

S.No	YEAR	I_A%	Shift of SCTE	Climatic type	W.D	W.S
1.	1972	44.2	28.54 (F,M.A)	$DA'da'$	540	0
2.	1973	26.3	31.6 (J,F,M)	$C_1B'da'$	245	0
3.	1974	49.04	26.6 (M,A,My)	$DB'da'$	89	0
4.	1975	20.4	29.5 (A,My,Jn)	$BA'wa'$	260	604
5.	1976	34.04	42.24 (J,F,Mr)	$BB'w_2a$	349	450
6.	1978	10.12	27.8 (M,A,My)	$C_1B'da'$	65	0
7.	1979	19.6	30.6 (N,D,J)	$C_1B'da'$	160	0
8.	1980	56.6	28.55 (J,F,M)	$DB'da'$	561	0
9.	1982	20.7	34.6 (M,A,My)	$C_1B'da'$	178	0
10.	1983	18.28	35.2 (S,O,N)	$C_1B'da'$	162	0
11.	1984	65.9	29.9 (M,A,My)	$DA'da'$	850	0
12.	1985	38.7	26.6 (F,M,A)	$DA'da'$	459	0
13	1986	63	26.7 (N,D,J)	$DA'da'$	822	0
14	1987	42.5	25.7 (!y,Ag,S)	$DA'da'$	559	0
15	1988	56	25.7 (My,Jn,Jy)	$DA'da'$	681	0
16	1989	47.6	26 (My,Jn,Jy)	$DA'da'$	610	0
17	1992	62.03	28.33 (Ma,Ap,My)	$DA'da'$	773	0
18	1995	41.5	26.73 (Ja,F,Ma)	$DA'da'$	503	0

sense due to the computational feasibility and so became popular now. The purpose of the present study is to know the frequency of occurrence of droughts and the shift of climatic types in the locality of Abaya Lake.

2. Material And Methods:

Temperature and precipitation data for three stations of AWTI (Arba Minch University campus), Mirab Abaya and Sille has been obtained from the Research and Publications office of the Arba Minch University and water balance studies for each year of Mirab Abaya and climatic water balance for whole of the period of 26 years for the three stations have been worked out using the book-keeping method of Thornthwaite (1948)) as worked out for Indian stations by Subrahmanyam (1956 and1980). Also different indices of humidity, aridity and moisture were computed and yearly shift of climatic types have been analyzed. Decennial variation of drought years has been examined basing on the march of aridity index to know the frequency and severity of drought occurrence at Mirab Abaya (Thornthwaite and Mather,1955).

3. Results And Discussion:

Tables 1 to 3 shows averaged monthly values for long period as mentioned on the respective table. The values serially are Temperature (T °C), Potential Evapotranspiration (P.E), Precipitation (P), Accumulated Potential water loss (APWL), Storage change (DS), Soil storage (S), Actual evaporation (AE), Water surplus (WS) and Water deficit (WD). All the values are given in millimeters. The field capacity for all the three stations is assumed as 200 millimeters for computation of water balance.

Table 6: Yearly Variations of Water Balance Parameters At Mirab Abaya

S.No	Year	Temp °C	P.E (mm)	P (mm)	A.E (mm)	W.S (mm)	W.D (mm)	Months of occurence
1.	1972	24	1219	679	679	0	540	Except Ap,My,Dec
2.	1973	24	930	685	685	0	245	Except My to Dec
3	1974	23.5	1113	567	567	0	546	except Ma to My and Sept
4.	1975	24.75	1274	1618	1014	604 (Ag to Oct)	260 (Jan to Apr)	Surplus utilized in Nov,Dec,Jan
5.	1976	21.33	1025	1126	676	450 (Jun,Jul)	349 (Jan,Feb,Mar)	Surplus utilized in Aug,sep and Dec,Jan
6.	1978	18.27	642	577	577	0	65	Jan,Feb and(May)
7.	1979	18.4	816	656	656	0	160	(Nov,Dec)
8.	1980	21.65	991	430	430	0	561	Except Apr to Jun,
9.	1982	19.58	858	680	680	0	178	During My to Sep.
10.	1983	19.41	886	724	724	0	162	During Jan to Mar and Dec.
11.	1984	24.66	1290	440	440	0	850	Except Sept
12.	1985	24.66	1186	727	727	0	459	Except My to Aug.
13.	1986	25	1303	481	481	0	822	All months.
14.	1987	24.9	1315	756	756	0	559	Except My to Jul.,
15.	1988	24.5	1216	535	535	0	681	Except Ap,My and Sep
16.	1989	24.9	1281	671	671	0	610	Except Dec
17.	1992	24.4	1246	473	473	0	773	Except Apr
18.	1995	24.25	1212	709	709	0	503	Except Apr to Jul

In the case of AWTI (Table 1), there is no water surplus in any month and there is an annual water deficit of 338 mm on an average. The humidity, aridity and moisture indices respectively are 0, 28.37% and -17.23%. The thermal efficiency is 119.1 cm and the Summer Concentration of Thermal Efficiency (SCTE) occurred during March to May is 19.47%. Basing on this the climatic type works out according to Thornthwaite as $C_1A'da'$ which means "dry sub humid mega thermal main and sub type with no adequate moisture any time of the year". Figure 1 further indicates that there is a small soil moisture storage of 81 mm during the period end of March to end of May which has been immediately used from early June to end of August to meet the requirements of Potential evapotranspiration (water need).Thus virtually from August onwards water deficit started and continued till March with a small neutral situation during October.

Similar situation is found in the case of Sille also (Table 2).The water deficit (302 mm) in Sille is little less than that of AWTI. This may be because of lesser potential evapotranspiration (1062 mm) as compared to that of AWTI (1191 mm). Actual evaporation and rainfall are also less in Sille compared to AWTI. Figure 2 shows the water balance chart of Sille. Here also small soil storage (93 mm) which does not meet the requirement of field capacity (200 mm) occurred for a brief period during late March to early June which was immediately utilized during late June through August to meet the potential evaporation requirements. Later the water deficit started in September which continued till March. It is interesting to note here the actual evaporation is equal to the precipitation (760 mm). The climatic type works out as $C_1B'da'$ meaning "Dry sub humid mesothermal with no adequate moisture".

Table 3 shows the water balance of Mirab Abaya. This station also shows annual water deficit of 402 mm without any water surplus at any time of the year. Here also actual evaporation and precipitation are equal (698 mm). Figure 3 show that only 15 mm has gone into soil during April and May and has immediately utilized during June and

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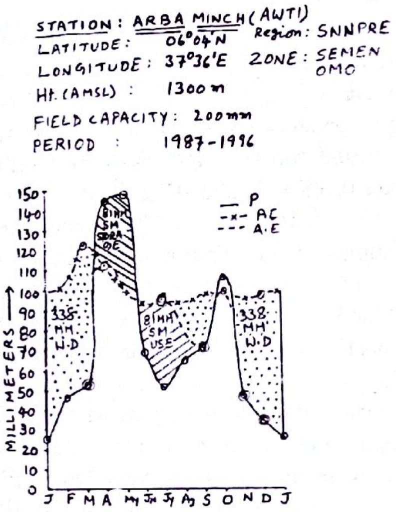

FIG.1 WATER BALANCE OF AWTI DURING THE PERIOD 1987-96

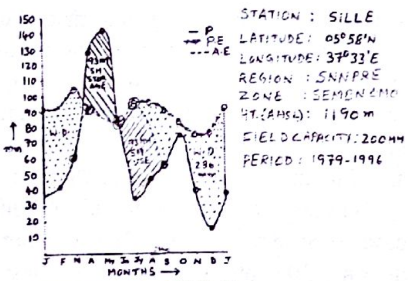

FIG.2. WATER BALANCE OF SILLE DURING THE PERIOD 1979-96

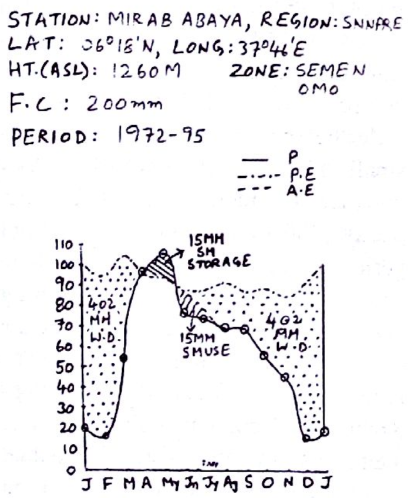

FIG.3. WATER BALANCE OF MIRAB ABAYA DURING THE PERIOD 1972 TO 1995

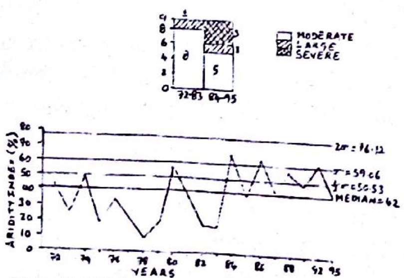

FIG.4. DECENNIAL FREQUENCY OF DROUGHT YEARS AT MIRAB ABAYA DURING 1972-1995

July. Rest of the period from July through March experiences a large water deficit. Table 4 indicates the detailed variation of different water balance terms during the surplus years 1975 and 1976.

Table 5 clearly indicates the shift of climatic type and shift of S.C.T.E during 1972 to 1995. While the climatic type is variable during 1972 to 1983, it remains same ($_{DA}$'da') from 1984 to 1995. During these 23 years water surplus was found only in two years (1975 and 1976) and in all the rest of the years significant water deficit was observed at Mirab Abaya.

Figure 4 shows the decennial variation of drought years. The categorization of droughts followed is as mentioned below in table 7 according to Thornthwaite (1945):

Category (Departure of I_a from median value)	Drought intensity
< ½σ	Moderate
½σ to σ	Large
σ to 2σ	Severe
> 2σ	Disastrous
Where I_a is Aridity index and σ is standard deviation $\sqrt{\frac{(X-\bar{X})^2}{N}}$ Where $\bar{X}$ is median and N number of years	

According to the above classification, while during the period 1972-83, moderate droughts are eight times and large drought is one time occurred whereas during 1984-95, moderate five, large one and severe droughts three times occurred as shown below in Table 8.

Category of drought	1972-1983	1984-1995
Moderate (< ½σ)	8	5
Large (½σ to σ)	1	1
Severe (σ to 2σ)	0	3
Disastrous (> 2σ)	0	0

When this compared with a similar Indian (tropical) station Visakhapatnam (17°42'N and 83°20'E) during the years 1901-1950, the categorization is as sowen below in table 9(according to Subrahmanyam, 1956 and Subrahmanyam and Subramaniam,1965):

Year	Moderate	Large	Severe	Disastrous	Total
1901-1910	2	1	2	0	5
1911-1920	2	3	1	0	6
1921-1930	1	2	1	0	4
1931-1940	2	1	0	1	4
1941-1950	3	2	2	0	7
Total during 1901-1950	10	9	6	1	

This indicates the severity of drought situation in Abaya Lake region. Visakhapatnam also has an annual water deficit of 704 mm without any surplus in any part of the year and has a large Potential evapotranspiration of 1666 mm and actual evaporation is equal to precipitation (962 mm) like that of Mirab Abaya. Although both the stations are similar in water balance, when the frequency of droughts is compared, Mirab Abaya is more prone and vigorous than that of Visakhapatnam. The reason for this may be due to erratic behavior of rainfall at Mirab Abaya (see table 10).

4. Conclusions:

The droughts are more frequent and intense in and around the stations of Abaya Lake. The reason for it is glaringly seen as due to the erratic behavior of rainfall year after year (as shown in table 10 through coefficient of rainfall variability and rainfall ratio) though the Potential evapotranspiration (PET, 1100 mm) is not very high compared to a similar tropical station (Visakhapatnam) of a different country (India) where PET is higher (1666 mm) but the rainfall is by and large uniform year to year.

5. Acknowledgements:

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Challenges in Management of Shared Water Resources: Case Studies from the Southern Region

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Abstract

Water is an important natural resource to sustain life. It is a major development element to reduce poverty and to attain food security objectives. However, with continuing population growth, recurrent drought and climate change, water scarcity will be a major challenge. Therefore, management of shared water resources is of significant importance to reduce and avoid disputes and conflicts that are triggered by the use of available water resources.

In addition, there is lack of understanding of policy principles and their application in a decentralized environment. The key issues that are treated in this paper include: basic policy principles, legal basis and case studies from the region for the purpose of illustration of the challenge. Finally, although in-depth study was not conducted , policy recommendations are forwarded in relation to the case studies and water resources management in the Ethiopian context.

1. Introduction

Water is a vital natural resource for countries like Ethiopia where food security is a challenge due to recurrent drought and climate change. Further more, it is expected that in the ensuing years water scarcity is becoming a serious problem as the population continues to grow and exert increasing pressure on the available water resources (especially during the long spell of dry seasons and at times of drought). This intensifies competition among various water uses (drinking water, irrigation, industry, etc) and water users and hence may trigger disputes and conflicts over the use of water.

In light of this, it is very essential to gear towards creating an enabling environment for integrated water resource management, capacitating the local communities for resolution of conflicts based on community interests in a decentralized environment and give more emphasis on stakeholder participation for sustainable utilization and management of water resources.

This paper, therefore, aims primarily at discussing the basic principles and concepts of Integrated Water Resources Management, Policy and legal issues related to utilization and management of water resources. It also describes two cases of conflicts in South Nations, Nationalities and Peoples' Regional State to illustrate how conflicts arose and negotiations were employed to protect water rights to the stakeholders.

2. Principles of Integrated Water Resources Management

Integrated Water Resources Management (IWRM) should be the foundation for supporting the management of shared river basins. IWRM is a comprehensive approach to water management that takes into account different types of water combining both quantitative and qualitative aspects. It also offers platform for managing actual and potential conflicts among various interests and users (households, agriculture, navigation, etc)

In fact , the concept of integrated water resource management is based on the principles enunciated by the Dublin Conference on Water and Environment (ICWE, 1992) , the famous agenda 21 of the Earth Summit in Rio de Janerio (UNCED, 1992). The main principles and associated concepts are shown as follows.

Box 1: Dublin Principles and Associated Concepts

Dublin Principles

❖ Water is finite, vulnerable and essential resource, which should be managed in an integrated manner.

❖ Water resources development and management should be based on a participatory approach, involving all relevant stakeholders

❖ Women play a central role in the provision, management and safeguarding of water

❖ Water has an economic value and should be recognized as an economic good, taking into account affordability and equity criteria.

Associated Key Concepts

❖ Integrated water resources management implying:

- An intersectoral approach
- Representation of all stakeholders
- All physical aspects of the water resources
- Sustainability and environmental considerations

❖ Sustainable development: sound socio-economic development that safeguards the resource base for future generations

❖ Emphasis on demand driven and demand oriented approaches

❖ Decision making at the lowest appropriate level

Box 2: Agenda 21

Dublin principles formed the basis of Chapter 18 (on fresh water resources) of the Earth Summit's key discussion document, Agenda 21. Chapter 18 identified seven focus areas for action. These are:

❖ Ensure the integrated management and development of water resources

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❖ Assess water quality, supply and demand
❖ Protect water resource quality and aquatic eco-system
❖ Improve drinking water supply and sanitation
❖ Ensure sustainable water supply and use for cities
❖ Manage water resources for sustainable food production and development

3. Policy and Legal Implications

3.1 Institutional Framework

The institutional framework rests on the foundation of diagnostic studies (information on socio-economic, physical and performance characteristics of the basin) and supported by three pillars of key institutional areas. Therefore, water management institutions are categorized into three main components, viz, water policies, water laws (legal aspects) and water administrations (procedures and organizations for management of water resources). Policy and legal components of institutional framework are further described as follows.

Box 3: Policy and Legal Components of Institutional Framework

Water Policy

- Use priority
- Project selection criteria
- Pricing and cost recovery
- Water allocation and transfers
- User participation
- Linkages with other economic Policies

Water Law

- Legal coverage of water and related resources
- Water rights
- Provisions for conflict resolution
- Provisions for accountability
- Scope for public/private sector participation
- Integrated natural resources management
- Integration of overall legal framework with water law

3.2 Policy Issues

The Ethiopian Water Resources Management Policy has been endorsed by the Council of Ministers in (1999/ 2000). The Ethiopian Water Resources Policy addresses water sector issues in a comprehensive and integrated framework consisting of studies, planning, development, conservation, protection & control of elements of various and inter connected uses of water in a holistic domain, i.e., known as Integrated Water Resources Management.

Fundamental policy principles

The following fundamental policy principles are stated in relation to sustainable development & efficient management of water resources.

The major ones, inter alia, include:

❖ Water is a natural endowment commonly owned by all peoples of Ethiopia
❖ Ethiopian citizens shall have access to sufficient water of acceptable quality to satisfy basic human needs. This means in water allocation and apportionment, recognize the basic minimum requirement for human and livestock as well as environment. This implies that water allocation gives the highest priority to water supply and sanitation
❖ Water is both an economic and social good
❖ Water resources development should be based on rural centered, decentralized management and participatory approaches. This focuses on promoting decentralized management, foster the participation of user communities and support community self-initiatives in water resources management
Social equity, system reliability and sustainability

3.3 Legal Implications

The umbrella laws with regard to the management of natural resources in general and water resources in particular in the country include: the Constitutions both at Federal and Regional levels and the Ethiopian Water Resources Management Proclamation

3.3.1 The Constitutions

The constitution, being the supreme law of the Federal Democratic Republic of Ethiopia, provides the framework for all national policies, laws and administrative systems of the country. The Constitution has several provisions which has policy, legal and organizational matters for the management of natural resources in general and water resource management in particular.

With regard to the management of natural resources (including water resources) and the protection of the environment the responsibilities of the Federal Government and the Regional States are clearly provided in the Constitution. The Federal Government is vested with the responsibility of formulating the national policies, strategies, define and enact laws of utilization and conservation of land and natural resources(Article 51:2,5,) and it shall determine and administer the utilization of the waters or rivers and lakes linking two or more States or crossing the boundaries of the national territorial jurisdiction (Article 51:11). Regional states are given the responsibility of administering land and other natural resources in accordance with the Federal Laws (Article 52:2(d))

Likewise, the States have given to formulate and execute economic, social and development policies, strategies and plans of the State and to enact and execute the State Constitution and other laws (Article 52: 2 (c). Moreover, according to , for instance the Revised Constitution,2001 of the Southern Nations, Nationalities and Peoples Regional State under Article 47:2(a, b), the state has the powers to formulate and execute Regional policy, strategy and plan with respect to economic and social development and issue and implement the State's Constitution and other regional laws.

3.3.2 Ethiopian Water Resources Management Proclamation (Proclamation no. 197/2000)

(a)Ownership and management of water resources

All water resources of the country are the common property of the Ethiopian people and the State (article 5). As regards to the management aspect, although Ethiopian citizens shall have access to sufficient water of acceptable quality to satisfy basic human needs,

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the management of water resources of Ethiopia shall be in accordance with a permit system (article 6:4). Moreover, domestic use of water shall have priority over all other uses (article 7:1). These articles generally imply the state has a major role in management and protection of water resources.

Accordingly, it is clearly defined that the Ministry of Water Resources shall be responsible for the planning, management, utilization and protection of water resources (article 8:1) and it shall determine the allocation and manner of use of water resources among various uses and users (8:1:c). Besides, Regional Water Bureaus are not mandated to plan and manage the water resources and issue permits unless delegated by the Ministry according to article 8:2.

(b) Right to use water resources

The right to use water resources for various activities requires permits (article 11:1). Nevertheless, there are water uses for which it is not necessary to obtain licenses (article 12). These are water use from hand-dug wells and use of water for traditional irrigation, artisanal mining, for traditional animal rearing as well as water mills.

(c) Settlement of Disputes

The supervisory body (Ministry of Water Resources) is mandated to examining and deciding on disputes between permit holders and third party concerning the rights or obligations arising from permits (article 9). The settlement is based on negotiations and arbitrations

3.3.3 Proclamation No. 4/1995

This is a proclamation for Definition of Powers and Duties of the Executive Organs of the FDRE. Under this proclamation, the Ministry of Water Resources is vested with powers to determine conditions and methods required for the optimum allocation and utilization of water that flows across or lies between more than one Regional Governments among various uses and regions (article 17:1).

The Water Resources Management Policy and the Proclamation (197/2000) laid the foundation for planning, utilization, management and protection of water resources. However, there are limitations in implementation due to the fact that the capacity of the Ministry of Resources to deal with such enormous and diverse activities is limited, weak institutional arrangements and highly centralized nature of water resources management are not concomitant to international principles and federal nature of political administration.

4.The Case Studies

4.1 Disputes and Conflict Resolution in Weito Catchment

4.1.1 Hydrology and Water Resources

Weito river is a perennial river found in the Abaya-Chamo- Chew-Bahir sub basin which is situated in the southern part of Rift Valley Lakes Basin. It flows along the borderlines shared among Konso, and Burji special woredas, South Ome zone and Oromia Regional State. The catchments covering a total area of 4500 sq. km receives an annual rainfall of about 650mm and the mean annual flow of Weito river is about 380 million cubic meter.

The low land plain of Weito catchment covers an area of about 300sq. km. with slope gradient of 5°. The annual rainfall in the low-lying plains varies from 300mm near Chew Bahir to 550mm in the northern part of the plain. It has a bimodal pattern with the main rains occurring during the periods of March to May and September to October the maximum being in April.

Weito river is characterized by very high flow during the rainy seasons and the discharge decreases during dry seasons. Sometimes, the river is experiencing no flow in the lowland plains, which is mainly due to the continued expansion of the Private irrigated farmland, and decrease in seasonal rainfall in the area. Therefore, the availability of water resources is a critical element for irrigation development since the catchments receives less than 800mm annual rainfall, frequent occurrences of drought and storage requirements for irrigable land of about 5000ha in the catchments.

4.1.2 Disputes between the farmers and Birale Agricultural Development PLC

The catchments has a potential irrigable land which ranges in order of 5000-10000 ha (Reconnaissance Master Plan for the Development of Natural Resources of Rift Valley Lakes Basin, 1992) .The Weito river is used for irrigation and other agricultural purposes by Birale Agricultural Development PLC, communities of Mesoya and Erobore and other downstream users. Mesoya small scale irrigation project was first constructed in 1984 by FAO in order to respond to the severe drought . The project was intended to irrigate an area of 254ha even though there is a potential of 1000ha. Later Birale PLC was constructed an irrigation scheme to irrigate more than 2500ha out of the 4000ha leased land. Because of bed erosion and sediment problem the previous intake structure of Mesoya project was abandoned. Therefore, another intake structure and main canal was designed and constructed in 1998 by Co-SAERSAR at a point about 450m upstream of Birale Diversion Weir. In addition, even though there is immense potential for irrigation, Tsemay communities are mainly dependent on livestock rearing.

Birale PLC, on the other hand, had started construction of storage pond with a capacity of 10million cubic meters that enables to increase the irrigable land by 400ha. Moreover, pumped irrigation system was designed and constructed in 2001 by CO-SAERSAR at Erbore to irrigate an area of 100ha. Thus, the beneficiaries are dependent on Weito river in terms of four aspects: first, those who are close to the main canal of Birale PLC and utilizing water from their adjacent canal (Enchete Duma PAs), secondly, those producing once a year but demanding to produce twice a year by utilizing the river (Tsemay communities), thirdly, those cultivating using flood regression farming after the rainy season but demanding for small scale irrigation project and finally, those purely dependent on cattle cultivation are also questioning the basic requirement for their cattles.

Due to the decrease in flow and the dry up of the river in dry periods for the downstream users brought about conflict between the Birale PlC and agro-pastoralists (10 PAs from South Omo Zone including Tsemay, Enchete Duma and Erbore) and farmers (Mesoya communities from Konso Special Woreda)

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residing along the river.

4.1.3 Conflict management

Conflict management is an important water management activity in resolving the aforementioned disputes among the Weito users. In this regard, basically three major points were considered. These are:

Creating an enabling environment

The regional government to play a catalytic role formed a committee from relevant organizations such as Water Resource Development Bureau, Bureau of Agriculture, Irrigation Authority, Cooperatives Bureau, and Representatives from Konso special woreda and South Omo zone. The role of this committee was by facilitating and creating an enabling environment for conflict resolution gives direction on the use of Weito river and capacitates the communities. In addition, it creates a forum for negotiations and confidence building among users.

Institutionalizing conflict resolution

It has been internationally accepted that the user communities manage natural resources best if the indigenous management systems are recognized and given institutional support. Therefore, discussion were made among community elder groups, community leaders, woreda administration, professionals from different organizations and levels and officials from Birale Plc. After the discussion, 2 or 3 representatives were elected from each community elder groups to be a member of the Water User Committee to oversee and monitor proper allocation and use of water among users, i.e the communities and Birale Plc employing customary water use rights of the local communities.

Water use and allocation

Birale Agricultural Development Plc was licensed to irrigate 4000ha. However, only 2500 ha was irrigated once a year from August to January. Based on the local institution, the users agreed to use the water on periodical basis. Accordingly, Birale Plc was supposed to use from June to November. If it needs to cultivate in other periods of the year, storage pond was suggested to use for drier periods. Mesoya and Tsemay communities allowed using from March to June. In doing so, there will be excess water that flows to downstream users especially to Erbore communities. Nevertheless, when there is no shortage of water, they agreed to cultivate at any time of the year.

Therefore, since currently Birale Plc is not operating at its full capacity because of other reasons, there is no conflicting situation in the catchments. However, because of the interest of other private investors in the area, the need for expansion of Birale irrigation project and the increase in awareness of the communities to sedentary life and irrigated agriculture, there is a potential for future conflict.

4.2 Conflict Over the Use of Keffo Spring

4.2.1 General Overview

The source of Keffo spring is located in Bonga kebele of Angecha woreda in Kembeta Tembaro zone and the yield of the spring is estimated to be 4.5 l/second during the dry season. It is used both for drinking and agricultural purposes for communities at the source as well as tail end users. The users include communities from Bonga, Hanja and Laloamo kebeles of Angecha Woreda and Megare kebele of Kedida Gamela woreda from Kembata-Tembaro zone and Hirkofofo and Hafto kebeles of Shashogo woreda from Hadiya zone. However, Ethiopian Social Rehabilitation and Development

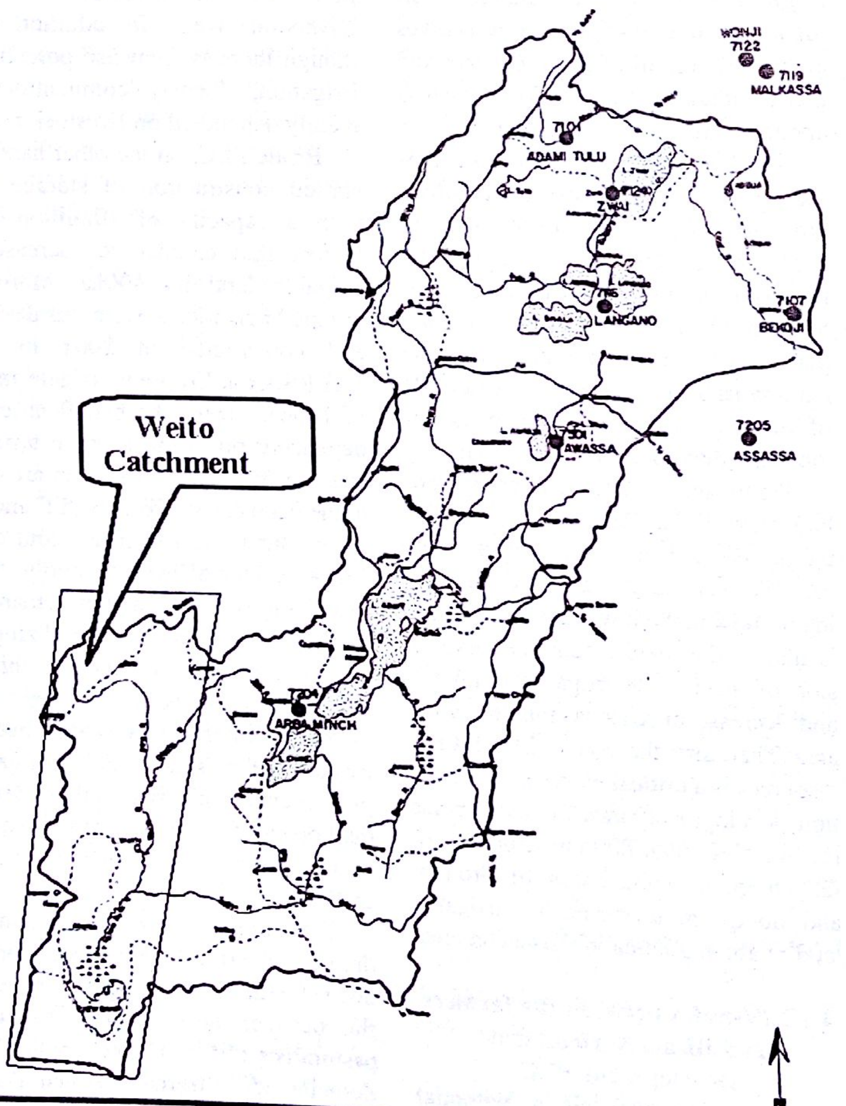

Figure 1: Location map of Weito River

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Table 1: Physical and Socio-economic characteristics of irrigation projects in Weito Catchment

Item	Irrigation Projects		
	Birale Plc	Mesoya	Erbore
Year of Construction	1991	1984 (FAO)	1998 (CO-SAERSAR)
Nature of Structure	Diversion Weir	Weir	Pumped Irrigation Sch.
Service Area	>2500 ha	254 ha	100ha
No. HH beneficiaries	>500	480	924
Rehabilitation and Expansion	pond (1998) 10mcm to irrigate 400ha	Intake structure (1998)	-

Fund have signed financial support agreement to develop Kefo spring with Bonga kebele communities, Development Associations and Woreda Administration in 1993EC.

2.2.2 Cause of the Conflict

A study has been conducted to develop Kefo spring for drinking water supply purpose for communities living in Kembata-Tembaro zone. Ethiopian Social Rehabilitation and Development Fund (ESRDF) financially supported the project and the construction was started in 1994 E.C. The construction was interrupted because of the claim from the down stream users fearing that discharge will decrease which will not be sufficient for their use especially during the dry season.

After several negotiations made with the community representatives, the pipe laying (90 per cent of the 7.5km), eight water points and reservoir construction is completed but spring capping structure, electromechanical installation and power house remained uncompleted since then. This is because the communities along the stream and those tail end users started to dispute over the unfair use of the spring water (it was only benefiting upstream user and affecting the down stream users). As a result, pipes were dismantled by the communities, 75 cubic meter reservoir started cracking since it was not filled with water for a long time and it was not able to hand over the project to the community.

Table 2: Monthly Hydrometric Discharge of Weito River (m^3/sec)

Month	Max.	Min.	Av.
January	7.59	4.03	5.23
February	6.60	3.13	4.42
March	5.10	0.75	3.56
April	88.20	0.94	28.77
May	193.70	23.40	58.80
June	40.50	6.28	15.38
July	14.70	2.92	6.63
August	32.40	1.99	5.03
September	18.30	2.34	6.78
October	13.70	5.13	6.85
November	22.00	1.19	5.66
December	5.67	0.33	1.65

***Source:** Co-SAERSAR: Feasibility study reports Erbore Irrigation Project, 1998*

2.2.3 Conflict Resolution

The Regional Water Resources Development Bureau as regulatory and facilitating organ created a forum for negotiation and discussion among user community representatives, ESRDF, Zonal Water Desks from Kembat-Tembaro and Hadiya zones and technical and managerial staffs from the Bureau. After long discussion, the community representatives from the both advantaged and affected communities agreed that:

❖ To assess for other water supply sources

❖ 4.5km. extension of the existing water supply system for Bonga, parts of Hanja and Aturancho villages, and

❖ to pump the water (2.5l/s discharge) for eight hours per day or so and to avail water for four hours in the water points and hence there will be continuous flow for the down stream users

Based on these ideas brought by the communities, after assessing the water resources of the area, a new water supply project was designed consisting of drilling of six shallow wells fitted with hand pumps and construction of distribution network including 50 mcu reservoir, about 9km pipe line work, seven water points, five cattle troughs and six washing basins with a total cost of Birr 1.6 million. This is planned to be implemented in 1997FY and hoped to resolve the conflict.

5. Summary and Conclusions

This paper is a result of review and study of available documents and records. Besides, interviews and discussions were the techniques employed for data and information gathering and analysis. Therefore, it is not a detail study and hence its scope is very limited to address ownership and management of water resources in Ethiopia and the cases of conflict and disputes in Weito river and Keffo spring. However, it will offer an introductory explanation about policy and legal frameworks for water resources management and the nature and causes of disputes over water uses in the region. It is a means to discuss our lessons and to stimulate ideas in sharing experiences from international as well as national levels.

Bearing in mind the incompleteness of the study in technical terms, the following conclusions were made from this shallow study:

1. Even though the country has well articulated Water Resources Management Policy (2000) and Water Resources Act (197/2000), as a result of deficiencies and weaknesses from institutional and legal framework, there is a clarity problem regarding the planning and management of water resources and how water resources are allocated and rights for use are applicable both formally and informally.

2. The water resource potential of Weito specifically and other sub-basins is not identified in detail and hence capacity development for resource assessment, collection and dissemination

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of data and information for water resources planning, development, allocation and management is a key challenge. Thus, a research on development of management modalities and tools as well as water resources allocation mechanisms is of critical importance.

3. Since water is a scarce resource, disputes about water allocation and utilization contributes to conflicts within a catchments, sub-basin and basin at national and international level. There are many principles developed at international level which are not easy to apply for shared river basins due to their inconsistencies and limitations to practical applications. Thus, it is very essential to develop water allocation mechanisms and conflict management systems based on research and development of local initiatives.

4. The policy mentions decentralized water resources management. However, in practice it is far from implementation due to legal constraints and the internalization of the importance of decentralization of water resources management is another major challenge. As a result, the mandates and responsibilities at Federal, Regional and community level should be clearly stated to improve the hitherto existing water management and potential conflicts through decentralized initiatives.

5. Disputes were mediated and arbitrations were made with the involvement of either elder groups or community leaders and hence informal mechanisms are used for conflict resolution. This is one of the successful approaches and internationally accepted notions. In the informal process, there are levels of decision making where conflicts are not settled at community level, referral system was established when the intervention of formal institutions is required (Shuka, A, et al, 1997). This was the case both in Weito and Keffo spring. Therefore, it is highly essential to capacitate and institutionalize the indigenous management systems and local communities in terms of conflict resolution.

6. Finally, as a concluding remark. I will pose a question, Are we going to manage water resources and conflicts arising from its utilization in a centralized and bureaucratic approach or enhance the community (local) capacity for joint management of shared water resources and replication of best experiences and process elsewhere in the country and scaling up of the local initiatives to the management of international water courses?

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The Identification Of Wetlands Using Landsat Etm Data Case Study: The Rift Valley Lakes Region

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1.Introduction

1.1 Location

As per Landsat ETM's World Reference System (WRS), the study area is within the 168 Path and 055 Row. The geodetic bounding coordinates is j = 6° 50'55" N to 7° 50' 35" N and l = 38° 15'45" E to 38° 40' 50" E.

Wetlands are often difficult to define. In scientific literatures, the definitions are so many, even some of them are bizarre. By and large, wetlands have unique and conspicuous identities.

· Wetlands have poor drainage;

· The soil types within wetlands are seasonally or permanently under field capacity and are necessarily hydric.

· The vegetation types within wetlands are hydrophylous;

· The fauna are adapted to living under wet conditions;

· Their spatial extent and water levels fluctuate from season to season.

A wetland is a typical ecosystem. The plants, animals, soil, water, the micro-organisms etc., in a wetland are dependent on each other and are linked to one another. If one of he components were affected by an external impact, it imparts an adverse effect to the other components.

In relation to the definition rarified during the Ramsar's convention (Syria, 1971), in Article 1.1 "wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent of temporary, static or flowing, fresh, brackish of salty, including areas of marine water the depth of which at low tide does not exceed sis meters" . On top of this, the convention in Article 2.1 supplements that, "wetlands may incorporate riparian and coastal zones adjacent to wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within wetlands".

1.2 Classification of Wetlands

Wetlands are classified base on three preset criteria, namely genesis, spatial distribution and biological and physical characteristics. Based on their genesis, wetlands are classified into natural and anthropogenic (man made). Though their spatial extent is limited, man-made wetlands include fish and shrimp ponds, farm ponds, irrigated lands, salt pans, reservoirs, factory waste disposals, gravel pits, sewage farms and canals.

If their spatial distribution were considered, wetlands are classified in to coastal and inland. In relation to their specific characteristics, wetlands are classified tin coastal lagoons, marshland, alluvial fans, delta, lakes, estuaries and peat bogs. "The Ramsar convention on wetland classification has thirty wetland categories based on their basic biological and physical characteristics" (Hughes, 1994). According to the comments given by (Hughes, 1994) "the classification of wetlands by Dugan is one of the most straight forward .and includes seven basic landscape units".

1. estuaries;
2. open coasts;
3. flood plains;
4. fresh water marshes;
5. lakes;
6. peatland;
7. swamp forests.

1.1 The Importance of Wetlands

The importance of wetlands may be viewed in terms of their functions, values and attributes.

1.3.1 The different ecosystem components i.e., water, soil, plant, animals, micro-organisms, physical, chemical and biological interactions have enabled to perform the following vital functions.

· Wetlands increase the infiltration of water in to soil, thus act as 'surface detention'. Because of this, wetlands reduce flooding. On the other hand, the seepage in due course of time would increase groundwater levels.

· Wetlands prevent soil erosion. Wetlands interception plays a very significant role in reducing the rate of erosion. As flash flood or rivers encounter wetlands, its velocity dissipates. As a result, it would precipitate the sediment it has transported.

· Help to purify water and so keep wetlands and rivers clean. Some countries like the U .S.A and some European countries are beginning to create artificial wetlands to deal with water pollution problems.[2]India, everyday 176 million gallon of sewage is pumped in to a wetland a few kilometers east of the city of Calcutta. Within 10 days, this waste water is transformed in to clean water that can be used for irrigation, stock watering and fish farming" (Hughes, 2000).

· Wetlands remove or neutralize the effect of toxic chemicals. Phosphate, nitrogen, sodium, chloride, calcium, magnesium, potassium etc., are some of the chemicals which are present in wetlands. If their level of presence is above the permissible dose of concentration, they would become toxic. Wetland plants more than other forms of plants are capable of removing toxic chemicals from water and use them for their growth. Wetland vegetation are also capable of removing heavy metals like mercury which are very toxic. Over and above this, they are able to kill pathogens.

· Wetlands stabilize the micro-climatic conditions of adjacent lands, especially temperature and humidity.

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• Wetlands serve as water storage, storm protection, thus stabilize shoreline.

• They play pivotal role in groundwater recharge and discharge.

2.2.2 The Values of Wetlands

Wetlands have appreciable values. This may be in terms of fulfilling man's basic requirements or for his economic activities etc. To site example, some of the most important values of wetlands are itemized as follows.

• Provision of potable water for human need including stock watering.

• Wetlands are among he most productive environments of the world. Because of this, they are one of the centers of biodiversity. So long they provide water for primary production, quite a large variety of plant and animals species depend on them for their survival. For instance, [2]estuaries are among the most productive systems of the world. The reason for this is due to the physical and chemical energy subsidies" (Goldman, 1983). According to some oceanographers estimations, [2]the mean net primary production of estuaries accounts for about 810 g per m^2 per year (Safyanov, 1987). Wetlands are habitats for birds, mammals, reptiles, amphibians, fish and invertebrate species. It is estimated that [2] of the 20 000 species of fish the world, more than 40% live in fresh water. Over 2/3 of world's fish harvest is linked to the so-called coastal upwelling zones and inland wetlands " (Barbier, 2004).

• Wetlands offer vital raw materials for industries. For instance, from soda lakes, sodium hydrocarbonate and sodium sesqauicarbonate sometimes also called as 'trona' or soda ash ($NaHCO_3$. $Na\ CO_3.2H_2O$) is extracted for the production of liquid or solid caustic soda.

• Wetlands are world's major arable lands. For one's recollection, 'the fertile crescent'(Mesopotamia0 in history used to be wetlands. Paddy rice, sugarcane are important commercial crops grown in wetlands. The same is true of jutes.

• Peat bogs extracted from wetlands are energy sources for domestic consumptions.

• Wetlands are vital transportation media and recreational centers.

2.2.2 Attributes of Wetlands

Wetlands have special attributes which may be viewed interms of aesthetic, culture, religious etc. The following are some of the salient attributes of wetlands.

• In areas fringing lakes are used for ritual practices. For instance, the Oromo ethnic groups in Ethiopia have been exercising a ritual called Érefecha'. Analogous ritual like baptism is being practiced by orthodox believers.

• Wetland are sources of aesthetic inspiration.

• Wetlands provide wildlife sanctuaries.

• Wetlands are excellent tourist attraction centers. Besides, crocodile farming for their leather and meat, in some countries in East African Rift Valley Lakes has been an important foreign currency generating centers.

3. Objective

The study peers achieving the following two principal objectives.

1. Through raster based image analysis, the identification of wetlands.
2. To instill the technical approaches so that, limnologists, hydrologists, environmentalist, agronomists can emulate the techniques to identify the potential Ramsar sites of the country.

4 Methods And Technical Approaches Persuaded

1.1 Image Processing

The image processing part of the activity may be tasseled in to data acquisition, image processing, information extraction and presentation.

3.1.1 Data Acquisition

The provision of tenable data from the visible up to the farinfrared (thermal) regions of the electromagnetic spectrum is one of the strongest asset of Landsat sensors. In view of this, unique vantage, Landsat ETM's sensor data was a preference in the study. Initially, care must be taken not to acquire Landsat ETM imageries of January, end of December or beginning of February. January is the month during which the sun becomes nearer to the earth. To nullify the tethering effect of the sun's gravitational pull, the earth would speed up its axial rotation for gaining more centrifugal force. The later creates satellite perturbation and the subsequent systematic error which is reflected in the data scanned by the satellite. Moreover, preference was made not to acquire cloud tinted, hazy and straked images which are the usual noises in satellite images.

The acquired Landsat ETM data was previewed and was found to be noise free. Though a Geocoded data, it was geo-referenced by first order polynomial transformation and bilinear resampling using twelve Ground Control Points i.e., tie points evenly distributed throughout the image. The georeferencing was ultimately accomplished by specifying the projection type (UTM) , spheroid (Clark 1880), the datum (Adindan Ethiopia) and the zone (37N) with RMS error (Root Mean Square Error) of 0.03 pixels.

2.2.2 Image Processing

Image ratio technique was chosen for three types of indicators, namely the wetness, brightness and areal green biomass. The three indicators would create a contrast of features so that subtle differences can be identified.

2.2.2.1 The Wetness Indicator

For the purpose, an absorptive band is essential. As a matter of fact, water is an asymmetric top (rotor) molecule. Its pyramidal molecular structure imparts it different moments of inertia in its rotational motion. All asymmetric rotor molecules have an absorptive band, because of this, water absorbs the infrared region of the spectrum, thus appears dark against the neighboring features. Therefore, in the image calculation, Landsat ETM band 4 (reflective infrared) band was loaded. The wetness indicator is given by the following formula.

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THE WETNESS INDEX OUTPUT

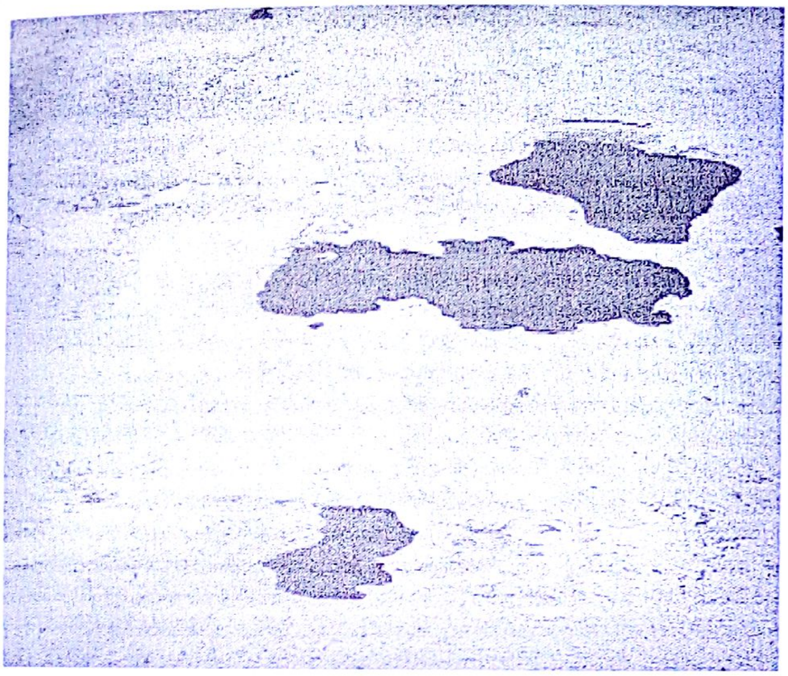

Plate (1) Wetlands in the Lakes region

THE COMPPOSITE OUTPUT

Plate (4) A composite image produced form wetness, bareness and arealgreen Biomass

$(x4 - x3) / (x4 + x3 + 0.01)$

Where:

X4 and x3 = Landsat ETM bands;

1.01 = is a constant added to avoid mathematical error when all the inputs are zero.

The output of the wetness indicator is exhibited in (Plate 1).

2.2.2.1 The Brightness Indicators

Is the sum of the input bands i.e., band 3, band 4 and band 5. The output of the image delineates bright areas from wetlands and vegetated areas. The brightness is given by the following formula.

$(x3 + x4 + x5)$

Where, x3, x4 and x5 are Landsat ETM spectral bands.

The output of the brightness indicator is exhibited in (Plate 2)

2.2.2.2 The Areal green Biomass indicator

The designation of the Landsat ETM bands ascribed to the following reason. So long as they are primary producers, terrestrial higher forms and aquatic macrophytes absorb the blue and red spectra from the so-called photosynthetic Active Radiation (PAR) which spans from 0.4mm to 0.7mm. The absorption of the blue and red spectra is for photosynthesis process. Higher form vegetation reflect medium in green and peak in the reflective infrared portion of the spectrum. The designation of Landsat ETM spectral bands is based on the following principle. As we have narrated above, band 4 contains vegetation spectral response in the reflective infrared while band 3 contains vegetation absorption of the red region of the spectrum for photosynthesis. In the image calculation the two bands were loaded. The NDLPI (the Normalized Difference Vegetation Index) is a good indicator to discrimi-

THE BRIGHTNESS INDEX OUTPUT

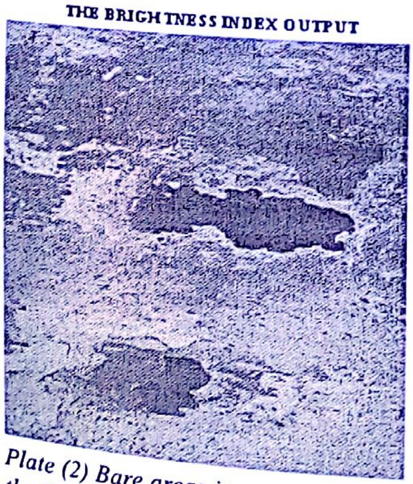

Plate (2) Bare areas in magenta within the Rift Lakes Region

THE GREENNESS INDEX OUTPUT

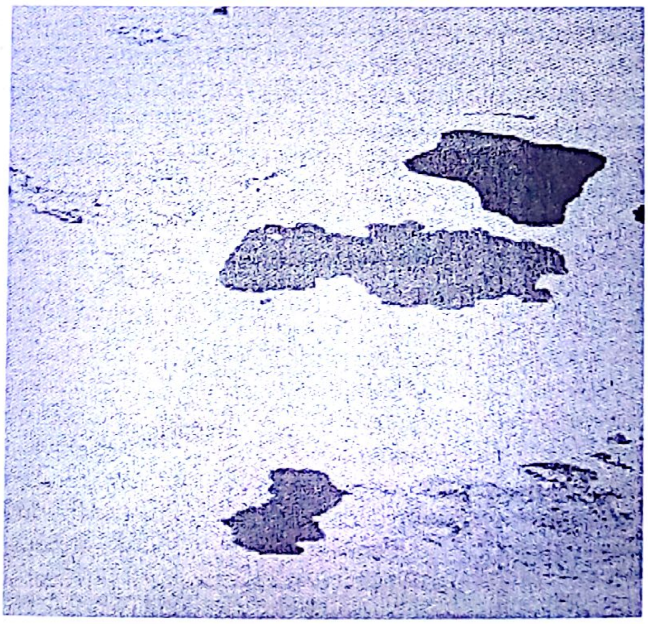

Plate (3)Areal green biomass within the Rift valley Lakes Region

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nate areal green biomass within the image frame. It is given by the following formula.

$$((x4 - x3) / (x4 + x3) +) * 127$$

Where:

X3 and x4 = Landsat spectral bands;

1 & 127 = constant to saturate radiometric values to their maximum dynamic range i.e. eight bit (2^8 = 256 grey levels).

The areal green biomass indicator (Plate 3) shows that the vegetated areas including aquatic macrophytes appear in red hue.

To see subtle differences in features, a composite image of the three indicators was produced, see (Plate 4).

The bareness, brightness and arealgreen biomass image ratio were attained using ILWIS software. If one were to use ERDAS IMAGINE 8x versions, the Tasseled Cap Transformation converts reflectance data from the individual image bands, which do not represent a quantitative evaluation tool to different image in which individual image bands represent the extent of brightness, greenness and wetness. The tasseled Cap Transformation optimizes the hyper ellipsoid multi-spectral image to the viewer's X and Y-axes. The TCT is based on three data structure axes, the greenness, brightness and wetness. The positive TCT coefficients signify positive loading while the negative TCT coefficients are negative loading. The Tasseled Cap Transformation

Wetland Areas

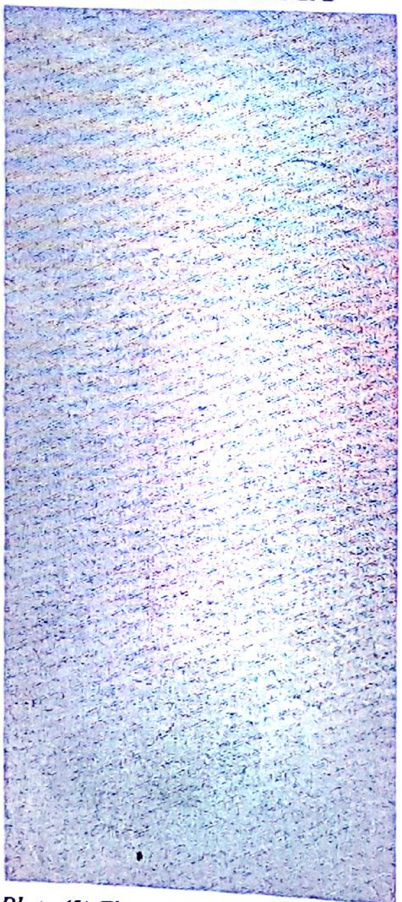

Plate (5) The Tasseled Cap Transformation output

Output has yielded analogous result, see (plate 5). Wetlands are in blue to cyan, green biomass is in light to deep green and bare land ranging from red to magenta.

In order to determine the spatial extent of wetlands, it is imperative to execute supervised or unsupervised classification, which would yield the areas in hectare. After the classification, it is possible to code the panchromatic image with pseudocoloring.

3. Conclusion and Recommendation

Wetlands are vital components of freshwater ecosystems and have great economic, environmental and cultural importance. This includes the provision of food source, raw material, and climatic modification, aesthetic, cultural, as habitats for many species of fish, fowl, other vertebrate and invertebrates.

Currently, wetlands all over the world have undergone succession with scaring social, economic and ecological consequences and costs. Conversions into agricultural land, construction of dams that would curtail the wetland seasonal replenishment. Thus, wetlands require persistent surveillance and monitoring. For the purpose, the technical approaches have far reaching significance.

The study has yielded profound results. The technical approaches persuaded to identify wetlands are very handy for hydrologists, limnologists, environmentalists and agronomists. Moreover, the technical approaches are very useful to determine the Ramsar sites of the county to be gazetted.

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Severity – Duration – Frequency (SDF) Analysis of Drought by using Geographical Information System (GIS)Case of: Abaya and Chamo Lakes basin, South Ethiopia

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Abstract

One of the famous and universally applied drought index known as Palmer Drought Severity Index (PDSI) was used to examine the drought parameters of the basin. This method used precipitation, evapotranspiration, soil moisture recharge and soil moisture loss as an actual and potential values as input data. The drought situation of the basin were studied by using 34 years (1970 – 2003) rainfall and mean temperature data from 18 stations which located in side the basin as well as the soil types to determine its available water holding capacity (AWC). The analysis shows that PDSI can be positive (moisture surplus) or it can be negative (moisture stress or drought) condition. Using the result of PDSI values of each station, SDF graph of the basin were developed. Based on SDF value of each station, the basin was regionalized by using of Arc View GIS environment.

Key words: PDSI, SDF, Drought index, GIS, return period, severity, AWC

1.Introduction

A part of Abaya – Chamo Basin (ACB) is a drought prone area. Through time the effects coming into an increasing manner, the expected main reason was the decreasing rate of rainfall amount in the basin. Therefore, the erratic distribution and less amount of rainfall from the long term mean value highly affects the production. As a result these can cause a problem of food security for the basin. Moreover in the basin farmers used mixed farming system; the problem of drought extends to their cattle's also. Severity, duration and frequency are drought parameters. By determining its magnitude and the return periods of certain duration of drought we can addresses some of the described elusive drought properties. Obviously, drought is unavoidable phenomenon but it can be mitigated through proper mitigation measures by studying the characteristics of its incidences.

The knowledge of regionalize drought maps are important to plan and manage the water resources potential of the basin. And also these maps are important to provide information about the recurrence behavior of drought for people's living inside the basin.

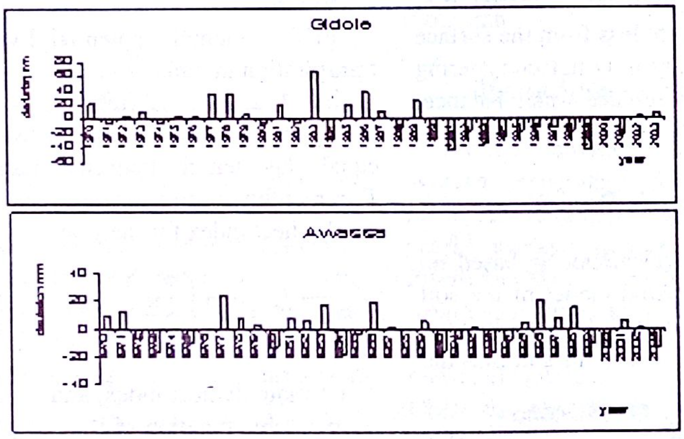

Fig1 Typical rainfall pattern at Gidole & Awassa

2. Drought Definition and its Indices

There is no universal definition of drought but some authors tried to define. These available definitions of drought might be categorized as either *conceptual or operational*. With conceptual, it refers to those definitions in general term to identify the boundaries of the concept of drought. For example "a long period with no rain, especially during the planting season." Conceptual definitions provide little guidance to those who wish to apply them to current (i.e. real – time) drought assessments. Drought is frequently defined according to disciplinary perspective. These definitions of drought are clustered in to four types: meteorological, agricultural, hydrologic, and socioeconomic (Donald, 1987). Generally the drought is expressed by using indices. Different indices can interpret drought in different time period, parameters and concept. For this paper the Palmer Drought Severity Index (PDSI) is used.

Palmer Drought Severity Index *(The Palmer; PDSI)*

In 1965, W.C. Palmer developed an index to measure the departure of the moisture supply (Palmer, 1965). Palmer based his index on the supply-and-demand concept of the water bal-

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ance equation, taking into account more than just the precipitation deficit at specific locations. The objective of the Palmer Drought Severity Index (PDSI), to provide measurements of moisture conditions that were standardized so that comparisons using the index could be made between locations and between months (Palmer 1965). The PDSI is a meteorological drought index, and it responds to weather conditions that have been abnormally dry or abnormally wet. When conditions change from dry to normal or wet, for example, the drought measured by the PDSI ends without taking into account stream flow, lake and reservoir levels, and other longer-term hydrologic impacts (Karl and Knight, 1985). The PDSI is calculated based on precipitation and temperature data, as well as the local Available Water Content (AWC) of the soil. From the inputs, all the basic terms of the water balance equation can be determined, including Evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. The analysis is not considering human impacts on the water balance, such as irrigation.

3. Analysis Procedure

The PDSI calculation is based on supply and demand model of the soil moisture at a location. The supply is the amount of moisture in the soil plus the

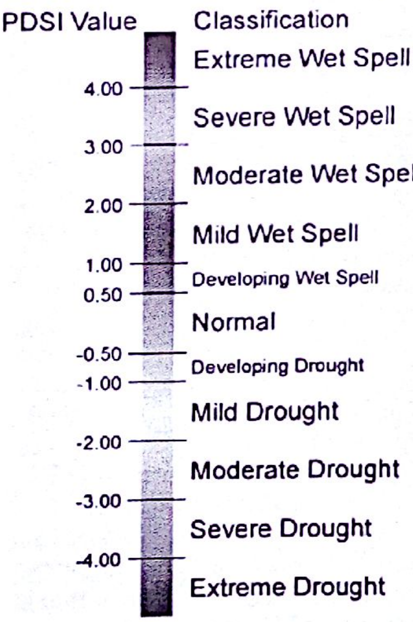

Fig. 2 PDSI value classification

amount that is absorbed into the soil from rainfall. The demand, however, is not so as easy to see, because the amount of water lost from the soil depends on several factors, such as temperature and the amount of moisture in the soil. This method used evapotransiration, runoff, soil moisture recharge and soil moisture loss all in its potential and actual values as input parameters.

A. Potential Values of Input Data

***Potential Evapotranspiration*, PET** is calculated using Thornthwaite's method. Thornthwaite's method is calculating PET in monthly basis.

An Empirical formula to determine Potential Evapotranspiration (PET) developed by Thornthwaite's is given by

$$PET = 16 * N_m \left(\frac{10 * T_m}{I}\right)^a \quad (1)$$

Where

PET = monthly potential Evapotranspiration in mm.

m = 1, 2, 3……12 (month)

N_m = is a factor to correct for unequal day length between months.

T_m = monthly mean temperature in °C.

I = heat index for the year.

$$I = \sum i_m = \sum \left(\frac{T_m}{5}\right)^{1.5} \quad (2)$$

i = monthly heat index, and

a = cubic function of I.

$$a = 6.7 * 10^{-7} * I^3 - 7.7 * 10^{-5} * I^2 + 1.8 * 10^{-2} * I + 0.49 \quad (3)$$

Potential Recharge, PR is the amount of water that could be absorbed by the soil, or the difference between the AWC and current soil moisture, so

$$PR = AWC - S_{i-1} \quad (4)$$

Where S_{i-1} – soil moisture content at the end of previous month or at the beginning of current month.

Potential Runoff, PR_O is calculated assuming any precipitation that falls is absorbed until the ground is saturated, and then the rest runs off. Thus, PR_O is the difference between the potential precipitation and the amount of moisture the soil can absorb. *Palmer decided to set the potential precipitation to AWC*, and the amount of moisture the soil can absorb is simply PR, so

$$PR_O = AWC - PR \quad (5)$$

Potential Loss, PL is slightly different; it involves the value of PET.

1. $S_{i-1} >= PET_i$, the moisture in the soil is enough to meet the demand, so the most moisture that can be lost is the amount in the soil.

$$PL = PET \quad (6)$$

2. $S_{i-1} < PET_i$, the moisture in the soil is not enough to meet the demand, therefore

$$PL = S_{i-1} \quad (7)$$

B. Actual Values of Input Data

Along with these four potential values (PET, PR, PR_O, and PL), their corresponding actual values (AET, R, R_o, and L) are also calculated depending on the relationship of precipitation P, PET, and the soil moisture model.

The moisture in the soil can be used up, when demand is higher than supply and to be recharged when there is a surplus of Precipitation and deficit of soil moisture. The maximum recharge is up to Available Water Content (AWC), which is the maximum water holding capacity of the corresponding soil type. There are several cases, sub cases, and sub-sub cases to consider determining how much moisture is gained or lost for each soil. The following relation shows the general relationship of water balance equation:

If $P_i >= PET_i$, then
a. $AET_i = PET_i$
b. $L_i = 0$

If $(P_i - PET_i) > AWC - S_{i-1}$, then
a. $R_i = AWC - S_{i-1}$
b. $Ro_i = P_i - (PET_i + R_i)$
c. $S_i = S_{i-1} + R_i$

II. If $(P_i - PET_i) <= AWC - S_{i-1}$, then
a. $R_i = P_i - PET_i$
b. $Ro_i = 0$
c. $S_i = S_{i-1} + R_i$

2 If $P_i < PET_i$, then

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a. $R_i = 0$
b. $Ro_i = 0$
c. $AET_i = P_i + L_i$

If $S_{i-1} > (PET_i - P_i)$, then
a. $L_i = PET_i - P_i$
b. $S_i = S_{i-1} - L_i$

If $S_{i-1} <= PET_i - P_i$, then
a. $L_i = S_{i-1}$
b. $S_i = 0$

Water Balance Equation

A. Moisture Departure, d

The Moisture Departure, d is basically the deficit or surplus of moisture for a given month. It is calculated by using the following formula:

$$d = P - \hat{p} \quad \text{.................................(8)}$$

Here, P is the precipitation and $\hat{p}$ is the CAFEC (Climatically Appropriate For Existing Conditions) precipitation. is calculated as follows:

$$\hat{P}_i = \alpha_m .PET_i + \beta_m .PR_i + \gamma_m .PRo_i - \delta_m .PL_i \quad (9)$$

are coefficients, the subscript $_m$ refers to the month of the year any they are determined by the following formulas:

$$\alpha_m = \frac{\sum_{all\ years} AET_m}{\sum_{all\ years} PET_m} \quad (10)$$

$$\beta_m = \frac{\sum_{all\ years} R_m}{\sum_{all\ years} PR_m} \quad (11)$$

$$\gamma_m = \frac{\sum_{all\ years} Ro_m}{\sum_{all\ years} PRo_m} \quad (12)$$

$$\delta_m = \frac{\sum_{all\ years} L_m}{\sum_{all\ years} PL_m} \quad (13)$$

B. Moisture Anomaly, Z

The moisture departure, d, is the deficit or surplus of moisture, adjusted for the seasonal changes in climate.

$$Z = dk \quad \text{.......................................(14)}$$

Where

d = Moisture Departure
z = Moisture Anomaly
K = Climatic Characteristics

The value of K changes depending on location and time of year, as is evident in the following formulas used to calculate it.

$$K_m = \frac{17.67}{\sum_{m=1}^{12} \overline{D}_m K'_m} K'_m \quad (15)$$

Where the value of 17.67 is an empirical value that Palmer derived.

$$K'_m = 1.5*\log_{10}\left[\frac{\frac{\overline{PET}_m+\overline{R}_m+\overline{Ro}_m}{\overline{P}_m+\overline{L}_m}+2.8}{\overline{D}_m}\right]+0.5 \quad (16)$$

$$\overline{D}_i = \frac{\sum_{all\ years} |d_i|}{N} \quad (17)$$

Where, N - Number of years record

C.The PDSI

Based on the above moisture departure and moisture anomaly values the drought index i.e. the PDSI is calculated. The PDSI itself can now be calculated using the following formula 4.

$$PDSI_i = 0.897 * PDSI_{i-1} + \frac{1}{3} Z_i \quad (18)$$

Where the subscript (i) and (i-1) indicate current and previous months respectively, and $PDSI_0 = 0$.

Data Analysis & Results

Rainfall, P

In most stations the distribution of rainfall has bimodal pattern. The first high rainfall was observed from March to May and the next high rainfall was observed from July to November. This shows that there are two cropping seasons per year. Therefore, moisture deficit occurred either one season only or both seasons and it may also extend for the next third consecutive seasons.

From 18 stations the minimum monthly average rainfall was recorded at Mirab Abaya (61.04 mm) and in the contrary the highest average monthly rainfall was recorded at Yirga Chefe (131.30 mm).

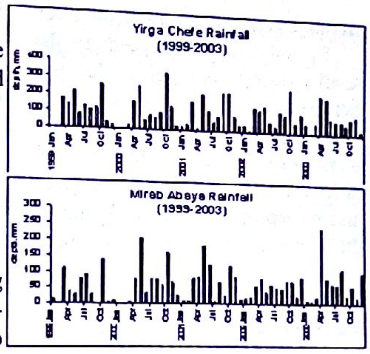

Fig 3: Rainfall Distribution Pattern for Mirab Abaya & Yirga Chefe stations for the selected year interval

Analyzing variation from the mean is important to determine the anomalies of rainfall. The highest standard deviation was shown at Yirga Chefe (111.38mm) and the lowest rainfall variation was shown at Awassa (56.72mm).

Mean Temperature, T

From 18 stations the highest yearly average temperature was occurred at Mirab Abaya (23.35°C) and the lowest yearly average temperature was at Fiseha Genet (17.37°C). But anomalies from mean temperature shows that the highest standard deviation was observed at Gidole (3.36 °c) and at Yirga Chefe the lowest value was observed i.e. 0.94 °c.

Potential Evapotranspiration, PET

For a station, if the difference between potential evapotranspiration and rainfall values for a specific month is small, roughly it can be concluded that the rainfall satisfies the PET demand of that month. A higher gap means there is an indication of moisture stress or moisture surplus in the area. A higher negative difference between mean rainfall and mean PET shows a higher moisture stress whereas a higher positive difference shows moisture surplus. Generally, a higher negative value was takes place at Mirab Abaya (-39.65mm) and a higher positive value was takes place at Yirga Chefe having a value of 63.97mm.

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Actual Evapotranspiration, AET

The value of AET depends on the supply condition of water i.e. the rainfall and the existing soil water content. If AET equal to PET, it shows that there is no moisture stress in the area. The difference between PET & AET gives hint on moisture condition. A higher difference between the two values shows a higher deficit on moisture supply. But AET by it self doesn't indicate the deficit and surplus of moisture in the soil. A higher variation was observed at Mirab Abaya i.e. its mean monthly PET value was 100.69 mm whereas the mean monthly AET was 55.71 mm.

Relation between Rainfall, Mean Temperature and PDSI Value

The following figure (Fig 4) shows that the condition at Arbaminch in the period from 1999 to 2003. Roughly, it shows that when the rainfall value is at increasing the corresponding mean monthly temperature is at relatively at decreasing value. As the result PDSI has a positive value i.e. it is wet spell and the reverse also true. But the previous month value of rainfall and temperature are influences the above remarking statement. For other stations, the relation between rainfall (P), mean temperature (T) and the corresponding PDSI value is similar to the above condition.

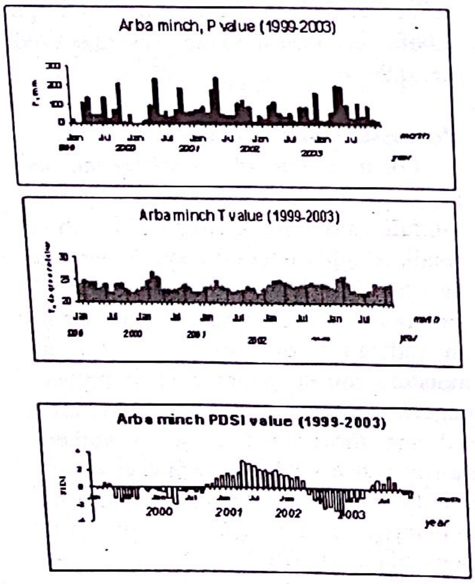

Fig 4: Relationship between P, T and PDSI for a typical station (Arba Minch)

Sensitivity Analysis

It is obvious that the variation of input data affects the output (PDSI value). But the degree of influence is different. Such characteristic of input data on output is evaluated by sensitivity analysis. High sensitive data means the influence on the result is significant. Therefore, by sensitivity analysis it can be evaluated which parameter has a great role to influence the PDSI value. The result shows that, if the rainfall amount reduced by 50% the corresponding average change of deviation of PDSI is by 50%. And also if PET value reduced by 50% the corresponding PDSI value is changed by 90%. Therefore, the analysis shows that PDSI is more sensitive on the change of PET value than rainfall i.e. PDSI is highly depends on mean temperature because PET value is mainly the result of mean temperature.

Drought Parameter Evaluation

The drought parameters are severity, duration and frequency. Each of these parameters is independent values. But the combination of these three parameters gives a logical meaning for drought monitoring.

Drought Severity

Severity shows the degree of moisture deficit or surplus. It can be expressed based on PDSI values (Fig 2) and it is calculated by equation 18 above.

For this analysis, drought occurs when PDSI is less than or equal to -1.00 (from mild drought to extreme drought). Mild drought (PDSI between -1.00 & -2.00) means, the degree of severity is low and the moisture deficit can be recovered by less amount of rainfall compared to moderate drought (PDSI between -2.00 & -3.00) and so on.

Drought Duration

The duration of drought is the number of successive months that which the PDSI value is in *mild, moderate, severe or extreme* conditions. A cumulative drought is the summation of all types of drought occurred within a certain return period successively i.e. it considers the worst combination of all forms of drought. Most of the time one follows the other, but sometimes it occurred randomly.

When counting the length of drought duration, a single wet month between dry periods doesn't show the drought was an end.

Drought Frequency

Drought frequency is the return period (in years) of a specified duration and severity of drought. The frequency is analyzed in a period of 8, and 10 years return periods. The method employed to determine the frequency of drought is by counting the specified drought severity and its duration at a station then by arranging its distribution by weibull plotting formula.

In general, the return period of mild drought is more frequent than moderate drought and so on.

Severity - Duration – Frequency (SDF) values

SDF value illustrates the severity of certain duration of drought having a specified return period (frequency). For most of stations when the degree of severity increases the corresponding duration for a specific return period are decreases. Based on SDF values the basin was regionalized. Regionalizing means delineating areas having similar values of SDF together; it is well suited for decision making procedures.

Predicting Drought Occurrences

Past experience was important to forecast for future events. So that past occurrence of drought severity, duration and frequency repeats it self in the future. For simplicity 8 and 10 years return periods are analyzed for 18 stations. Based on these data the point data were changed into area data by linearly interpolating between stations. These gives SDF curves of the basin. By doing so, it can be regionalize the basin based on drought parameters. Thus the results are interpreted by the help of Arc View GIS using different colors. Similar color shows areas having equal SDF values.

8 years Return Period Drought

The eight years return period drought expresses that the length of drought in months occurred within eight years. In this case the frequency

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of drought is constant i.e. 8 year but the duration and severity is variable depending upon locations.

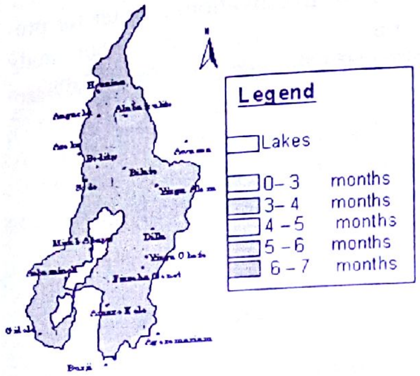

Fig 5: MD – 8 maps

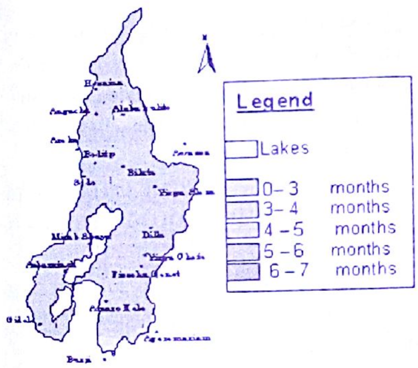

Fig 6: MoD – 8 map

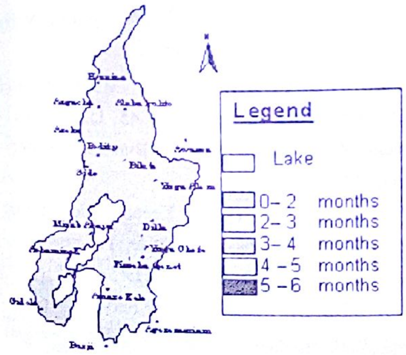

Fig 7: SD - 8 map

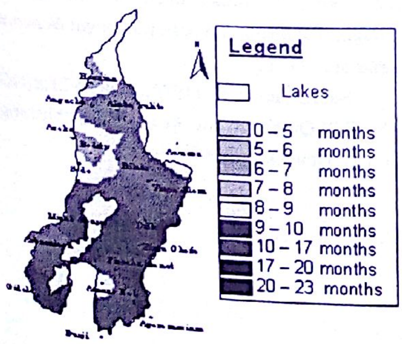

Fig 8: CUM – 8 maps

Mild Drought (MD- 8)

MD – 8 means mild drought 8 years return period. MD – 8 map displayed by Fig 5, the map shows that 85 percent of the basin areas have duration of less than 5 months and around Mirab Abaya the duration extends to 6 – 7 months.

Moderate Drought (MoD- 8)

MoD – 8 means moderate drought having 8 years return period. MoD – 8 map shown by Fig 6, the map depicts that most of the eastern part of the basin areas have drought duration of 3 – 4 months and the western part of the basin areas have a duration of less than 3 months. Around Alaba Kulito, Burji and Ageremariam small areas have 4 to 5 months of moderate drought.

Severe Drought (SD- 8)

Severe drought having 8 years return period is abbreviated by SD – 8. Fig 7 shows, most of the area have less than 2 months of severe drought. Near to Gidole, Fiseha Genet and Yirga Chefe the length of drought extends to 3 - 4 months

Cumulative Drought (CUM- 8)

CUM – 8 means a cumulative drought having eight years return period. It shows that the length of drought occurs during this period is greater than six months. Hence in the basin all areas are affected by drought. A minimum duration will occur around Bodity which have 6 to 7 months of drought. In the vicinity of Gidole, Alaba Kulito, western and eastern border areas of Abaya Lake at least one completely failure of production for both season will be happen within eight years, for other areas the condition of drought will be between this two events and it is illustrated by Fig 8 bellow. The duration of drought will be increase from north to south of the basin.

10 years Return Period Drought

The ten years return period drought in different severity conditions are shown by the following successive figures. Showing the different trends of drought, it is important to think over its convalescence opportunity.

Mild Drought (MD- 10)

MD – 10 means mild drought 10 year return period. MD – 10 maps illustrated by Fig 9, the map shows that 58 percent of the basin areas have duration of less than 5 months of mild drought and close to Mirab Abaya small area have 7 to 8 months of mild drought.

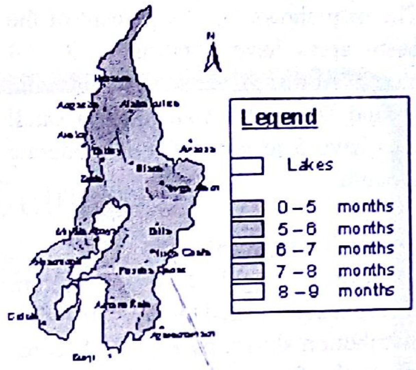

Fig 9: MD – 10 maps

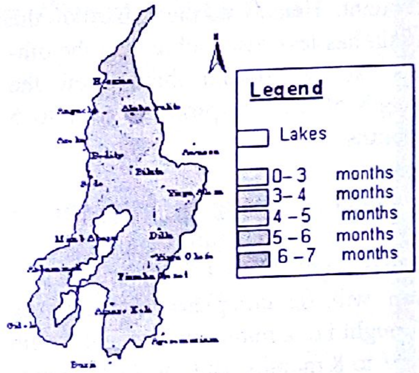

Fig 10: MoD – 10 maps

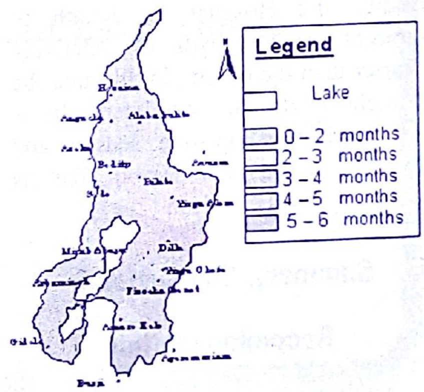

Fig 11: SD – 10 maps

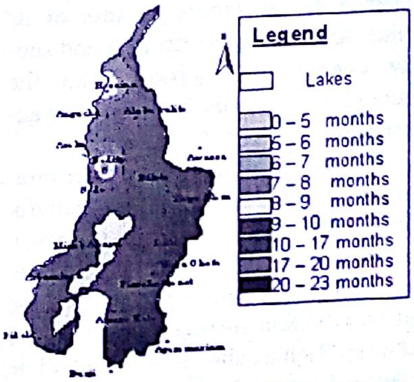

Fig 12: CUM – 10 maps

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Moderate Drought (MoD- 10)

Moderate drought having 10 year return period is abbreviated by MoD – 10 and it is clarified by Fig 10 bellow. The map shows that 68 percent of the basin areas have duration of 3 – 4 months of moderate drought and around Burji and Alaba Kulito small area have 5 to 6 months of moderate drought.

Severe Drought (SD- 10)

Severe drought of 10 years return period is abbreviated by SD – 10 and its distribution shown by Fig 11. According to the figure most of the northern part (it covers 50 percent of the basin) have less than 2 months of severe drought. Hence, northern part of the basin has less susceptible than the others but area around Yirga Chefe the length of drought prolongs to 4 to 5 months.

Cumulative Drought (CUM- 10)

The 10 year return period cumulative drought shows that at least one season will be completely affected by drought i.e. a minimum drought length of 7 to 8 months. But most of the area (92 percent) will be completely lost both season productions. Around Bodity and Hosaina the length of drought moment will be relatively shorter than the others. In this area the drought length can completely affects the production on one season and slightly on the next season. This is shown by Fig 12 bellow.

Summary, Conclusion & Recommendation

Different literature's concludes that PDSI method of drought evaluation is superior to the others because of its value depends on the demand and supply concept of moisture. But the method doesn't consider man made adjustments like Irrigation practices.

Almost, in all the stations the rainfall distribution has a bimodal pattern. This shows that two cropping season per year. It is important because, if one season fails the next season covers the problem within relatively short period of time. High trouble of drought will be expected when the length of drought extends to both seasons and a more catastrophic when it extends to the third consecutive seasons.

The main input data for PDSI are rainfall, evapotranspiration, soil moisture recharge and soil moisture loss both its potential and actual values and also available water holding capacity of the soil. But all input data were resulting from either rainfall or mean temperature. Therefore, the sensitivity analysis shows that PDSI is more sensitive on temperature.

In order to regionalize the basin, the point SDF value at a station should be changed to areas value by linearly interpolating between stations. The result was essential to show drought maps of a basin. These maps were used to know the coverage of a specific type of drought. For example, from the map a mild drought having less than 5 months of drought duration occurred within 10 year return periods covers 58% of the basin areas similarly; a moderate drought having less than 3 months of duration occurred within 10 year return periods covers 9% of the total basin area. From this, it can be conclude that the rate of raising drought duration for moderate case is higher than mild.

A successive drought maps shows that, the most drought prone areas are located at the southern part of the basin comparatively around Gidole, Mirab Abaya and Burji than the northern part of the basin. But the result may be doesn't make proportionate to the recent available conditions what people observing it because of the study doesn't consider the existing irrigation practices.

Recommendations

Rainfed agriculture in areas which are frequently affected by drought is not possible, therefore in such areas it should be construct irrigation schemes in order to reduce the hazards of drought. But sometimes to construct irrigation schemes in drought prone areas may be difficult due to lack of enough and good quality of water and also available irrigable land. In that case less drought prone areas should be selected to resettle the population from high drought prone areas.

Integrated environmental managements like protection of natural resource from erosion, wild fire etc must be considered together with drought management strategy.

This investigation is better for preliminary reference for further study about the drought situation of the basin as well as to extend the studying area.

The study focused on only meteorological drought but for better analysis in addition to this agricultural drought assessment is important.

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