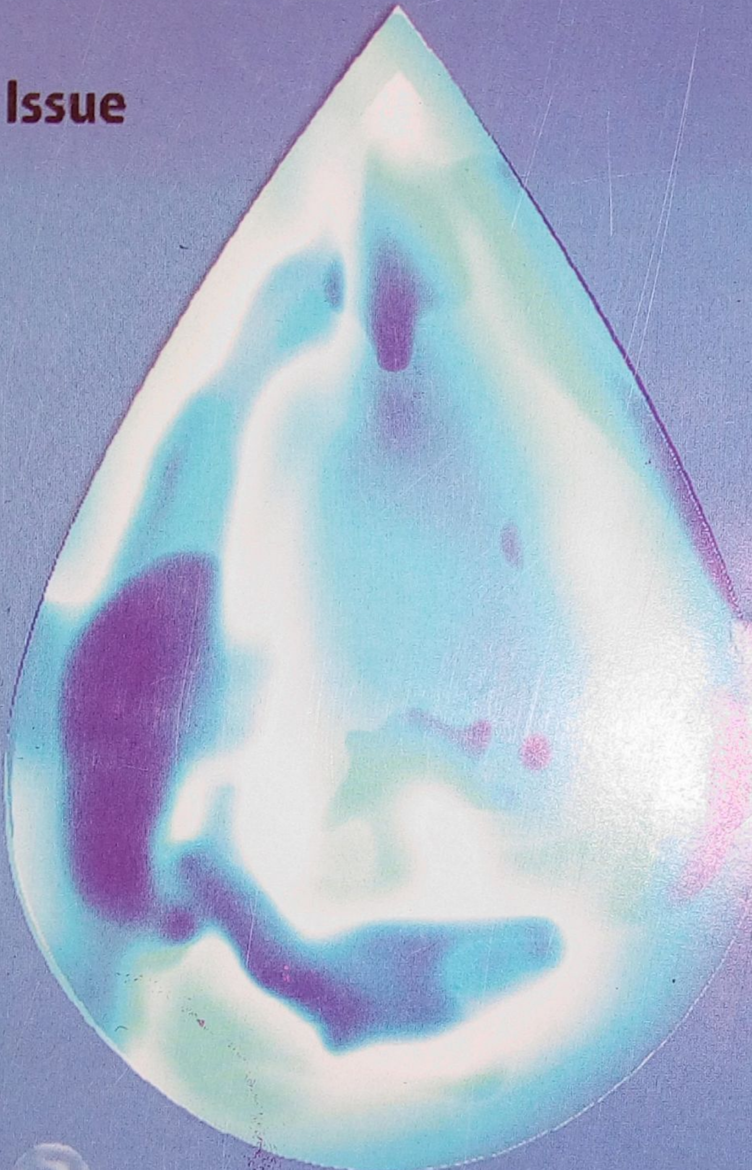
# Water

## Ethiopian Journal of Water Science and Technology

**Special Issue**



Proceeding of the 13th Symposium on Sustainable Water Resources Development Held at Arba Minch University from June 27-28, 2013

Arba Minch

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Ministry of Water & Energy

MOST

Community Management project Approach

IWMI International Water Management Institute

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# Water

## Ethiopian Journal of Water Science and Technology

ISSN: 222-07643

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The Water Journal publishes original research papers which are of international significance in the fields of water science and technology that encompass water resources and management, hydrology, hydraulic and hydropower, water and environment, irrigation and drainage, water management and institutions, hydrometeorology, water management and development technologies, water resources and climate change. In addition to these areas the journal invites also papers related to efficient utilization of water, soil and water conservation, management of extreme hydrological events (flood and drought), water harvesting etc.

Guidelines for authors can be requested and obtained from the editorial office at Arba Minch University

## Content

## Foreword from the editor

Water is the most important natural resource upon which all life on earth depend. It plays a pivotal role in health, economy, energy, food production , and environmental sustainability etc. However, its availability in the required quantity  and quality is increasingly threatening the development endeavours of humankind. With increasing population, demand for good quality water also increases and the available water per capital will decrease. It is also widely recognized that the available water must be shared not only by humans but also by terrestrial ecosystem.

The four Dublin Principles state that, firstly, freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment; secondly, water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels; thirdly, women play a central part in the provision, management and safeguarding of water; and fourthly, water has an economic value in all its competing uses, and should be recognized as an economic good. These principles have got universal support from the international community as the foundations of integrated water resources management, a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Sustainable development is an organizing principle for human life on this planet with scarce resources. It envisages a desirable future state for human societies in which living conditions and resource-use meet human needs without undermining the sustainability of natural systems and the environment, so that future generations may also have their needs met. In Ethiopia, the recognition of water as a mean of sustaining agricultural production (irrigation) and generation of energy to enhance economic growth is increasingly developing. Consequently several projects have been implemented during the last few years and many more are in the process of implementation. The country is seriously addressing the issues of climate change and natural resources conservation in its development programs. Examples for this are program of climate change resilient green economy and widespread activities of afforestation and soil water conservation. There is no doubt that researches can contribute to the effectiveness of these activities and sustainability of the results of the development programs. Definitely there are several researches and project studies conducted allover the country in the areas related to water resources development whose result need to be communicated and shared. Arba Minch University has been organizing symposia on "Sustainable Development of Water Resources" for the last consecutive 13 years.

The objectives of these symposia were to create a platform for researchers, professionals from wider ranges of disciplines such as water resources, energy, environment, agriculture, and climate change as well as practitioners, decision-makers and development agents to come together and share experiences and knowledge by presenting papers, displaying products and technologies that address sustainable water resources management and development. This year the symposium marks the 13th cycle in the series. The organizing committee has received more than 45 papers in different thematic areas announced in call for papers. After review process, about 23 pares have been selected for oral presentation and 10 papers for poster presentation. This proceeding provides full contents of 20 presented papers during the symposium. I believe that the research results presented in these papers can be useful references for the readers. On behalf of the organizing committee and myself I thank all contributors to this Symposium.

Mekonen Ayana, Ph.D
Director, Water Resources Research Center
Editor

## Welcome Address

**Dr. Negash Wagesho, Scientific Director, Institute of Technology**

**Dear Distinguished Guest,**
**Dear University Officials,**
**Dear Scholars and Research Paper Contributors,**
**Dear invited Participants,**

**On Behalf of Arba Minch Institute of Technology and myself as well I would like to welcome you all to this 13th symposium on Sustainable Water Resources Development hosted by Arba Minch University, Arba Minch Institute of Technology.**

**Arba Minch University has been organizing and hosting the sustainable water resources development symposium in series for the last thirteen years, i.e for about half-life of the university. Its contribution while sharing various scientific research outputs among researchers from home and abroad, the academic community and other stakeholders has been becoming manifold. The symposium remain unique in its kind at national level and given top priority by the University and its close partners over the last decade plus years while ensuring academic and research excellence in water resources engineering sector. This has been testified from the vast majority of high caliber research papers contributed every year. Over the years, the symposium was supported/sponsored by both national institutions such as Ministry of Water & Energy and Regional Water Bureaus and international organization such as GTZ.**

**Our two-days symposium is focusing on the following five thematic areas**

- **Hydrology and Integrated Water Resources**
- **Renewable Energy**
- **Irrigation and Drainage**
- **Water Supply and Sanitation**
- **Emerging Challenges – Climate Change**

**With this brief introduction I once again welcome you all to Arba Minch University and expect a very fruitful discussions and deliberations.**

**I would like to invite Dr. Feleke, President of Arba Minch University to provide an opening speech and bless our distinguished guests, contributors and participants gathered from across the country.**

**Thank you.**

## Opening speech

**Dr. Feleke Woldeyes, Arba Minch University President**

**Dear Workshop Participants**
**Ladies and Gentlemen,**

**First and foremost it gives me great pleasure to welcome you all to this 13th Symposium on Sustainable Water Resources Development.**

**Water is an indispensable natural resource upon which all lives depend on. Hence water security is crucial to sustain life. When we say water security, we are referring to a situation of reliable and secure access to water over time. Some regions are characterized by abundant physical water resources whereas others are suffering from water scarcity. Capacity to harness the available water resources so as to ensure its availability and accessibility in the required quantity and quality is also different from country to country.**

**With increasing population and improved living standards the demand for good quality water also increases. However, water scarcity is threatening many regions of the world and hence more than 1.2billion people in the world lack access to this important resource.**

**With regards to water availability, literature makes distinctions between physical, economical and technical water scarcity. Although Ethiopia is considered as a country with vast water resources potential, the availability and accessibility of water both in terms of quantity and quality to different uses has been limited. This was mainly accounted to lack of the required technical and financial capacities and capabilities to harness our water bresources potential. Hence, as per the definitions of literature, Ethiopia has been belonging to one of those regions suffering from economical and technical water scarcity.**

**Generally, the term water scarcity describes the relationship between demand for water and its availability. Not only the availability but also the demands may vary considerably between different regions within a given country, depending on the sectoral usage of water. Agricultural sector has been considered as the dominant user of freshwater. However, with the development of industries and urbanization, demand for water is also increasing from industrial and domestic uses. Sustenance of ecosystem functions also requires water of specific quality and quantity. With increasing population growth and demand for food production the water demand will increase. Therefore, efficient allocation of water among different uses including ecosystem is required.**

**The freshwater cycle in Ethiopia is governed by 12 major river basins with annual runoff potential of 123 BCM. These rivers are feed by heavy winter rainfalls over Ethiopian highlands which makes most often concentration times of flows short. As a result high water availability periods or peak runoff times are concentrated to only 3 to 4 months of the year. This uneven distribution of water makes water storage crucial to ensure sustain economic growth and eradicate poverty. Our water storage facility per capacity is among the least in the world which requires attention.**

**Following the results of river basin master plan studies, we are progressing to implement water resources development projects in many of our river basins. In the course of project identification, feasibility studies, design, construction and operation of our water resources projects, we follow international standard procedures of social and environmental impact assessments. As these projects are created with huge investments, sustaining their positive impacts requires minimizing possible negative social and environmental impacts.**

**With increasing population our watersheds are increasingly threatened by poor land use systems such as deforestation, overgrazing, over-cultivation and so on. With this regards, the consequences of land degradation and soil erosion on water resources development infrastructure is becoming priority concern.**

Silting-up of water storage structures like dams and reservoirs as well as irrigation canals are major problems we are facing. Parallel to investments in development of new projects, due emphasis should be given to integrated watershed management.

Many soil and water conservation efforts are underway in different regional states of our country. These interventions need to be supported by scientific knowledge to sustain their positive impacts.

Climate change and variability is another emerging issue that deserves attention. The Sub Saharan part of Africa in general has been affected by major drought and flood events over the last Century. The adverse effect of such climate variability has significantly been observed on agriculture, water supply and hydropower sectors in Ethiopia. In order to minimize the negative consequences of ensuing climate variability, introduction of appropriate climate change adaptive mechanisms at different levels and development of climate resilient green economy is vital.

Our water resources development and management endeavors need to be supported by scientific researches. However, research capacities and experiences in water resources are still at infant stage. The existence and availability of water is affected by the interaction of many environmental and socio-economic factors. Its trans-boundary nature connects different nations and nationalities with different levels of economic development, cultures and values. Research is important to generate information and knowledge related to the likely change in demand and supply of water in different time horizons, socio-economic and environmental impacts of intervention, adoption and adaptation of appropriate technologies to enhance efficient use of water and so on.

To contribute to the research capacity building, Arba Minch University has completed the necessary preparation to launch PhD program in Water resources engineering. The first batch of PhD candidates will be admitted as of the beginning of the next academic year.

I am informed that several research papers addressing various areas of water resources are selected and ready for oral and poster presentation. This platform will definitely create opportunity for you to share experiences, exchange ideas, disseminate your results and learn from each other.

Ladies and Gentlemen,

Finally, I would like to thank the financial contribution of Ministry of Science and Technology, Community Managed Project Approach (CMP) in the Ministry of Water resources and Energy, Water Works Design and Supervision Enterprise and International Water Management (IWMI). I thank also the organizing committee of this symposium who has worked hard to realize this.

I wish you fruitful deliberations during these two days and declare that the symposium is officially opened.

Thank You.

# Field experimentation based simulation of yield response of maize crop to deficit irrigation using AquaCrop model

**Yemane Gebreselassie[1], Mekonen Ayana[2] and Kassa Tadele[2]**
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## Abstract

*This experiment was conducted during February to June 2012 in Demonstration farm of Arba Minch University located in the central rift valley of Ethiopia. The aim was investigate the effects of different levels of deficit irrigation imposed at different growth stages of maize (BH-140) crop on its development, grain yield and water use efficiency. AquaCrop Model was calibrate and validated using field experimentation data. The crop water requirement of maize for full irrigation application was calculated using CropWat 8.0. The water application levels considered were 100%ETc, 75%ETc, 50%ETc and 25%ETc. The crop was imposed to these water application levels during different growing stages. Accordingly there were ten treatments including a control treatment. These treatments were replicated three times. Data collected during the experiment were: crop biomass, soil moisture content, irrigation depths and final yield.*

*The result showed that the highest yield was found in T6 (8842 Kg/ha) which was subjected to water deficit during mid- and maturity-stages; whereas minimum yield of about 5264 Kg/ha was obtained under T8 which was irrigated imposed to deficit during the whole growing season except during the initial stage. The highest (2.11 kg/m$^3$) and lowest (0.93 kg/m$^3$) water use efficiency was recorded under T8 and T4.*

*Generally, water deficit of 50%ETc during third and fourth growth stages had no significant effect on the grain yield of maize and it is worthwhile to save irrigation water during these growth stages.*

*The model performed well in simulating the growth of aboveground biomass, grain yield, and canopy cover (CC) for most of the treatments but it was less satisfactory in simulating the growth performance of treatments under prolonged water-deficit. The fact that the AquaCrop model is easy to use, requires less input data, and its sufficient degree of simulation accuracy make it a valuable tool for estimating crop productivity under deficit irrigation, and on-farm water management for improving the efficiency of water use in agriculture.*

## 1. Introduction

Globally, irrigated agriculture is the dominate user of fresh water. Water is becoming scarce and hence irrigation water supplies are decreasing in many areas of the world. Climate change predictions of increase in temperature and decrease in rainfall mean water will become increasingly scarce.

Generally Ethiopia is considered as water abundant country. However, water availability for crop production is highly erratic both in space and time. Where in some areas there is substantial rainfall and surface runoff during some months of the year while in others there are high dry spell periods (Awulachew et al., 2007). This calls for storage of excess rainfall and runoff that can be utilized during the dry season. Efforts to ensure food self-sufficiency at house-hold level requires efficient use of the stored water and appropriate water application technologies that can be adopted for small-scale irrigation development. The traditional irrigation development paradigm is aiming at applying sufficient water to crops to avoid water stress during the whole growing stage, so as to achieve maximum yields (Doorenbos and Pruit, 1992). However, the limitations in water availability oblige to adopt alternative irrigation schedules with different frequencies of irrigation to cope with the water scarcity. Because of water availability constraints in most areas of the world, the above paradigm is changing (English et al., 2002) and quite often, the allocation of irrigation water to field is below maximum crop water requirement for maximum yield (Lorite et al., 2007).

In order to optimize crop yields and water use efficiency in irrigated environments, irrigations should be timed in a way that non-productive soil water evapotranspiration and drainage losses are minimized, and possible inevitable water deficits coincide with least sensitive growth period. Therefore, it is critical that conservative irrigation water management practices has to be implemented in order to optimize crop yield by employing deficit irrigation principles that provide a means of conserving irrigation water while maintaining reasonable yield level.

Deficit irrigation scheduling practice is the technique of withholding, or reducing the amount of water applied per irrigation at some stages of the crop growth with the aim of saving water, labor, and in some cases energy.

The main objective of this study was therefore, to investigate the effects of different levels of deficit irrigation imposed at different growth stages of maize crop on its development, grain yield and water use efficiency.

The specific objectives of the study were:

- to evaluate the effects of different irrigation water application levels on crops yield and water use efficiency at different crop growth stages.
- to calibrate and validate the AquaCrop model using the data generated during the experiment and evaluate its applicability for deficit irrigation management.

## 2. Materials and Methods

### 2.1 Description of the study area

The Field experiment was conducted in the south western zone of SNNP regional state, at the Demo-farm of Arba Minch located 500km south of Addis Ababa during the period from February to June, 2012. The AMU demonstration site was set as a practical illustration for irrigation and drainage related teaching and research purposes right after the establishment of the Arba Minch Water Technology Institute (AWTI) in 1986.

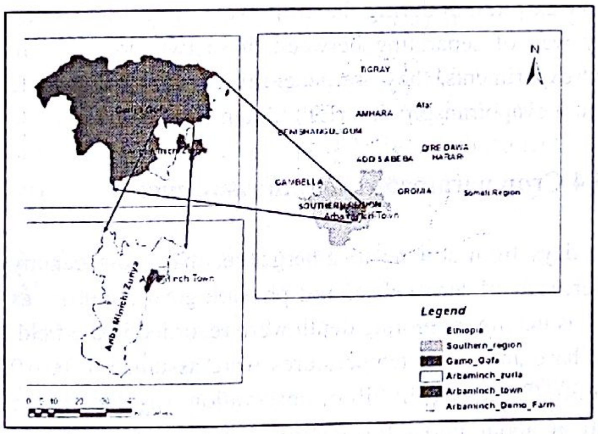


Figure 2.1: Location map of the study area

The study area is situated at 37°34' E longitude and 6° 04' N latitude, and at an altitude of 1203 m. a.s.l. The location map of the study area is presented in Figure 2.1.

The rainfall at Arbaminch station follows a bi-modal pattern with average annual precipitation of 750 mm. The average minimum and maximum temperature amounts to 13°C and 29.6°C, respectively.

### 2.2. Experimental design

The experiment was conducted in an intensively cultivated area of Arba Minch University demonstration site. It was designed to expose maize crop (BH-140) to water deficit during one or more of its growing stages. Considering four growing stages of the crop (FAO, 1998) there were ten treatments as indicated in Table 2.2. The treatments were watered at the levels of: 100%ETc, 75%ETc, 50% ETc, and 25%ETc to that of the total crop water requirement during four growing stages of the selected crop (Table 2.1).

Table 2.1: Details of irrigation treatments

| Strategies | Symbol | Supply conditions |
|---|---|---|
| Full Irrigation | FI | 100% Irrigation water application |
| Light Deficit Irrigation | LDI | 75% Irrigation water application |
| Deficit Irrigation | DI | 50% Irrigation water application |
| Extreme Deficit Irrigation | EDI | 25% Irrigation water application |

In order to illustrate the impacts of water deficit on yield and some agronomic characteristics of maize, a study was conducted as Randomized Complete Blocks Design (RCBD) and three replications to yield a total of 30 experimental plots. The size of each experimental plot was 5 ×4 m. The space between plots and replications were 1.50 m and 2m respectively. The BH-140 hybrid of maize was selected for the study and it was planted with 40 cm between plant and 80 cm raw spacing. This crop variety was selected for its good adaptability and most usable in the study area. The growing season of the crop was mainly divided into four major growth periods: initial, development, flowering and maturity stages based.

Each plot had five furrows for irrigation water application and five planting rows. The furrows were regularly maintained to sustain their water storage capacities over the season. These treatments were arranged in a way that a single treatment was not subjected to one level of deficit for the whole growing stage with the exception of control one, T1. The field layouts of the experimental plots could be schematized as shown in Figure 2.2.

Table 2.2: Total number of treatment combinations over crop growing stages.

| Treatments | Crop growing stages/Level of water application in % | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| T1 | 100 | 100 | 100 | 100 |
| T2 | 100 | 75 | 75 | 75 |
| T3 | 100 | 100 | 75 | 75 |
| T4 | 100 | 100 | 100 | 75 |
| T5 | 100 | 50 | 50 | 50 |
| T6 | 100 | 100 | 50 | 50 |
| T7 | 100 | 100 | 100 | 50 |
| T8 | 100 | 25 | 25 | 25 |
| T9 | 100 | 100 | 25 | 25 |
| T10 | 100 | 100 | 100 | 25 |

Note: this was replicated three times

## 2.3. Agronomic practices and water application

Land preparations was done using labor forces for seed-bed preparation and the experiment was conducted during the dry season using irrigation water only (no rainfed) in which shelters were used to exclude rain. Maize (BH-140) cultivar was sown by hand at the end of January and harvested at the end of June of the same year. The 90% Seedling emergence was observed about 7 days later. After germination and establishment, thinning was carried out to maintain the spacing between plants to be 40 cm. 12 Kg/ha DAP (diammonium phosphate) was applied during sowing period where as 10 Kg/ha urea was applied twice during vegetative stage and at the beginning of flowering stage, respectively.

First the required crop water was calculated using CROPWAT 8.0 computer program (Allen et al., 1998) on daily basis. Calculations of water and irrigation requirements were done using inputs of climatic, crop and soil data, as well as irrigation and rain data. Daily reference evapotranspiration was calculated from max- and min- temperature, humidity, sunshine/radiation, and wind-speed data, according to the FAO Penman-Monteith method (FAO, 1998). After determining the total irrigation water requirement, the different water application levels (Table 2.2) to induce water deficits were quantified. Accordingly, the corresponding irrigation amount has supplied to each experimental plot using calibrated siphon tubes through furrow irrigation method and appropriate flow control equipment was used. Water was carefully controlled to avoid the flow of water into water deficit plots. Since the furrows are close ended all water flowing into the furrows were infiltrated over the entire length, that is, there was no runoff. To maintain the capacity of furrows constant throughout the growing season, maintenances were done every time before irrigation.

All plots were protected from possible supply of water through rainfall using plastic shelters. The shelters were designed in such a way that they can easily be rolled-up when there is no rainfall and unrolled when rainfall occurs and during night.

At the end of each irrigation application or before the next irrigation leaf area and aboveground biomass were collected by removing one plant per plot.

### 2.3.3 Crop water productivity

Crop water productivity (WP) or irrigation water use efficiency (IWUE), as reviewed by Molden (2003), is a key term in the evaluation of Deficit Irrigation (DI) strategies. The water productivity with dimensions of kg /m$^3$ is defined as the ratio of the mass of grain yield (Ya, Kg/ha) to the volume of water consumed by the crop (Eta, mm):

$$WP = \frac{Y_a}{ET_a}$$

ETa refers to water lost both by soil evaporation and by crop transpiration during the crop cycle. Since there is no easy way of separating between these two processes in field experiments, they are generally combined under the term of evapotranspiration (ET) (Allen et al., 1998).

### 2.3.4 Crop parameters and measurements

The days from sowing to emergence, maximum canopy cover, start of senescence, and physiological maturity, as well as maximum rooting depth were recorded in the field. The base and upper temperatures were assumed to be 10 and 30 $^0$C respectively. Root observation was done in the field at about maximum canopy cover and at maturity from all plots. Leaf length, L (cm) and leaf width, W (cm) of plants from each treatment was measured using tape meter at 10-day intervals throughout the growing season. The total leaf area A (cm$^2$) for maize leaves was therefore obtained using the following relationship:

$$A = 0.759 \sum_{i=1}^{m} L_i \times W_i$$

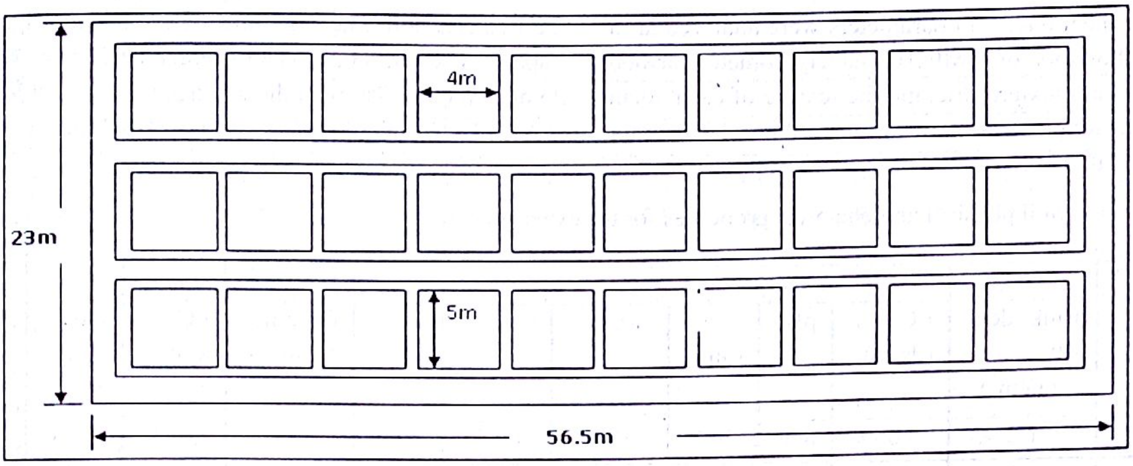


Figure 2.2: Layouts of the experimental plots

The LAI was obtained by the ratio of total leaf area of per unit ground area.

$$LAI = \frac{\text{Measured leaf area per plant (cm}^2\text{)}}{100 \times 100 \text{ cm}^2} \times \frac{\text{number of plants}}{\text{m}^2}$$

AquaCrop simulates transpiration in terms of canopy cover (CC) of the crop, but often experimental studies measure LAI but not canopy cover. Therefore, Canopy cover was estimated from leaf area index based on Theodore C. et.al, (2009).

$$CC = 1.005 \times [1 - \exp(-0.6LAI)]^{1.2}$$

Where CC (%) is canopy cover and LAI is leaf area index. An empirical relationship between CC and LAI of maize was obtained by regression, plus slight adjustments at the extreme low and high end of CC values.

### 2.3.5 Data collection and analysis

All relevant data including weather conditions, soil and crop characteristics ( such as open air dried aboveground biomass and yield, leaf area), and amount and timing of irrigation have been collected from the experimental plots and analysis was made to identify optimal deficit irrigation management practices based on crop yield responses and water use efficiency. For this purpose JMP5, GenStat 12[th] Edition softwares were used. The open air dried grain yield and above ground dry biomass weight was measured at 13% moisture content.

### 2. 4 Model performance evaluation

The performance of the model was evaluated using the following statistical parameters of the Root Mean Square Error (RMSE), calculated as:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(O_i - S_i)^2}$$

And the Model Efficiency (ME) (Nash and Sutcliffe, 1970) is calculated as:

$$ME = 1 - \frac{\sum_{i=1}^{N}(O_i - S_i)^2}{\sum_{i=1}^{N}(O_i - \bar{O}_i)^2}$$

Where Si and Oi are the simulated and observed (measured) values as samples taken along the season, or at the end of the season, N is the number of observations, and $\bar{O}$ is the mean value of $O_i$.

ME ranges from negative infinity to positive 1; the closer to 1, the more robust the model. The RMSE in Eq.2 represents a measure of the overall, or mean, deviation between observed and simulated values, that is, a synthetic indicator of the absolute model uncertainty. In fact, it takes the same units of the variable being simulated, and therefore the closer the value is to zero, the better the model simulation performance.

## 3. Results and Discussions

### 3.1 Soil Characteristics of the Study Area

Soil samples from the study area were collected from each horizon up to 120 cm depth to characterize the soil in terms of physical characteristics such as textural class (soil texture), EC, pH, organic matter, and the average bulk density.

The above mentioned soil parameters were analyzed at in the soil laboratory of AMU. Using Hydrometer method and USDA soil textural triangle the texture of each 30cm layer was determined as shown in the Table 3.1 below for the total depth of 120 cm and the texture of the whole profile was clay soil. The experimental site had average Field Capacity (FC) of 34.25% and average Permanent Welting Point (PWP) 18.7% with the average total available water (TAW) 15.5% in volume percentage (Teshome, 2006).

Table 3.1: Soil physical and chemical properties for the experimental site

| Soil depth (cm) | Type of analysis | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bulk density ($gm/cm^3$) | EC (ds/m) | pH | % sand | % silt | % clay | Texture | Organic Matter% | FC Vol. % | PWP Vol. % | TAW Vol. % |
| 0 – 30 | 1.2 | 0.059 | 8.3 | 20.7 | 12.0 | 67.3 | clay | 13.0 | 39.3 | 21.3 | 18.0 |
| 30 – 60 | 1.2 | 0.059 | 8.1 | 14.0 | 34.7 | 51.3 | clay | 13.9 | 34.7 | 19.7 | 15.0 |
| 60 – 90 | 1.3 | 0.058 | 8.3 | 16.7 | 26.0 | 57.3 | clay | 12.6 | 31.6 | 17.0 | 14.6 |
| 90 - 120 | 1.1 | 0.060 | 8.1 | 20.7 | 20.0 | 59.3 | clay | 12.4 | 31.4 | 16.8 | 14.6 |
| Average | 1.2 | 0.059 | 8.2 | 18.0 | 23.2 | 58.8 | clay | 13.0 | 34.25 | 18.7 | 15.55 |

The soil pH was determined in 1:2.5 soil: water suspension ratio by potentiometric method using glass electrode. The pH of soils was alkaline ranged from 8.1 to 8.3 with an average of 8.2 and it does not show significant difference throughout the profile.

Electrical conductivity was determined in 1:5 soil: water ratio extract using cell electrode and expressed as dS $m^{-1}$ and appropriate temperature conversion factors for correcting conductivity data to standard temperature of 25 °C was used. Measured soil salinity was low as indicated by electrical conductivity (EC) values throughout the profile which ranged from 0.058 to 0. 060 ds $m^{-1}$. The highest EC (0.060 dS/m) was recorded in the lower horizon of the soil profile and lowest in the second from the bottom (60 – 90 cm) horizon of the soil profile.

The soil infiltration rates were measured with the help of double ring infiltro-meter and it was on the average of 4.3 mm/min.

### 3.2 Crop Water Requirements and Irrigation Scheduling

The daily crop water requirements were calculated by multiplying the reference evapotranspiration values with the maize crop coefficients (0.3, 0.5, 1.2 and 0.5) initial, development, flowering and maturity stages, respectively given by Allen et al. (1998). The Amount of irrigation water required at 10 days interval, number of irrigation events is summarized in Table 3.3. Fixed interval (every ten days) and variable depth (refill to field capacity) irrigation scheduling technique was selected. Optimal or "no stress" irrigation was calculated using the FAO CROPWAT program as the net amount of irrigation required to refill the soil moisture deficit with weekly application of irrigation water. The depth applied to other treatments was taken simply as percentage of the optimal irrigation at specific growth stage or throughout the growing season.

### 3.3 Yield and Water use Efficiency of Maize Crop

The result in Table 3.4 indicated that yield of maize was significantly ($p<0.05$) affected by the deficit irrigation. The highest yield was found in T6 (8.842 t/ha) which was subjected to water deficit during mid and maturity-stages whereas minimum yield of maize was obtained under T8 (5.264 t/ha) which was deficit during the whole growing season except during the initial stage.

According to the result shown in Table 3.4 both T2, T3, T6, and T7 are within the yielding potential of the hybrid (BH-140) maize crop yield collected from the research center which is 7.5 to 8.5 t/ha, and the remaining treatment were also in the range of yield collected from the farmer which is 4.7 to 6.0 t/ha (source; Bako Agricultral Mechanization Research Center).

There was significant different between the yield of T6 (8.842 t/ha) and T8 (5.264 t/ha) which was giving 25%Etc during development-, middle-, and late /maturity-stages of the crop growing season.According to the result obtained, giving 25%ETc during development-, middle-, and late / maturity-stages of the crop growing season has affected more the yield of maize as compared to other treatments.

Table 3.3: Amount of irrigation water required for maize in 10 days interval (mm).

| Date | Treatments | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 |
| 10-Feb | 61.1 | 61.1 | 61.1 | 61.1 | 61.1 | 61.1 | 61.1 | 61.1 | 61.1 | 61.1 |
| 20-Feb | 30.7 | 30.7 | 30.7 | 30.7 | 30.7 | 30.7 | 30.7 | 30.7 | 30.7 | 30.7 |
| 2-Mar | 30.4 | 22.8 | 30.4 | 30.4 | 15.2 | 30.4 | 30.4 | 7.6 | 30.4 | 30.4 |
| 12-Mar | 36.6 | 27.5 | 36.6 | 36.6 | 18.3 | 36.6 | 36.6 | 9.2 | 36.6 | 36.6 |
| 22-Mar | 55.5 | 41.6 | 55.5 | 55.5 | 27.8 | 55.5 | 55.5 | 13.9 | 55.5 | 55.5 |
| 1-Apr | 63.7 | 47.8 | 63.7 | 63.7 | 31.9 | 63.7 | 63.7 | 15.9 | 63.7 | 63.7 |
| 11-Apr | 68.3 | 51.2 | 51.2 | 68.3 | 34.2 | 34.2 | 68.3 | 17.1 | 17.1 | 68.3 |
| 21-Apr | 60.1 | 45.1 | 45.1 | 60.1 | 30.1 | 30.1 | 60.1 | 15 | 15 | 60.1 |
| 1-May | 55.7 | 41.8 | 41.8 | 55.7 | 27.9 | 27.9 | 55.7 | 13.9 | 13.9 | 55.7 |
| 11-May | 60.7 | 45.5 | 45.5 | 60.7 | 30.4 | 30.4 | 60.7 | 15.2 | 15.2 | 60.7 |
| 21-May | 66.1 | 49.6 | 49.6 | 66.1 | 33.1 | 33.1 | 66.1 | 16.5 | 16.5 | 66.1 |
| 31-May | 61 | 45.8 | 45.8 | 45.8 | 30.5 | 30.5 | 30.5 | 15.3 | 15.3 | 15.3 |
| 10-Jun | 42.6 | 32 | 32 | 21.3 | 21.3 | 21.3 | 10.7 | 10.7 | 10.7 | 10.7 |
| 20-Jun | 27.6 | 20.7 | 20.7 | 13.8 | 13.8 | 13.8 | 13.8 | 6.9 | 6.9 | 6.9 |
| 26-Jun | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | 720.1 | 563 | 609.6 | 687.3 | 406 | 499.1 | 654.5 | 248.9 | 388.5 | 621.7 |

Giving 50%ETc of crop water requirement during middle- and maturity-stages were better than giving 100%ETc of crop water requirement throughout the growing season.
On the other hand, ANOVA showed that irrigation water use efficiency (IWUE) was significantly different. Thus, T8 (2.11 $kg/m^3$) and T4 (0.93 $kg/m^3$) had the highest and the lowest irrigation water use efficiency respectively. This result elaborated that applying 25%ETc of crop water requirement during development-, mid-, and late / maturity-stages of the crop growing season has better water use efficiency than applying optimal irrigation with (100%ETc) crop water requirement.

As indicated in Table 3.5, T6 had the highest and T8 the lowest yield. From the treatments highest amount of water was saved in T8 (65%) and 5% of water was saved in T4 taking into account T1 as a control (crop water requirement base). The amount of water saved in T6 was 31% which is higher than the other six treatments (T1, T2, T3, T4, T7, and T10). When the treatments are compared in terms of yield reduction/increase, T6 had (-23%) which shows there is no yield reduction rather 23% yield increase compare to the control treatment (T1) and T8 (27%) the highest yield reduction since T1 is considered as control.

Table 3.4: Grain yield, aboveground biomass and harvest index for different irrigation treatments of maize.

| Treatment | Yield (t/ha) | Above ground dry biomass (t/ha) | HI (-) |
|---|---|---|---|
| T1 | 7.212 | 13.385 | 0.539 |
| T2 | 7.576 | 11.827 | 0.641 |
| T3 | 8.088 | 12.202 | 0.663 |
| T4 | 6.418 | 12.723 | 0.504 |
| T5 | 6.189 | 10.394 | 0.595 |
| T6 | 8.842 | 10.484 | 0.843 |
| T7 | 8.369 | 11.675 | 0.717 |
| T8 | 5.264 | 8.862 | 0.594 |
| T9 | 5.929 | 9.327 | 0.636 |
| T10 | 6.736 | 10.29 | 0.655 |
| LSD (0.05) | 2.103 | 2.031 | ns |
| CV (%) | 18.1 | 21.22 | 20.34 |

The grain yield and aboveground dry-biomass of the maize plant is presented in Table 3.4. ANOVA test showed that there is a significant difference between treatments in terms of grain yield and total aboveground dry-biomass. It shows that there is no significant difference between treatments T1, T3, T4, and T7 in terms of above ground dry-biomass

Table 3.5: The amount of water saved and yield reduction.

| Treatments | Irrigation (m3/ha) | Yield (kg/ha) | IWUE (kg/m3) | Water saved (%) | Yield Reduction / increase |
|---|---|---|---|---|---|
| T1 | 7201 | 7212 | 1.01 | 0 | 0 |
| T2 | 5630 | 7576 | 1.35 | 22 | -5 |
| T3 | 6096 | 8088 | 1.33 | 15 | -12 |
| T4 | 6873 | 6418 | 0.93 | 5 | 11 |
| T5 | 4060 | 6.189 | 1.52 | 44 | 14 |
| T6 | 4991 | 8842 | 1.77 | 31 | -23 |
| T7 | 6545 | 8369 | 1.28 | 9 | -16 |
| T8 | 2489 | 5264 | 2.11 | 65 | 27 |
| T9 | 388.5 | 5929 | 1.53 | 46 | 18 |
| T10 | 621.7 | 6736 | 1.08 | 14 | 7 |

The harvest index (HI) which refers to the percentage dry matter allocated to grain yield, increasing with increasing magnitude of deficit from all except under T6. The lowest HI is 0.53 and the highest is 0.84. These values are relatively higher than the values of 0.31 – 0.55 reported by Farre and Faci (2009) as cited by Mekonen Ayana (2011).

## 3.4 Simulation using AquaCrop Model

### 3.4.1 Model calibration and validation

The Model has been calibrated based on the measured crop data of all the treatments. The main calibration parameters for CC include the canopy growth coefficient (CGC), the canopy decline coefficient (CDC), water stress ($P_{upper}$, $P_{lower}$ and the shape factor) affecting leaf expansion and early senescence. Canopy cover per seedling was estimated based on the general knowledge of the crop characteristics by specifying row spacing and plant spacing. Then, simulation was done for the above crop phonologies and the results were compared with the measured values.

In the model, initial canopy cover (CCo) was estimated based on the data from agronomic practice from row planting, row spacing (0.80m) and plant spacing (0.40m). Hence, the estimated initial canopy cover (CCo) for the given maize crop has been found 0.16% (3.1 plants/m2 or 31, 250 plants/ha).

To estimate the canopy expansion rate, phonological data (listed in Table 3.6) such as dates to emergence, maximum canopy cover, senescence and maturity were used. The model resulted fast canopy expansion and moderate canopy decline. The canopy growth coefficient (CGC) and canopy decline coefficient (CDC) were 1.46%/°C /day and 0.114 % /°C/day respectively.

The crop parameters used for calibrating the model were maize phenological development, different crop parameters and the values used for calibrating the model. Stress parameters such as canopy expansion and canopy senescence coefficients were adjusted and re adjusted to simulate the measured canopy cover.

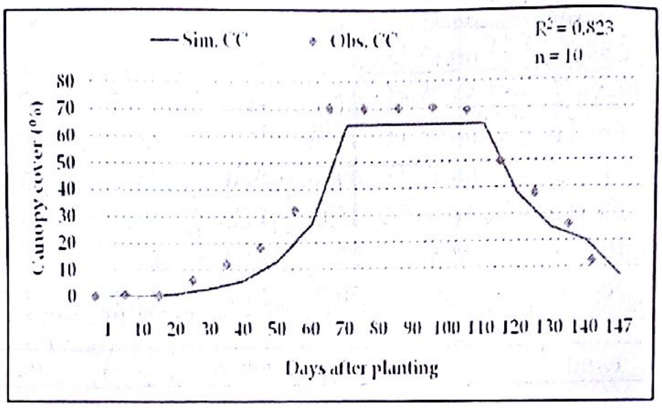


Figure 3.2: Simulated and observed canopy cover.

The simulated above ground dry biomass agreed well with the observed biomass (Fig. 3.3). There was strong relationship between the observed and simulated biomass ($R^2$ > 0.85).

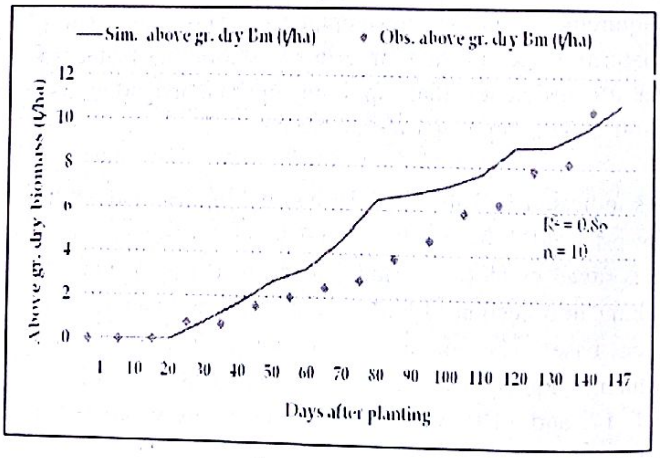


Figure 3.3: Simulated and observed above ground dry biomass.

The average harvest index value obtained from field experiment for the highest yield production was 80%.

Table 3.7: Crop data input used in AquaCrop to simulate maize.

| Description | Value | Units | Interpretation |
|---|---|---|---|
| Canopy cover per seedling at 90% emergence (CCo) | 0.16 | % | Increase in CC relative to existing CC. (3.1 cm2 per plant). |
| Canopy growth coefficient (CGC) | 1.46 | %/°C/day | Increase in CC relative to existing CC per GDD |
| Maximum canopy cover (CCx) | 90 | % | well covered |
| Maximum crop coefficient | 1.25 | - | At max canopy |
| Canopy decline coefficient (CDC) at senescence | 1.14 | %/°C/day | Decrease in CC relative to CCx per GDD |
| Water productivity | 32 | $g/m^2$ | Biomass per $m^2$ |
| Upper threshold for canopy expansion | 0.20 | - | Leaf growth stop completely at this P value |
| lower threshold for canopy expansion ($P_{lower}$) | 0.55 | - | Above this leaf growth is inhibited |
| Leaf expansion stress coefficient curve shape | 3.1 | - | |
| Upper threshold for stomatal closure | 0.55 | - | Moderately tolerant to water stress but above this stomata begins to close |
| Stomata stress coefficient curve shape | 3.1 | - | |
| Canopy senescence stress coefficient (Pupper) | 0.55 | - | Above this canopy senescence begins |
| Senescence stress coefficient curve shape | 3.1 | - | |
| Reference harvest index (HIo) | 70 | - | Common for good condition |
| Coefficient, HI increased by inhibition of leaf growth at flowering | 0.85 | - | Upper threshold for increase in HI due to inhibition of leaf growth |
| Coefficient, HI increased due to inhibition of leaf growth before flowering | 12 | % | Maximum HI increased by inhibition of leaf growth before flowering |
| Coefficient, HI decreased due to water stress affecting stomata closure during yield formation | 5 | - | Moderate |
| Coefficient, HI increased due to water stress affecting leaf expansion during yield formation | 2 | - | Moderate |

As shown in Figure 3.2 the simulated and observed canopy cover was well correlated with strong relationship ($R^2 > 0.80$).

Table 3.8: Simulated and observed grain yield and above ground dry biomass of treatments and % of deviations from observed.

| | Yield | | | Above ground dry biomass | | |
|---|---|---|---|---|---|---|
| Treatment | Observed (t/ha) | Simulated (t/ha) | Dev. (%) | Observed (t/ha) | Simulated (t/ha) | Dev. (%) |
| T1 | 7.21 | 7.61 | 5.23 | 13.39 | 14.85 | 9.87 |
| T2 | 7.58 | 8.27 | 8.39 | 11.83 | 12.51 | 5.46 |
| T3 | 8.09 | 9.27 | 12.75 | 12.20 | 12.96 | 5.85 |
| T4 | 6.42 | 7.61 | 15.66 | 12.72 | 13.85 | 8.14 |
| T5 | 6.19 | 4.56 | -35.72 | 10.39 | 33.78 | 69.23 |
| T6 | 8.84 | 10.27 | 13.90 | 10.48 | 10.78 | 2.75 |
| T7 | 8.37 | 8.34 | -0.35 | 11.68 | 11.99 | 2.63 |
| T8 | 5.26 | 2.70 | -94.96 | 8.86 | 56.76 | 84.39 |
| T9 | 5.93 | 6.42 | 7.65 | 9.33 | 9.99 | 6.64 |
| T10 | 6.74 | 7.61 | 11.48 | 10.29 | 10.74 | 4.19 |

Table 3.8 shows a deviation of the simulated grain yield and above ground dry biomass from their corresponding observed data. The deviation of the simulated above ground dry biomass from the observed data for both T5 (69.23%) and T8 (84.39%) shows there was over estimated of above ground dry biomass by the model. Whereas the deviations of the simulated grain yield from the observed data for both T5 (-35.72%) and T8 (-94.96%) shows there was under estimation of grain yield of maize crop by the model. Although not largely different, the above ground dry biomass was better simulated by the model when compared with the grain yield which is in line with Araya (2010).

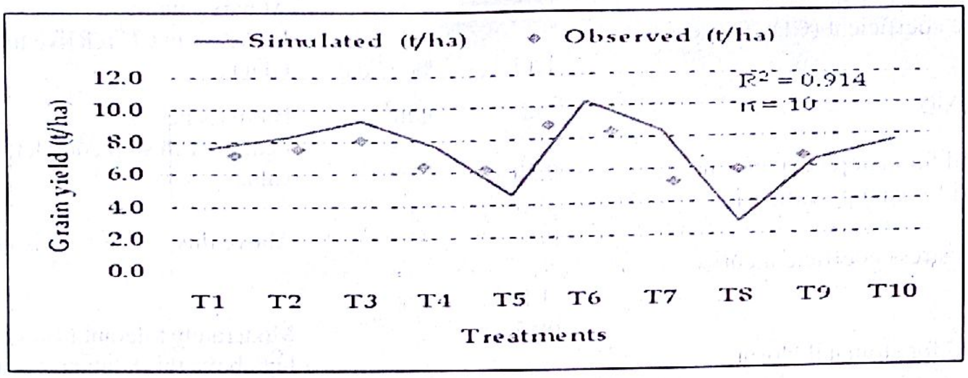


Figure 3.4: Comparison of simulated and observed grain yield of each treatment.

Both grain yield and above ground dry biomass were adequately simulated by the model. The simulated above ground dry biomass (Fig. 3.5) and grain yield (Fig. 3.4) agreed well with their observed above ground dry biomass and grain yield except for both T5 and T8 which was consecutively subjected to water deficit from development to maturity stages. There was strong relationship between the observed and simulated above ground biomass and grain yield ($R^2 > 0.91$).

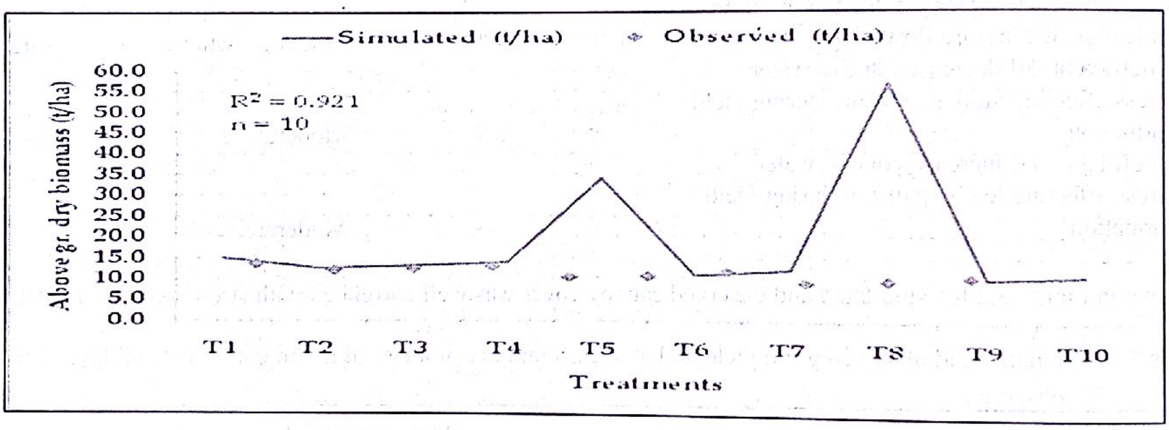


Figure 3.5: Comparison of simulated and observed above ground dry biomass of each treatment.

### 3.4.2 Model performance evaluation

The model efficiency (ME) and root mean square of error (RMSE) was used to evaluate the model performance. These parameters showed good to moderate performance for above ground dry biomass (ME=0. 99, RMSE = 0.81 t/ha) and grain yield (ME =0.97, RMSE = 1.25 t/ha). Model efficiency and Mean square error for above ground dry biomass was done by removing the two most outliers (T5 and T8). According the validation results, the calculated ME were close to one that is the more the robust the model. Also, moderate RMSE values indicate the good performance of the model.

## 3.5 Sensitivity analysis

Before applying a model, it is necessary to have some familiarity with its behavior and sensitivity to input parameters. Sensitivity analysis helps to recognize the parameters that have significant impact on model output.

To assess the robustness of the AquaCrop model for maize crop under Arbaminch condition and the required quality of the input data, a sensitivity analysis was worked out by altering inputs and by keeping some inputs constant such as normalized water productivity (WP* = 32 for C4 crops). Temperature (base temperature =10 and upper temperature = 30). The inputs for sensitivity analysis for this research were agronomic data, soil, meteorology, and irrigation management data. In order to compare the model outputs, the inputs were changed by trial and error in each step. After changing the values of input parameters, the model outputs were compared with the observed data. The results showed that the most sensitive agronomic parameter in AquaCrop model were time to senescence, reference harvest index (HIo), canopy development, canopy decline. However, the model showed less sensitive to time of seed emergence, length of flowering period, days to flowering. The difference in simulated above ground biomass and grain yield was used for the assessment. In general, the most sensitive parameters were those which are cultivar specific parameters (with white cell box) and less sensitive parameters are those with silver cell box in the model.

## 4. Conclusions and Recommendations

### 4.1 Conclusions

The advantage of deficit irrigation lies in saving water while maintaining optimum yield as close to fully irrigated farm (Mekonen Ayana, 2011).

From the results of the experiment, continuously applied 25% of the total crop water requirement showed more yield reduction. On the other hand, slightly deficit treatments had less yield reductions. However, even 50%Etc water application throughout the growing season except the first stage had significant yield reduction. This indicates that prolonged water deficit below 50% of crop water requirement could significantly affect the yield.

There was no yield reduction observed under treatments which was irrigated 50%ETc during third and forth growth stage, followed by treatments irrigated 75%ETc during first, second, and third growth stages and plot irrigated 25% of crop water requirement only during the last stage. That means with this application, water and other irrigation expenses can be saved. By doing so more land can be irrigated with the saved water to enhance more production. Besides to this, the most sensitive stage of any crop must be investigated to reduce sever yield reduction effects. The knowledge of the most sensitive stages of any crop to water deficit is crucial to manage and apply deficit irrigation technologies. Identifying sensitive growth stages of a particular cultivar under local conditions of climate and soil fertility allows irrigation scheduling for both maximum crop yield and most efficient use of scarce water resources. Hence, we found the most sensitive stage was during the third stage if we irrigate below 50%Etc.

AquaCrop model's calibration and validation is necessary for each crop and in every climate. The results of this research showed that this model is capable of simulating above ground biomass, canopy cover, and grain yield of maize for full supplied irrigation and treatments with some water deficit; but under sever water deficit ( 25%ETc of full irrigation), and prolonged 50% water stress, the model performed less satisfactorily. According to the validation or model evaluation results, the calculated RMSE and ME values were 0.81 t/ha and 0.99 for grain yield; and 1.25 t/ha and 0.97 for above ground dry biomass, respectively.

### 4.2 Recommendations

The highest yield was found from T6 (8.84 t $ha^{-1}$) by giving 50% of crop water requirement during the third growth stage which is still better than giving 100% of crop water requirement (full irrigation) throughout the growing season. Therefore, we can recommend that this application of irrigation water (100%, 100%, 50%, and 50%) is best for Arba Minch condition.

AquaCrop version 3.1 has adequately simulated the above ground dry biomass, grain yield, HI, and canopy cover of maize under various irrigation water conditions.

There was over estimation of above ground dry biomass and under estimated of grain yield of maize crop by the model for treatment consequently subjected to water deficit (T5) and for the severely deficit treatment (T8). From this we can recommend that, AquaCrop model is less satisfactory simulating treatments with sever or prolonged water deficit below50%ETc.

Assuming that water is scarce and land is not scarce, the model has indicated the possibility of obtaining more grain and biomass from relatively larger maize crop by applying less water. This result may contribute to food security improvement through increasing crop yields especially in water deficit areas.

This research was done one season experimentation test. Therefore, to evaluate and validate the model under Arba Minch condition, It is recommended to repeat the experiment in different woreda's/ areas under Gamo Gofa zone so as to provide the best deficit irrigation practice for the end users of the area and places having similar climate and soil condition.

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# Investigation of Beressa River Water Quality for Urban and Peri-Urban Irrigation in Debre Berhan, Ethiopia

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## Abstract

*Due to various socio-economic activities in urban areas the prevalence of water pollutant and water quality deterioration is high. Most water bodies within and around the urban centers of developing countries are already heavily contaminated due to poor water management and widespread negligence of water quality considerations. Along Beressa River various socio-economic activities and development of industries are increasing and hence wastes are discharged to the river and the river receives different effluents from different sources. The objective of this research was to investigate and characterize the water quality of Beressa River with special emphasis to its suitability for irrigation in urban and peri-urban areas of Debre Berhan. Water samples were collected from five representative points along the river reach every 15 days from April to June 2012. The samples were analyzed for water quality parameters such as salinity (EC). Cation of sodium, calcium, magnesium and anion of bicarbonate, chloride, and sulfate as well as pH. The results indicated that most of the irrigation water quality parameters investigated in this research showed an increase as the river drains from rural zone to the urban area and there was a significant variation in pH, EC, $Na^+$, $Ca^{2+}$, $Cl^-$, $NO_3^-$ and B at a significance level of ($P \leq 0.05$) between sampling points. Whereas, parameters such as T, TDS, TSS, $K^+$, $Mg^{2+}$, $CO_3^{2-}$, $HCO_3^-$, $SO_4^{2-}$, $PO_4^{2-}$ and $NH_4$ showed no significant spatial variations ($P \leq 0.05$). The concentrations of most irrigation water quality parameters in the sampling stations investigated during the study period were found within the FAO acceptable limit for irrigation.*

*Keywords: Urban and peri-urban, water quality, Baressa River, irrigation*

## 1. Introduction

With the ever-increasing demand on irrigation water supply, farmlands are frequently becoming irrigated with poor quality irrigation water. Waste waters that are discharged to wells, ponds, streams and treatment plants are being used as a source of irrigation water in several parts of Ethiopia (Alemtsehaye, 2002). But the continued application of poor quality irrigation water is reducing cropland productivity. Water quality for agricultural purposes is determined on the basis of the effect of water on the quality and yield of the crops, as well as the effect on characteristic changes in the soil (FAO, 1994).

Debre Berhan is one of the towns in Ethiopia in which various socio-economic activities are taking place. Within the town industries and organizations like wool factory, leather factory, floriculture, Debre Berhan University, Teachers Training College and others discharge their waste to Beressa River. Despite the fact that many farmers and enterprises have been using the river for irrigation for a long time; no study has been conducted on the quality of the river into which the effluents are discharged.

The main objective of the study is to investigate and characterize the water quality of Beressa River with special emphasis to its suitability for irrigation in urban and peri-urban areas of Debre Berhan. The impact of the river water on irrigation water quality was assessed by determining the concentrations in the irrigation water samples of $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, B ,$CO_3^{2-}$, $HCO_3^-$ , $Cl^-$, $SO_4^{2-}$, $NO_3^-$, $NH_4^+$, $PO_4^{2-}$and the values of pH, EC, TDS and TSS in laboratory. In addition the river irrigation water quality was evaluated by determining parameters like SAR, Na %, RSC, Mg %, PI and LDP of the river water.

## 2. Materials and Methods

### 2.1. Selection of sampling locations

Five sampling stations along the length of Beressa River at Debre Berhan district were selected to represent the downstream water quality variations. One sampling station was selected at a location at about 5 km away from the town upstream of the river. This sampling station is located where urban interferences are considerably less. The other four sampling stations were selected based on the rate of human interferences, industrial activities, point of extraction or diversion to irrigation canals and irrigation activities that are taking place near the river.

The five sampling stations which are indicated in Figure 2.1 are:

1. BS-1: is located upstream of Debre Berhan town. It is located at a place where the urban interferences are very minimal.
2. BS-2: is located below the blanket factory, floriculture and Debre Berhan University.
3. BS-3: is located near the bridge that is found on the main road from Addis Ababa to Dessie. It was selected at a point where the gauge station is installed.
4. BS-4: is located below Debre Berhan Teachers Training College and irrigation project.
5. BS-5: is located below Debre Berhan leather factory. This point is found at downstream of the Debre Berhan town.

## 2.2 Sample Collection and Analysis

Grab water sampling method was used during sample collection. Water Samples were collected in good quality polyethylene bottles of 1 liter capacity. Samples from the river were taken from the fastest flowing part, the midway along the width of the river. Before taking final water samples, the polyethylene bottles were rinsed three times with the water to be collected. The sample bottles were labeled with date, time and sampling station number and were taken to the laboratory. Total of 50 water samples (25 in the morning and 25 in the afternoon) (Table 2.1) from five sampling stations of Beressa River were taken and investigated for three consecutive months from April to June 2012.

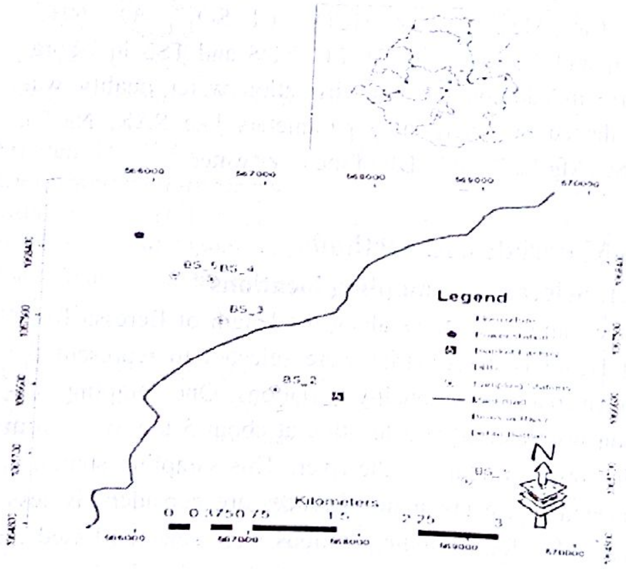


Figure 2. 1: Location map of study area and sampling station

Table 2.1: Water samples collection times during morning and afternoon

| Sampling Stations | Number of Samples Collected (1/2 Morning + 1/2 Afternoon) | Collected during morning time @ | Collected during afternoon time @ |
|---|---|---|---|
| BS-1 | 10 | 7:00 a.m. | 3:00 p.m. |
| BS-2 | 10 | 7:30 a.m. | 3:30 p.m. |
| BS-3 | 10 | 8:00 a.m. | 4:00 p.m. |
| BS-4 | 10 | 8:15 a.m. | 4:15 p.m. |
| BS-5 | 10 | 8:30 a.m. | 4:30 p.m. |

Water samples were analyzed for constituents like pH, EC, TDS, $K^+$, $Na^+$, $Mg^{2+}$, $Ca^{2+}$, $Cl^-$, $SO_4^{2-}$, $NO_3^{2-}$, $PO_4^{2-}$, $NH_4^+$ and B following the standard procedure for American Public Health Association (Browen et al., 1974; APHA, 1985; APHA, 1998). Apart from these parameters, sodium adsorption ratio (SAR), magnesium content (Mg %), Sodium percentage (Na %), residual sodium carbonate (RSC), permeability index (PI) and lime deposition potential (LDP) were also determined using the following equations.

- Sodium Adsorption Ratio, SAR

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (2.1)$$

- Magnesium Content, Mg %

$$Mg(\%) = \left[\frac{Mg^{2+}}{Mg^{2+} + Ca^{2+}}\right] \times 100 \quad (2.2)$$

- Sodium Percentage, Na %

Doneen, 1964 method was used to calculated the sodium percentage

$$Na(\%) = \left[\frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+}\right] \times 100 \quad (2.3)$$

- Residual Sodium Carbonate, RSC

$$RSC = [CO_3^{2-} + HCO_3^-] - [Ca^{2+} + Mg^{2+}] \quad (2.4)$$

- Permeability Index, PI

PI was calculated by the method suggested by Domenico and Schwartz, 1990.

$$PI = \left[\frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+}\right] \times 100 \quad (2.5)$$

Lime Deposition Potential, LDP: The amount of lime formed is equivalent to the lesser of carbonates (bicarbonate + carbonate) or divalent cations (calcium +

magnesium) in the water (Bryan et al., 2007).

Note: Concentrations are in meq/L.

One way analysis of variance (ANOVA) was employed to compare the temporal and spatial differences of irrigation water quality variables ($p < 0.05$; least significance difference, LSD). All the statistical procedures were conducted using statistical product and service solution (SPSS) 16.0 for Windows. The results that were obtained from the field and laboratory examination of water samples were analyzed and interpreted based on irrigation water quality standards.

## 3. Results and Discussions

### 3.1 Statistical Variations of Water Quality Parameters

One way analysis of variance (ANOVA) was employed to compare the temporal and spatial differences of irrigation water quality variables; and the results obtained are shown in Table 3.1. It can be seen that there was significant spatial variation of pH, $Na^+$, $Ca^{2+}$, $Cl^-$, $NO_3^-$ and B at a significance level of ($P<=0.05$) among the sampling stations. Whereas, there was no significant spatial variation of T, EC, TDS, TSS, $K^+$, $Mg^{2+}$, $CO_3^{2-}$, $HCO_3^-$, $SO_4^{2-}$, $PO_4^{2-}$ and $NH_4^+$ at significance level of ($P<=0.05$) among the sampling stations considered.

Table 3.1: Variations of water quality parameters among stations using one way ANOVA

| | ANOVA | | | | |
|---|---|---|---|---|---|
| Parameter | Sum of Squares | Df | Mean Square | F | Sig. |
| T | 0.97 | 4.00 | 0.24 | 0.04 | 1.00 |
| pH | 2.19 | 4.00 | 0.55 | 5.53 | 0.00 |
| EC | 18064.85 | 4.00 | 4516.21 | 2.02 | 0.11 |
| TDS | 3847.00 | 4.00 | 961.75 | 0.42 | 0.79 |
| TSS | 4750.00 | 4.00 | 1187.50 | 1.68 | 0.21 |
| Na | 91.16 | 4.00 | 22.79 | 2.79 | 0.04 |
| K | 15.30 | 4.00 | 3.83 | 1.05 | 0.39 |
| Ca | 540.42 | 4.00 | 135.11 | 5.38 | 0.00 |
| Mg | 17.46 | 4.00 | 4.36 | 1.36 | 0.26 |
| HCO3 | 1697.51 | 4.00 | 424.38 | 1.49 | 0.22 |
| Cl | 365.78 | 4.00 | 91.44 | 3.39 | 0.02 |
| SO4 | 343.38 | 4.00 | 85.85 | 0.51 | 0.73 |
| NH4 | 22.28 | 4.00 | 5.57 | 1.02 | 0.43 |
| NO3 | 0.10 | 4.00 | 0.02 | 6.53 | 0.03 |
| PO4 | 0.74 | 4.00 | 0.19 | 1.72 | 0.28 |
| B | 0.01 | 4.00 | 0.00 | 5.85 | 0.04 |

Multiple comparisons of parameters between sampling stations ($P<=0.05$; Least Significance Difference, LSD) also revealed that pH, EC, $Na^+$, $Ca^{2+}$, $Cl^-$ show significant variation between sampling station BS-1 and the other sampling stations. Temporally there was no significant variation between morning and afternoon concentrations of all parameters investigated except water temperature and pH at significance level of ($P<=0.05$).

### 3.2 Physical Water Quality Parameters

Table 3.2: Average morning (M) and afternoon (A) values of physical parameters

| Sampling Station | T ($^oC$) | | pH | | EC (μs/cm) | | TDS (mg/L) | | TSS (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | A | M | A | M | A | M | A | M | A |
| BS-1 | 14.90 | 19.90 | 7.47 | 8.08 | 153.62 | 142.56 | 170.96 | 166.50 | 35.00 | 55.00 |
| BS-2 | 16.30 | 19.20 | 7.15 | 7.33 | 188.22 | 205.58 | 172.30 | 180.50 | 40.00 | 30.00 |
| BS-3 | 14.60 | 20.40 | 7.14 | 7.30 | 204.36 | 186.30 | 207.10 | 178.86 | 40.00 | 45.00 |
| BS-4 | 15.80 | 19.00 | 7.07 | 7.45 | 203.60 | 185.56 | 188.00 | 168.48 | 50.00 | 105.00 |
| BS-5 | 16.30 | 19.00 | 7.22 | 7.50 | 197.48 | 193.48 | 170.62 | 168.00 | 50.00 | 25.00 |

The physical water quality parameters investigated in this study include water temperature (T), pH, electrical conductivity (EC), total dissolved solids (TDS) and total suspended solids (TSS). The averages values for both morning and afternoon time are given in Table 3.2.

The average temperature values of water at five sampling stations of river Beressa during the study period varied between 14.60 $^{0}C$ to 20.40 $^{0}C$. Stream water temperature varies naturally by both location (spatial) and time (temporal). Daily fluctuation occurs with maximum temperatures in the afternoon and minimum temperatures in the late night or early morning (Boyd and Studevant, 1997). Similarly, average temperature values of Beressa River water were found lower during morning time for all sampling stations.

The average pH values at five sampling stations of river Beressa during the study period varied from 7.07 to 8.08. Values of morning water samples were found lower than that of afternoon samples at all sampling stations. The reason for the temporal variation in pH between morning and afternoon time may be due to the increase in carbon dioxide during the morning time. Water in large cities is often treated to be "soft," or more acidic than in rural areas (Papagiorgio, 2012). Sampling station BS-1 has the highest average pH value of all the sampling stations because of less urban influences on this point.

Average EC values at five sampling stations of Beressa River varied between 142.56 and 205.58 µS/cm. Lower values were found at sampling station BS-1 indicating that the human and industrial activities near this sampling station were considerably less. In all sampling stations except sampling station BS-2 the EC average values obtained during morning time were found greater than EC average values measured during afternoon time.

TDS values of Beressa River at five sampling stations varied between 166.50 mg/L to 207.10 mg/L during the study period. The lowest concentration of total dissolved solids was found at sampling station BS-1. The maximum TDS value was occurred at sampling station BS-3. TDS concentrations were found similar to that of EC values. The TSS result of all sampling stations of river Beressa ranges from 25.00 mg/L to 105.00 mg/L during the study period. In most sampling stations the average TSS level was found higher during afternoon time than that of morning time. The higher TSS levels during afternoon time may be resulted due to human interferences in the river during the day time than during night time.

## 3.3 Chemical Water Quality Parameters

The chemical water quality parameters investigated in this study include $Na^{+}$, $Ca^{2+}$, $Mg^{2+}$, $K^{+}$, $CO_3^{2-}$, $HCO_3^{-}$, $Cl^{-}$, $SO_4^{2-}$, $NH_4^{+}$-N, $PO_4^{-}$-P, $NO_3^{-}$-N and B. Average values of these parameters for both morning (M) and afternoon (A) time are given in Table 3.3.

Table 3. 3: Average morning and afternoon values of chemical parameters

| Station | mg/L | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Na^{+}$ | | $Ca^{2+}$ | | $Mg^{2+}$ | | $K^{+}$ | | $HCO_3^{-}$ | | $Cl^{-}$ | |
| | M | A | M | A | M | A | M | A | M | A | M | A |
| BS-1 | 9.29 | 9.20 | 25.96 | 28.38 | 3.99 | 3.41 | 3.52 | 3.42 | 120.15 | 121.10 | 8.71 | 9.05 |
| BS-2 | 11.72 | 12.76 | 34.49 | 30.93 | 3.94 | 6.07 | 4.79 | 5.37 | 134.64 | 142.51 | 13.47 | 17.08 |
| BS-3 | 12.44 | 12.66 | 34.92 | 31.18 | 3.33 | 4.55 | 4.95 | 4.70 | 136.53 | 127.10 | 15.06 | 13.36 |
| BS-4 | 12.58 | 12.78 | 39.61 | 33.30 | 3.23 | 3.48 | 4.78 | 4.22 | 130.97 | 126.10 | 16.30 | 16.40 |
| BS-5 | 12.84 | 12.88 | 37.46 | 34.20 | 3.35 | 3.57 | 4.75 | 4.58 | 127.73 | 128.17 | 16.03 | 15.60 |

| Station | mg/L | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $SO_4^{2-}$ | | $NH_4^{+}$-N | | $PO_4^{-}$-P | | $NO_3^{-}$-N | | B | | $CO_3^{2-}$ | |
| | M | A | M | A | M | A | M | A | M | A | M | A |
| BS-1 | 10.02 | 12.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.10 | 0.056 | 0.053 | - | - |
| BS-2 | 16.03 | 12.25 | 1.18 | 3.08 | 0.29 | 1.13 | 0.08 | 0.19 | 0.004 | 0.032 | - | - |
| BS-3 | 18.34 | 12.25 | 0.06 | 4.40 | 0.06 | 0.06 | 0.28 | 0.39 | 0.004 | 0.032 | - | - |
| BS-4 | 19.25 | 11.41 | 0.14 | 0.00 | 0.00 | 0.61 | 0.25 | 0.19 | 0.081 | 0.067 | - | - |
| BS-5 | 21.45 | 16.89 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.25 | 0.060 | 0.046 | - | - |

The average sodium concentrations of river Beressa at five sampling stations during the study period varied from 9.20 mg/L to 12.88 mg/L. Sodium concentration in Sampling station BS-1 was found lower than that of the other sampling stations. This is because of the urban influences are considerably less. Average concentrations of sodium during morning time were found lower than average concentrations of sodium during afternoon time.

The average calcium concentration level of river Beressa at Debre Berhan District during the study period ranges between 25.96 to 39.61 mg/L. Concentration of calcium was found higher at sampling stations BS-2, BS-3, BS-4 and BS-5, which are located where urban influences present, than sampling station BS-1, which is located far from urban area. Average concentrations of calcium during morning time were found higher than afternoon concentrations in all sampling stations except BS-1. This is similar to the result of electrical conductivity.

Average magnesium concentrations of river Beressa in Debre Berhan district at five sampling stations during the study period varied between 3.23 mg/L to 6.07 mg/L. Maximum concentration of magnesium was found at sampling station BS-2, the diversion weir found where effluent discharges from Debre Berhan University, Debre Berhan Blanket factory and irrigation return flows from Debre Berhan floriculture mixed. The average magnesium concentrations of all sampling stations except BS-1 during afternoon time were found higher than the concentrations during morning time. The higher magnesium concentrations during afternoon time may be resulted from greater human interferences during the day time than during night time.

The average potassium concentration of river Beressa during the study period ranges from 3.42 mg/L to 5.37 mg/L. Maximum potassium concentration was found at sampling station BS-2. The higher concentration of the potassium ions at BS-2 may be related with the raw material used for blanket and dying agent that contain large potassium content that get discharged to the river water. Similar past study conducted near this sampling station show that the average concentration was high i.e. 9.6 mg/L and the cause for this is most textile factories release dying effluents including potassium and other persistent aromatic compounds (Ermias, 2007). Average concentrations of potassium during morning time were found higher than that of afternoon time except at sampling station BS-2.

Laboratory analysis results of carbonate concentration of river Beressa at five sampling stations showed the level of carbonate on the river was found trace. Whereas, the average bicarbonate concentration of river Beressa at five sampling stations during the study period varied between 120.15 mg/L to 142.51 mg/L. Low concentration of bicarbonate was found at sampling station BS-1 while high concentration of bicarbonate was found at sampling station BS-2. The low concentration of bicarbonate at sampling station BS-1 may be resulted due to less urban and industrial influences. Whereas, high concentration of bicarbonate at sampling station BS-2 may be due to high urban and industrial influences at this point.

Average chloride concentration levels at five sampling stations of river Beressa during the study period varied between 8.71 mg/L to 17.08 mg/L. Chloride concentration at sampling station BS-1 was found lower than concentrations at other sampling stations (BS-2, BS-3, BS-4 and BS-5). This indicates that there was an increase in chloride concentrations at sampling stations located where urban and human interferences are high. There was also temporal variation in chloride concentrations between samples taken during morning time and afternoon time. The temporal variation was large at sampling stations BS-2 and BS-3 because of greater variations of interferences at those sampling stations than the others.

The average sulfate concentrations of river Beressa at five sampling stations in Debre Berhan district varied between 10.02 mg/L, at sampling station BS-1 to 21.45 mg/L, at sampling station BS-5. The high concentration of sulfate at sampling station BS-5, which is located where Debre Berhan Tannery Factory effluent mixed with the river water, may be resulted due to discharge of Sulfate containing salts used in the tannery process. Average sulfate concentration levels during morning time were found higher than average concentration levels during afternoon time at all sampling station except BS-1. The dominance of sulfate of the anions in river is usually characteristic of acidification (Chernogaeva, 1994). Similarly, in Beressa River the sulfate concentration was found higher during the morning because the pH was found lower during the morning time than that of afternoon time.

Average ammonium level of river Beressa during the study period at five sampling stations varied from 0.00 to 4.40 mg/L. Maximum ammonium concentration was found at sampling station BS-3. Higher levels of ammonium at sampling stations BS-2 and BS-3 were due to higher disposal of waste from DBU at sampling station BS-2 and municipal waste discharge at sampling station BS-3.

Higher average concentrations of ammonium during afternoon time than morning time were found. This high concentration during afternoon time is due to the reason that there is more human and animal interferences during the day time than during night time.

Average concentrations of phosphate at five sampling stations of river Beressa during the study period varied from 0.00 to 1.13 mg/L. The level of phosphate at river Beressa was low which is below 2 mg/L at all sampling stations investigated. Similar past study shows that level of phosphate contamination at Beressa River was relatively insignificant indicating that disposal of phosphate from domestic and industrial sewage as a washing powder, intensive rearing of livestock and the use of phosphate containing fertilizer is very less (Ermias, 2007).

The average nitrate level of river Beressa at five sampling stations varied from 0.02 mg/L to 0.39 mg/L. The concentration of nitrate in Beressa River was found very low. Like the other chemical parameters nitrate concentration at sampling station BS-1 was found lower than that of the other sampling stations which are located in the urban area.

The average boron level of river Beressa at Debre Berhan district at five sampling stations ranges between 0.004 mg/L to 0.081 mg/L during the study period. Boron concentration Less than 0.5 mg/L is generally safe, 0.5-1.0 mg/L is slight to moderate, and greater than 1.0 mg/L is considered severe (Connery, 2011). The boron level of river Beressa is much lower than 0.5 mg/L and it is generally safe for irrigation purpose in terms of boron concentration.

### 3.4 Suitability for Irrigation

#### 3.4.1 Salinity Hazard

Salts in a water sample are measured by total dissolved solids (TDS) or electrical conductivity (EC). For a given irrigation water the higher the TDS or EC, the higher the salt hazard will be. Based on EC value (salinity hazard) irrigation waters are classified as very low hazard (<250 µS/cm), low hazard (250-750 µS/cm), medium hazard (750-2000 µS/cm), medium-high hazard (2000-3000 µS/

Table 3. 4: Average morning and afternoon values of SAR, Na %, RSC and PI

| Sampling Station | SAR (meq/L) | | Na (%) | | RSC (meq/L) | | PI (%) | |
|---|---|---|---|---|---|---|---|---|
| | M | A | M | A | M | A | M | A |
| BS-1 | 0.45 | 0.43 | 23.22 | 22.30 | 0.35 | 0.29 | 89.24 | 86.84 |
| BS-2 | 0.51 | 0.54 | 23.50 | 25.02 | 0.16 | 0.30 | 78.11 | 82.41 |
| BS-3 | 0.54 | 0.56 | 24.83 | 25.71 | 0.22 | 0.15 | 80.11 | 81.59 |
| BS-4 | 0.52 | 0.56 | 23.11 | 25.18 | -0.09 | 0.12 | 72.60 | 79.87 |
| BS-5 | 0.55 | 0.57 | 24.30 | 25.31 | -0.05 | 0.10 | 74.91 | 78.94 |

#### 3.4.2 Sodium Hazard

The sodium hazard of Beressa River water was checked by comparing calculated values of sodium adsorption ratio (SAR), sodium percentage (Na %) and residual sodium carbonate (RSC) (Table 3.4) of the river with standard irrigation water quality values.

Based on SAR values irrigation waters can be classified as low (S1 < 10), medium (S2:10 – 18), high (S3:18 – 26) and very high (S4 > 26) (Rao, 2006). The SAR values of river Beressa at all sampling stations in Debre Berhan district varied from 0.43 to 0.57, which is much lower value than 10. Hence, the river water will not have sodium hazard on the crops to be grown in the area and it is classified as low sodium water (S1 < 10). The classification of river water can be also grouped based on percent Sodium as Excellent (<20 %), Good (20 – 40%), Permissible (40 – 60%), Doubtful (60 – 80%) and Unsuitable (> 80%) for irrigation (Wilcox, 1995; Sadashivaiah et al.,2008; Nishanthiny et al., 2010). The result of sodium percent of river Beressa revealed that the river water is categorized as excellent to good for irrigation.

Irrigation water can be classified into different RSC classes like class 1: low (<0 meq/L), class 2: medium (0.0 -1.0meq/L), class 3: high (1.0-2.5meq/L) and class 4: very high (>2.5 meq/L) (Stevens, 1994).

Based on this Beressa River water is classified under class 2: medium water for irrigation based on the RSC values obtained during the study. Such water may cause some problems related to RSC and monitoring of infiltration and soil pH is necessary.

### 3.4.3 Infiltration Problems

To check the suitability of the river with respect to infiltration problems, both salinity (EC) and sodium adsorption ratio (SAR) as well as permeability index of the river were used (Table 3.4).

The mean salinity level (EC) of river Beressa was found ranging from 148.09 μS/cm to 196.90 μS/cm at and the mean SAR level was found varying from 0.43 to 0.57. Very low EC water dilutes and/or leaches calcium and makes soil aggregates susceptible to disintegration, causing water infiltration problems(Bryan et al., 2007). Regardless of the sodium content, water with an electrical conductivity less than about 200 μS/cm causes degradation of the soil structure, promotes soil crusting, and reduces water penetration (Hoffman and Shannon, 2007). Water with EC value below 200 μS/cm and SAR value between 0 to 3 is categorized under highly restricted water for irrigation because it can cause infiltrations problems (Ayers and Westcot, 1985). Hence, water of river Beressa is categorized under severe degree of restriction on use. Such water, with low salinity level (EC) can cause infiltration problems on the soil and this may create adverse effects on crop growth and yield.

The average permeability index values at five sampling stations of river Beressa varied between 76.24 % to 88.04 %, while the average total concentrations of salts was found varying between 4.62 meq/L to 5.69 meq/L. As per Doneen's classification, the water in almost all sampling stations lies under permeability class-II and that of sampling station BS-1 lies under permeability class-III. This implies that the permeability will be reduced to 25 % of the maximum permeability of soil if river water from sampling station BS-1 is used for irrigation. Whereas, if river water is used for irrigation from the sampling stations located in urban area, the permeability will be reduced to 75 % of the maximum permeability of the soil. Hence, the water of the river in urban area is better than that of rural area in alleviating permeability problems of soil.

## 4. Conclusions and Recommendations

### 4.1 Conclusions

Most of the irrigation water quality parameters investigated in this research showed an increase as the river drains from rural zone to the urban area. According to USSL (1954) classification, the irrigation water quality of river Beressa lies under $C_1$-$S_1$, i.e. low salinity hazard and low sodium (alkali) hazard. There may be potential problems related to the bicarbonate and pH values like clogging of irrigation drippers and nozzles when using pressurized irrigation systems and hence, lowering the bicarbonate level and pH level by adding sulfur or acid materials when using pressurized irrigation systems is very important.

### 4.2 Recommendations

From the research study on 'Investigation of Beressa River Water Quality for Urban and Peri-urban Irrigation in Debre Berhan' the following statements are recommended.

- Beressa river water can cause problems related to infiltration (permeability) of the soil and corrosion of irrigation pipes and equipments. Therefore, soil management practices that increase infiltration of the soil and techniques to avoid corrosion should be practiced.
- The pH and bicarbonate level of river Beressa may create clogging problems on irrigation equipments. Hence, the pH and bicarbonate level of the river should be lowered by adding sulfur or other acid materials especially when using pressurized irrigation methods.
- When using Beressa River water for irrigation, it is better to irrigate during morning time than afternoon time in order to minimize the irrigation water quality problems of the river.
- Although currently the river water pollution is not so serious problem, linked to the growth of urbanization and population there may be increase in concentration of pollutants in the future. Hence, appropriate monitoring and controlling mechanism of pollutants from different sources is vital.
- Further studies should be conducted in different seasons for longer period of time considering other irrigation water quality parameters and including soil samples from different irrigated lands.

# Potential Characterization of Traditional Watermills for Upgrading to Small-Scale Hydropower Plants in Ethiopia: *The Case of Southwestern Oromia*

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## Abstract

*Energy security and environmental protection are the major bottlenecks of development policies and strategies in developing countries. Renewable energy technologies especially Small/Micro Hydropower (MHP) schemes have been identified as one of the best options for decentralized power generation in rural areas. However, as to other renewable technologies the power generation cost of MHP developed in conventional approach is not attractive for the stakeholders in the sector. In this study representative site selection followed by intensive field survey was undertaken to technically and socio economically characterize traditional watermills in the study area and to determine its feasibility for being upgraded to electric generating MHP scheme. Towards this it is evident that 64% of the watermill schemes have a beneficiary of more than 120 households (HHs) and 53% of HHs in the study area are characterized in having annual income of more than $405/yr with a capacity of paying $0.104/kwht for electricity service. The watermills have a potential of being upgraded to MHP schemes with minimum and maximum existing capacity of 5.6kw and 23kw respectively. Net head of 11.8m which belongs to more than 83% of the watermill schemes and a reliable design discharge of 120liter/sec available for 80% of the schemes in the study area is proved to deliver the typical energy demand of 126.23kwh/day/village. Hence, this article communicates a study result which will help different stakeholders to develop MHP schemes in techno-economically feasible approach.*

**Keywords:** Micro hydropower, Watermill characterization, Socio economics, Sustainability

## 1. Introduction

Like other Sub-Saharan African (SSA) countries the lion's share (~94%) of the rural household energy demand in Ethiopia is supplied by non-sustainable provision of biomass which was yet characterized by 78% supply deficiency in 2004[1]. Energy supply for the agriculture sector, which supplies more than 50% of the country's GDP, is 100% from imported petroleum. In the Millennium Development Goals of SSA and the Growth and Transformation Plan (increasing total electricity access from 41% in 2010 to 75% in 2015) of Ethiopia, increased access to modern energy in all sectors is one of the pillars. In most instances the possible role of small scale hydropower has been recognized, as in the new draft for energy strategy of the World Bank that does specifically highlight small scale hydropower as an important component of future World Bank activities in Africa [2]. Small Scale hydro power is recognized as one of the most viable sources of clean, renewable and abundant alternative energy resources for sustainable development in isolated rural areas of SSA countries [3]. In addition to policy and financial issues, the major phenomenon hindering the large scale utilization of Small/Micro hydro power is a missing awareness on renewable energy uptake by political, government and regulatory entities in the least developed countries [4]. Estimated economic potential of hydropower in Ethiopia is between 15 to 30 GW. However, only a small proportion (~ 2 %) is developed to date. The total potential for Micro- and Pico-hydro power is estimated to be 100 MW and most of this is located in the western and south western areas of the country [5].

Oromia regional state with a total area of 352,632km$^2$, population of more than 25 million living within around 4 million households has the highest investment potential of MHP and has available potential of 35MW with only 8.6% of the population in the region having access to electricity [6]. There are few small scale hydropower schemes developed by involvement of government entities and mainly funded by international multilateral organizations based in the country [7-9]. However, these schemes are claimed to have difficulty in convincing their customers and private developers on their techno – economic feasibility as they are developed following the conventional approach consists of importing many system component parts from abroad.

The search for alternative approach of small scale hydro-power development in Ethiopia is strongly backed up with the availability of more than 600 traditional watermills that could be upgraded for power generation [10]. This study is aimed to review the current status of the traditional watermills in southwestern Oromia and analyze its techno-economic characteristics with regard to upgrading for electric generation scheme in techno-economically feasible and sustainable approach.

## 2. Study Approach

### 2.1. Description of the Study Area

The study covers 2,320HHs in and around 24 watermill sites purposively selected from five zones (East, West and Kelem Wallega, Jimma, Iluababor) and 16 administrative waredas in south western oromia. Geographically the study area is found in a position of 7° N - 10° N latitude and 34° - 37° E longitude.

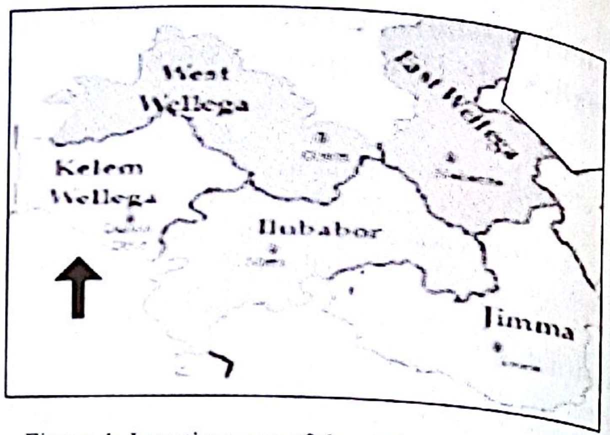


Figure 1: Location map of the study area

Table 1: Location of the river streams used for the characterization of watermills

| Zone | Wareda | Kebele | Village | River |
|---|---|---|---|---|
| Iluababor | Bedele | Teba Chabali | Sota | Sota |
| | " | Gema Gamada | Teba | Teba |
| | Mettu | Tobeecha | Janet | Keber |
| | Suphie | Wayuu | Wayuu | Wayuu |
| | Bure | Seechaa | Seechaa | Goree |
| Jimma | Mana | Kore Lelisa | Turchi | Chedo |
| | Seka | Buyo Chala | Hursa | Hursa Gibe |
| | Seka | Boba Roge | Abono | Abono |
| | Seka | Boba Roge | Meti | Meti |
| | Shebe | Leku Migra | Hemexo | Duko |
| | Gera | Gangi Chala | Gure Ganji | Atta |
| E/Wallaga | Wayyu Tuka | Migna Kura | Kiltu Bala | Fite |
| | Wayyu Tuka | Migna Kura | Tube | Hadhesa |
| | Wayyu Tuka | Gutte Badiya | Lalisa | Tatto |
| | Wayyu Tuka | Gida Aballo | Warago | Allaltu |
| | Diga | Gudisa | Dire Homi | Maka |
| W/Wallaga | Jarso | Babo Torban | Tulu Balla | Gumgum |
| | Boji Dirmaji | Bikiltu Dila | Lalistu Dila | Dilla |
| | | Lalisa Jeto | Sandabo | Gabi |
| | Manasibu | Haro Korke | Gambela | Melka Alati |
| | Ayra | Lelisa Birbir | Birbo | Birbo |
| | | Ayra 01 | Iffa Doyyo | Doyyo |
| K/Wallaga | Seyyo | Kure Gayib | Doyyu | Otta |
| | Jima Horo | Keto | Melka Keto | Keto |

### 2.3. Data Collection and Analysis

Different approaches were used for collecting primary data from the purposively selected schemes. For the socio-economic and technical data semi structured questioners and interview check lists were used. Moreover, standard instruments (GPS and Digital Flow meter) are also used for measuring significant technical parameters in each of the twenty four schemes. Both the qualitative and quantitative data is analyzed using descriptive statistics method. Result and Discussion

## 3. Results and Discussions

### 3.1. Socio-Economic Characterization

Energy access is limited in the study area and it is a bottleneck for sustainable development as the only supply of modern energy is EEPCO's grid. Utilization of locally available resource for electrification of the rural HHs should be of high priority. Efforts to develop infrastructures like road and telephone service could be taken as inputs to develop MHP since they bring the local supply centers 3km - 5km to the load centers. Average length of power transmission line is 560m with the minimum and the maximum of 450m and 1.2 km respectively. Moreover, the settlement of the beneficiary HHs is characterized as shown in Figure 2.

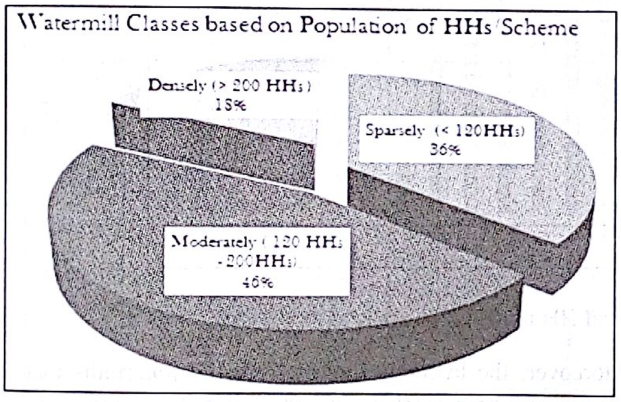


Figure 2: Characteristic nature of beneficiary HHs in the study area

Agriculture [Coffee and Chat] is dominant [83%] source of income in southwestern oromia. However; trade, pottery and wood processing can also be taken as additional source. The HHs in the study area is characterized as shown in Fig.3 based on their annual income. Apart from level and source of income; parameters of significant importance for the watermill upgrading are the capacity to pay (CTP) and willingness to pay (WTP) of the beneficiary HHs to the service and development of MHP scheme. CTP is considered in terms of avoided cost of energy. Fuel consumption of kerosene lantern is 0.02kg/hr [11] considering single device per HH with a working time of 5hrs/day and kerosene price of 24ETB/kg in the study area the avoided cost is calculated to be 2.4ETB/day [1.92ETB/kwht].

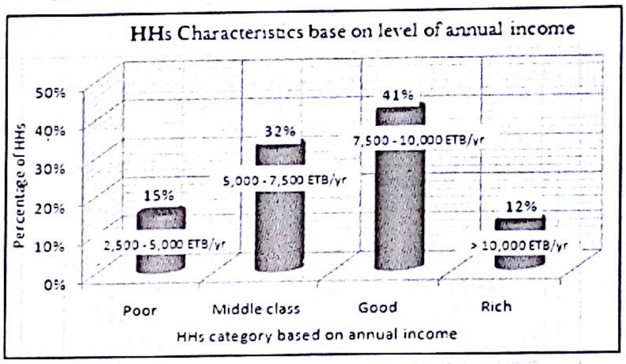


Figure 3: Nature of the beneficiary HHs based on their level of annual income

The HHs willingness in paying for the service and development of MHP scheme is a direct implication of their awareness level and HHs income level is a determining factor for the level of awareness. In this regard out of the total HHs 23% has shown hesitation for participation and 78% of which are from poor income HH group. Of the watermill schemes in the study area 68.56% are functional and majority of them are owned by private farmers. The three dominant ownership types for the watermills and their implication on functionality are summarized in Figure 4. The study on the ownership modelFig.5 used for the existing electric generating MHPs revealed that it has major drawbacks with regard to lack of appropriate follow up which results in lack of project techno-economic sustainability.

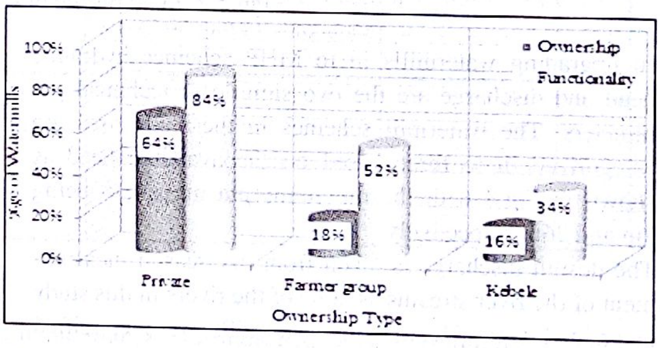


Figure 4: Relationship between watermill ownership type and functionality

Public private partnership [PPP] business model is appropriate for MHPs to be developed in the study area. However, awareness and experience of using this model is very limited among all stakeholders in the sector. In this regard a new ownership model (Figure 6) is proposed in trying to avoid the lack of techno-economic sustainability of the projects through injecting more public entities in to the model. However, it is in need of more effort from all parties involved as it is new for all stakeholders in the sector.

### 3.2. Technical Characterization

Energy demand of the HHs in the study area was estimated considering a typical appliances used in rural household, small clinic and primary school with their minimum standard. Moreover, the load profile (Figure 7) was developed using the estimated demand indicating the base and peak demand of the HHs to be 5.75kw /day and 15.1kw/day respectively.

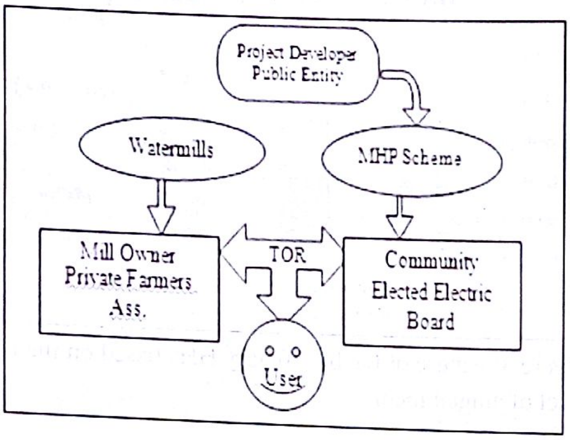


Figure 5: Existing MHP ownership model

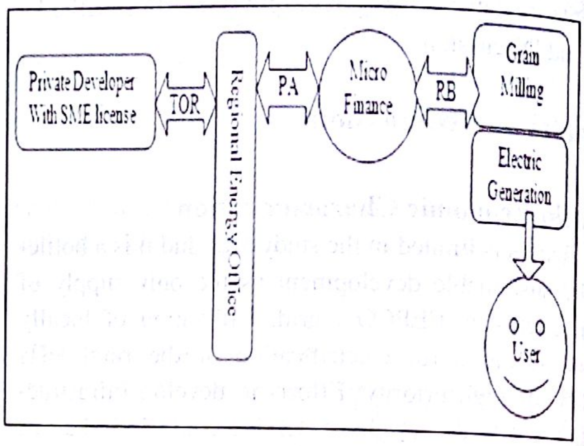


Figure 6: Newly proposed MHP ownership model

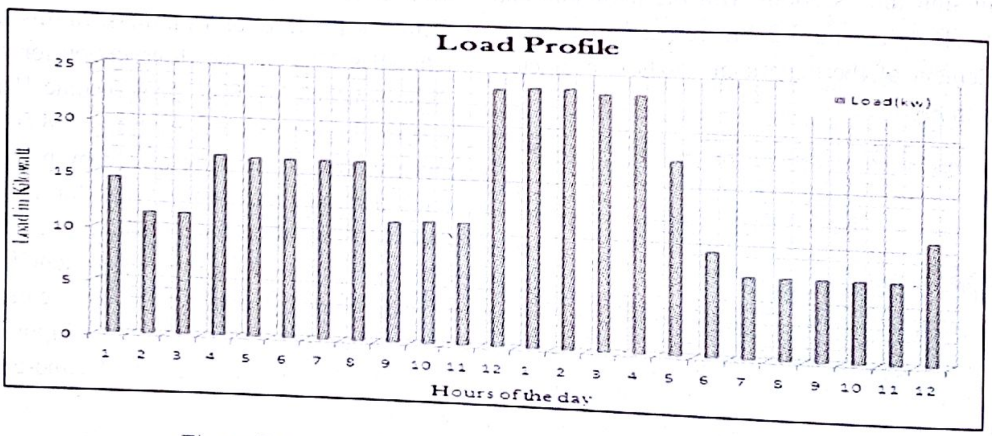


Figure 7: Load profile of typical HH in the study area

In upgrading watermills in to MHP schemes hydraulic head and discharge are the two significant technical parameters. The watermill schemes in the study area are categorized in to three based on the available head as shown in Fig.8 with the minimum and maximum being 7m and 26m respectively.

The design discharge is taken from dry season measurement of the river streams as none of the rivers in this study is gauged type. Hence, the watermills were classified based on the reliable discharge in each stream as presented in Figure 9.

Moreover, the hydraulic power from the watermills that could serve both mechanical and electrical purpose is determined in taking the average of the hydraulic head loss interval (5% -10%) and turbine efficiency of 50% [12].

Cost competence of the upgraded scheme is much influenced by its distance from the grid, as the scheme is nearer to the grid its feasibility for electrification drops and rather be considered for productive use. In this regard the study indicated that more than 88% of the watermill schemes could be upgraded for electrification at least for the coming seven to ten years.

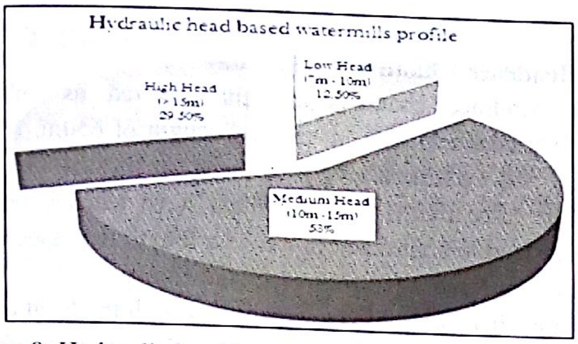


Figure 8: Hydraulic head based profile of the watermills in the study area

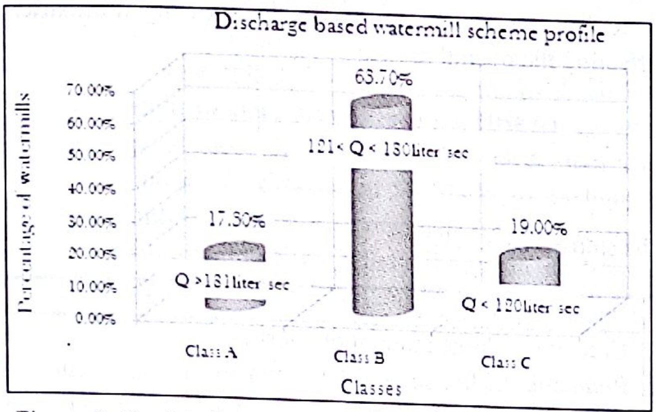


Figure 9: Design discharge based classification and profile of watermill in the study area

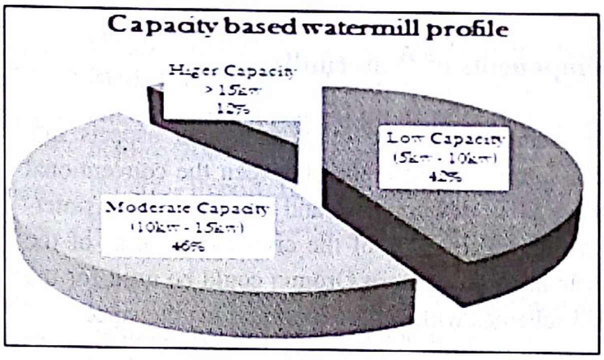


Figure 10: Watermills classified based on their capacity in the study area

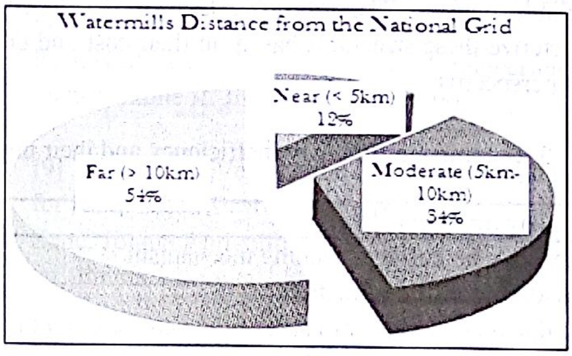


Figure 11: Location of watermill schemes with respect to the national grid

Table 2: Nature of watermill's diversion weirs in the study area

| *Type* | *Material* | *Life span* | *Cost* | *Effectiveness* |
|---|---|---|---|---|
| Type I (25%) | Shrubs and piece of wood supported by small gravel | One year | Negligible | Poor quality<br>Continuous repair and maintenance<br>Very cheap<br>Simple to construct and maintain |
| Type II (55%) | Timber ,gravel and stone | < Three years | 250 ETB/m up to 475ETB/m | Moderate quality<br>Used in smaller and medium steam<br>Require lower level skilled man power for construction and maintenance |
| Type III (20%) | Stone masonry | > Ten years | More than 3500ETB/m | Good quality<br>Expensive<br>Difficult to construct and maintain with local skill and knowledge |

N.B: The percentage distribution of each type in the study area is indicated in the 1st column

## 3.3. Components of Watermills

Watermill components are other important aspects that will set a significant difference between the conventional methods of MHP development and upgrading from watermills. In this regard 52% of the civil components of the watermills in south western Oromia could be used for the upgraded schemes with slight repair and maintenance.

### i. Diversion Weir

The diversion weirs in the study area are constructed from locally available material and skill in techno-economically justifiable manner. The following table is developed to characterize these structures based on their cost and durability perspective.

### ii. Headrace Channel and Forebay

The headrace channels are characterized as unlined earthen channels with an average length of 650m. Minimum and maximum length of these canals is 450m and 1.8km respectively. 84% of them have leakage points which lead to significant power loss due to the associated water loss especially for electric generation.

The channels have good compatibility with the local environment and are more stable. The inefficiency of the forebay is accountable for more than 30% water loss in the watermills and they exhibited the following drawbacks affecting the overall system

Table 3: Summery of fore bay inefficiency and their impact in the study area

| Fore bay drawback | Impact on the overall system |
|---|---|
| They have no defined cleaning mechanism<br>Provides no settling function<br>The thickness and overall size of the penstock and the runner are enlarged so that they could sustain the impact | Creeping in large amount of energy loss<br>Reducing the life span of the mechanical components<br>Overall effectiveness and efficiency of the system is significantly reduced |

In reducing technical complexity and achieving cost effectiveness, it is advantageous to use a single structure which can serve both as settling basin and fore bay for such small capacity schemes [12]. This study indicated that it is mandatory to construct standard but economical forebay structure to keep the techno – economic feasibility of the schemes viable and sustainable.

### iii. Penstock

In a typical MHP development project a civil work structure that consumes the third largest cost in the overall system is the penstock [12]. Hence, it was possible to classify the penstocks in watermill schemes based on their construction material which has a direct impact on their cost and durability.

Table 4: Characteristic nature of Penstock classes in south western oromia

| No | Class | Material | Est. Cost | Est. life span | Effectiveness |
|---|---|---|---|---|---|
| 1 | Class – A<br>*54.2%* | Old Barrel | 84 ETB/m | 7 years | Susceptible to leakage<br>Once damaged difficult to maintain and reuse<br>Difficult to get Old barrel for this purpose<br>Moderate frictional loss |
| 2 | Class -B<br>*18.6%* | Wood and old barrel | 58 ETB/ m | 4 years | Easily damaged by water flow<br>Difficult to maintain<br>Leads deforestation<br>No flexibility<br>High frictional loss |
| 3 | Class - C<br>*27.2%* | Sheet Metal | 867ETB /m | >15years | Relatively expensive<br>Longer life span<br>Less frictional loss<br>Minimal effect by the water |

N.B: The percentage distribution of each class in the study area is indicated in the 1st column

## 4. Conclusion

For any sustainable development to be successful three major factors need to be in an optimum harmony: Energy, Economy and Ecology .Energy access and consumption level is an indicator for the wellbeing and development level of a Household [13].In this regard it was evident from this study that more than 78% of the rural households in southwestern oromia could be electrified using a local renewable energy resource through upgrading of traditional watermills. The socio-economic study indicated that social and economic situation of the HHs in the study area is well suited for community oriented development practice with more than 53% of the HHs having an annual income of more than $ 405/yr. Moreover, they currently have an energy expense of $0.104/kwht for lighting service only. Technically, more than 76% of the watermills could be upgraded to deliver minimum of 10kw power and serve a 178% demand increase from the current situation. Finally, using the new approach of MHP development from upgrading traditional watermills a minimum of 18% generation cost reduction could be achieved in using 52% of the civil work components in the watermill for the upgraded MHP scheme with complete replacement of the electro-mechanical components.

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# Determination of Irrigation Requirement and Irrigation Scheduling of onion at Ribb and Kobo, Ethiopia

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## Abstract

*Irrigation scheduling is an essential daily water management practice for small holder farmers who are growing irrigated crops. It is a plan to determine when and how much water to apply for a given crop in order to maintain optimum plant growth. Field experiments were conducted to determine the irrigation water requirement and irrigation scheduling of onion at Ribb in Fogera district and Kobo areas of the Amhara region during 2010 and 2011 irrigation seasons. Irrigation requirement and optimal irrigation scheduling for onion was determined using CROPWAT version 8. In the field verification trial, combination of different levels of irrigation depths and irrigation frequencies were selected on the bases of CROPWAT model and local water application experiences of the farmers. Accordingly, 4 and 7 days irrigation intervals and four fixed and one variable irrigation depths were combined to generate ten treatments at Ribb in Fogera. At Kobo research station, combination of 5, 7, and 9 days irrigation intervals and 23, 30, and 38 mm irrigation depths were used. The treatments were arranged in RCBD and factorial RCBD with three replications at Ribb and Kobo respectively. Onion (Bombay red variety at Ribb and Adama red variety at Kobo) were planted and Agronomic parameters were collected and subject to analysis using SAS software. The results of the two years study has shown significant difference in marketable and total yield as well as the water use efficiency. Since year and year by treatment effect is significant for onion, the results could not be combined over year both at Kobo and Ribb. Therefore, at Ribb, independent results show that application of 33 mm irrigation water at 7 days interval gave 20.0-34.0 t ha$^{-1}$, 20.0-35.0 t ha$^{-1}$ and 4.0-7.0 kg m$^{-3}$ marketable yield, total yield and water use efficiency respectively. Whereas at Kobo, independent results of the two years show that application of 38 mm irrigation water at 7 days interval gave 17.0-27.5 t ha$^{-1}$, 17.0-28.0 t ha$^{-1}$ and 3.2-5.3 kg m$^{-3}$ marketable yield, total yield and water use efficiency respectively. Irrigation water requirements of onion were found to be 462 mm and 570 mm corresponding to 14 and 15 irrigations at Ribb and Kobo respectively. Therefore, in order to attain an optimum yield and water use efficiency, at Ribb and Kobo areas onion can be irrigated with 33mm water at 7 days interval and 38 mm water at 7 days interval respectively.*

Key words: Irrigation scheduling, Onion, Kobo, Ribb

## 1. Introduction

In Ethiopia, the population is growing rapidly and is expected to continue growing, which inevitably lead to increased food demand. To maintain self-sufficiency in food supply, one viable option is to raise the production and productivity per unit of land through irrigation. Proper amount and timing of irrigation water applications is a crucial decision for a farm manager to meet the water needs of the crop to prevent yield loss and maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources (Richard *et.al* 1998).

Onions need frequent irrigation to maintain high soil moisture. Irrigation scheduling highly matters in onion production. This is because; onions are extremely sensitive to water stress. Regardless of the type of irrigation system used, both yield and quality can suffer if irrigation is delayed and available soil moisture is allowed to drop too low (Shock et al., 2010). Studies made in Turkey gave clear proof that the bulb and dry matter production of onion were highly dependent on appropriate water supply (Serhat and Cigdem, 2009).

Among the common irrigated vegetables, onion (*Allium cepa* L.) shares the largest in both area coverage and local consumption in Ethiopia. Particularly, it is the popular vegetable grown under irrigation in most of the traditional and the recent modern irrigation schemes in Amhara region. However, the largest production of onion is not supported with improved water management practices to improve its productivity and bulb quality. There is lack of location specific research results of how much water and when to irrigate onion.

The objective of this study was to determine the crop water requirement and irrigation schedule of onion grown under irrigation for specific localities of Kobo and Fogera Woredas

## 2. Materials and Methods

### 2.1. Description of the study area

The experiments were conducted at Ribb and Kobo irrigation schemes for two years (2010 and 2011). Ribb is located at about 60 kilometres from Bahir-Dar city to the North-East direction in Fogera woreda. It is situated at $37^{0}44''55'$ E longitude and $11^{0}58''45'$ N latitude at an altitude of 1800m above mean sea level. The average annual rainfall of the area is about 1118 mm. The mean maximum and minimum temperatures are 27.3 $^{0}$C and 11.3$^{0}$C respectively. The highest temperature (29.5$^{0}$C) of the area occurs from February to May. The lowest temperature (9.8$^{0}$C) occurs only in January. The soil type is generally Fluvial in its nature.

Kobo research station is located at about 50 kilometers from Woldia town to the North-East direction in Kobo woreda and situated at 12.08$^{0}$ N latitude and 39.28$^{0}$ E longitudes at an altitude of 1470 m above sea level. The 15 year mean annual rainfall is about 630 mm and average and maximum daily reference evapo-transpiration rate of 5.94 mm and 7.69 mm respectively. The soil type in the experimental site is silty clay loam with average FC and PWP of 11.5% and 3.2% on volume basis respectively. The site is characterized by average infiltration rate of 8 mm/hr and pH value of 7.8.

### 2.2. Experimental setup

The experiments are conducted in two phases.

***Phase One: Estimation of net irrigation requirements and optimal scheduling***

CROPWAT version 8.0 for Windows was used to generate the crop water requirement and the irrigation schedule for onion in the study areas. Calculations of the crop water requirements and irrigation schedule were carried out taking inputs of climatic, soil and crop data. In order to estimate the climatic data (wind speed, sunshine hours, relative humidity, and minimum and maximum temperature) local climate estimator software (FAO, 1992) was used at Ribb where there is no class A meteorological station and to estimate missing data at Kobo. The estimator uses real mean values from the nearest neighbouring stations and it interpolates and generates climatic data values for the study site. Assuming 90% and 80 % application efficiency at Ribb and kobo respectively, the gross water requirement was calculated.

***Phase Two: Verifying the CROPWAT generated scheduling in the field***

Principally, CropWat outputs generated by default were used to identify irrigation timing of when 100% of readily available moisture occurs and application depth where 100% of readily available moisture status is attained. To verify this model output, field experiments were carried out for two consecutive years at Kobo and Ribb. Rainfall data was recorded for the experimental season and calculated to be used and daily adjustment was done when there was an occurrence of unpredictable and too much amount of rainfall than the predetermined irrigation depth.

Based on the model estimation and farmers traditional practice in the area, at Ribb two irrigation intervals, i.e. 4 and 7 days were selected. The amounts of irrigation depths were selected systematically depending on these two intervals and total length of growing period (LGP) of onion. The treatment is composed of treatments with four levels of fixed depths at all stages, and one treatment with variable depths at four onion growth stages (initial stage, crop development stage, mid-season stage and late season stage). These five water levels were obtained independently for 4 and 7 days irrigation intervals. A total of 10 treatments which is a combination of irrigation depth and irrigation interval were selected (Table 1). Fixed application depths were included in the treatment purposely. This is because; they are easily taken by farmers as compared to the variable depths which need frequent adjustment throughout the crop growing season.

At Kobo, the CROPWAT generated average depth and interval was 30 mm and 7 days. A factorial combination of three irrigation intervals (5, 7, and 9 days) and three irrigation depths (23, 30, 38 mm) were used which are based on initial estimated CROPWAT generated depth (CWGD) and plus or minus 25% of the optimum depth (Table 1). The experimental design was simple RCB at rib and RCB factorial at Kobo with three replications.

Table 1. Treatment setup for the experiments done at Ribb and Kobo in 2010 and 2011

| | Ribb | | | Kobo | | |
|---|---|---|---|---|---|---|
| Treat-ments | Irrigation Inter-val (days) | Irrigation Depth (mm) | Seasonal irrigation (mm) | Irrigation Inter-val (days | Irriga-tion Depth (mm) | Seasonal irrigation (mm) |
| 1 | 4 | 17 | 425 | 5 | 30 | 630 |
| 2 | 4 | 20 | 500 | 7 | 30 | 450 |
| 3 | 4 | 24 | 600 | 9 | 30 | 390 |
| 4 | 4 | 27 | 675 | 5 | 23 | 483 |
| 5 | 4 | 20 (initial stage: 20 days)<br>27 (dev. stage: 30 days)<br>24 (mid season stage: 30 days)<br>17 (late season stage: 15 days) | 559 | 7 | 23 | 345 |
| 6 | 7 | 31 | 434 | 9 | 23 | 299 |
| 7 | 7 | 33 | 462 | 5 | 38 | 798 |
| 8 | 7 | 37.5 | 525 | 7 | 38 | 570 |
| 9 | 7 | 40 | 560 | 9 | 38 | 494 |
| 10 | 7 | 33 (initial stage: 20 days)<br>37.5 (dev. stage: 30 days)<br>40 (mid season stage: 30 days)<br>31 (late season stage: 15 days) | 502 | | | |

The field experiments were carried out from December to April at Ribb and from February to June at Kobo. The test crop was onion, variety Adama red at Kobo and Bombey red at Ribb, was planted on 1.8 m by 2 m plot size at kobo and 2.4m X 3m at ribb with 40 cm spacing between rows, 20cm between plant rows and 10 cm between plants in double rows. DAP fertilizer was applied at a rate of 200 kg $ha^{-1}$ at planting. And 100 kg $ha^{-1}$ Urea split applied half at planting and the remaining half 45 days after planting. All the agronomic practices were equally done for each treatment.

Agronomic data such as stand count, total bulb yield, marketable yield, bulb diameter, bulb weight, and unmarketable yield were measured. Irrigation water productivity (IWUE) was calculated as the ratio of crop yield (marketable yield) and irrigation water applied (IW).

## 3. Results and Discussions

Some of the physical and chemical properties of the soils of the experimental field were analysed. The laboratory analysis result is presented in table 2.

As it is presented in Table 3 and 4, the ANOVA result shows that treatment and treatment by year interaction effects were significant for most agronomic parameters of onion at Kobo and Ribb.

Table 2. Selected soil properties for the study sites ( Ribb and Kobo)

| Loca-tion | Depth (cm) | pH | EC mmohs/g | % OM | Av.K mg/kg |
|---|---|---|---|---|---|
| Kobo | 0-30 | 8.05 | 0.125 | 4.25 | 0.49 |
| | 30-60 | 7.60 | 0.09 | 3.65 | 0.36 |
| Ribb | 20 | 6.02 | 0.042 | 3.29 | 0.52 |
| | 40 | 5.96 | 0.047 | 3.12 | 0.52 |

Where: EC- electrical conductivity, OM-organic matter, Av.K-available Potassium

### 3.1. Results at Kobo

The ANOVA Table 3 shows that the two year results and their interaction with the treatments are significantly different. Accordingly, the results of the two years were discussed separately. Even though the optimum seasonal irrigation water requirement was 450 mm applied in 15 irrigations, the field experiment verified that the irrigation requirement should be increased up to 570 mm in 15 irrigations at Kobo. Though irrigation requirement is highly location specific, similar study on onion done in Turkey showed that seasonal water requirement ranges from 350 to 450 mm for optimum bulb yield depending on the environmental conditions of each year (Halim and Mehmet, 2001).

Table 3. ANOVA for marketable, unmarketable, total yield and water productivity at Kobo (2010 and 2011)

| Source | Df | Mean Square | | | | |
|---|---|---|---|---|---|---|
| | | Marketable yield | Total yield | Bulb Weight | Bulb diameter | Water productivity |
| Yr | 1 | 1.944** | 0.934** | 2.12** | 0.0975** | 0.204** |
| Trt | 8 | 4.125** | 1.982** | 4.49* | 0.2069** | 0.433* |
| Rep(Yr) | 4 | 0.698 | 0.923 | 1.07 | 0.0548 | 0.210 |
| Yr*Trt | 8 | 5.834* | 2.803* | 6.35* | 0.2926* | 0.612** |
| Error | 34 | 3.516 | 3.433 | 7.78 | 0.3583 | 0.749 |

Where: Yr-year, Trt-treatment, Rep – Replication , Df – Degree of freedom and ** highly significant

Table 4. ANOVA for marketable, unmarketable, total yield and water productivity at Ribb (2009/10 and 2010/11)

| Source | df | Mean Square | | | | |
|---|---|---|---|---|---|---|
| | | Marketable yield (t $ha^{-1}$) | Un marketable Yield (t $ha^{-1}$) | Total yield(t $ha^{-1}$) | Bulb Weight (gm) | Water productivity ($kg/m^3$) |
| Yr | 1 | 556.7** | 34.7** | 869.4** | 5360 | 18.5** |
| Tret | 9 | 45.4** | 2.7** | 41.4** | 183.3 | 3.6** |
| Rep(Yr) | 4 | 2.9 | 2.1** | 2.97 | 278.2 | 0.09 |
| Yr*Tret | 9 | 35.01** | 3.1** | 29.1 | 284.3 | 1.53** |
| Error | 36 | 1.59 | 0.4 | 2.07 | 85.4 | 0.057 |

Where: Yr-year, Trt-treatment, Rep – Replication, Df – Degree of freedom, and ** highly significant

In 2011, the overall productivity was high as compared to the first year. All agronomic parameters respond significantly to water application depth at different application intervals (Table 5). Maximum (33.7 t $ha^{-1}$) and minimum (19.3t $ha^{-1}$) marketable yield was obtained by applying 38 mm every 5 days and 23 mm every 9 days interval respectively. With respect to the WUE except the application of 38 mm every 5 days, all have comparable WUE ranging between 4.3 and 6.5 kg $m^{-3}$. The highest WUE (6.5 kg $m^{-3}$) was obtained at 23 mm every 9 days and the lowest WUE (4.22 kg $m^{-3}$) was recorded by applying 38 mm every 5 days interval. The highest bulb weight (72.7 g) was obtained by the application of 38mm every 5 days followed by the application of 38 mm every 7 days (70.0 g).

In general, although there is highest yield of onion by applying 38 mm every 5 days, the water productivity was the lowest. Study conducted at Melkasa Research Centre also showed 50 mm of water application at 3-6 days interval gave the highest yield with the optimum water use efficiency (Lemma and Hearth, 1992). Therefore, considering the two year results the optimums marketable yield (16.8 t $ha^{-1}$, 27.6 t $ha^{-1}$) and WUE (3.21, 5.33 kg $m^{-3}$) was obtained by applying 38 mm every 7 days in 2010 and 2011 respectively.

### 3.2 Results at Ribb

As can be seen in table 4, year and year by treatment effect showed significant difference at Ribb. Hence, we can't use the two years data for combined analysis. Generally reduction in the amount of most biological traits (yield and yield related traits) was seen during the second year. This is primarily due to the occurrence of pest (onion trips) during the irrigation season in the area.

Even if the values/results of the biological parameters are low as compared to the previous year, the trend is more or less similar in the two years. Summarized results of selected parameters are indicated below independently for the two years in table 6 below.

The irrigation water requirement of onion at Ribb was found to be 462 mm. As can be clearly seen in Table 6, almost all biological parameters respond considerably for irrigation depth at a given irrigation frequency.

There was statistically significant difference in mean values of marketable yield. Application of 33 mm of water at 7 days interval brought the highest marketable yield of 33.8 and 19.0 t $ha^{-1}$ in 2009/10 and 2010/11 respectively. The least yield of 19.5 t $ha^{-1}$ in 2009/10 and 14.9 t $ha^{-1}$ in 2010/11 was obtained with the application of 20 mm irrigation depth at 4 days irrigation interval. The unmarketable yield is also statistically significant.

Table 5: Mean values of total bulb yield, marketable yield, bulb diameter, bulb weight and water productivity in 2010 and 2011 at Kobo

| Treatments | 2010 Total yield (t ha$^{-1}$) | 2010 Marketable yield (t ha$^{-1}$) | 2010 Bulb diameter (cm) | 2010 Bulb weight (gm) | 2010 Water productivity (kg/m$^3$) | 2011 Total yield (t ha$^{-1}$) | 2011 Marketable yield (t ha$^{-1}$) | 2011 Bulb dia. (cm) | 2011 Bulb weight (gm) | 2011 Water productivity (kg/m3) |
|---|---|---|---|---|---|---|---|---|---|---|
| 30mm,7days | 13.3$^{b}$ | 12.95$^{bcd}$ | 3.80$^{bc}$ | 29.60$^{ab}$ | 3.09$^{a}$ | 20.15$^{bc}$ | 19.9$^{bc}$ | 5.00$^{bc}$ | 56.61 | 4.69 |
| 30mm,5days | 13.4$^{ab}$ | 13.05$^{abc}$ | 3.63$^{bc}$ | 28.60$^{ab}$ | 2.13$^{abc}$ | 27.09$^{ab}$ | 26.78$^{a}$ | 5.27$^{ab}$ | 62.18 | 4.30 |
| 30mm,9days | 9.14$^{cd}$ | 8.94$^{de}$ | 3.50$^{bc}$ | 21.70$^{bc}$ | 2.34$^{ab}$ | 20.26$^{abc}$ | 20.17$^{abc}$ | 4.47$^{c}$ | 46.75 | 5.20 |
| 23mm, 7days | 6.28$^{e}$ | 5.97$^{f}$ | 3.47$^{cd}$ | 22.13$^{bc}$ | 1.79$^{d}$ | 20.69$^{abc}$ | 20.42$^{abc}$ | 4.90$^{bc}$ | 52.05 | 6.00 |
| 23mm,5days | 9.91$^{cd}$ | 9.74$^{de}$ | 3.33$^{cd}$ | 22.87$^{abc}$ | 2.05$^{bcd}$ | 23.92$^{ab}$ | 23.43$^{ab}$ | 5.00$^{bc}$ | 57.35 | 4.95 |
| 23mm,9days | 8.55$^{de}$ | 6.53$^{ef}$ | 2.87$^{d}$ | 19.80$^{c}$ | 2.86$^{a}$ | 19.44$^{c}$ | 19.23$^{c}$ | 5.07$^{ab}$ | 56.04 | 6.50 |
| 38mm, 7days | 16.83$^{a}$ | 16.79$^{a}$ | 3.83$^{b}$ | 25.97$^{ab}$ | 3.21$^{a}$ | 27.99$^{a}$ | 27.52$^{a}$ | 5.50$^{ab}$ | 70.07 | 5.33 |
| 38mm,5days | 16.02$^{ab}$ | 15.94$^{ab}$ | 4.10$^{a}$ | 33.40$^{a}$ | 2.01$^{cd}$ | 33.66$^{a}$ | 33.66$^{a}$ | 5.83$^{a}$ | 72.73 | 4.22 |
| 38mm,9days | 11.33$^{bc}$ | 11.24$^{cd}$ | 3.53 | bc | 2.29$^{ab}$ | 29.12$^{a}$ | 29.12$^{a}$ | 5.27$^{ab}$ | 62.99 | 5.90 |
| Cv% | 15.1 | 16.6 | 16.6 | 5.8 | 15.9 | 18.3 | 18.7 | 6.4 | 16.4 | 18.5 |
| Lsd | 3.04 | 3.23 | 3230.1 | 0.3595 | 7.023 | 7.82 | 7.90 | 0.573 | ns | ns |
| mean | 11.63 | 11238. | 11238 | 3.563 | 25.50 | 24.70 | 24.47 | 5.144 | 59.6 | 5.23 |

Table 6: Summary of ANOVA table for marketable, total yield and water use efficiency at Ribb (2009/10 and 2010/11)

| No | Treatments | 2009/10 | | | | | 2010/11 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Marketable yield (t ha$^{-1}$) | Total yield (t ha$^{-1}$) | WUE (kg/m$^3$) | Average Bulb dia (mm) | Average bulb wt. (gm) | Marketable yield (t ha$^{-1}$) | Total yield (t ha$^{-1}$) | WUE (kg/m$^3$) | Average Bulb dia (mm) | Aver-age bulb wt. (gm) |
| 1 | 4D-17mm | 24.5c | 26.6dc | 5.3b | 19.1e | 80.1d | 14.6c | 16.0e | 3.1dc | 20.4c | 77.3 |
| 2 | 4D-20mm | 19.5d | 21.6e | 3.6de | 19.4e | 78.0d | 14.9c | 16.3de | 2.73fe | 20.3c | 76.9 |
| 3 | 4D-24mm | 22.2c | 26.4dc | 3.6de | 25.8dc | 85.1d | 19.1a | 19.8ba | 3.07dce | 20.3c | 68.6 |
| 4 | 4D-27mm | 27.6 b | 30.7b | 3.93de | 31.1ba | 101.9ba | 17.9ba | 18.6bdac | 2.6f | 21.3bc | 66.8 |
| 5 | 4D-(20mm, 27mm, 24mm, 17mm) | 22.47c | 24.5d | 4.0dc | 27.5bc | 86.1bdc | 15.4c | 16.9dec | 2.8dfe | 21.2bc | 68.6 |
| 6 | 7D-31mm | 17.71d | 20.8e | 4.37c | 31.3ba | 77.8d | 19.3a | 19.6ba | 4.8a | 21.1bc | 68.1 |
| 7 | 7D-33mm | 33.8a | 34.9a | 7.07a | 23.0de | 111.7a | 19.0a | 20.3a | 4.0b | 21.8bac | 67.8 |
| 8 | 7D-37.5mm | 24.5c | 25.5dc | 4.4c | 25.0dc | 85.7dc | 17.9ba | 18.6bdac | 3.2c | 20.6c | 67.1 |
| 9 | 7D-40mm | 22.4c | 27.6c | 3.57e | 34.5a | 101.6bac | 16.0bc | 17.5bdec | 2.5f | 22.8ba | 71.5 |
| 10. | 7D-(33mm, 37.5mm, 40mm, 31mm) | 17.7d | 19.8e | 3.7de | 32.8a | 92.7bdc | 17.5ba | 18.7bac | 3.7b | 23.7a | 79.0 |
| CV(%) | | 5.7 | 5.8 | 5.64 | 9.3 | 10.4 | 6.95 | 7.6 | 7.2 | 5.7 | 12.8 |
| Lsd (0.05) | | 2.28 | 2.56 | 0.421 | 0.43 | 16.1 | 2.05 | 2.38 | 0.399 | 0.21 | 15.6 |
| Mean | | 23.2 | 25.8 | 4.35 | 26.9 | 90.1 | 17.2 | 18.2 | 3.24 | 21.3 | 71.2 |

The lowest value (0.89 t/ha) was obtained with application of 37.5mm of irrigation water at 7- days interval. Total yield also showed statistically significant difference. The highest total yield (34.9 t/ha) was recorded with application of 33mm of water at 7-days interval. The unmarketable yield obtained at this depth and frequency (1.2 t/ha) is reasonably acceptable as compared to the lowest value (0.89 t/ha).

Irrigation of 33mm at 7day interval gave a better Water productivity (7.1 kg/m$^3$) & 40 mm with 7 days interval brought the least (3.5 kg/m$^3$). The yield response for water at different water level over season is indicated in Fig. 1.

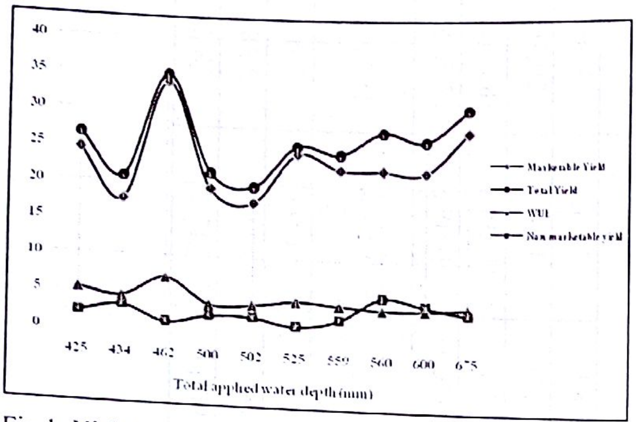


Fig 1. Yield response for water (marketable yield (MY) - t ha$^{-1}$, unmarketable yield (UMY) - t ha$^{-1}$, total yield (TY) - t ha$^{-1}$ Water productivity (WUE) - kg/m3)

## 5. Conclusions and recommendations

### Conclusions

In Ribb area, two irrigations for establishment and a total of 14 (fourteen) irrigations afterwards were applied during the growing season. The irrigation water requirement was found to be 462 mm. In a three-year experiment conducted at Werer Agricultural Research Center, onion was found to respond better at frequent rather than prolonged intervals of irrigation which is 50mm water at 3-6 days interval (Michael, 2001). But at Rib, application of 33 mm irrigation depth at 7 days interval gave significantly better marketable yield, maximum total yield, and WUE and bulb weight as compared to the optimum level (variable water application at four different crop growth stages).

At kobo, the irrigation requirement is a bit higher than the value determined by cropwat model. It is 25% more than the normal cropwat estimated value for the area. Hence, there is a need to validate cropwat in kobo area.

### Recommendations

The results of the two years data analysis verified in Fogra and other areas having similar agro ecology, onion can be irrigated with 33mm water at 7 days interval for yield range between 20 and 34 t ha$^{-1}$ and water use efficiency between 4 and 7 kg m$^{-3}$.

In case of Kobo, application of 125% of CROPWAT generated depth which is about 38 mm at 7 days interval gave the highest marketable yield between 17.0 and 28.0 ton ha$^{-1}$ and water productivity between 3.2 and 5.3 kg m$^{-3}$. This calls for a need to validate the CROPWAT model under local conditions. It is therefore advisable to apply 38 mm irrigation water every 7 days interval to produce tomato at kobo and similar agro ecologies.

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# Evaluation of Regulated Deficit Irrigation on the Yield of Potato at Adet, Amhara Region

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## Abstract

*Regulated deficit irrigation (RDI) aims to optimize water use efficiency and the crop yield from a unit of water applied. In this study, three deficit irrigation water levels (20%, 40% and 60%) were applied at different potato growth stages independently namely: i) initial stage which includes the time from sowing to 10% ground cover, ii) crop development stage which is from 10% to 70% ground cover, iii) mid-season stage including flowering and yield formation, and iv) late season stage including rippening and harvest. The objective of this study was to improve water productivity with application of deficit irrigation so as to enhance crop production and save water for various uses. Field work was conducted at Adet Agricultural Research Centre for two years (2009 and 2010). The experiment was laid down in a randomized complete block design with three replications. Irrigation water was applied using furrow irrigation method. Data collected from Field experiment was analysed using SAS statistical software. The results of the combined analysis of the two years data showed that deficit irrigation did not significantly affect most biological parameters. Despite this, 60% deficit irrigation (375 mm net irrigation) at crop development stage (day 25 to day 55) gave highest marketable yield (16 ton ha$^{-1}$) and total yield (21ton ha$^{-1}$) and dry matter content (22%) which is within the acceptable industrial standard (20-25%). Moreover, results of the experiments revealed that 51 mm (510 m$^3$ ha$^{-1}$) of irrigation water, which is about 12% of the total net irrigation, could be safely saved without significant potato yield loss at Adet.*

***Keywords**: Regulated Deficit Irrigation, Furrow method, Water Productivity.*

## 1. Introduction

Efficient use of irrigation water enhances production and thus the income of the people and the country as well. Frequent occurrence of drought requires a proactive and rational water management approach, which could be helpful to both managers and farmers. Related to water restriction, a recent study shows that a decrease of 10% in water supply would result a reduction of about 2% net agricultural product (El Amam, 2001). Under high and very high demand conditions, the gross margin per unit of water applied decreases for the potato and the tomato crops but increases for the wheat crop. So, considering an average year, the adoption of a deficit irrigation scheme is feasible for the potato and tomato crops, while for the wheat crop it is not economically advantageous to use deficit irrigation, this is the reason why the crop is usually grown in rain fed conditions (El Amam, 2001).

In times when irrigation water is limiting, the farmer may not have enough water to irrigate all the crop fields. In this case, the farmer may decide to spread the available water over a large area, although it is less than the optimal amount. Here, it is good to know i) the crops which suffer most from water shortage and ii) the growth stages during which the various crops suffer most from water shortage (Awulachew *et al.*, 2009). If various crops are grown on a given field, it is advisable to give priority to irrigate the most drought sensitive crops.

The total growing season of a given crop is usually divided into four stages. These are i) initial stage which includes the time from sowing to 10% ground cover; ii) crop development stage which is from 10% to 70% ground cover; iii) mid-season stage including flowering and grain setting or yield formation; and iv) late season stage including rippening and harvest. In general, it is stated that out of the four growth stages, the mid season stage is the most sensitive to water shortages. This is mainly because it is the period of the highest crop water needs. Hence, if water shortage occurs during this stage, the negative effect on yield will be pronounced.

To see the effect of limited water application on yield and production, consideration must be given to the effect of the limited water application during the individual growth periods of the crops (FAO, 1979). If crops under consideration are less sensitive to water deficit and can be grown with acceptable yields but without meeting full water requirements, scheduling of supply is based on minimizing water deficits in most sensitive growth periods. During periods of unpredictable water shortages, within season adjustment of water scheduling must be made in relation to the difference in yield response to water deficits on the crops and their individual growth periods.

In terms of water management this means water allocation of limited supply should be directed towards meeting full water requirements of these sensitive stages rather than spreading the available limited supply to the crop equally over the total growing period.

Maintaining a reduced soil moisture deficit keeps vegetative growth under control while photosynthesis remains unaltered. A reduced moisture deficit therefore has been stated as the most agronomic desirable soil moisture level. Excessive water stress should be avoided, as it reduces photosynthetic activity which will affect both vegetative and reproductive growth. Regulated deficit irrigation (RDI) may be implemented during part of the growing season by regulating moisture within a desired deficit range. RDI aims to optimize water use efficiency and therefore the yield returned per unit of water applied. Any minor yield loss which may result from the implementation of a mild moisture deficit/stress under RDI is compensated by the benefits of saved water to irrigate additional areas. The most desirable benefits associated with implementing a RDI strategy are: i) the reduction in excessive vegetative growth; ii) maintenance of soil moisture in the most agronomic desirable range; and iii) an increase in water use efficiency (FAO, 2002).

## 2. Objective

- The objective of the study were: to improve water productivity of potato with application of deficit irrigation and
- to identify possible crop growth stage where deficit irrigation can be safely applied

## 3. Materials and methods

### 3.1 Description of the study area

The experiment was conducted at Adet research station 43 km from Bahir Dar during 2009 and 2010. Adet is located at 11$^{0}$ 17' N latitude and 37$^{0}$ 43' longitudes at an altitude of 2240 m above mean sea level. The mean daily maximum temperature ranges from 22.5$^{0}$C (July and August) to 29.4 $^{0}$C (March) and the mean daily minimum temperature ranges from 5.4 $^{0}$C (January) to 12.1 0C in August. The soil is characterized by pH of about 5.41, organic matter content of 2.2%, bulk density of about 1.39 and its texture is basically clay.

### 3.2 Determination of irrigation Schedule

To calculate the irrigation water requirement of potato at Adet metrological and other necessary data were collected from the National Meteorological Agency and other reliable sources. Potential evapotranspiration of the area was calculated for the recent ten years data and the resulting value was fitted to 80% probable value (Table 1).

Table 1: Potential evapo-transpiration values (mm day$^{-1}$) for Adet research station

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1996 | 3.62 | 4.52 | 4.69 | 4.67 | 3.9 | 3.73 | 3.24 | 3.05 | 3.67 | 4.03 | 3.42 | 3.42 |
| 1997 | 3.62 | 4.39 | 4.51 | 4.80 | 4.35 | 3.60 | 3.16 | 3.30 | 3.97 | 3.62 | 3.51 | 3.57 |
| 1998 | 3.86 | 4.43 | 4.64 | 5.25 | 4.57 | 4.08 | 2.70 | 2.77 | 3.44 | 3.68 | 3.54 | 3.57 |
| 1999 | 3.56 | 4.5 | 5.01 | 5.12 | 4.56 | 3.95 | 3.00 | 3.17 | 3.56 | 3.43 | 3.68 | 3.41 |
| 2000 | 3.74 | 4.21 | 4.89 | 4.10 | 4.56 | 4.07 | 3.15 | 2.82 | 3.49 | 3.36 | 3.39 | 3.30 |
| 2001 | 3.59 | 4.09 | 4.23 | 4.83 | 4.37 | 3.22 | 2.95 | 2.90 | 3.67 | 3.66 | 3.39 | 3.34 |
| 2002 | 3.32 | 4.17 | 4.36 | 5.04 | 4.83 | 3.94 | 3.45 | 3.19 | 3.57 | 3.76 | 3.54 | 3.46 |
| 2003 | 3.72 | 4.2 | 4.56 | 5.19 | 5 | 3.79 | 2.84 | 2.80 | 3.24 | 3.89 | 3.56 | 3.43 |
| 2004 | 3.64 | 4.21 | 4.77 | 4.49 | 5.04 | 3.62 | 3.23 | 3.04 | 3.39 | 3.66 | 3.40 | 3.31 |
| 2005 | 3.42 | 4.18 | 4.39 | 4.55 | 4.62 | 3.91 | 2.69 | 3.22 | 3.57 | 3.67 | 3.37 | 3.16 |
| Mean | **3.61** | **4.29** | **4.61** | **4.80** | **4.58** | **3.79** | **3.04** | **3.03** | **3.56** | **3.68** | **3.48** | **3.40** |
| Fitted (@80%) | **3.72** | **4.36** | **4.79** | **5.08** | **4.83** | **3.99** | **3.23** | **3.17** | **3.70** | **3.80** | **3.56** | **3.49** |

Based on ten years meteorological data of the area and fitted potential $ET_0$, crop water requirement and the respective irrigation schedules were worked out for potato using CROPWAT model (Tables 2 and 3). It was determined under the conditions of field efficiency of 70% and irrigating at critical depletion level to refill the soil moisture to the level of field capacity. The irrigation schedule or potato in Table 3 was determined on the basis of predetermined seven days irrigation interval and 0.5% yield loss level.



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Table 2: Crop water requirement and irrigation requirement of potato at Adet research station

| Month | Decade | Growth Stage | Kc | ET crop (mm/ day) | ET crop (mm/dec) | Eff. rain (mm/dec) | Irr. req. (mm/ day) | Irr. req. (mm/ |
|---|---|---|---|---|---|---|---|---|
| Dec | 3 | Initial | 0.5 | 1.79 | 3.6 | 0.2 | 1.68 | 3.4 |
| Jan | 1 | Initial | 0.5 | 1.82 | 18.2 | 2.4 | 1.59 | 15.9 |
| Jan | 2 | Initial | 0.5 | 1.86 | 18.6 | 2.6 | 1.6 | 16.0 |
| Jan | 3 | Initial/Dev. | 0.59 | 2.32 | 25.5 | 2 | 2.13 | 23.4 |
| Feb | 1 | Dev. | 0.78 | 3.26 | 32.6 | 0.6 | 3.2 | 32.0 |
| Feb | 2 | Dev. | 1.0 | 4.39 | 43.9 | 0 | 4.39 | 43.9 |
| Feb | 3 | Dev/Mid | 1.13 | 5.12 | 40.9 | 2 | 4.86 | 38.9 |
| Mar | 1 | Mid | 1.15 | 5.37 | 53.7 | 5.8 | 4.79 | 47.9 |
| Mar | 2 | Mid | 1.15 | 5.52 | 55.2 | 8.2 | 4.7 | 47.0 |
| Mar | 3 | Mid | 1.15 | 5.63 | 62 | 10.7 | 4.66 | 51.3 |
| Apr | 1 | Mid/Late | 1.14 | 5.68 | 56.8 | 12.8 | 4.4 | 44.0 |
| Apr | 2 | Late | 1.06 | 5.39 | 53.9 | 15.1 | 3.88 | 38.8 |
| Apr | 3 | Late | 0.92 | 4.62 | 46.2 | 19.4 | 2.68 | 26.8 |
| May | 1 | Late | 0.8 | 3.94 | 31.5 | 19.3 | 1.53 | 12.2 |
| Total | | | | | 542.6 | 101.1 | | 441.4 |

ET = Evapotranspiration, Kc = Crop coefficient, Eff. rain = Effective rain, Irr. Req. = Irrigation requirement, Initial = Initial growth stage, Dev. = Development growth stage, Mid = Mid growth stage, Late = Late growth stage.

Table 3: Irrigation schedule of potato at Adet research station

| Date | Day | Growth Stage | Rainfall (mm) | Depletion (%) | Kc frac | ETa (%) | Net irr. (mm) | Deficit (mm) | Loss (mm) | Gross irr. (mm) | Flow (l/s/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5-Jan | 7 | Initial | 0 | 24 | 1 | 100 | 11.5 | 0 | 0 | 16.4 | 0.27 |
| 12-Jan | 14 | Initial | 0 | 22 | 1 | 100 | 11.6 | 0 | 0 | 16.6 | 0.27 |
| 19-Jan | 21 | Initial | 0 | 20 | 1 | 100 | 11.7 | 0 | 0 | 16.7 | 0.28 |
| 26-Jan | 28 | Dev. | 0 | 23 | 1 | 100 | 14.7 | 0 | 0 | 21.0 | 0.35 |
| 2-Feb | 35 | Dev. | 0 | 26 | 1 | 100 | 18.1 | 0 | 0 | 25.9 | 0.43 |
| 9-Feb | 42 | Dev. | 0 | 30 | 1 | 100 | 22.5 | 0 | 0 | 32.2 | 0.53 |
| 16-Feb | 49 | Dev. | 0 | 37 | 0.96 | 99 | 29.4 | 0 | 0 | 42.1 | 0.70 |
| 23-Feb | 56 | Mid | 1.0 | 38 | 0.97 | 100 | 31.7 | 0 | 0 | 45.3 | 0.75 |
| 2-Mar | 63 | Mid | 0 | 41 | 0.92 | 99 | 34.8 | 0 | 0 | 49.8 | 0.82 |
| 9-Mar | 70 | Mid | 0 | 41 | 0.93 | 99 | 34.2 | 0 | 0 | 48.9 | 0.81 |
| 16-Mar | 77 | Mid | 0 | 40 | 0.94 | 99 | 33.9 | 0 | 0 | 48.4 | 0.80 |
| 23-Mar | 84 | Mid | 5.7 | 39 | 0.96 | 99 | 32.8 | 0 | 0 | 46.9 | 0.78 |
| 30-Mar | 91 | Mid | 0 | 40 | 0.95 | 99 | 33.5 | 0 | 0 | 47.8 | 0.79 |
| 6-Apr | 98 | Mid | 0 | 39 | 0.96 | 99 | 32.7 | 0 | 0 | 46.8 | 0.77 |
| 13-Apr | 105 | Late | 8.0 | 37 | 1 | 100 | 30.8 | 0 | 0 | 44.0 | 0.73 |
| 20-Apr | 112 | Late | 0 | 35 | 1 | 100 | 29.7 | 0 | 0 | 42.4 | 0.7o |
| 27-Apr | 119 | Late | 10.9 | 14 | 1 | 100 | 12.2 | 0 | 0 | 17.4 | 0.29 |
| 4-May | 126 | Late | 0 | 19 | 1 | 100 | 15.7 | 0 | 0 | 22.4 | 0.37 |
| 9-May | End | Late | 0 | 9 | 1 | 0 | | | | | |
| Total | | | | | | | 441.5 | | | 631 | |

Initial = Initial growth stage, Dev. = Development growth stage, Mid = Mid growth stage, Late = Late growth stage, Kc = crop coefficient, ETa = actual evapotranspiration, Net irr.= net irrigation, Gross irr. = Gross irrigation.

Three deficit levels, viz, 20%, 40% and 60% were applied at four potato growth stages namely: i) initial stage (IS) which includes the time from sowing to 10% ground cover, ii) crop development stage (CDS) which is from 10% to 70% ground cover, iii) mid-season stage (MSS) including flowering and yield formation, and iv) late season stage (LSS) including rippening and harvest.

A plot which is fully irrigated (0% deficit) was also included in the experiment. Treatments were arranged in randomized complete block design with three replications with a plot size of 3 m X 6 m each. Land preparation and planting were carried out in December. Potato variety called Wochecha was used as a test crop. Eighty potato seeds were planted along the ridge at 30 cm spacing and 75 cm between ridges in each plot. Fertilizer was applied at the rate of 69 kg $P_2O_5$ $ha^{-1}$ and urea was split applied at the rate of 81 kg N $ha^{-1}$ at planting and flowering stages. Depending on the CROPWAT results, the irrigation schedule for each treatment setup was worked out (Table 4). Irrigation water was applied using furrow irrigation method and irrigation water was applied on weekly basis.

Table 4: Amount of gross irrigation applied in liters for $18m^2$ plot area at each potato growth stage in the season

| Date | Gross Irr. (lit) | Growth Stage | 20% @ IS | 40% @ IS | 60% @ IS | 20% @ CDS | 40% @ CDS | 60% @ CDS | 20% @ MSS | 40% @ MSS | 60% @ MSS | 20% @ LSS | 40% @ LSS | 60% @ LSS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5-Jan | 295 | IS | 236 | 177 | 118 | 295 | 295 | 295 | 295 | 295 | 295 | 295 | 295 | 295 |
| 12-Jan | 299 | IS | 239 | 179 | 120 | 299 | 299 | 299 | 299 | 299 | 299 | 299 | 299 | 299 |
| 19-Jan | 301 | IS | 240 | 180 | 120 | 301 | 301 | 301 | 301 | 301 | 301 | 301 | 301 | 301 |
| 26-Jan | 378 | CDS | 378 | 378 | 378 | 302 | 227 | 151 | 378 | 378 | 378 | 378 | 378 | 378 |
| 2-Feb | 466 | CDS | 466 | 466 | 466 | 373 | 280 | 186 | 466 | 466 | 466 | 466 | 466 | 466 |
| 9-Feb | 580 | CDS | 580 | 580 | 580 | 464 | 348 | 232 | 580 | 580 | 580 | 580 | 580 | 580 |
| 16-Feb | 758 | CDS | 758 | 758 | 758 | 606 | 455 | 303 | 758 | 758 | 758 | 758 | 758 | 758 |
| 23-Feb | 815 | MSS | 815 | 815 | 815 | 815 | 815 | 815 | 652 | 489 | 326 | 815 | 815 | 815 |
| 2-Mar | 896 | MSS | 896 | 896 | 896 | 896 | 896 | 896 | 717 | 538 | 359 | 896 | 896 | 896 |
| 9-Mar | 880 | MSS | 880 | 880 | 880 | 880 | 880 | 880 | 704 | 528 | 352 | 880 | 880 | 880 |
| 16Mar | 871 | MSS | 871 | 871 | 871 | 871 | 871 | 871 | 697 | 523 | 348 | 871 | 871 | 871 |
| 23Mar | 844 | MSS | 844 | 844 | 844 | 844 | 844 | 844 | 675 | 507 | 338 | 844 | 844 | 844 |
| 30Mar | 860 | MSS | 860 | 860 | 860 | 860 | 860 | 860 | 688 | 516 | 344 | 860 | 860 | 860 |
| 6-Apr | 842 | MSS | 842 | 842 | 842 | 842 | 842 | 842 | 674 | 505 | 337 | 842 | 842 | 842 |
| 13-Apr | 792 | LSS | 792 | 792 | 792 | 792 | 792 | 792 | 792 | 792 | 792 | 634 | 475 | 317 |
| 20-Apr | 763 | LSS | 763 | 763 | 763 | 763 | 763 | 763 | 763 | 763 | 763 | 611 | 458 | 305 |
| 27-Apr | 313 | LSS | 313 | 313 | 313 | 313 | 313 | 313 | 313 | 313 | 313 | 251 | 188 | 125 |
| 4-May | 403 | LSS | 403 | 403 | 403 | 403 | 403 | 403 | 403 | 403 | 403 | 323 | 242 | 161 |
| 9-May | | LSS | | | | | | | | | | 0 | 0 | 0 |
| Total | 11358 | | 11179 | 11000 | 10821 | 10922 | 10485 | 10049 | 10156 | 8954 | 7752 | 10904 | 10449 | 9995 |

The required amount of irrigation water for each treatment was applied to the furrow using a siphon. Geo-membrane was used as a lining material for the furrows to avoid lateral seepage of irrigation water to the adjacent plots. On average, two irrigations for establishment and fourteen irrigations afterwards were made throughout the potato growing season. Agronomic data such as number of tuber, tuber weight, total and marketable yield, unmarketable yield, dry matter content was collected. The collected data were then subjected to statistical analysis using SAS software.

## 4. Results and discussion

Using the past ten years meteorological data, the daily maximum and minimum potential evapotranspiration rates were found to be 5.1 mm and 3.2 mm which occur during April and August, respectively. The average daily potential evapotranspiration was 3.98 mm. The seasonal crop evapotranspiration was then estimated to be 543 mm for Adet. Considering effective rainfall, the Cropwat model estimated 441 mm and 631 mm net and gross irrigation water requirements, respectively for potato at Adet.

Results of analysis showed that the number of tubers per plant, average tuber weight, marketable yield, total yield, unmarketable yield and dry matter content were not affected significantly by deficit irrigation. Generally, it was observed that the highest marketable yield, highest tuber number, and the highest total yield occurred with deficit application at crop development stage which gives an impression that deficit application at crop development stage is feasible (Table 5). On the contrary, the satellite plot (which is fully irrigated at all stages in the season) gave only 15.09 t/ha marketable yield and water productivity of 3.54.

This relatively low yield may be attributed to the fact that potato yield and quality are susceptible to excess soil water as well. Excess soil water from frequent or intensive irrigation or rainfall during any growth stage leaches nitrate below the plant root zone, potentially resulting in nitrogen-deficient plants, reduced fertilizer use efficiency. Saturation of the soil profile for more than 8-12hours can cause root damage due to a lack of oxygen required for normal respiration. Excess soil water at planting promotes seed piece decay and delays emergence due to decreased soil temperature (Bradley A. King and Jeffrey C. Stark, 1997).

Table 5: Effect of deficit irrigation on yield and yield components of potato at Adet (2009 and 2010 combined)

| Treatments | No. of tubers/ plant | Av. Tuber weight (gm) | Marketable yield (t/ ha) | Total yield (t/ha) | Unmarketable yield (t/ ha) | % Dry matter | Water productivity (kg/m$^3$) | Water saved (mm) |
|---|---|---|---|---|---|---|---|---|
| 20% @ IS | 8.6 | 62.4 | 15.11 | 19.85 | 4.74 | 22.3 | 3.61 | 7 |
| 40% @ IS | 8.6 | 59.2 | 12.1 | 18.96 | 6.86 | 22.3 | 2.94 | 14 |
| 60% @ IS | 8.4 | 57.8 | 12.34 | 18.17 | 5.83 | 21.6 | 3.05 | 21 |
| 20% @ CDS | 9.1 | 53.2 | 13.76 | 18.45 | 4.69 | 22.1 | 3.36 | 17 |
| 40 % @CDS | 8.7 | 58.6 | 15.12 | 19.15 | 4.03 | 20.6 | 3.86 | 34 |
| 60% @ CDS | 9.9 | 55.6 | 16.44 | 21.02 | 4.58 | 22 | 4.38 | 51 |
| 20% @ MSS | 9 | 62.9 | 14.37 | 19.95 | 5.58 | 22.2 | 3.79 | 47 |
| 40% @ MSS | 8.5 | 62.5 | 15.13 | 19.97 | 4.84 | 22.3 | 4.54 | 93 |
| 60% @ MSS | 8.7 | 56.3 | 12.57 | 18.68 | 6.11 | 22 | 4.4 | 140 |
| 20% @ LSS | 8.6 | 58.8 | 14.76 | 20.42 | 5.66 | 20 | 3.58 | 14 |
| 40% @ LSS | 7.4 | 65.6 | 12.89 | 17.05 | 4.16 | 22.3 | 3.25 | 22 |
| 60% @ LSS | 8.5 | 58 | 15.32 | 19.13 | 3.81 | 22.5 | 4.01 | 37 |
| LSD (5%) | NS | NS | NS | NS | NS | NS | | |
| CV (%) | 20.5 | 19.6 | 16.8 | 12.6 | 19 | 8.2 | | |

## 5. Conclusion and Recommendations

### Conclusion

Most biological parameters respond non-significantly for the application of deficit irrigation application at different crop growth stages for both years. Hence, conclusion is made by critically looking into marketable yield, non-marketable yield, total yield, dry matter content and water productivity of potato. Accordingly, the combined analysis result of the two years data showed that, 60% deficit irrigation application at crop development stage (day 25 to day55) gave maximum marketable and total yield of 16.4 ton $ha^{-1}$ and 21.0 ton $ha^{-1}$ respectively and dry matter content (22%) which is within the acceptable industrial standard (20-25%).

Crops are more sensitive to water deficit during emergency, flowering & early yield formation than crop development and late stage (Doorenbos and Kassam, 1979). Moreover, studies made at Colorado state university also indicated the critical period for potato is the time from tuber formation to harvest. Management allowable deficit (MAD%) for potato is found to be 40-60 % at early vegetative period, 30-40% at tuber bulking period and 65% at ripening period (M.M. Al-Kaisi and I. Broner, 2009). Hence, the result of this study goes in line with the above fact.

### Recommendation

It can be seen that by applying 60% deficit irrigation at crop development stage, the crop used only 375 mm net irrigation water whereas full application with no deficit at all potato growth stage took net irrigation amount of 426 mm during the whole growing season. This implies that 51 mm irrigation water which is about 12% of the total net irrigation could be saved without significant potato yield loss at Adet. This is equivalent to saving 510 $m^3$ of irrigation water from a hectare of potato field. Therefore, application of 60% deficit irrigation at crop development stage (days 25 to 55) could be used to produce potato in Adet and areas having similar agro-ecology.

## Acknowledgement

We would like to acknowledge all soil and water research directorate staff for their collaborative effort. Especial thanks goes to Ato Derejie Abebe for his continuous assistance and attendance of the experiment both at field and laboratory.

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# Evaluation of Stage-wise Deficit Furrow Irrigation Application on Maize Production at Koga Irrigation Scehem, Blue Nile River

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## Abstract

*Efficient irrigation management has an imperative role in managing transboundary water. Deficit irrigation water application is among the most effective water management solutions. This study was conducted with the aim of evaluating the performance of stage-wise deficit irrigation (DI) application on irrigation efficiencies and to identify crop growth stages during which the crop can withstand water deficit with limited effect on yield and water productivity (WP). Maize (Melkassa-4 type) was selected as test crop as it is known to respond well to deficit irrigation. The experiment was conducted in Koga Irrigation Scheme, Blue Nile River Basin. The field experiment was arranged in randomized complete block design (RCBD) with three replications. The result showed that level of stage-wise deficit irrigation water application had a significant ($P<0.05$) impact on performance indices except distribution uniformity. Application efficiency increased with deficit level increases. The maximum application efficiency (83.5%) was noted when 0.25ETc throughout the growing season was applied. Effect of stage-wise application level had a significant ($P<0.05$) effect on agronomic parameters. The highest yield (58.92 qt/ha) was obtained when full irrigation was applied in all growth stages. The highest Physical water productivity (CWP) (1.65 kg/m$^3$) and economic water productivity (CWP) (4.17 Birr/m$^3$) were obtained when 50% deficit applied during 2$^{nd}$ and 3$^{rd}$ growth stages. On average, the crop was found to be moderately sensitive to water deficit since the average seasonal maize response factor (Ky) (1.04) value is slightly greater than one. In conclusion, this study showed that much water is saved when the crop is stressed by 50% during 2$^{nd}$ and 3$^{rd}$ growth stages.*

**Key words:** *Irrigation Performance indices, Koga Irrigation scheme, Stage-wise deficit, irrigation, water productivity*

## 1. Introduction

Water is an invaluable resource in the Nile Region. Hence, efficient and effective use wherever it is being consumptively used will have far reaching implications. In the Ethiopian part of the Blue Nile, the subsistence rain-fed agriculture is under the mercy of the erratic rainfall and the water resource development is known to have an imperative role in the agricultural, socio-economic and industrial development. Though the country is known to have plenty of water resources, its availability is constrained by number of factors. One among these is the poor water productivity and inefficient irrigation water application.

Recently deficit irrigation (DI) application to enhance water productivity is getting a new momentum (English and Raja, 1996; Geerts and Raes, 2009). Deficit irrigation (DI) is a watering strategy that can be applied by different types of irrigation application methods (Perry *et al.*, 2009). The correct application of DI requires thorough understanding of the yield response to water (Kirda and Kanber, 1999) and of the economic impact of reductions in harvest.

The specific reason for initiating the research was that Koga and many other developed schemes suffers from serious water shortage, specifically during late in the dry season. Though the Koga small scale irrigation scheme was designed to irrigate 7000 ha, only about 5000 ha was developed at the time of the study. The specific objectives of the study were to determine the efficiency of furrow irrigation system with deficit irrigation water application, and to evaluate the effect of stage-wise deficit irrigation application to yield components and water productivity.

## 2. Materials and Methods

### 2.1. Description of the study area

The study was conducted in Koga Irrigation Scheme which is located at 11.37$^0$ N latitude and 37.12$^0$ E longitudes in the Blue Nile Basin. The source of water for the scheme is the Koga River, which is one of the perennial rivers in Mecha Woreda sub-catchment of the Nile River Basin (Fig 1). The mean annual rainfall in the study area is between 800 to 2,200 mm with a mean value of about 1,420 mm. The mean annual minimum and maximum temperatures are 9$^0$C and 32$^0$C, respectively. The dominant soil type of the area is mainly paleosol with clay texture.

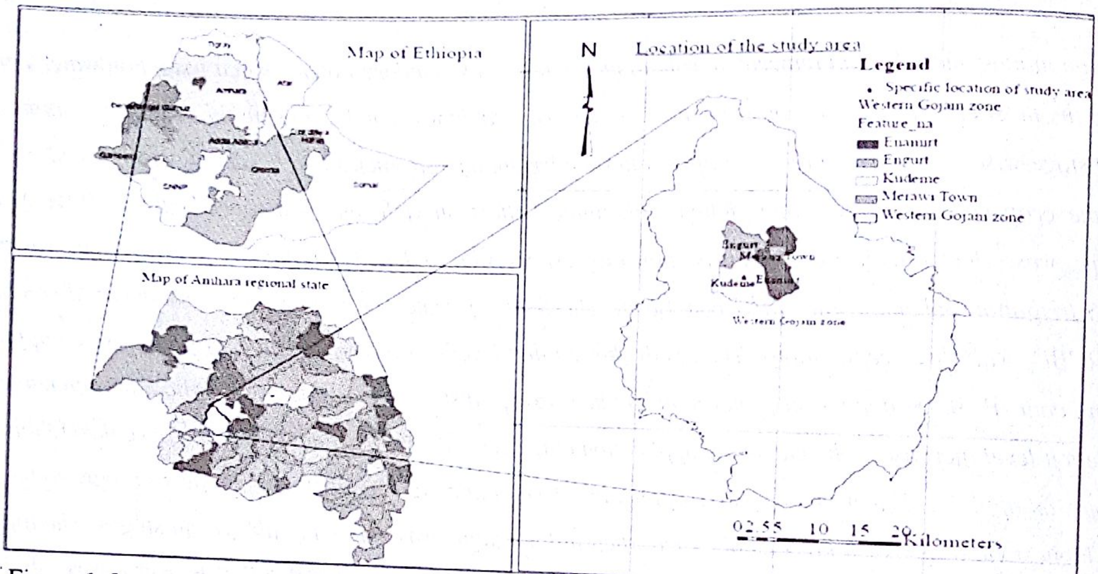


Figure 1: Location map of Koga irrigation scheme

### 2.2. Experimental Designs and Field Layout

The experiment was designed as randomized complete block design (RCBD) with three replications. There were a total of six treatments made by varying the level of irrigation water throughout the growing season (i.e. 100%, 75%, 50%, and 25% of ETc) and at a specific growth stages. The experiment was considering four growing stages of the crop such as initial (S1), development (S2), flowering (S3) and maturity (S4) stages. Treatment combinations tested are shown in (Table 1).

The experimental area was divided into 18 plots with 40 m × 30 m of net size, maintaining a barrier zone of 2 m between adjacent blocks (Fig 2). Each plot had four planting ridges having 10 m length and five furrows having 0.15 m bottom width, 0.30 m top width for irrigation water applications and having 30 cm distance between plants. Siphon with 1.5 inch (3.81 cm) diameter was used to deliver water to every furrow. The average slope of the experimental plot was 0.28% along the irrigation furrow. Sowing was done on January 01/2012 at a row spacing of 76 cm and 30 cm spacing between plants. There was no any incidence of diseases during the experimental season. Harvesting of two internal rows per plot in all the plots was done on May 05/2012. At harvest a sample area of 15.20 m$^2$ (i.e. 10 m x 1.52 m) per plot was selected and the grain yield as well as number of plants in that sample plot area was measured. This was then converted to per hectare basis.

### 2.3. Estimation of Maize Water Requirement

FAO Cropwat model for window 8.0 was used to determine reference crop evapotranspiration (ETo) using climatic data. Crop factor (Kc) for every growth stage was taken from Allen *et al.* (1998) and then, ETc was calculated using equation 2.1.

$$ET_c = ET_o \, x \, K_c \qquad (2.1)$$

Where; ETc is crop evapotranspiration in mm, Kc is crop factor in fraction and ETo is reference crop evapotranspiration in mm.

After setting out of crop evapotranspiration, it is possible to determine net irrigation water requirement by subtracting effective rainfall during the investigational season and it can be expressed by using equation 2.2.

$$NIR = ET_c - P_e \qquad (2.2)$$

Where: NIR is net irrigation water requirement of the crop in mm, and $P_e$ is effective rainfall during the growth period of the crop in mm.

But there was no rainfall at all from the starting to the end of the experimental season in the study area. Therefore, net irrigation water requirement of the crop was equal to only the crop evapotranspiration (ETc).

Application efficiency of 60%, recommended for furrow irrigation was used to estimate the gross irrigation requirement using equation 2.3. Furrow irrigation application efficiencies in general vary from 45-60% (Allen *et al.*, 1998).

$$GIR = \frac{NIR}{E_a} \qquad (2.3)$$

Where: GIR is gross irrigation water requirement of the crop in mm, NIR is net irrigation water requirement of the crop in mm and Ea is application efficiency in %.

Table 1: Description of irrigation treatments

| Treatment | Growth stage | | | | Description |
|---|---|---|---|---|---|
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | |
| | One growth stage stress (25% and 50% deficit) | | | | |
| 0011 | 0 | 0 | 1 | 1 | Stress during $S_1$ and $S_2$ with 25% |
| 1001 | 0 | 1 | 1 | 0 | Stress during $S_2$ and $S_3$ with 50% |
| 1100 | 1 | 1 | 0 | 0 | Stress during $S_3$ and $S_4$ with 50% |
| | Partial stress | | | | |
| 75% deficit | 75% | 75% | 75% | 75% | Throughout the growing stage |
| 50% deficit | 50% | 50% | 50% | 50% | Throughout the growing stage |
| | No stress | | | | |
| 1111 | 1 | 1 | 1 | 1 | Full irrigation at all growth stages |

Note: 1 indicates normal watering or irrigating 100% of ETc: 25% Deficit indicates irrigating 75% of ETc: 50% Deficit indicates watering 50% of ETc and 75% deficit indicates irrigating 25% of ETc.

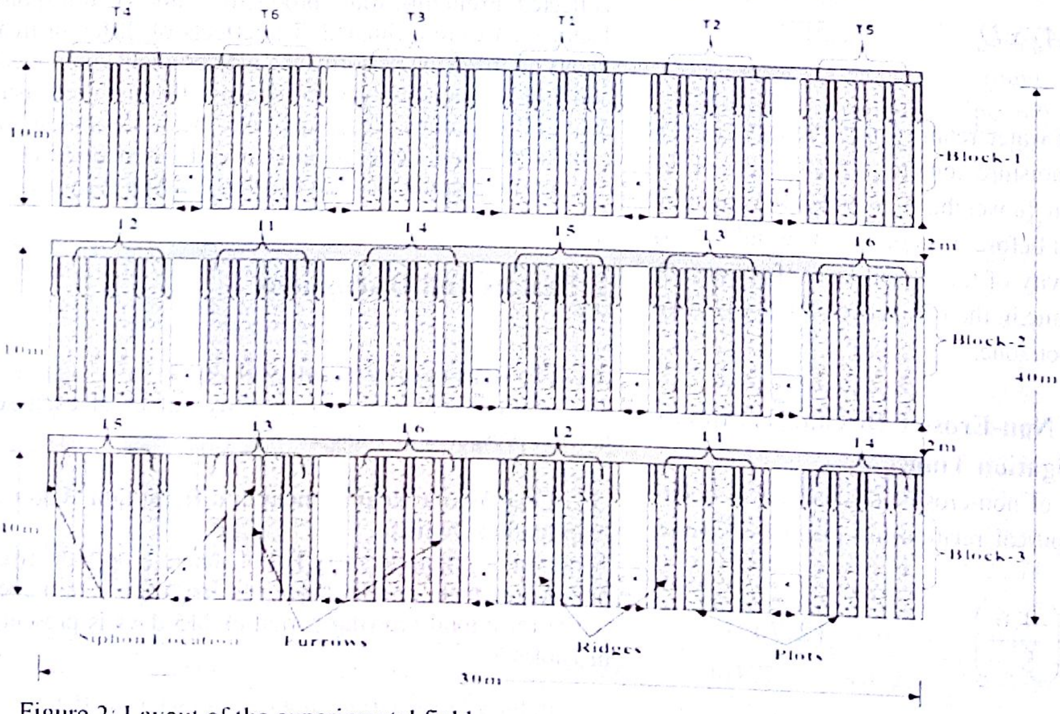


Figure 2: Layout of the experimental field

## 2.4. Determination of the required application depth

The amount of water needed to refill the crop root zone to field capacity at the time of irrigation or the required application depth ($Z_{req}$) was calculated from field evaluations of the soil moisture content before irrigation which were used to compute the soil moisture deficit SMD (mm), using equation 2.4 in the root zone (Yonts and Eisenhauer, 2007).

$$Z_{req} = SMD = 10 \times (\theta_{FC} - \theta i) \times D_i \qquad (2.4)$$

Where: SMD is soil moisture deficit (mm), $Z_{req}$ is the required application depth (mm), $\theta_{FC}$ is moisture content at field capacity (% volume), $\theta_i$ moisture content before irrigation event (% volume) and $D_i$ is effective root depth (m).

## 2.5. Determination of the depth of water retained in the soil profile

It is necessary to identify the amount of water applied to the furrow and the depth of water retained in the root zone in order to know the technical performance indicators of deficit irrigation. The depth of water retained in root zone of the soil was computed based on the moisture contents of the soil samples taken using auger before irrigation and two days after irrigation. The samples were taken within three meter interval from three points (i.e. at 3 m, 6 m and 9 m) along the furrow at four depths with an interval of 25 cm (i.e. 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm) depths. Finally the depth of water retained in the root zone was calculated using equation 2.5 (Michael, 1996).

$$d = \sum_{i}^{n} \frac{(\theta_f - \theta_i)}{10} x A_{si} \, x D_i \qquad (2.5)$$

Where: d is depth of water retained into the root zone of the soil (mm). $\theta_f$ is moisture content in the $i^{th}$ layer of the soil after irrigation on % weight. $\theta_i$ is moisture content in the $i^{th}$ layer of the soil before irrigation on % weight. $A_{si}$ is apparent specific gravity of the $i^{th}$ soil layer (fraction). $D_i$ is depth of the root zone in the $i^{th}$ layer (cm) and n is number of layers in the root zone.

## 2.6. Estimation of Non-Erosive Discharge, Siphon Discharge and Irrigation Time

The maximum value of non-erosive discharge was determined using the empirical relationship given by Cuenca (1989) (equation 2.7).

$$Q_{max} = \left(\frac{0.6}{S_o}\right) \qquad (2.7)$$

Where: $Q_{max}$ is maximum non-erosive discharge (l/s) and $S_o$ is furrow slope in the direction of flow (fraction). The selected non-erosive discharge was 1.28 l/s calculated based on equation 2.8 (Cuenca, 1989) by considering 10 cm constant hydraulic head. This was less than the maximum non-erosive discharge estimated by using equation 2.6 (i.e. 2.14 l/s) by using 0.28% average slope of the experimental plot along the irrigation furrow.

$$Q = CA\sqrt{2gh} \qquad (2.8)$$

Where: Q is siphon discharge ($m^3$/s). C is coefficient of discharge (0.6). A is cross sectional area of the siphon ($m^2$). g is gravitational acceleration (m/$s^2$) and h is hydraulic head (m).

The time required to apply the desired amount of irrigation depth into each furrow using rigid siphon was estimated by using equation 2.9 (Cuenca, 1989).

$$t = \left(\frac{NIR \times l \times w}{6 \times Q_o \, x E_a}\right) \qquad (2.9)$$

Where: t is application time (min). NIR is net irrigation requirement (cm). $l$ is furrow length (m). w is furrow spacing (m). $Q_o$ is flow rate (discharge) (l/s) and $E_a$ is application efficiency (fraction).

## 2.7. Data collection and analysis

Technical performance (i.e. application efficiency, water storage efficiency, distribution uniformity and deep percolation ratio), and yield and yield related variables, were collected. From this, water productivity and yield response factor ($K_y$) were estimated. The effects of different treatments on irrigation performance indices, yield components and water productivity were statistically analyzed using analysis of variance technique and mean separation was computed using Least Significance difference (LSD) at 5% and 1% significance levels using GenStat software.

# 3. Results and Discussions

## 3.1. Physical properties of soil

The result of physical soil property values at each soil layer is presented in Table 2.

## 3.2. Crop Water Requirement and Irrigation Water Application Depths

Total water requirement (ETc) of maize crop, net irrigation requirement (NIR) and gross irrigation requirement (GIR) for a total growing period of 115 days is presented in Tables 3.

Table 2: Soil physical properties of the experimental site

| Pit no | Depth (cm) | BD (gm/cm³) | $\theta_{FC}$ (%) W/W | $\theta_{FC}$ (%) V/V | $\theta_{PWP}$ (%) W/W | $\theta_{PWP}$ (%) V/V | TAW (mm/m) | Particle size distribution (%) Sand | Clay | Silt | Textural class |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0-25 | 1.15 | 38.02 | 43.61 | 21.90 | 25.12 | 184.90 | 3.01 | 55.99 | 41.00 | clay |
| | 25-50 | 1.25 | 34.60 | 43.15 | 24.51 | 30.56 | 125.82 | 1.20 | 77.50 | 21.30 | clay |
| | 50-75 | 1.32 | 35.94 | 47.40 | 24.61 | 32.46 | 149.44 | 1.00 | 74.00 | 25.00 | clay |
| | 75-100 | 1.40 | 35.78 | 50.16 | 25.49 | 35.74 | 144.27 | 0.95 | 80.05 | 19.00 | clay |
| 2 | 0-25 | 1.02 | 37.22 | 38.00 | 22.09 | 22.55 | 154.48 | 6.97 | 72.00 | 21.03 | clay |
| | 25-50 | 1.10 | 35.93 | 39.59 | 23.22 | 25.59 | 140.06 | 1.00 | 70.00 | 29.00 | clay |
| | 50-75 | 1.40 | 34.35 | 48.09 | 24.79 | 34.71 | 133.84 | 1.11 | 77.97 | 20.92 | clay |
| | 75-100 | 1.42 | 35.24 | 50.01 | 24.54 | 34.82 | 151.83 | 1.00 | 80.00 | 19.00 | clay |
| 3 | 0-25 | 1.12 | 38.79 | 43.56 | 22.07 | 24.78 | 187.77 | 5.00 | 56.00 | 39.00 | clay |
| | 25-50 | 1.28 | 37.43 | 47.80 | 24.56 | 31.36 | 164.35 | 1.09 | 83.19 | 15.72 | clay |
| | 50-75 | 1.40 | 34.24 | 47.76 | 25.06 | 34.96 | 128.06 | 1.00 | 76.00 | 23.00 | clay |
| | 75-100 | 1.46 | 35.51 | 51.99 | 24.99 | 36.59 | 154.01 | 0.93 | 82.00 | 17.07 | clay |
| 4 | 0-25 | 1.08 | 42.16 | 45.41 | 23.63 | 25.45 | 199.57 | 4.00 | 63.00 | 33.00 | clay |
| | 25-50 | 1.16 | 36.72 | 42.63 | 25.17 | 29.22 | 134.10 | 1.07 | 79.00 | 19.93 | clay |
| | 50-75 | 1.42 | 35.25 | 50.09 | 24.86 | 35.33 | 147.64 | 1.00 | 82.00 | 17.00 | clay |
| | 75-100 | 1.49 | 37.88 | 56.59 | 25.89 | 38.68 | 179.13 | 4.00 | 78.00 | 18.00 | clay |
| Mean | 0-100 | 1.28 | 36.57 | 46.71 | 24.21 | 30.93 | 157.84 | 2.15 | 74.17 | 23.69 | clay |

Minimum crop water requirement (ETc) of 8.06 mm was obtained during the initial growing season and maximum ETc of 42.55 mm per period was estimated during the mid growing season (Table 3) using Kc values of maize crop estimated by Allen *et al.* (1998).

Amount of water required during the growing season and amount of irrigation water applied to each treatment plots is presented in Tables 4.

Table 3: Crop water requirement (ETc) and irrigation schedule at the experimental site

| Date | Irrigation interval (day) | Growth stage | Kc (-) | ETo (mm/day) | ETo (mm/period) | ETc (mm/period) | NIR* (mm/period) | GIR** (mm/period) |
|---|---|---|---|---|---|---|---|---|
| 8-Jan | 8 | Initial | 0.30 | 3.36 | 26.88 | 8.06 | 8.06 | 13.44 |
| 16-Jan | 16 | Initial | 0.30 | 3.36 | 26.88 | 8.06 | 8.06 | 13.44 |
| 24-Jan | 24 | Dev | 0.48 | 3.36 | 26.88 | 12.90 | 12.90 | 21.50 |
| 1-Feb | 32 | Dev | 0.79 | 3.94 | 31.52 | 24.90 | 24.90 | 41.50 |
| 9-Feb | 40 | Dev | 0.79 | 3.94 | 31.52 | 24.90 | 24.90 | 41.50 |
| 17-Feb | 48 | Dev | 1.09 | 3.94 | 31.52 | 34.36 | 34.36 | 57.26 |
| 25-Feb | 56 | Mid | 1.19 | 3.94 | 31.52 | 37.51 | 37.51 | 62.51 |
| 5-Mar | 64 | Mid | 1.19 | 4.47 | 35.76 | 42.55 | 42.55 | 70.92 |
| 13-Mar | 72 | Mid | 1.19 | 4.47 | 35.76 | 42.55 | 42.55 | 70.92 |
| 21-Mar | 80 | Mid | 1.19 | 4.47 | 35.76 | 42.55 | 42.55 | 70.92 |
| 29-Mar | 88 | Mid | 1.19 | 4.47 | 35.76 | 42.55 | 42.55 | 70.92 |
| 6-Apr | 96 | End | 1.04 | 4.79 | 38.32 | 39.85 | 39.85 | 66.42 |
| 14-Apr | 104 | End | 0.75 | 4.79 | 38.32 | 28.74 | 28.74 | 47.90 |
| 22-Apr | 112 | End | 0.54 | 4.79 | 38.32 | 20.69 | 20.69 | 34.49 |
| 25-Apr | End | End | 0.00 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 112 | | 12.03 | 58.09 | 464.72 | 410.20 | 410.20 | 683.64 |

* NIR simulation was done excluding of rainfall.

** GIR was calculated using 60% application efficiency.

Table 4. Depths of water applied for each treatment with respect to crop growth stage (mm)

| Date | Irrigation Interval (day) | Growth Stage | GIR (mm) | Treatments | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $D_{1,2}25$ (T1) | $D_{2,3}50$ (T2) | $D_{3,4}50$ (T3) | $D_{all}75$ (T4) | $D_{all}50$ (T5) | $D_{all}0$ (T6) |
| 8-Jan | 8 | Init | 13.44 | 10.08 | 13.44 | 13.44 | 3.36 | 6.72 | 13.44 |
| 16-Jan | 8 | Init | 13.44 | 10.08 | 13.44 | 13.44 | 3.36 | 6.72 | 13.44 |
| 24-Jan | 8 | Dev | 21.50 | 16.13 | 10.75 | 21.50 | 5.38 | 10.75 | 21.50 |
| 1-Feb | 8 | Dev | 41.50 | 31.13 | 20.75 | 41.50 | 10.38 | 20.75 | 41.50 |
| 9-Feb | 8 | Dev | 41.50 | 31.13 | 20.75 | 41.50 | 10.38 | 20.75 | 41.50 |
| 17-Feb | 8 | Dev | 57.26 | 42.95 | 28.63 | 57.26 | 14.32 | 28.63 | 57.26 |
| 25-Feb | 8 | Mid | 62.51 | 62.51 | 31.26 | 31.26 | 15.63 | 31.26 | 62.51 |
| 5-Mar | 8 | Mid | 70.92 | 70.92 | 35.46 | 35.46 | 17.73 | 35.46 | 70.92 |
| 13-Mar | 8 | Mid | 70.92 | 70.92 | 35.46 | 35.46 | 17.73 | 35.46 | 70.92 |
| 21-Mar | 8 | Mid | 70.92 | 70.92 | 35.46 | 35.46 | 17.73 | 35.46 | 70.92 |
| 29-Mar | 8 | Mid | 70.92 | 70.92 | 35.46 | 35.46 | 17.73 | 35.46 | 70.92 |
| 6-Apr | 8 | End | 66.42 | 66.42 | 66.42 | 33.21 | 16.61 | 33.21 | 66.42 |
| 14-Apr | 8 | End | 47.90 | 47.90 | 47.90 | 23.95 | 11.98 | 23.95 | 47.90 |
| 22-Apr | 8 | End | 34.49 | 34.49 | 34.49 | 17.25 | 8.62 | 17.25 | 34.49 |
| 25-Apr | End | End | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | | | 683.64 | 636.48 | 429.67 | 436.14 | 170.91 | 341.82 | 683.64 |

The total maximum application depth (637 mm) was obtained at 25% deficit during the first and the second growth stages ($D_{all}25$ ($T_1$)) while minimum (171 mm) value was recorded in treatment $D_{all}75$ ($T_4$) which was 75% deficit throughout the whole growth period.

Table 5 shows the total amount of water applied and the amount of water saved per treatment assuming a maximum furrow irrigation attainable efficiency of 60%. The amount of water varied from as high as 684 mm to as low as 171 mm.

Table 5: Irrigation water applications and water saving under different treatments

| Treatment | NIR (mm) | NIR ($m^3$/ha) | GIR (mm) | GIR ($m^3$/ha) | Water saved | | |
|---|---|---|---|---|---|---|---|
| | | | | | (mm) | ($m^3$/ha) | (%) |
| $D_{all}0$ (T6) | 410.20 | 4102.00 | 683.64 | 6836.40 | 0.00 | 0.00 | 0 |
| $D_{1,2}25$ (T1) | 381.88 | 3818.80 | 636.48 | 6364.80 | 47.16 | 471.6 | 7 |
| $D_{3,4}50$ (T3) | 261.68 | 2616.80 | 436.14 | 4361.40 | 247.5 | 2475.0 | 36 |
| $D_{2,3}50$ (T2) | 257.79 | 2577.90 | 429.67 | 4296.70 | 253.97 | 2539.7 | 37 |
| $D_{all}50$ (T5) | 205.09 | 2050.90 | 341.82 | 3418.20 | 341.82 | 3418.2 | 50 |
| $D_{all}75$ (T4) | 102.54 | 1025.40 | 170.91 | 1709.10 | 512.73 | 5127.3 | 75 |

Table 6: The effect of irrigation application level on the mean application efficiency related with crop growth stages

| Treatment | Mean application efficiency (%)* | | | |
|---|---|---|---|---|
| | Growth stages | | | |
| | Initial | Development | Mid | Late |
| $D_{1,2}25$ (T1) | $53.93^{b}$ | $58.00^{c}$ | $59.67^{d}$ | $63.00^{d}$ |
| $D_{2,3}50$ (T2) | $44.21^{c}$ | $71.46^{b}$ | $72.96^{c}$ | $66.50^{c}$ |
| $D_{3,4}50$ (T3) | $44.21^{c}$ | $57.54^{c}$ | $72.92^{c}$ | $79.25^{b}$ |
| $D_{all}75$ (T4) | $65.72^{a}$ | $78.59^{a}$ | $81.75^{a}$ | $83.50^{a}$ |
| $D_{all}50$ (T5) | $63.60^{a}$ | $76.47^{a}$ | $77.36^{b}$ | $79.14^{b}$ |
| $D_{all}0$ (T6) | $40.95^{c}$ | $55.46^{c}$ | $60.22^{d}$ | $62.02^{d}$ |
| SEm± | 1.559 | 1.489 | 1.251 | 0.751 |
| LSD (0.05) | 3.474 | 3.319 | 2.787 | 1.673 |
| CV (%) | 3.7 | 2.8 | 2.2 | 1.3 |

**Application efficiency** - the effect of irrigation treatments on mean values during initial, development, mid and late season shows that application efficiency were statistically significant (P<0.05) (Table 6).

**Storage efficiency** - the storage efficiency mean values during initial, development, mid and late season shows that the effect of irrigation treatments on storage efficiency were statistically significant (P<0.05) (Table 7).

Table 7: The effect of irrigation application level on the mean storage efficiency

| Treatment | Mean storage efficiency (%)* | | | |
|---|---|---|---|---|
| | Growth stages | | | |
| | Initial | Development | Mid | Late |
| $D_{1,2}25$ (T1) | $86.91^{b}$ | $45.96^{b}$ | $24.99^{b}$ | $20.68^{c}$ |
| $D_{2,3}50$ (T2) | $95.22^{a}$ | $31.27^{c}$ | $21.94^{c}$ | $31.48^{a}$ |
| $D_{3,4}50$ (T3) | $97.12^{a}$ | $53.42^{a}$ | $27.53^{a}$ | $25.33^{b}$ |
| $D_{all,}75$ (T4) | $11.88^{d}$ | $8.23^{c}$ | $6.43^{c}$ | $4.46^{c}$ |
| $D_{all,}50$ (T5) | $29.90^{c}$ | $17.23^{d}$ | $12.72^{d}$ | $10.03^{d}$ |
| $D_{all,}0$ (T6) | $97.19^{a}$ | $49.53^{ab}$ | $24.89^{b}$ | $30.61^{a}$ |
| SEm± | 2.177 | 1.840 | 0.766 | 0.801 |
| LSD (0.05) | 4.850 | 4.101 | 1.708 | 1.784 |
| CV (%) | 3.8 | 6.6 | 4.8 | 4.8 |

*mean of three observations. Treatment means followed by the same superscript letter(s) are not significantly different.

**Distribution uniformity**- the distribution uniformity mean values during initial, development, mid and late season shows that the effect of irrigation treatments on distribution uniformity were not statistically significant at 5 % probability level (Table 8).

**Deep percolation ratio**- the deep percolation ratio mean values during initial, development, mid and late season shows that the effect of irrigation treatments on deep percolation ratio were statistically significant (P<0.05) (Table 9).

Table 8: The effect of irrigation application level on the mean distribution uniformity

| Treatment | Mean distribution uniformity (%)* | | | |
|---|---|---|---|---|
| | Growth stages | | | |
| | Initial | Development | Mid | Late |
| $D_{1,2}25$ (T1) | $94.04^{a}$ | $95.97^{a}$ | $96.17^{a}$ | $95.50^{a}$ |
| $D_{2,3}50$ (T2) | $95.96^{a}$ | $98.50^{a}$ | $96.96^{a}$ | $97.03^{a}$ |
| $D_{3,4}50$ (T3) | $97.33^{a}$ | $96.60^{a}$ | $97.35^{a}$ | $97.46^{a}$ |
| $D_{all,}75$ (T4) | $96.72^{a}$ | $94.44^{a}$ | $95.58^{a}$ | $96.66^{a}$ |
| $D_{all,}50$ (T5) | $96.82^{a}$ | $98.25^{a}$ | $97.81^{a}$ | $96.49^{a}$ |
| $D_{all,}0$ (T6) | $98.55^{a}$ | $98.26^{a}$ | $96.61^{a}$ | $96.83^{a}$ |
| SEm± | 1.476 | 1.949 | 1.660 | 2.727 |
| LSD (0.05) | Ns | Ns | Ns | Ns |
| CV (%) | 1.9 | 2.5 | 2.1 | 3.5 |

*mean of three observations. Treatment means followed by the same superscript letter(s) are not significantly different. Ns = no significant difference among effects of treatments.

Table 9: The effect of irrigation application level on the mean deep percolation ratio

| Treatment | Mean deep percolation ratio (%)* | | | |
|---|---|---|---|---|
| | Growth stages | | | |
| | Initial | Development | Mid | Late |
| $D_{1,2}$25 (T1) | 46.07$^{b}$ | 42.00$^{a}$ | 40.33$^{a}$ | 37.00$^{a}$ |
| $D_{2,3}$50 (T2) | 55.79$^{a}$ | 28.54$^{b}$ | 27.04$^{b}$ | 33.50$^{b}$ |
| $D_{3,4}$50 (T3) | 55.79$^{a}$ | 42.46$^{a}$ | 27.08$^{b}$ | 20.75$^{c}$ |
| $D_{all}$,75 (T4) | 34.28$^{c}$ | 21.41$^{d}$ | 18.25$^{d}$ | 16.50$^{d}$ |
| $D_{all}$,50 (T5) | 36.40$^{c}$ | 23.53$^{d}$ | 22.64$^{c}$ | 20.86$^{c}$ |
| $D_{all}$,0 (T6) | 59.05$^{a}$ | 44.54$^{a}$ | 39.78$^{a}$ | 37.98$^{a}$ |
| SEm± | 1.559 | 1.489 | 1.251 | 0.751 |
| LSD (0.05) | 3.474 | 3.319 | 2.787 | 1.673 |
| CV (%) | 4.0 | 5.4 | 5.2 | 3.3 |

**Crop Yields and Yield Components:** Irrigation treatments on the mean grain yield were statistically significant ($p<0.05$). Maximum grain yield of 58.92 qt/ha was obtained when full irrigation was applied in all growth stages ($D_{all}$,0 (T6)). On the other hand, minimum yield of 13.10 qt/ha was obtained under 0.25ETc throughout the growth period ($D_{all}$,75 (T4)). Both treatment $D_{2,3}$50 (T2) and $D_{3,4}$50 (T3) provided with full irrigation during the initial growing season, and followed by a period of stress at the development and mid stages for treatment $D_{2,3}$50 (T2), and at the mid and late season stages for treatment $D_{3,4}$50 (T3) resulted grain yields of 42.62 qt/ha and 39.62 qt/ha, respectively. This tendency might be attributed to the fact that water stressing conditions during highly sensitive stages of maize crop in the season affected grain yield by affecting root development, cob length, number of grains per cob and leaf area cover.

**Yield reduction and harvest index:** Water deficit by 50% during third and fourth consecutive growing seasons ($D_{3,4}$50 (T3)) had a 7 % yield reduction as compared to the yield obtained under $D_{2,3}$50 (T2) (Table 4). Treatments which were stressed 50% during second and third ($D_{2,3}$50 (T2)) as well as third and fourth ($D_{3,4}$50 (T3)) growth stages had a yield reduction of about 22.92 and 28.34 % respectively, as compared to the yield obtained under treatment $D_{1,2}$25 (T1).

Table 10: Relative yield reduction of maize and Harvest index with respect to the optimum irrigation level

| Treatment | GIR (mm) | Actual yield (qt/ha) | Aboveground biomass (qt/ha) | Harvest index (%) | Yield reduction (qt/ha) | Yield reduction (%) | Rank based on yield reduction |
|---|---|---|---|---|---|---|---|
| $D_{1,2}$25 (T1) | 636.48 | 55.29 | 161.89 | 34.15 | 3.63 | 6.16 | 5 |
| $D_{2,3}$50 (T2) | 429.67 | 42.62 | 152.29 | 27.99 | 16.30 | 27.66 | 4 |
| $D_{3,4}$50 (T3) | 436.14 | 39.62 | 153.90 | 25.74 | 19.30 | 32.76 | 3 |
| $D_{all}$,75 (T4) | 170.91 | 13.10 | 130.34 | 10.05 | 45.82 | 77.77 | 1 |
| $D_{all}$,50 (T5) | 341.82 | 27.62 | 144.20 | 19.15 | 31.30 | 53.12 | 2 |
| $D_{all}$,0 (T6) | 683.64 | 58.92 | 164.28 | 35.87 | 0.00 | 0.00 | 6 |

Mansouri-Far et al. (2010) also found that deficit irrigation of maize during reproductive stage resulted in more yield reduction than during vegetative stage. The maximum yield reduction of 77.8% and 53% were observed under the application of one fourth of ETc throughout the plant growing season ($D_{all}$,75 (T4)) as compared to optimum application level ($D_{all}$,0 (T6)) and the application of half of ETc throughout the plant growing season ($D_{all}$,50 (T5)), respectively. Water stressed throughout the whole season by half of the optimum application level ($D_{all}$,50 (T5)) has a yield reduction of about 35.19% and 30.29% as compared to the yield obtained under treatment $D_{2,3}$50 (T2) and $D_{3,4}$50 (T3), respectively.

**Water Productivity:** The effect of irrigation application level on mean Physical water productivity (CWP) values were statistically significant ($P<0.05$).

However, there was no difference between treatment $D_{1,2}25$ (T1) and $D_{all}0$ (T6). Physical water productivity increased as deficit irrigation level increased up to 25% stressed during first and second growth stage ($D_{1,2}25$ (T1)) and then declined after continuously stressed by half of the total ETc ($D_{all}50$ (T5)). Treatment $D_{2,3}50$ (T2) had maximum CWP as compared to treatment $D_{3,4}50$ (T3) with the same percentage of water stressed during flowering and late season. Minimum CWP was found to be 1.29 kg/m$^3$ at 75% water stressed treatment throughout the growing season and less than the values presented in Yenesew and Ketema (2009) which was 2.96 kg/m$^3$ with the same percentage of water stressed throughout the growth period. Zhang et al. (2004) reported CWP of corn that varied from 1.39 to 1.72 kg/m$^3$. The variations of these figures might be due to the variation of the environmental conditions. Mohammed et al. (2012) conducted a field experiment to investigate yield and water productivity of maize under deficit irrigation practices in Egypt and reported a mean value of 1.86 kg/m$^3$. The variations of these figures may be attributed to crop variety, environment and field management conditions.

Table 11: Effect of irrigation treatments on water productivity and yield response factor (Ky) of maize crop.

| Treatment | NIR (m$^3$/ha) | Mean CWP (kg/m$^3$)* | GIR (m$^3$/ha) | Mean EWP (Birr/m$^3$)* | Ky (-)* |
|---|---|---|---|---|---|
| $D_{2,3}50$ (T2) | 4102.00 | 1.65$^a$ | 6836.40 | 4.17$^a$ | 0.745$^c$ |
| $D_{3,4}50$ (T3) | 3818.80 | 1.51$^b$ | 6364.80 | 3.82$^b$ | 0.904$^b$ |
| $D_{1,2}25$ (T1) | 2616.80 | 1.45$^c$ | 4361.40 | 3.65$^c$ | 0.891$^b$ |
| $D_{all}0$ (T6) | 2577.90 | 1.44$^c$ | 4296.70 | 3.62$^c$ | --- |
| $D_{all}50$ (T5) | 2050.90 | 1.35$^d$ | 3418.20 | 3.39$^d$ | 1.062$^a$ |
| $D_{all}75$ (T4) | 1025.40 | 1.29$^e$ | 1709.10 | 3.22$^e$ | 1.037$^a$ |
| SEm± | | 0.0291 | | 0.0734 | 0.0347 |
| LSD (0.05) | | 0.0648 | | 0.1635 | 0.0773 |
| CV (%) | | 2.5 | | 2.5 | 5.5 |

*mean of three observations. Treatment means followed by the same superscript letter (s) are not significantly different.

**Seasonal maize response factor:** The variability of the seasonal crop yield response factor (Ky) was statistically significant ($P<0.05$). The maximum of 1.06 and minimum of 0.745 Ky values were calculated under treatment $D_{all}50$ (T5) and $D_{2,3}50$ (T2), respectively.

## 4. Conclusions and Recommendations

In terms of application efficiency, the overall maximum of 83.50% was obtained when the field is continuously stressed by 50% and 75% of ETc, while good storage efficiency was measured when the field is irrigated by full application level.

The stage comparisons showed that the maximum amount of water (253.97 mm) during the growing season relatively with minimum yield reduction (16.30 qt/ha), applying deficit irrigation at the middle stages was found more beneficial. Maximum CWP (1.65 kg/m$^3$) and EWP (4.17 Birr/m$^3$) were obtained when 50% deficit irrigation was applied during development and mid-season stage stresses.

In conclusion when water is **not a limiting factor**, application of 75% during 1$^{st}$ and 2$^{nd}$ growth stages results the maximum yield (55.29 qt/ha). But when water is a limiting factor, stress at the second and 3$^{rd}$ maximum crop water productivity (4.17 Birr/m$^3$) was obtained when application of 50% during 2$^{nd}$ and 3$^{rd}$ growth stages is better.

The selection of stage-wise deficit irrigation application treatments was very much restricted to taking two consecutive growth stages. This is purely due to logistical constraints. Therefore, future work with more resource needs to be designed by considering every stage individually or in combination with different deficit levels, and the test of deficit irrigation application should also be made for other crops for comprehensive irrigation water management recommendations.

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# Stochastic analysis of dry/wet spell for crop production in the Upper Awash Basin, Ethiopia

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## Abstract

*The aim of this study was to analyze the probability of occurrence of wet and dry spell events in the Upper Awash Basin, Ethiopia, using Markov Chain model based on dekadal time steps. The stations which covered in the analysis are Debrezeit, Wonji, Melkassa and Metehara areas. Crop water requirement in a specific dekad in each growth stage was considered as a threshold value to classify the dekad as wet or dry in Kiremt (main rainy season). However, only at early stage of growth were assumed in Belg season (small rainy season). The reason of selecting the threshold value of crop water requirement at early stage of growth for the Belg season is that, the available rain in study areas usually do not cover all the growth stages, it ceases in the early stage of growth and less probably in the crop development stages. In most of the cases, the probabilities of occurrences of dry spells [$P_D$] in the Belg season were found to be more than 50% at all stations and a continuous dry spells resulted in short periods of droughts during critical growth stage appeared in the analysis period. However, the study revealed that the moisture available from the rainwater during the main rainy season can support cereal crop productions in the study area except at Metehara station, where wet dekads with low probability of occurrence and lasting for short duration have been recorded. Moreover, the study also indicated that excess amounts of rainwater are recorded in Debrezeit and Wonji areas during the Kiremt season which might be harvested and used to offset the soil moisture stresses during the dry spell periods.*

*Keywords: Upper Awash, Markov Chain, length of growing period, onset of growing period, end of growing period, dry/wet spell.*

## 1. Introduction

The distribution of dry/wet spells during the monsoon period is essential for successful rainfed farming. It is also important to know the chances of occurrence of dry spells during the critical growth stages of the crops for deciding the sowing date, cropping pattern and planning for supplemental irrigation and other agricultural operations.

Instead of dealing with the amount of rainfall alone, it is better to consider the rainfall along the crop water requirement (Engida, 2003, and Girma, 2011). Crop water requirement over the dry land areas of Ethiopia is different for different crops and furthermore, different at different stages of crop development. The choice of the threshold limit for Markov Chain model is very important when used for agricultural purposes.

Literature available in this subject indicates that the crop yield will not be affected adversely if plants get about 30-70% of the reference evapotranspiration depending on the growing stage of the crop (Khambete and Biswas, 1984). Reddy (1990) investigated that 3mm of rainfall per day was assumed to satisfy the crop water requirement on average and for a ten-day (dekad) interval, 30mm was selected as a threshold value and a dekad with 30mm or more of rainfall was considered as a wet dekad. Besides, Fistume (2009) and Mersha (2003) used the same assumption as Reddy (1990) to assess the moisture availability over the highlands and, arid and semi-arid zones of Ethiopia using Markov Chain model.

The purpose of estimating probabilities with respect to a given amount of rainfall is extremely useful for agricultural planning. These initial and conditional probabilities would help in determining the relative chance of occurrence of a given amount of rainfall. The degree of wetness could be defined in terms of any amount of rainfall. The choice of any threshold amount of rainfall depends on the purpose for which the different probabilities may be used (Virmani, 1976). The Markov Chain analysis was used in India (Srinivasa, *et al.*, 2008), Pakistan (Faqir and Ghulam, 1991), Greece (Tsakeris, 1989; and Maria, 1983), and Ethiopia (Girma, 2011 and Fistume, 2009).

**The objectives of the study were:**

⇒ to characterize the distribution of dry and wet spells in the Upper Awash Basin, Ethiopia, based on the dekadal meteorological variables and water requirements of commonly growing crops on specific dekads.

⇒ to investigate the chances of occurrence of dry spells during the critical growth stages of the crops for deciding the sowing date, cropping pattern and planning for supplemental irrigation and other agricultural operations.

## 2. Methodology

In this study, a minimum of 31years data of rainfall have been used for analysis and the areas are highly dominated by clay soil. The dominant crop in the study areas are *Tef* in Debrezeit, Maize in Wonji and Metehara and Sorghum in Melkassa. The dekadal crop water requirement commonly grown in the selected area of Upper Awash Basin (UAB) (Fig. 1) was taken as a threshold value for classifying a dekad as a dry or wet.

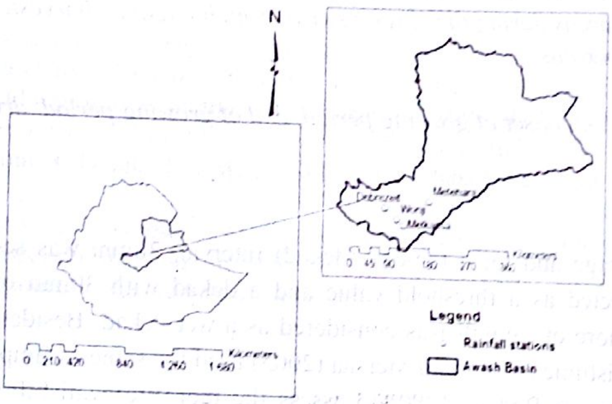


Figure 1: Location of the Upper Awash Basin (Debrezeit, Wonji, Melkasa and Metehara)

The following parameters were estimated for the Markov Chain analysis (Srinivasa, *et al*., 2008):

**Initial Probability:**

$$P_D = \frac{F_D}{n} \quad (1)$$

$$P_W = \frac{F_W}{n} \quad (2)$$

**Conditional Probabilities:**

$$P_{WW} = \frac{F_{WW}}{F_W} \quad (3)$$

$$P_{DD} = \frac{F_{DD}}{F_D} \quad (4)$$

$$P_{WD} = 1 - P_{DD} \quad (5)$$

$$P_{DW} = 1 - P_{WW} \quad (6)$$

**Consecutive dry and wet dekad probabilities:**

$$2D = P_{Dd1} \cdot P_{DDd2} \quad (7)$$

$$2W = P_{Wd1} \cdot P_{WWd2} \quad (8)$$

The distributions of the spells by length or duration are found to be geometric (Gabriel and Neuman, 1962) with the probability of wet and dry spell lengths for three consecutive events (k = 3) given by the following equation:

$$3D = P_{Dd1} \cdot P_{DDd2} \cdot P_{DDd3} \quad (9)$$

$$3W = P_{Wd1} \cdot P_{WWd2} \cdot P_{WWd3} \quad (10)$$

Where,

| | |
|---|---|
| $P_D$ | the probability of a dekad being dry |
| $F_D$ | the number of dry dekads |
| $P_W$ | the probability of a dekad being wet |
| $F_W$ | the number wet dekads |
| n | the number of observations |
| $P_{WW}$ | the probability of wet dekad preceded by another wet dekad |
| $F_{WW}$ | the number of wet dekads preceded by another wet dekad |
| $F_{DD}$ | the number of dry dekads preceded by another dry dekad |
| $P_{DD}$ | the probability of a dry dekad preceded by an other dry dekad |
| $F_{DD}$ | the number of dry dekad preceded by another dry dekad |
| $P_{WD}$ | the probability of a wet dekad preceded by an other dry dekad |
| $P_{DW}$ | the probability of a dry dekad preceded by a wet dekad. |
| 2D | the probability of two consecutive dry dekads starting with any dekad |
| 3D | Probability of 3 consecutive dry dekads starting with any dekad |
| 2W | Probability of 2 consecutive wet dekads starting with any dekad |

| | |
|---|---|
| 3W | Probability of 3 consecutive wet dekads starting with any dekad |
| $P_{D d1}$ | Probability of the dekad being dry (first dekad) |
| $P_{DD d2}$ | Probability of the second dekad being dry, given the preceding dekad dry |
| $P_{DD d3}$ | Probability of the third dekad being dry, given the preceding dekad dry |
| $P_{W d1}$ | Probability of the dekad being wet (first dekad) |
| $P_{WW d2}$ | Probability of the second dekad being wet, given the preceding dekad wet |
| $P_{WW d3}$ | Probability of the third dekad being wet, given the preceding dekad wet |

An average dekadal reference evapotranspiration ($ET_0$) during the onset of the *Belg* season and the crop coefficient factor ($K_c$) during the initial growth stage of the selected crops were considered to determine the crop water requirement (threshold value) in all the study areas (Table 1).

Table 1: Crop water requirement (threshold value) during *Belg* season in the study areas (Girma, 2011)

| Study area | Onset dekad | $ET_0$ (mm/dekad) | $K_c$* | ETc (mm/dekad) |
|---|---|---|---|---|
| Debrezeit | 9 | 51.70 | 0.3 | 15.5 |
| Wonji | 8 | 44.60 | 0.3 | 13.4 |
| Melkassa | 8 | 54.12 | 0.3 | 16.2 |
| Metehara | 9 | 51.70 | 0.3 | 15.5 |

*$K_c$ value taken from Allen et al. (1998), and considers only the initial crop coefficient.*

For the *Kiremt* season, the crop coefficient factor ($K_c$) in each growth stage were taken from Brouwer and Heibloem (1986) and converted to dekadal $K_c$. These values of dekadal reference evapotranspiration and crop coefficient factors were used to compute the dekadal crop water requirement in each growth stage.

## 3. Results and Discussions

### 3.1. Initial and Conditional Probability

The initial and conditional probabilities of rainfall occurrence in *Belg* and *Kiremt* seasons in the four locations, which satisfy the threshold value, were estimated by using Markov chain probability analysis and results are presented in Tables 2 to 5.

It can be noted from the tables that the probability of occurrence of dry dekads [$P_D$] during *Belg* season (from 7th to 9th dekads) ranged from 69-41%, 67-58%, 75-53% and 75-50% at Debrezeit, Wonji, Melkassa and Metehara, respectively. These results indicates that, the probability of being dry seems to reduce in March (7th to 9th dekads), but relatively high dry spell dominated in subsequent dekads of the year had been observed in all study areas.

Furthermore, maximum dry dekad occurred in dekad 14 (83%) at Metehara, in dekad 12 (70%) at Wonji, and in dekad 7 at Melkassa (75%) and Debrezeit (69%). These results indicate that the *Belg* season is less reliable in terms of rainfall availability since the probability of occurrence of dry spell is more than 50% at all stations.

In Debrezeit and Wonji areas, the highest probability of occurrence of wet dekad [$P_W$] during the *Kiremt* season ranged from 72 to 94% (during 17th to 24th dekads) and 64 to 82% (during 18th to 24th dekads), respectively. However, in Melkassa area the occurrence of wet spell is less frequent as compared to the previous stations. In Metehara area, the wet spell occurred in between July 1st and August 1st dekads only; the rest of the dekads experienced dry spells. Therefore, unlike the other three stations, in Metehara the crop water needs often exceeds the total available rainfall causing yield reductions during the main rainy season unless dry spells are bridged through appropriate water management techniques.

The conditional probability of dry dekad preceded by a dry dekad [$P_{DD}$] was also high in *Belg* season at Debrezeit (52-100%), Wonji (50-86%), Melkassa (56-96%) and Metehara (58-94%). During this period a dry dekad, which is less than 50% has been occurred only in dekad 12, 14, and 11 in three of the stations (except at Metehara), respectively. In general, the probability of occurrence of wet dekad preceded by a wet dekad in *Belg* season during the analysis period indicate that the season is not able to support even the water requirement of crops during their initial growth stage.

In contrast, the conditional probability of one wet dekad preceded by a wet dekad [$P_{WW}$] during *Kiremt* season indicates the occurrences of high rainfall events in all the study areas except Metehara, which has a $P_{WW}$ value of greater than 50% lasting for a short period of time (from dekad 20-23). It is also illustrated from the table that the frequency of rainfall distribution through dekads with in years is highly temporal.

### 3.2. Probability of Occurrence of Two/Three Consecutive Wet/Dry Dekad

Dry spells due to inadequate rainfall may occur throughout the rainy season. If the rainfall is less than the threshold value at a location in *Belg* and *Kiremt* season for two or more consecutive dekads, the crops are likely to be subjected to moisture stress in the absence of supplemental irrigation.

During *Belg* season, probability of occurrence of two consecutive dry dekads starting with any dekad [2D] having maximum value of 79% in dekad 14 (2[nd] dekad of May) at Metehara and minimum value of 23% in dekad 9 (3[rd] dekad of March) observed at Debrezeit areas, respectively. Besides in *Kiremt* season the probability of occurrence of consecutive dry spells is too high at the end of September (dekad 27) in three of the study areas except at Metehara which encounters the late onset of consecutive wet spells and early termination at the end of August in which the area struck with highly dry spells in successive dekads (Table 2-5).

Probability of two consecutive wet dekads starting with any dekad [2W] for the *Belg* season in Table 2-5 indicated that, a maximum value of 45% in dekad 9 (3[rd] dekad of March) experienced at Debrezeit only and the rest of the season in all locations encountered below 45%. While in *Kiremt* season, it was observed a higher consecutive wet periods [2W] at Debrezeit (69-88%), and Wonji (50-67%) through 18[th] to 23[rd] and 19[th] to 22[nd] dekads, respectively. Besides in Melkassa and Metehara areas, the consecutive wet periods were observed only in dekad 20 (65 and 51%) and dekad 21 (61 and 70%), respectively.

The probability of three consecutive wet dekad starting with any dekad [3W] in *Belg* season experienced less probability of wet period at Debrezeit (6-30%), Wonji (5-13%), Melkassa (2-12%) and Metehara (1-7%) except in dekad 8 and 9 with 18 and 20% probability, respectively. While in *Kiremt* season, unlike the other study areas, higher probability of long wet period observed in Debrezeit area (69-83%) through dekad 18 to 22, only. In Wonji and Melkassa areas, the *Kiremt* season [3W] experienced above 50% only in dekad 20, whereas in Metehara area the entire dekads was kept below 50%. These indicate that, the probability of getting three consecutive wet dekads in *Kiremt* season at Wonji, Melkassa and Metehara areas were rare.

In general, a *Belg* season experienced low probabilities of occurrences of a wet dekad [$P_W$], a wet dekad preceded by wet dekad [$P_{WW}$], two consecutive wet dekads starting with any dekad [2W] and three consecutive wet dekads starting with any dekad [3W] but has extended dry dekads. This indicates that growing crops in this season is less likely. Whereas, the main rainy season provides enough amount of rainfall to grow cereal crops in the study area except at Metehara has low probability of wet dekads lasting for a short period. The successive dry dekades [2D and 3D] hint for the need of supplemental irrigations and moisture conservation practices whereas, successive wet weeks [2W and 3W] give an idea of excessive runoff water availability for rainwater harvesting and to take up suitable measures to control soil erosion (Srinivasa, *et al.*, 2008). Therefore, only in Debrezeit and Wonji areas, it was found that surplus rain water can be recorded during the *Kiremt* season. Hence, the surplus water might be harvested and used to supplement rainfed crops during the dry spell period. Meanwhile, continuous dry spells of at least three dekads [3D] in between the wet dekads were observed during the *Belg* season in all the study areas, which may cause yield reductions or complete crop failure. The dekadal rainfall and its corresponding crop water requirements for the selected crops are shown in Figures 2 -5.

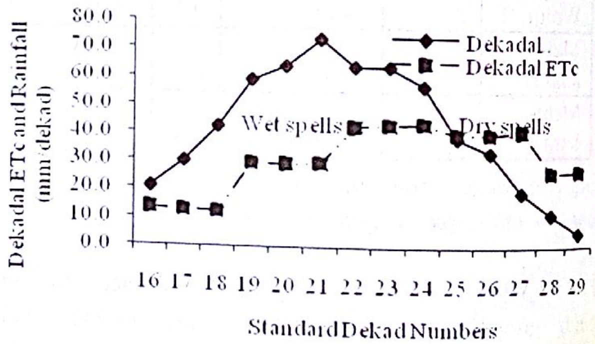


Figure 2: Dekadal ETc and Rainfall in *Kiremt* season at Debrezeit area

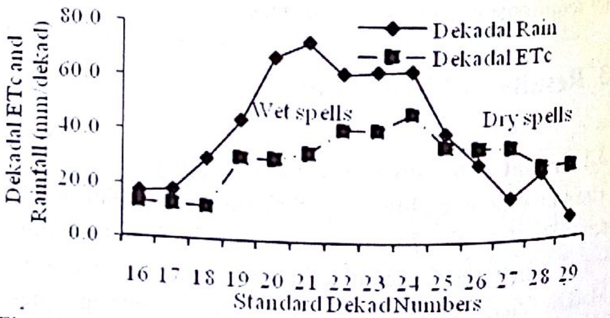


Figure 3: Dekadal ETc and Rainfall in *Kiremt* season at Wonji area

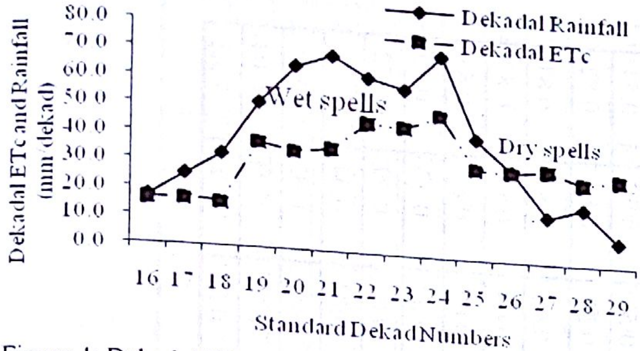


Figure 4: Dekadal ETc and Rainfall in *Kiremt* season at Melkassa area

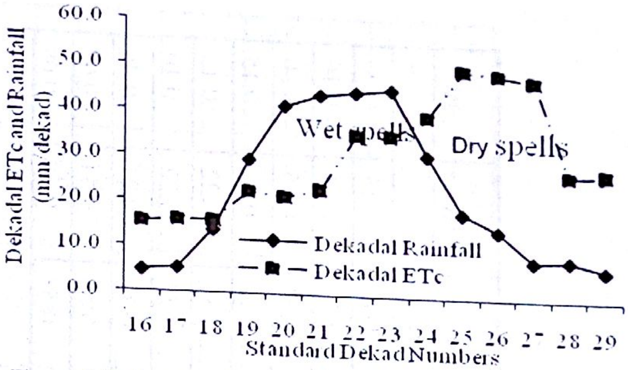


Figure 5: Dekadal ETc and Rainfall in *Kiremt* season at Metehara area

## 4. Conclusion

In general, a *Belg* (small rainy) season experienced low probabilities of occurrences of a wet dekad [$P_W$], a wet dekad preceded by wet dekad [$P_{WW}$], two consecutive wet dekads starting with any dekad [2W] and three consecutive wet dekads starting with any dekad [3W] but has extended dry dekads. This indicates that growing crops in this season is less likely. Whereas, the main rainy season provides enough amount of rainfall to grow cereal crops in the study area except at Metehara has low probability of wet dekads, lasting for a short period. According to Srinivasa *et al.*, 2008, the successive dry weeks [2D and 3D] hint for the need of supplemental irrigations and moisture conservation practices whereas, successive wet weeks [2W and 3W] give an idea of excessive runoff water availability for rainwater harvesting and to take up suitable measures to control soil erosion. Therefore, only in Debrezeit and Wonji areas, it was found that surplus rain water can be recorded during the *Kiremt* (main rainy) season. Hence, the surplus water might be harvested and used to supplement rainfed crops during the dry spell period. Meanwhile, continuous dry spells of at least three dekads [3D] in between the wet dekads were observed during the *Belg* (small rainy) season in all the study areas, which may cause yield reductions or complete crop failure.

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Table 2: Distribution of dry and wet spells at Debrezeit area (1976-2007).

| Dekad no | $F_D$ | $F_{DD}$ | $P_D$ | $P_{DD}$ | $P_{WD}$ | 2D | 3D | $F_W$ | $F_{WW}$ | $P_W$ | $P_{WW}$ | $P_{DW}$ | 2W | 3W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Belg* (small rainy) season | | | | | | | | | | | | | | |
| 7 | 22 | 22 | 0.69 | 1.00 | 0.00 | 0.53 | 0.37 | 10 | 0 | 0.31 | 0.00 | 1.00 | 0.13 | 0.06 |
| 8 | 18 | 14 | 0.56 | 0.78 | 0.22 | 0.39 | 0.22 | 14 | 6 | 0.44 | 0.43 | 0.57 | 0.21 | 0.16 |
| 9 | 13 | 9 | 0.41 | 0.69 | 0.31 | 0.23 | 0.15 | 19 | 9 | 0.59 | 0.47 | 0.53 | 0.45 | 0.30 |
| 10 | 16 | 9 | 0.50 | 0.56 | 0.44 | 0.32 | 0.15 | 16 | 12 | 0.50 | 0.75 | 0.25 | 0.33 | 0.15 |
| 11 | 17 | 11 | 0.53 | 0.65 | 0.35 | 0.25 | 0.16 | 15 | 10 | 0.47 | 0.67 | 0.33 | 0.22 | 0.12 |
| 12 | 19 | 9 | 0.59 | 0.47 | 0.53 | 0.38 | 0.20 | 13 | 6 | 0.41 | 0.46 | 0.54 | 0.22 | 0.10 |
| 13 | 17 | 11 | 0.53 | 0.65 | 0.35 | 0.28 | 0.19 | 15 | 8 | 0.47 | 0.53 | 0.47 | 0.21 | 0.09 |
| 14 | 21 | 11 | 0.66 | 0.52 | 0.48 | 0.46 | 0.34 | 11 | 5 | 0.34 | 0.45 | 0.55 | 0.14 | 0.07 |
| 15 | 20 | 14 | 0.63 | 0.70 | 0.30 | 0.46 | 0.23 | 12 | 5 | 0.38 | 0.42 | 0.58 | 0.18 | 0.09 |
| *Kiremt* (main rainy) seasons | | | | | | | | | | | | | | |
| 16 | 15 | 11 | 0.47 | 0.73 | 0.27 | 0.23 | 0.12 | 17 | 8 | 0.53 | 0.47 | 0.53 | 0.27 | 0.20 |
| 17 | 8 | 4 | 0.25 | 0.50 | 0.50 | 0.13 | 0.00 | 24 | 12 | 0.75 | 0.50 | 0.50 | 0.58 | 0.54 |
| 18 | 2 | 1 | 0.06 | 0.50 | 0.50 | 0.00 | 0.00 | 30 | 23 | 0.94 | 0.77 | 0.23 | 0.88 | 0.82 |
| 19 | 2 | 0 | 0.06 | 0.00 | 1.00 | 0.00 | 0.00 | 30 | 28 | 0.94 | 0.93 | 0.07 | 0.88 | 0.81 |
| 20 | 2 | 0 | 0.06 | 0.00 | 1.00 | 0.00 | 0.00 | 30 | 28 | 0.94 | 0.93 | 0.07 | 0.87 | 0.80 |
| 21 | 3 | 0 | 0.09 | 0.00 | 1.00 | 0.01 | 0.01 | 29 | 27 | 0.91 | 0.93 | 0.07 | 0.83 | 0.83 |
| 22 | 9 | 1 | 0.28 | 0.11 | 0.89 | 0.28 | 0.19 | 23 | 21 | 0.72 | 0.91 | 0.09 | 0.72 | 0.69 |
| 23 | 9 | 9 | 0.28 | 1.00 | 0.00 | 0.19 | 0.06 | 23 | 23 | 0.72 | 1.00 | 0.00 | 0.69 | 0.52 |
| 24 | 9 | 6 | 0.28 | 0.67 | 0.33 | 0.09 | 0.05 | 23 | 22 | 0.72 | 0.96 | 0.04 | 0.54 | 0.36 |
| 25 | 16 | 5 | 0.50 | 0.31 | 0.69 | 0.28 | 0.22 | 16 | 12 | 0.50 | 0.75 | 0.25 | 0.33 | 0.25 |
| 26 | 23 | 13 | 0.72 | 0.57 | 0.43 | 0.56 | 0.50 | 9 | 6 | 0.28 | 0.67 | 0.33 | 0.21 | 0.04 |
| 27 | 28 | 22 | 0.88 | 0.79 | 0.21 | 0.78 | 0.70 | 4 | 3 | 0.13 | 0.75 | 0.25 | 0.03 | 0.01 |

Table 3: Distribution of dry and wet spells at Wonji area (1977-2009).

| Dekad no | $F_D$ | $F_{DD}$ | $P_D$ | $P_{DD}$ | $P_{WD}$ | 2D | 3D | $F_W$ | $F_{WW}$ | $P_W$ | $P_{WW}$ | $P_{DW}$ | 2W | 3W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Belg* (small rainy) season | | | | | | | | | | | | | | |
| 7 | 22 | 19 | 0.67 | 0.86 | 0.14 | 0.47 | 0.29 | 11 | 4 | 0.33 | 0.36 | 0.64 | 0.13 | 0.05 |
| 8 | 20 | 14 | 0.61 | 0.70 | 0.30 | 0.38 | 0.26 | 13 | 5 | 0.39 | 0.38 | 0.62 | 0.17 | 0.10 |
| 9 | 19 | 12 | 0.58 | 0.63 | 0.37 | 0.38 | 0.26 | 14 | 6 | 0.42 | 0.43 | 0.57 | 0.25 | 0.10 |
| 10 | 21 | 14 | 0.64 | 0.67 | 0.33 | 0.42 | 0.26 | 12 | 7 | 0.36 | 0.58 | 0.42 | 0.15 | 0.09 |
| 11 | 18 | 12 | 0.55 | 0.67 | 0.33 | 0.33 | 0.23 | 15 | 6 | 0.45 | 0.40 | 0.60 | 0.27 | 0.08 |
| 12 | 23 | 14 | 0.70 | 0.61 | 0.39 | 0.49 | 0.22 | 10 | 6 | 0.30 | 0.60 | 0.40 | 0.09 | 0.05 |
| 13 | 20 | 14 | 0.61 | 0.70 | 0.30 | 0.27 | 0.14 | 13 | 4 | 0.39 | 0.31 | 0.69 | 0.21 | 0.13 |
| 14 | 20 | 9 | 0.61 | 0.45 | 0.55 | 0.30 | 0.15 | 13 | 7 | 0.39 | 0.54 | 0.46 | 0.24 | 0.11 |
| 15 | 20 | 10 | 0.61 | 0.50 | 0.50 | 0.30 | 0.18 | 13 | 8 | 0.39 | 0.62 | 0.38 | 0.18 | 0.10 |
| *Kiremt* (main rainy) season | | | | | | | | | | | | | | |
| 16 | 18 | 9 | 0.55 | 0.50 | 0.50 | 0.33 | 0.23 | 15 | 7 | 0.45 | 0.47 | 0.53 | 0.24 | 0.11 |
| 17 | 20 | 12 | 0.61 | 0.60 | 0.40 | 0.42 | 0.14 | 13 | 7 | 0.39 | 0.54 | 0.46 | 0.17 | 0.11 |
| 18 | 10 | 7 | 0.30 | 0.70 | 0.30 | 0.10 | 0.05 | 23 | 10 | 0.70 | 0.43 | 0.57 | 0.44 | 0.34 |
| 19 | 9 | 3 | 0.27 | 0.33 | 0.67 | 0.14 | 0.02 | 24 | 15 | 0.73 | 0.63 | 0.38 | 0.57 | 0.46 |
| 20 | 6 | 3 | 0.18 | 0.50 | 0.50 | 0.03 | 0.00 | 27 | 21 | 0.82 | 0.78 | 0.22 | 0.67 | 0.52 |
| 21 | 6 | 1 | 0.18 | 0.17 | 0.83 | 0.02 | 0.01 | 27 | 22 | 0.82 | 0.81 | 0.19 | 0.64 | 0.46 |
| 22 | 10 | 1 | 0.30 | 0.10 | 0.90 | 0.10 | 0.05 | 23 | 18 | 0.70 | 0.78 | 0.22 | 0.50 | 0.36 |
| 23 | 12 | 4 | 0.36 | 0.33 | 0.67 | 0.18 | 0.10 | 21 | 15 | 0.64 | 0.71 | 0.29 | 0.45 | 0.37 |
| 24 | 12 | 6 | 0.36 | 0.50 | 0.50 | 0.20 | 0.11 | 21 | 15 | 0.64 | 0.71 | 0.29 | 0.52 | 0.32 |
| 25 | 16 | 9 | 0.48 | 0.56 | 0.44 | 0.27 | 0.16 | 17 | 14 | 0.52 | 0.82 | 0.18 | 0.32 | 0.08 |
| 26 | 20 | 11 | 0.61 | 0.55 | 0.45 | 0.36 | 0.29 | 13 | 8 | 0.39 | 0.62 | 0.38 | 0.10 | 0.00 |
| 27 | 29 | 17 | 0.88 | 0.59 | 0.41 | 0.73 | 0.53 | 4 | 1 | 0.12 | 0.25 | 0.75 | 0.00 | 0.00 |

Table 4: Distribution of dry and wet spells at Melkassa area (1977-2008)

| Dekad no | $F_D$ | $F_{DD}$ | $P_D$ | $P_{DD}$ | $P_{WD}$ | 2D | 3D | $F_W$ | $F_{WW}$ | $P_W$ | $P_{WW}$ | $P_{DW}$ | 2W | 3W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *Belg* (small rainy) season | | | | | | | |
| 7 | 24 | 23 | 0.75 | 0.96 | 0.04 | 0.66 | 0.40 | 8 | 1 | 0.25 | 0.13 | 0.88 | 0.10 | 0.06 |
| 8 | 17 | 15 | 0.53 | 0.88 | 0.12 | 0.32 | 0.18 | 15 | 6 | 0.47 | 0.40 | 0.60 | 0.27 | 0.08 |
| 9 | 20 | 12 | 0.63 | 0.60 | 0.40 | 0.35 | 0.15 | 12 | 7 | 0.38 | 0.58 | 0.42 | 0.11 | 0.03 |
| 10 | 18 | 10 | 0.56 | 0.56 | 0.44 | 0.25 | 0.15 | 14 | 4 | 0.44 | 0.29 | 0.71 | 0.13 | 0.07 |
| 11 | 18 | 8 | 0.56 | 0.44 | 0.56 | 0.35 | 0.23 | 14 | 4 | 0.44 | 0.29 | 0.71 | 0.24 | 0.05 |
| 12 | 21 | 13 | 0.66 | 0.62 | 0.38 | 0.43 | 0.29 | 11 | 6 | 0.34 | 0.55 | 0.45 | 0.07 | 0.02 |
| 13 | 20 | 13 | 0.63 | 0.65 | 0.35 | 0.43 | 0.33 | 10 | 2 | 0.31 | 0.20 | 0.80 | 0.10 | 0.07 |
| 14 | 19 | 13 | 0.59 | 0.68 | 0.32 | 0.45 | 0.32 | 13 | 4 | 0.41 | 0.31 | 0.69 | 0.30 | 0.12 |
| 15 | 21 | 16 | 0.66 | 0.76 | 0.24 | 0.46 | 0.28 | 11 | 8 | 0.34 | 0.73 | 0.27 | 0.14 | 0.05 |
| | | | | | | | *Kiremt* (main rainy) season | | | | | | | |
| 16 | 20 | 14 | 0.63 | 0.70 | 0.30 | 0.39 | 0.24 | 12 | 5 | 0.38 | 0.42 | 0.58 | 0.14 | 0.04 |
| 17 | 21 | 13 | 0.66 | 0.62 | 0.38 | 0.40 | 0.24 | 11 | 4 | 0.34 | 0.36 | 0.64 | 0.11 | 0.08 |
| 18 | 13 | 8 | 0.41 | 0.62 | 0.38 | 0.24 | 0.10 | 19 | 6 | 0.59 | 0.32 | 0.68 | 0.42 | 0.27 |
| 19 | 12 | 7 | 0.38 | 0.58 | 0.42 | 0.16 | 0.06 | 20 | 14 | 0.63 | 0.70 | 0.30 | 0.40 | 0.33 |
| 20 | 7 | 3 | 0.22 | 0.43 | 0.57 | 0.08 | 0.03 | 25 | 16 | 0.78 | 0.64 | 0.36 | 0.65 | 0.53 |
| 21 | 8 | 3 | 0.25 | 0.38 | 0.63 | 0.09 | 0.02 | 24 | 20 | 0.75 | 0.83 | 0.17 | 0.61 | 0.34 |
| 22 | 11 | 4 | 0.34 | 0.36 | 0.64 | 0.07 | 0.03 | 21 | 17 | 0.66 | 0.81 | 0.19 | 0.36 | 0.18 |
| 23 | 14 | 3 | 0.44 | 0.21 | 0.79 | 0.16 | 0.07 | 18 | 10 | 0.56 | 0.56 | 0.44 | 0.28 | 0.15 |
| 24 | 14 | 5 | 0.44 | 0.36 | 0.64 | 0.20 | 0.10 | 18 | 9 | 0.56 | 0.50 | 0.50 | 0.30 | 0.22 |
| 25 | 13 | 6 | 0.41 | 0.46 | 0.54 | 0.20 | 0.12 | 19 | 10 | 0.59 | 0.53 | 0.47 | 0.45 | 0.00 |
| 26 | 20 | 10 | 0.63 | 0.50 | 0.50 | 0.36 | 0.30 | 12 | 9 | 0.38 | 0.75 | 0.25 | 0.00 | 0.00 |
| 27 | 28 | 16 | 0.88 | 0.57 | 0.43 | 0.72 | 0.55 | 4 | 0 | 0.13 | 0.00 | 1.00 | 0.00 | 0.00 |

Table 5: Distribution of dry and wet spells at Metehara area of 24 years

| Dekad no | $F_D$ | $F_{DD}$ | $P_D$ | $P_{DD}$ | $P_{WD}$ | 2D | 3D | $F_W$ | $F_{WW}$ | $P_W$ | $P_{WW}$ | $P_{DW}$ | 2W | 3W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Belg* (small rainy) season | | | | | | | | | | | | | | |
| 7 | 18 | 17 | 0.75 | 0.94 | 0.06 | 0.59 | 0.44 | 6 | 2 | 0.25 | 0.33 | 0.67 | 0.08 | 0.05 |
| 8 | 14 | 11 | 0.58 | 0.79 | 0.21 | 0.44 | 0.34 | 10 | 3 | 0.42 | 0.31 | 0.69 | 0.24 | 0.18 |
| 9 | 12 | 9 | 0.50 | 0.75 | 0.25 | 0.38 | 0.23 | 12 | 7 | 0.50 | 0.58 | 0.42 | 0.36 | 0.20 |
| 10 | 13 | 10 | 0.54 | 0.77 | 0.23 | 0.33 | 0.19 | 11 | 8 | 0.46 | 0.73 | 0.27 | 0.25 | 0.05 |
| 11 | 15 | 9 | 0.63 | 0.60 | 0.40 | 0.36 | 0.27 | 9 | 5 | 0.38 | 0.56 | 0.44 | 0.08 | 0.01 |
| 12 | 19 | 11 | 0.79 | 0.58 | 0.42 | 0.59 | 0.42 | 5 | 1 | 0.21 | 0.20 | 0.80 | 0.03 | 0.01 |
| 13 | 16 | 12 | 0.67 | 0.75 | 0.25 | 0.47 | 0.44 | 8 | 1 | 0.33 | 0.13 | 0.88 | 0.17 | 0.07 |
| 14 | 20 | 14 | 0.83 | 0.70 | 0.30 | 0.79 | 0.54 | 4 | 2 | 0.17 | 0.50 | 0.50 | 0.07 | 0.00 |
| 15 | 18 | 17 | 0.75 | 0.94 | 0.06 | 0.51 | 0.47 | 7 | 3 | 0.29 | 0.43 | 0.57 | 0.00 | 0.00 |
| *Kiremt* (main rainy) season | | | | | | | | | | | | | | |
| 16 | 22 | 15 | 0.92 | 0.68 | 0.32 | 0.84 | 0.79 | 2 | 0 | 0.08 | 0.00 | 1.00 | 0.00 | 0.00 |
| 17 | 23 | 21 | 0.96 | 0.91 | 0.09 | 0.90 | 0.60 | 1 | 0 | 0.04 | 0.00 | 1.00 | 0.00 | 0.00 |
| 18 | 17 | 16 | 0.71 | 0.94 | 0.06 | 0.47 | 0.13 | 7 | 0 | 0.29 | 0.00 | 1.00 | 0.08 | 0.05 |
| 19 | 9 | 6 | 0.38 | 0.67 | 0.33 | 0.11 | 0.04 | 15 | 4 | 0.63 | 0.27 | 0.73 | 0.37 | 0.27 |
| 20 | 7 | 2 | 0.29 | 0.29 | 0.71 | 0.10 | 0.05 | 17 | 10 | 0.71 | 0.59 | 0.41 | 0.51 | 0.48 |
| 21 | 6 | 2 | 0.25 | 0.33 | 0.67 | 0.14 | 0.06 | 18 | 13 | 0.75 | 0.72 | 0.28 | 0.70 | 0.49 |
| 22 | 9 | 5 | 0.38 | 0.56 | 0.44 | 0.16 | 0.09 | 15 | 14 | 0.63 | 0.93 | 0.07 | 0.44 | 0.18 |
| 23 | 14 | 6 | 0.58 | 0.43 | 0.57 | 0.34 | 0.29 | 10 | 7 | 0.42 | 0.70 | 0.30 | 0.17 | 0.17 |
| 24 | 19 | 11 | 0.79 | 0.58 | 0.42 | 0.68 | 0.62 | 5 | 2 | 0.21 | 0.40 | 0.60 | 0.21 | 0.00 |
| 25 | 22 | 19 | 0.92 | 0.86 | 0.14 | 0.84 | 0.80 | 2 | 2 | 0.08 | 1.00 | 0.00 | 0.00 | 0.00 |
| 26 | 23 | 21 | 0.96 | 0.91 | 0.09 | 0.92 | 0.92 | 1 | 0 | 0.04 | 0.00 | 1.00 | 0.00 | 0.00 |
| 27 | 24 | 23 | 1.00 | 0.96 | 0.04 | 1.00 | 1.00 | 1 | 0 | 0.04 | 0.00 | 1.00 | 0.00 | 0.00 |

# Response of Onion (*Allium cepa L.*) to Deficit Irrigation Under Alternate, Fixed and Conventional Furrow Irrigation Systems

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## Abstract

*Onion is one of the major economic important crops in the central rift valley (CRV) of Ethiopia and irrigation is necessary for crop production in the area. However, water resources are becoming scarce resource in the area for crop production due to increasing competition for irrigation water. A deficit irrigation practice has been considered as one of water saving technique thereby improving agricultural water use efficiency. This study was conducted at Melkassa Agricultural Research center (MARC) to investigate the effect of deficit irrigation under different furrow irrigation practices on yield and WUE of onion in CRV of Ethiopia. The experimental design was split plot arranged in RCBD with three replications. The treatments included three levels of deficit irrigation (25%ETc, 50%ETc, 75%ETc) and control (100%ETc) as main plot and three furrow irrigation practices (AFI, FFI and CFI) as subplot. The analysis of variance indicated highly significant (P < 0.01) differences in yield, yield components and WUE's. The highest marketable bulb yield of 22.0 t ha was obtained from the control with CFI which was not significantly different to the 75%ETc with AFI system. In terms of irrigation and water use efficiency, 75%ETc deficit irrigation application with AFI system gave the highest IWUE which was highly significantly (P < 0.01) different from all other treatment combinations. The economic advantage obtained for AFI at 75%ETc from saved irrigation water per hectare over CFI at 100%ETc was 120,090.5 birr. AFI at 75%ETc application level had also the highest MRR (5522.6%) of all treatment combinations. Therefore, it can be concluded that increased water saving and associated water productivity through the use of AFI at 75%ETc can solve problem of water shortage.*

## 1. Introduction

Onion (*Allium cepa* L.) is among the most important vegetable crops and is widely grown throughout the world (Brewster, 1997). It is cultivated as a source of income by many farmers in many parts of the country. It is also one the most important vegetable crops in Ethiopia. The crop is widely cultivated as cash crop by small-scale, private and large-scale farmers. The crop is exclusively produced under furrow irrigation. The country has a great potential to produce onion throughout the year both for local consumption and export.

The crop could be produced throughout the year provided dependable rain and/or irrigation water is available. The majority of onion production is found in the Central Rift Valley (CRV) of Ethiopia. The climate and soil condition of the region favours the production of the crop. Nevertheless, rainfall is unreliable and insufficient to support onion production. As a result, irrigation is an indispensable practice for onion production in the region.

Shortage of water in this region is severe and a major limiting factor for increased agricultural production and food security in the area. The great challenge for the coming decades will therefore be the task of increasing food production with less water, particularly in countries with limited water, land resources and inefficient water use (FAO, 2002). According to Kirda (2002), with increasing municipal and industrials demands for water, its allocation for agriculture is decreasing rapidly. Therefore, water-saving in agriculture is more and more a necessity and a concerted and coordinated effort is required to increase the efficiency with which available irrigation water used.

Deficit irrigation has been suggested as an alternative strategy for making better use of irrigation water. Deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield (English and Nakamura, 1989; English and Raja, 1996; Mugabe and Nyakatawa, 2000; Bazza, 1999; Ghinassi and Trucchi, 2001; Kirda, 2002; Mao et al., 2003; Panda et al., 2003; Zhang et al., 2004). In this method, the crop is exposed to a certain level of water deficit either during a particular period or throughout the whole growing season (English and Raja, 1996). The expectation is that any yield reduction will be insignificant compared with the benefits gained through diverting the saved water to irrigate other crops (Eck et al., 1987).

The response of Onion to water deficit has been reported by Samson Bekele and Ketema Tilahun (2007). Aweke Nigatu *et al.* (2010), Abdisa Debela et al. (2013) and Tadesse et al., (2013) and had shown deficit irrigations to increase the water use efficiency of onion.

Furrow irrigation is often characterized by low irrigation efficiency. With proper irrigation management practices, the efficiency of furrow irrigation can be raised to a level compatible with other method irrigation. To conserve moisture and enhance irrigation water management, Grimes et al. (1968), Musick and Dusek (1974) and Aliyu (1987) have used alternate furrow irrigation system. Less water is usually applied in alternate and fixed furrow irrigation as compared to conventional furrow irrigation. Moreover, alternate and fixed furrow irrigations greatly reduce the amount of surface wetted, leading to less evapotranspiration and less deep percolation. Stone et al. (1979) have suggested that the reduced evapotranspiration in the alternate furrow irrigation is due to a reduction in the amount of wet soil surface compared to that every-furrow irrigation. Musick and Dusek (1974) reported that water advances more slowly in an alternate-furrow irrigation system due to the greater potential for lateral movement. Rates of advance of water down the furrow in every -furrow irrigation system ranged from 1.23 to 1.48 times greater than in the alternate-furrow irrigation depending upon soil type and slope (Hodges et al., 1989).
This study investigated the response of onion to deficit irrigation under alternate, fixed and conventional furrow irrigation system on yield and water use efficiency in central Ethiopian rift valley region. Thus, the study was undertaken with specific objectives of: (a) determined the effect of deficit irrigation on growth, yield, yield components and water productivity of onion, and (b) identified applicable practices of deficit and furrow irrigation under water scarce condition for optimum yield and quality of onion.

## 2. Materials and Methods

### 2.1. Description of the Study Area

The research work was conducted at Melkassa Agricultural Research Center (MARC) of the Ethiopian Institute of Agricultural Research (EIAR). The center is located in the Central Rift Valley of Ethiopia, Oromia Regional state [8°24'55" - 8°25'44" N latitude, 39°18'27" - 39°19'28" E longitude] at altitude of 1,550 m.a.s.l. Long-term (1977 – 2010) climatic data indicated that annual rainfall and potential evapotranspiration in the area is about 768 mm and 1994 mm, respectively. The mean maximum temperature varies from 26.4 °C to 30.9 °C while the mean minimum temperature varies from 11.1 °C to 16.5 °C. The soil is predominantly loam to clay loam texture soils of the area. The source of irrigation water in the study area is Awash River.

### 2.2. Experimental design and treatments

Three deficit irrigation levels, viz., 75%ETc, 50%ETc and 25%ETc and a control irrigation of 100%ETc, and three furrow irrigation methods, viz., CFI (conventional furrow irrigation), AFI (Alternate furrow irrigation) and FFI (Fixed furrow irrigation) was arranged in split plot design in RCBD with three replications, in which the four irrigation levels were main plots and the three furrow systems were the sub-plots. A total of 12 treatment combinations were evaluated in plots size of 2.4m by 3m that accommodate four furrows with spacing of 60cm and furrow length of 3m.

### 2.3. Crop agronomy and management practices

Onion (*Allium cepa*) seed variety Adama red was raised in nursery bed and transplanted to experimental plots at spacing of 20cm and 10cm between rows and plants, respectively. DAP was applied at the rate of 200kg/ha at transplanting and urea at the rate of 100kg/ha was applied in split application at transplanting and 10 days after transplanting (Olani and Fikre, 2010). Irrigation water was applied at allowable soil moisture depletion (p = 0.25) of the total available soil moisture throughout crops growth stage. The amount of water applied in each irrigations was measured using Parshall flume measuring devices.
The study will be supplemented with soil moisture determination gravimetrically at 20cm interval from the surface to the depth of maximum root zone depth (60cm). All other cultural practices other than treatment variables were done in accordance with the recommendation made for the area.

### 2.4. Data collection and analysis

Data collected comprised plant height, leaf number per plant, bulb yield and yield components such as the bulb number, bulb weight, bulb diameter and dry matter of bulb. Water productivity and effect of water stress on crop performance were quantified from WUE and yield response factors (ky), respectively.
The crop water use efficiency was determined using the expression:

$$CWUE\ (kg\ ha^{-1}mm^{-1}) = \frac{Total\ buld\ yield\ (kgha^{-1})}{Crop\ water\ use\ (mm)} \quad (1)$$

Crop water use (ETc) was determined for each treatment for the growing period using the soil-water balance equation:

$$ETc = I + Rc + \Delta S - D + Gc \quad (2)$$

where: I is irrigation water (mm); Rc is effective rainfall (mm) and ΔS is the change in soil water storage for the period (mm). D is drainage below the root zone (mm) and Gc is the groundwater contribution (mm). The contribution of D and **Gc** were assumed to be negligible. The ΔS was assumed same at the beginning and at harvest and have no contribution to plant ET.

The field water use efficiency was calculated from the expression:

$$IWUE\ (kg\ ha^{-1}mm^{-1}) = \frac{Total\ buld\ yield\ (kgha^{-1})}{Gross\ irrigation\ applied\ (mm)} \quad (3)$$

The yield response factor (Ky) of onion which relates relative yield decrease to relative ET deficit under this study was estimated from the relationship:

$$\left(1 - \frac{Ya}{Ym}\right) = ky\left(1 - \frac{ETa}{ETm}\right) \quad (4)$$

Where: Ya and Ym are actual and maximum yield respectively, ky is yield response factor, ETa and ETm are actual and maximum evapotranspiration respectively

Net income (NI) in Birr/ha, generated from onion crop, was computed by subtracting the total cost (TC) in Birr/ha from the total return (TR) in Birr/ha obtained from onion sale as:

$$NI = TR - TVC \quad (5)$$

TC is the sum of FC and VC. Fixed costs (FC) are those that do not vary between irrigation treatments, i.e. onion seeds, fertilizer, pesticides, land rent and farm implements. Variable costs (VC), on the other hand, are those that do vary between irrigation treatments, i.e. irrigation water and labor. The marginal rate of return (MRR) measures the increase in net income and expressed as:

$$MRR\ (\%) = \frac{\Delta NI}{\Delta TVC} \times 100 \quad (6)$$

Where.: ΔNI is change in NI and ΔTVC is change in TVC

The amount of saved water (SW) per hectare of land due to irrigation scheduling was computed by subtracting deficit water application levels from the irrigation treatment that used the highest irrigation water level, i.e. 100%ETc and CFI. The extra irrigable land area (A) which would be served by the saved irrigation water was determined from:

$$A = \frac{SW\ (m^3)}{Irrigation\ water\ used\ (m^3ha^{-1})} \quad (7)$$

The net income from saved water ($NI_{sw}$) in Birr that was obtained from irrigating extra land of area (A) in hectare was expressed as:

$$NI_{sw} = \Delta NI \times A \quad (8)$$

The data collected were statistically analyzed using GEN-stat software. Whenever treatment effects were significant, Least Significance Differences (LSD) test was used to assess the mean difference among treatments

## 3. Results and Discussions

Statistical analysis has revealed that plant growth parameters, yield and yield components were all affected significantly ($P<0.01$) by the level of deficit and furrow irrigation application. The data on Table 1 to 3 present measured data on plant growth parameters, yield and yield components. In all case the control irrigations, 100%ETc irrigation application and conventional furrow irrigation application gave the highest measured values and had no significant differences with a 75%ETc deficit irrigation and alternate furrow irrigation. All the measured data increase with subsequent increase in irrigation amount. This shows that irrigation had significant effect on growth parameters of onion and subsequently influenced the crop yield.

In all case, the lowest measured data were recorded from deficit irrigation at 25%ETc and fixed furrow irrigation applications. These values had no significant difference with a deficit application of 50%ETc and fixed furrow irrigation application except for plant height, bulb number, leaf dry matter, total and marketable bulb yield. Deficit irrigation application of 50%ETc and fixed furrow irrigation application gave below the mean values of plant growth parameters, yield and yield components. From the result, it can be concluded that for optimum plant growth and yield performance, up to 25% water deficit was tolerable and further about 62% reduction of water use by crop was possible under alternate furrow irrigation without (Table3).

Table1: Effect of deficit and furrow irrigation on leaf number, plant height and yield component

| Treatments | Leaf # per plant | Plant height (cm) | Bulb number | Bulb diameter (mm) | Bulb weight (gm) | Bulb dry matter (%) | Leaf dry matter (%) |
|---|---|---|---|---|---|---|---|
| 25%ETc | $7.47^{b}$ | $33.99^{c}$ | $46.11^{c}$ | $34.17^{b}$ | $41.37^{b}$ | $10.23^{b}$ | $8.94^{c}$ |
| 50%ETc | $8.7^{bc}$ | $42.32^{b}$ | $55.93^{b}$ | $40.67^{b}$ | $49.86^{b}$ | $11.76^{b}$ | $9.41^{b}$ |
| 75%ETc | $10.57^{ac}$ | $51.6^{a}$ | $67.44^{a}$ | $53.18^{a}$ | $59.96^{a}$ | $14.29^{a}$ | $9.99^{a}$ |
| 100%ETc | $12.51^{a}$ | $53.78^{a}$ | $67.78^{a}$ | $54.67^{a}$ | $67.02^{a}$ | $15.06^{a}$ | $10.24^{a}$ |
| L.S.D (1%) | 2.97 | 3.71 | 5.49 | 12.66 | 12.98 | 1.94 | 0.55 |
| SE± | 0.57 | 0.71 | 1.07 | 2.00 | 2.47 | 2.93 | 0.07 |
| CV (%) | 10.0 | 2.7 | 3.1 | 7.7 | 7.9 | 7.5 | 1.3 |
| AFI | $10.39^{d}$ | $48.87^{d}$ | $59.48^{d}$ | $48.79^{c}$ | $58.67^{c}$ | $13.04^{c}$ | $9.97^{d}$ |
| FFI | $7.77^{c}$ | $38.23^{c}$ | $55.72^{c}$ | $36.03^{d}$ | $43.39^{d}$ | $12.14^{d}$ | $8.73^{c}$ |
| CFI | $11.28^{d}$ | $50.67^{d}$ | $62.75^{d}$ | $51.11^{c}$ | $61.59^{c}$ | $13.32^{c}$ | $10.23^{d}$ |
| L.S.D (1%) | 1.32 | 4.15 | 5.07 | 6.42 | 6.37 | 0.94 | 0.59 |
| SE± | 0.32 | 1.01 | 1.23 | 1.26 | 1.54 | 0.23 | 0.13 |
| CV (%) | 11.2 | 7.6 | 7.2 | 9.6 | 9.8 | 6.1 | 5.0 |

Table 2: Effect of deficit and furrow irrigation on total bulb yield

| Deficit level | Yield (t/ha) |
|---|---|
| 25%ETc | $5.83^{c}$ |
| 50%ETc | $13.19^{b}$ |
| 75%ETc | $21.16^{a}$ |
| 100%ETc | $22.87^{a}$ |
| L.S.D (1%) | 2.68 |
| SE± | 0.52 |
| CV (%) | 5.7 |
| AFI | $16.28^{d}$ |
| FFI | $13.89^{c}$ |
| CFI | $17.12^{d}$ |
| L.S.D (1%) | 1.49 |
| SE± | 0.36 |
| CV (%) | 7.9 |

Table 3: Effect of deficit and furrow irrigation on marketable bulb yield

| Deficit Levels | Irrigation systems | | | |
|---|---|---|---|---|
| | AFI | FFI | CFI | Mean |
| 25%ETc | $2.9^{c}$ | $2.6d^{c}$ | $3.16^{c}$ | 2.91 |
| 50%ETc | $10.04^{c}$ | $7.08^{d}$ | $12.28^{c}$ | 9.80 |
| 75%ETc | $21.74^{a}$ | $13.57^{b}$ | $21.74^{a}$ | 19.02 |
| 100% ETc | $21.80^{a}$ | $14.83^{b}$ | $22.10^{a}$ | 19.58 |
| Mean | 14.12 | 9.54 | 14.82 | 12.83 |
| L.S.D (5%) = 2.49 | | SE± = 0.84 | | |

The marketable yield was selected based on size of the bulb (45 cm □ 60 cm diameter) and these were considered as medium size, healthy and weighing greater than 30gm with no doubles or splits. The highest marketable yield of 22.1 t/ha was obtained from 100%ETc application under CFI system, and this was not significantly different to the marketable yield obtained at 75%ETc under AFI system ($P < 0.05$). Generally, under all irrigation systems the proportion of marketable bulb yield showed increasing trend for an increase in the irrigation application level

Table 4 and 5 present the crop water use and irrigation water use efficiencies. The highest CWUE and IWUE were obtained from 75%ETc application. Treatment receiving 75%ETc irrigation under AFI application resulted in higher CWUE and this had no significant difference with the 100%ETc and AFI irrigation application. The lowest CWUE and IWU were obtained from 25%ETc under CFI application. However, the CWUE at 25%ETc application under all furrow irrigation application had shown no significant difference among them.

Table 4. Effect of deficit and furrow irrigation on CWUE

| Deficit Levels | Irrigation systems | | | |
|---|---|---|---|---|
| | AFI | FFI | CFI | Mean |
| 25%ETc | $32.39^{f}$ | $29.30^{f}$ | $25.18^{f}$ | 29.0 |
| 50%ETc | $62.08^{c}$ | $53.76^{d}$ | $44.17^{c}$ | 53.3 |
| 75%ETc | $83.31^{a}$ | $71.71^{b}$ | $53.87^{d}$ | 69.6 |
| 100% ETc | $81.81^{a}$ | $67.54^{bc}$ | $50.31^{de}$ | 66.6 |
| Mean | 64.9 | 55.6 | 43.4 | 54.6 |
| L.S.D (1%) = 7.71 | | | SE± = 10.49 | |
| CV(%) = 8.8 | | | | |

Table 5: Effect of deficit and furrow irrigation on IWUE

| Deficit Levels | Irrigation systems | | | |
|---|---|---|---|---|
| | AFI | FFI | CFI | Mean |
| 25%ETc | 52.2 | 47.2 | 34.5 | 44.6 |
| 50%ETc | 90.6 | 78.5 | 55.8 | 75.0 |
| 75%ETc | 112.4 | 96.8 | 64.3 | 91.2 |
| 100% ETc | 98.2 | 81.1 | 55.8 | 78.4 |
| Mean | 88.35 | 75.9 | 52.6 | 72.3 |
| L.S.D (5%) = 10.76 | | SE± = 3.66 | | |
| CV(%) = 9.6 | | | | |

The result of WUEs` indicated that more efficient water use could be attained with 25% reduced water use under conventional furrow irrigation application and about 62% reduced water use under AFI and FFI application. Hodges et al. (1989) reported that one way to improve efficiency is to reduce water and consequently, pumping costs without significantly reducing yield through use of alternate furrow irrigation.

Table 6 presents the relative yield reduction, relative ETc deficit and yield response factor, Ky. Observed yield response factors (Ky) ranged between 0.43 and 1.91, the lowest. The magnitude of ky value indicates the sensitivity of the crop for water stress and subsequent yield decrease. All furrow irrigation application at 25%ETc application gave the highest Ky-value. The lowest was observed at 75%ETc application under all furrow irrigation application. According to Smith and Kivumb (2002), the Ky value greater than unity indicates the relative yield decrease is higher than the water deficit.

The detail evaluation of the economic water productivity of irrigation treatments has shown that there was increasing trend of net income (NI) for increase in water application level. Table 12 reveals that AFI application at 75% ETc deficit level had the highest benefit obtained from saved irrigation water. It had also an economic advantage of 120,090.5 birr from saved irrigation water per hectare over the conventional method of furrow irrigation ($T_{12}$). The extra income which can be obtained from unit increment in investment cost is described as marginal rate of return (MRR). The highest MRR was 5522.6% obtained from AFI application at 75%ETc deficit level ($T_7$).

Table 6: Relative yield decrease, relative ETc deficit and yield response factor for onion

| Irrigation method | Deficit level | Yield (t/ha) | $ET_a$ (mm) | $\frac{ET_a}{ET_m}$ | $\frac{Y_a}{Y_m}$ | $1-\frac{ET_a}{ET_m}$ | $1-\frac{Y_a}{Y_m}$ | $K_y$ |
|---|---|---|---|---|---|---|---|---|
| AFI | 25%ETc | 5.83 | 180.10 | 0.62 | 0.24 | 0.38 | 0.76 | 1.91 |
| | 50%ETc | 13.47 | 217.00 | 0.74 | 0.56 | 0.26 | 0.44 | 1.70 |
| | 75%ETc | 21.94 | 263.40 | 0.90 | 0.92 | 0.10 | 0.08 | 0.83 |
| | 100%ETc | 23.89 | 292.00 | 1.00 | 1.00 | 0.00 | 0.00 | - |
| FFI | 25%ETc | 5.28 | 180.10 | 0.62 | 0.27 | 0.38 | 0.73 | 1.91 |
| | 50%ETc | 11.67 | 217.00 | 0.74 | 0.59 | 0.26 | 0.41 | 1.59 |
| | 75%ETc | 18.89 | 263.40 | 0.90 | 0.96 | 0.10 | 0.04 | 0.43 |
| | 100%ETc | 19.72 | 292.00 | 1.00 | 1.00 | 0.00 | 0.00 | - |
| CFI | 25%ETc | 6.39 | 253.70 | 0.51 | 0.26 | 0.49 | 0.74 | 1.52 |
| | 50%ETc | 14.44 | 327.00 | 0.66 | 0.58 | 0.34 | 0.42 | 1.24 |
| | 75%ETc | 22.64 | 420.20 | 0.85 | 0.91 | 0.15 | 0.09 | 0.61 |
| | 100%ETc | 25.00 | 496.90 | 1.00 | 1.00 | 0.00 | 0.00 | - |

This shows that $T_7$ can be the most preferable type of irrigation schedule to all other tested irrigation schedules as it can generate more profit per extra addition investment. The highest CWUE and/or IWUE and reduced labor costs associated with $T_7$ enabled the combination to attain the highest MRR of all other treatment combinations. Maximum yield could be obtained with the fulfillment of the entire crop water requirements. However, practicing deficit irrigation can increase the irrigated area or the frequency of cultivation. For many crops, high yields as well as high water use efficiency values can be obtained provided the right choice of the period of water application is made. With a limited yield reduction, the cropped area can be also doubled, with a substantial increase in economic returns (Bazza, 1999).

Table 7: Partial budgeting and MRR analysis for onion production in Awash Melkassa

| Treatments | UMY (t/ha) | AMY (t/ha) | TR (birr/ha) | TVC (birr/ha) | NI (birr/ha) | MRR (%) | $NI_{sw}$ (birr) |
|---|---|---|---|---|---|---|---|
| T1 | 2.9 | 2.6 | 14355 | 837.7 | 13517.3 | 1613.6 | 40687.1 |
| T2 | 2.7 | 2.4 | 13365 | 837.7 | 12527.3 | 1495.4 | 37707.2 |
| T3 | 3.2 | 2.9 | 15840 | 1674.2 | 14165.8 | 846.1 | 20115.4 |
| T4 | 10.1 | 9.1 | 49995 | 1281.7 | 48713.3 | 3800.7 | 97913.7 |
| T5 | 7.1 | 6.4 | 35145 | 1281.7 | 33863.3 | 2642.1 | 68065.2 |
| T6 | 12.3 | 11.1 | 60885 | 2562.1 | 58322.9 | 2276.4 | 42575.7 |
| T7 | 19.0 | 17.1 | 94050 | 1672.7 | 92377.3 | 5522.6 | 120090.5 |
| T8 | 13.6 | 12.2 | 67320 | 1672.7 | 65647.3 | 3924.6 | 85341.5 |
| T9 | 21.6 | 19.4 | 106920 | 3344.2 | 103575.8 | 3097.2 | 27965.5 |
| T10 | 22.9 | 20.6 | 113355 | 2184.1 | 111170.9 | 5090.0 | 93383.6 |
| T11 | 14.8 | 13.3 | 73260 | 2184.1 | 71075.9 | 3254.2 | 59703.8 |
| T12 | 23.6 | 21.2 | 116820 | 4367.1 | 112452.9 | 2575.0 | 0.0 |

## 4. Conclusions

The field experiment on deficit irrigation under CFI, FFI and AFI practices has revealed that high crop performance, yield and yield components of onion could easily be sustained with no crop water use reduction and a crop water use reduction up to 25% had no significant reduction under CFI. Moreover, further crop water use reduction of about 62% was possible for onion without a significant yield reduction using AFI. The CWUE and IWUE of onion were highest under 75%ETc a deficit irrigation and AFI application and had no significant difference with the control irrigation of 100%ETc and AFI application. The Ky-values was greater than one for deficit irrigation application of 50%ETc and 25%ETc in all furrow irrigation application and the value indicates the sensitivity of the crop for the water deficit irrigations. The control irrigation and 75%ETc deficit application under all furrow irrigation gave Ky-values less than one. The economic water productivity of irrigation treatments has shown that there was increasing trend of NI for increase in water application level and AFI application at 75%ETc deficit level had the highest benefit obtained from saved irrigation water. It had also an economic advantage of 120,090.5 birr from saved irrigation water per hectare over the conventional method of furrow irrigation. The water saved under the condition of 75%ETC deficit irrigation application and using AFI irrigation application was about 62% of crop water use.

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# Groundwater quality issues in the Geba basin, Tigray, Northern Ethiopia.

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## Abstract

*The Geba basin is found in the northern part of Ethiopia, the river is one of the tributaries for Tekeze_Atbara which is a feeder to Nile river. Groundwater is the main source of water supply in the Northern part of Ethiopia including Geba basin, where the rainfall is small and erratic. With the current socioeconomic situation the need for more groundwater is increasing from time to time. The main Aquifer system in the area is characterized by carbonate rocks which are known as the Antalo supper sequence. A total of 24 samples has been collected from the basin and analyzed for all major ions including minor and trace elements. The groundwater were found to fall into three groups: Ca-SO4 , Ca-Mg-SO4 or Mg-Ca-SO4, or Ca-Mg-HCO3, or mixture of the two. The ground water from the Antalo super sequence particularly from the shale-marl-limestone intercalation were found to be high in salinity, sulfate, boron and arsenic with concentration above the WHO limits. Gypsum and basic volcanics appears to be the main source contributing arsenic and boron to these waters. Since arsenic and boron are hazardous to health, proper water management practices should be implemented to use the potable water from the shale-marl-limestone aquifer. Therefore it is recommended to drill deep wells to tap better quality water from the Limestone formation*

Keywords: Ethiopia, *Geba basin, groundwater quality, Antalo supersequence, groundwater management, Enticho sandstone*

## 1. Introduction

Water availability, water quality and food insecurity have been the major issues of Ethiopia. According to the ministry of water resources (MoWR, 2001) the probability of normal rainfall in the northern half of Ethiopia is decreasing every year. The majority of the rural community does not have access for safe drinking water. The national drinking water coverage stand at 49 percent as of 2011as reported by the WHO and UNICEF joint monitoring program (JMP, 2013). Present supply of water for the major towns and rural areas of the Tigray Region is from wells and springs.

In order to mitigate these challenges, extensive use of groundwater has been considered as the viable option. The efficient use of this underground resource is not only controlled by its availability but also by its usability, which is mainly related to its chemical quality and also proper management practices. There is no systematic study on the hydrgeochemistry of the groundwater for the whole Tigray region. These issues in the region motivated us to undertake this investigation on the Geba basin.

In order to address these problems, a hydrogeologically representative smaller basin, the Geba basin, within the Tigray region (Fig.1) has been chosen to address issues related to the groundwater quality with special emphasis on salinity, boron, arsenic and sulfate concentration in terms of their sources.

## 2. Description of the study Area

The Geba catchment is situated in northern part of Ethiopia between 13°16' and 14°16' N and 38°38' and 39°49' E (Fig.1). The area is drained by the rivers Suluh, Genfel, Agulae and Illala that are tributaries of the River Geba which flows mainly during the rainy season extending from June to September. The Geba River itself is a major tributary of Tekeze River that joins the Nile in Atbara, Sudan. The Geba basin covers an area of about 5,150 km$^2$ with elevations varying from slightly over 900 m at the discharge site towards the southwest of the basin, to about 3,300 m at its watershed boundary near Adigrat (Figs. 1). The basin is semi-arid with an average annual rainfall varying from 400 mm to 950 mm, and temperature varying from a minimum average of 6.5°C in the Atsbi plateaus to a maximum average of 32°C near to the discharge site. The total annual average precipitation for the basin, based on 17 stations throughout the catchment, is 626 mm. Most of the annual rainfall in the area (77%), like in most other parts of the country, is confined to a short period locally called 'kiremt', which extends from June to September.

The rest of the year (8 months) is generally dry with occasional light precipitation in some parts of the basin. The water balance of the basin estimated using wetSpass model (Batelaan. and De Smedt. 2001. Gebreyohanne. 2009) shows that 76% of the precipitation is lost through evapotranspiration. 18% as surface runoff, and only 6% of the precipitation recharges the aquifers.

Hydrogeologically the area is characterized by complex geological, hydrological and topographic conditions. As a result, it is difficult to define a regional aquifer. Most of the groundwater systems are either local flow system or intermediate flow systems which in some cases, are intercepted by faults. Enticho sandstone, metavolcanics, Antalo supersequence are the main water supply aquifers that are being tapped by the tube wells (Figure 2).

## 3. Methodology

Samples were collected from functional wells currently serving the water supply need of both urban and rural community. The wells are selected mainly because of their representativeness from geological, hydrogeological and environmental perspective. Most of the sampled tube wells are shallow, with depth varying between 30 and 50 m and an average depth of 35 m. The static groundwater water level in the shallow tube wells vary between 4.4 m and 32 m. However, there are few deep tube wells with depth varying between 57 and 120 m. Samples were collected in clean polythene water bottles and immediately transported to India with appropriate packing. pH and electrical conductivity of the samples were measured in the field using Orion 4 star pH and conductivity meter.

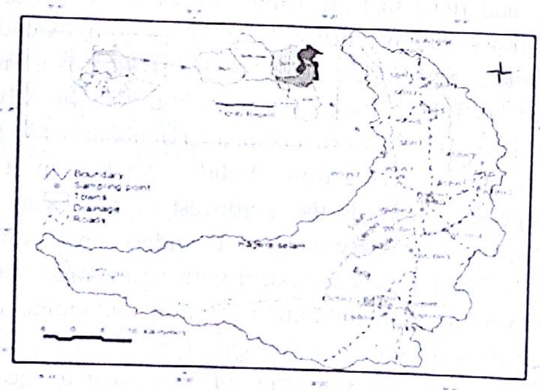


Figure 1: Location map of crescent shaped Geba basin showing the drainage and sample location

Major ions ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $HCO_3^{1-}$, $SO_4^{2-}$, $Cl^{-}$), trace elements (Fe, Mn, Al, B, As, Cr, Cd, Ni, Zn, Pb) and $SiO_2$, $F^-$ (Table 3) concentrations in the water samples were determined at the Department of Earth sciences, Indian Institute of Technology Bombay using conventional methods such as, titration for alkalinity, ion selective electrodes for ($F^-$ and $Cl^-$) and turbidimetric method for sulfate. Inductively coupled plasma - atomic emission spectroscopy (ICP-AES) was used to measure the cations and trace elements. Duplicate samples were analyzed to check the reproducibility of the data. To evaluate the accuracy of the chemical analyses, electro neutrality has been examined and it has shown a value of less than 5 %. The duplicate samples have also shown almost exact repetition with $R^2$ of 0.999.

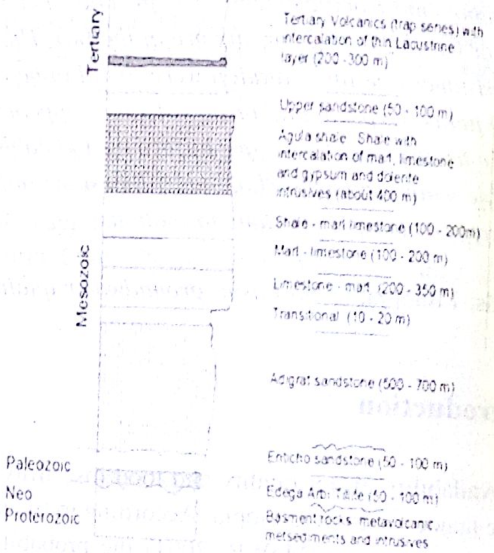


Figure 2: Geological column of Geba basin (After Gebreyohannes. 2009).

## 5. Results and Discussion

**Hydrochemistry of groundwater from Enticho sandstone and Metavolcanics aquifers**

These aquifer constitute mainly recharge area between 2554 and 2721 (masl). Maximum depth of sampled wells is about 80 m. Maximum static water level is 32.3 m. The EC ranges from 85 μS/cm (SBH3) to 397 μS/cm (SBH2) with an average value of 192 μS/cm in sandstone and from 423 μS/cm to 1056 μS/cm in metavolcanics (Figure 3). The low EC value in Enticho sandstone related to the nature of the rock and its topographic position. The dominant cation is $Ca^{2+}$ with an average concentration of 48 mg/L followed by $Mg^{2+}$ with an average concentration of 16 mg/L. The dominant anion is $HCO_3^{1-}$ with 177 mg/L followed by Cl (33 mg/l in metavolcanics.) The groundwater type is Ca-Mg-$HCO_3$ (Figure 4).

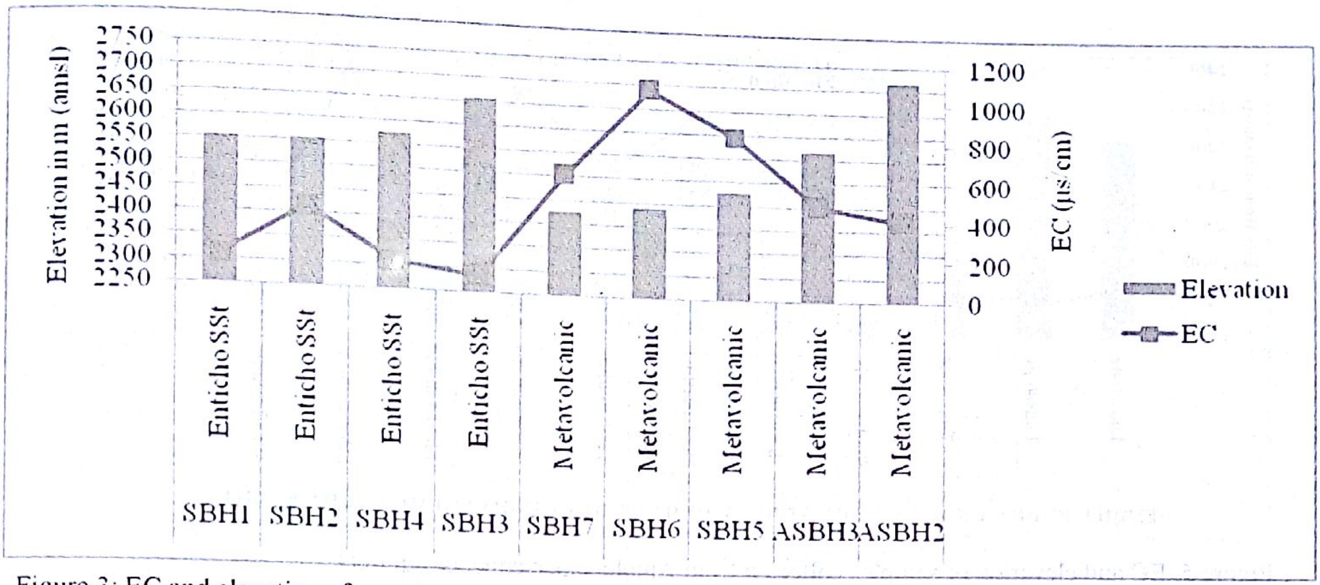


Figure 3: EC and elevation of samples collected from Enticho sandstone and Metavolcanic aquifers

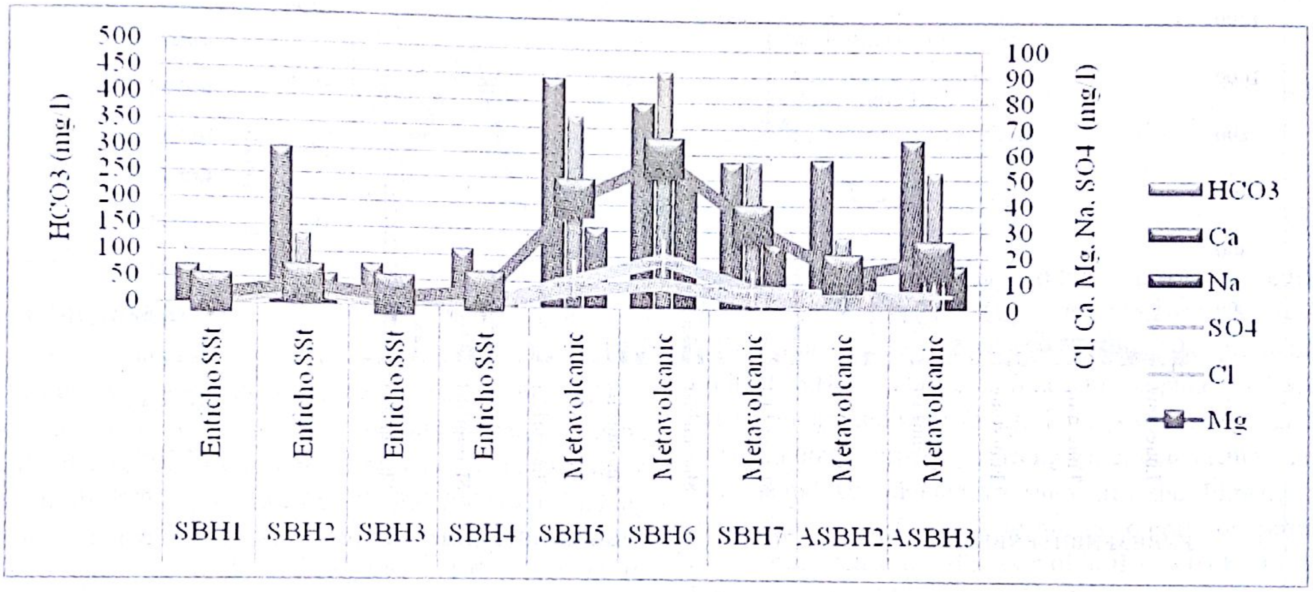


Figure 4: Major ions concentration in mg/l for samples collected from Enticho sandstone and metavolcanic aquifers

**Hydrochemistry of groundwater from Antalo Supersequence**

The Antalo super sequence constitutes the main discharge area of the Geba basin. This sequence has two main aquifers: limestone and shale-marl-limestone intercalation. The electrical conductivity of the groundwater from the limestone ranges from 746 µS/cm to 879 µS/cm with an average value of 812 µS/cm (Figure 5). The average elevation for the sampled wells from this aquifer is 2244 m above sea level. The dominant cation is found to be $Ca^{2+}$ (average concentration 116 mg/L) followed by $Mg^{2+}$ (33 mg/L) where as the dominant anion was found to be $HCO_3^{1-}$ (253 mg/L) followed by $SO_4^{2-}$(93 mg/L) (Figure 6). The water type is mainly Ca-Mg-$HCO_3$ type (Figure 7).

The groundwater from this formation has conductivity value in the range of 1245 µS/cm to 2290 µS/cm. The average elevation of the wells is 2053 m above sea level. Groundwater from this aquifer shows high electrical conductivity and total dissolved solids. The dominant cation is $Ca^{2+}$ (average concentration 291 mg/L) followed by $Mg^{2+}$ (57 mg/L) where as the dominant anion is $SO_4^{2-}$ (657 mg/L) followed by $HCO_3^{-1}$ (277 mg/L). The water type is mainly of Ca-Mg-$SO_4$ type. The water samples in this formation registered high B content ( 0.25 to 0.83 mg/L) compared to the rest of the samples from other formations (< 0.17 mg/L) (Figure 6 and table 1). The water type in Antalo supersequence is mainly Ca-SO4 or Ca-Mg-SO4 or Mg-Ca-SO4 (Figure 7)

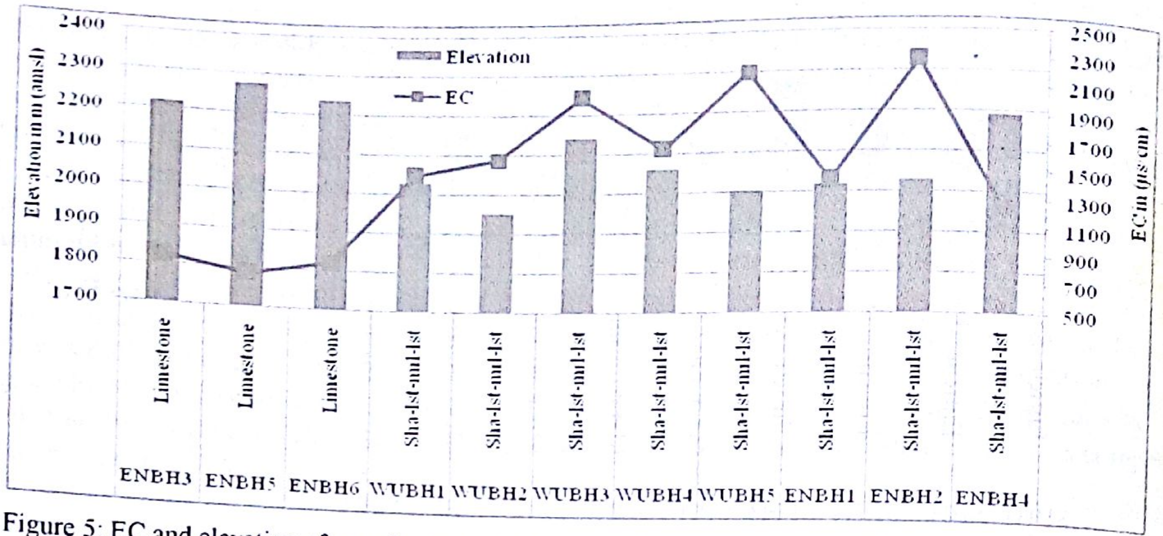


Figure 5: EC and elevation of samples collected from Antalo supersequence aquifers

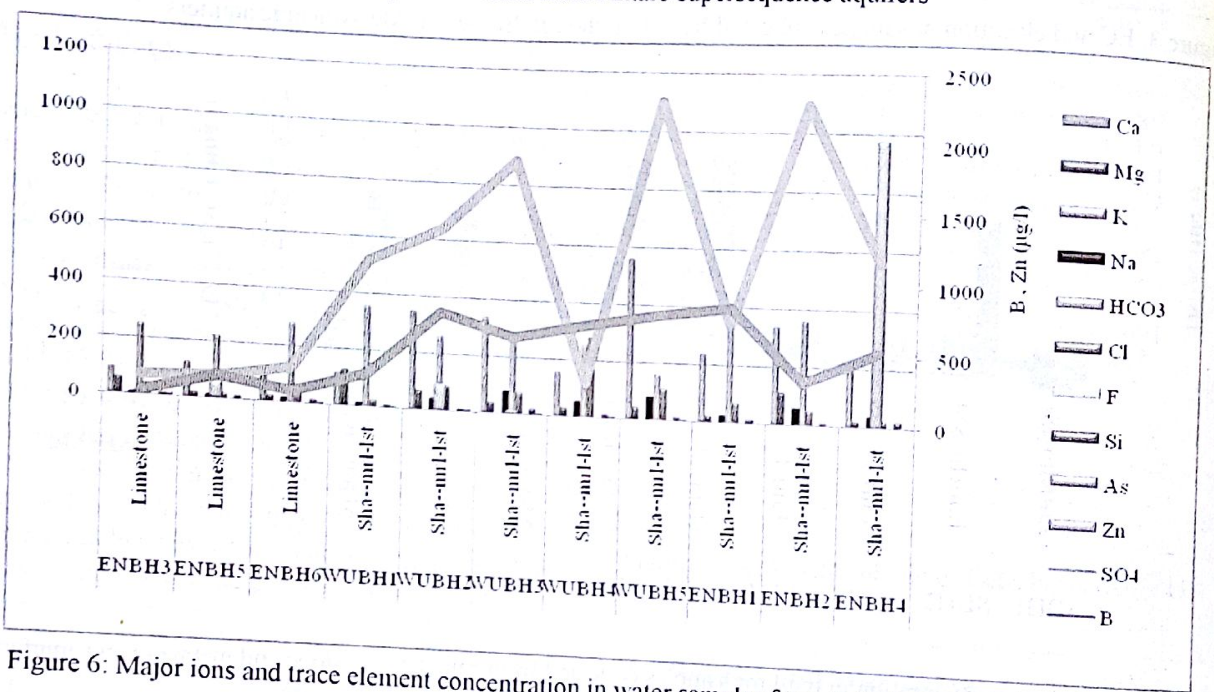


Figure 6: Major ions and trace element concentration in water samples from Geba basin. As, B and Zn concentration

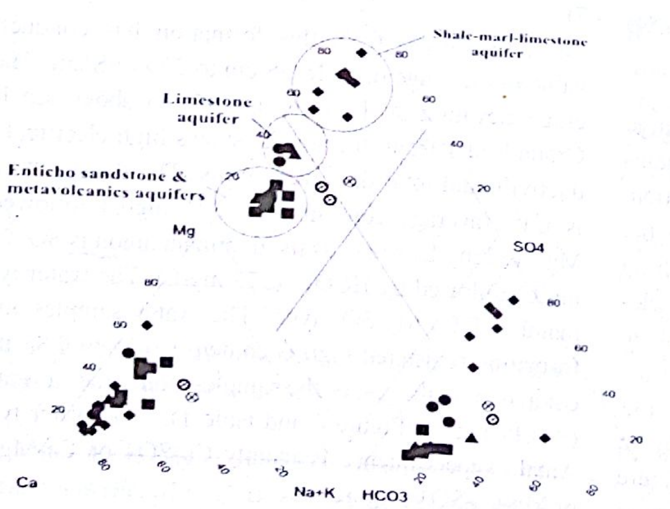


Figure 7: Piper (Piper, 1944) diagram showing the water types in Geba basin aquifers. Solid squares: Enticho sandstone, solid triangles: metavolcanics, solid circles: limestone, solid diamonds: shale-marl-limestone, circle with cross: surface water sample from Geba upstream.

Table 1: Samples having one or more elements above the WHO standards

| Sample ID | As (μg/l) | B (μg/l) | SO4 (mg/l) | Cl (mg/l) | Aquifer type |
|---|---|---|---|---|---|
| WUBH5 | | 760 | **1103** | | Shale-marl-limestone |
| WUBH4 | | 670 | | 279 | Shale-marl-limestone |
| SBH4 | 11.63 | | | | Enticho sandstone |
| ENBH3 | 12.62 | | | | Limestone |
| ENBH2 | | | **1094** | | Shale-marl-limestone |
| WUBH1 | | | **518** | | Shale-marl-limestone |
| WUBH2 | 10.6 | 720 | **640** | | Shale-marl-limestone |
| WUBH3 | | 560 | **887** | | Shale-marl-limestone |
| ENBH1 | | 860 | | | Shale-marl-limestone |
| ENBH4 | | 530 | **562** | | Shale-marl-limestone |
| WHO 2003 | 10 | 500 | 500 | 250 | |

## 6. Conclusion

The quality of groundwater (except for one sample SBH4) occurring in Enticho sandstone and Metavolcanics is good with all the dissolved ions and trace elements falling within the limits prescribed by WHO (2003) for drinking water. Sample SBH4 has registered arsenic content ( 11.6 μg/L) above the limit prescribed by WHO (2003) of 10 μg/L. Moreover, groundwater occurring in older limestone of Antalo super sequence (lying above Adigrat sandstone see fig. 2) is also having all the dissolved ions and trace element within the potable limits prescribed by WHO except for one sample (ENBH3) that has arsenic 12.65 μg/L which is above the limit for safe drinking water (Table 1).

The major groundwater quality problem in the area is associated with the shale-marl-limestone aquifer where some samples have shown very high sulfate (>500 mg/L), boron (>0.5 mg/L), arsenic (> 10 μg/L) and chloride (> 250 mg/L) which is above the recommended value of WHO (Table 3). Incidence of boron related diseases are common in the world and the common disease is the prostate cancer. This problem is very severe in population working in boron mines (Müezzinoğlu et al., 2011). It is fortunate that the shale-marl limestone aquifer is found at the downstream side of the groundwater flow system therefore Enticho sandstone and the metavolcanic remains fit for human consumption except for the water from well SBH 4 that contains arsenic just above the permissible limit of WHO (Table 2). Since the population heavily depend on groundwater for drinking as well as for agricultural and other purposes, a strong water management practice should be adopted to safeguard the Enticho and metavolcanic aquifers. There are no reports on prostate cancer occurrence in villages within the Geba basin. Perhaps it is advisable to investigate this problem, like that has been done in Turkey recently (Muezzinoglu et al., 2011) to take appropriate remedial measure to save the population. Besides As and B, groundwater sampled from shale-marl-limestone aquifer near Mekelle town has very high content of Zn, possibly due to contamination from sewage. Zinc toxicity to vegetables is very common in Ethiopia where groundwater is used for irrigating such crops. Accumulation of zinc in soils (consequently in groundwater) is reported to be due to contamination from sewage ( Prabhu, 2009).

## Acknowledgements

This work is made possible by the support of the Department of Science and Technology, Government of India, through C.V. Raman fellowship for African researchers granted to one of the author (DN). Groundwater sample collection campaign in Ethiopia was supported by the IUC -MU project. We would also like to acknowledge the support of Trupti, Poonam, Jane and Yanesh during the analytical work on water samples at IIT Bombay.

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# Bacteriological quality of drinking water at Arba Minch town, Southern Ethiopia

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## Abstract

*Background: Access to safe water is a fundamental human need and, therefore, a basic human right. Poor sanitation practices in a community seriously affect their health conditions. As a result, the quality of protected water sources can be deteriorated due to poor site selection, inadequate protection and unhygienic management facilities.*

*Objectives: The aim of this study was to assess bacteriological quality of drinking water and to survey the possible sanitary risk factors which associated with water handling practices at household level in Arba Minch town, Southern Ethiopia.*

*Methods: A cross- sectional community based study was carried out in Arba Minch town from November, 2010 to January, 2011. A total of 126 water samples were collected from main source, reservoir, pipes and household water in 3 rounds for bacteriological analysis and it was conducted in Arba Minch Regional Laboratory. Level of contamination was determined on the bases of total coliform and fecal thermotolerant coliform existence in sampled water. Finally, data on water handling practices at household level were also surveyed by using a pre- tested structured questionnaire method.*

*Results: Twenty (100%) and eleven (55%) of household water samples were contaminated with total coliform and faecal coliform bacteria respectively. Similarly, two (10%) and one (5%) pipe water samples had total coliform and faecal coliform bacteria respectively. But 100% of water samples that taken from both main source and reservoir water were free from any indicator bacteria.*

*Conclusions: Water samples at pipes and household level were contaminated with indicator bacteria in the study area. Poor sanitation, low level of hygiene, differences in socio- economic background & education level, inadequate treatment and corrode pipes in distribution lines might be the causes for indicator bacterial contamination. Therefore, training of local people to look after the water supply system, extension of hygiene and health education on sanitation could have a notable impact for the provision of safe water supply both at community as well as household level.*

**Key words:** *Indicator bacteria, main source, reservoir, pipe, household water, hygiene, Arba Minch*

## Introduction

Contaminated water jeopardizes both the physical and social health of all peoples. According to WHO, more than 80% of diseases in the world are attributed to unsafe drinking water or to inadequate sanitation practices (1). Globally, 1.1 billion people rely on unsafe drinking water sources from lakes, rivers, springs and open wells (2). In Ethiopia, three-fourth of the health problems of children is communicable diseases arising from the environment, especially water and sanitation (3).

Water may be contaminated with indicator bacteria at the source but contamination may also occur during distribution, transportation, or handling in households or other working places (4). Inadequate protection of water collection and storage vessels, and unhygienic/unsafe water handling practices also contribute for contamination of drinking water at household level (5).

Detection, differentiation and enumeration of Entrobacteriaceae family particularly coliform groups are of primary importance in the microbiological quality control of drinking water. This is because of they are used to measure/evaluate contamination level of drinking water and its efficiency of treatment (6).

Assessing water quality is significantly contributed to reduce water borne-diseases, to increase hygiene status of the society and to improve quality life for both rural and urban populations. However, quality of drinking water is being questioned due to reduction in sanitation and increment of environmental pollutions. Access to clean potable water in most of Ethiopia is estimated at about 15% and most people are required to drink water from unprotected sources (7).

Analysis of drinking water from source to the point of use has been done in different parts or regions of Ethiopia by different researchers. However, no study has been done on the bacteriological quality of drinking water from main source water to household water, and surveying of water handling practices at individual home level in Arba Minch town. The aim of this study, therefore, to assess bacteriological quality of drinking water at main source, reservoir, along pipes and household level, and to survey the possible sanitary risk factors which are associated with water handling practices at individual home level in Arba Minch town, Southern Ethiopia.

## 2. Materials and Methods

Across-sectional community based study was carried out in Arba Minch town from November, 2010 to January, 2011. One main source and one reservoir water sampling sites were selected by using convenient non- probability techniques. But, 20 private pipes and 20 households were selected through probability sampling techniques particularly systematic sampling methods from 11 kebeles which could be grouped into 4 different strata based on geographical location and population sizes. Frequency of water sampling techniques was determined according to the guidelines of WHO (8) and Cheesbrough Monica (9). Bacteriological quality of drinking water from main source, reservoir, private pipes and household were analyzed in 3 rounds. The water handling practices at individual home level were also investigated by using pre- tested structured questionnaire survey method.

For bacteriological analysis, 200 ml of water sample was collected using a sterile 250 ml glass bottle and transported to the testing laboratory (Arba Minch Regional Laboratory) by using insulated Cold Box within 6-8 hours of interval. However, to transport chlorinated water from reservoir site, 0.1- 0.2 ml of Sodium thiosulphate ($Na_2S_2O_3.5H_2O$) was added to each sample collection bottle to neutralize chlorine or chloramines chemical. The number of total coliforms and thermotolerant coliforms was determined with the membrane filtration methods using Membrane- Endo agar (Wagtech international Ltd.) medium (9, 10). For the determination of total coliforms and thermotolerant coliforms, incubation was carried out at $37^0$C and 44°C, respectively. Confirmatory tests were also done to ensure the existence of total coliforms and thermotolerant coliforms as well as pathogenic bacteria by using biochemical test methods such as indole test, citrate utilization test, Oxidase test, lysine decarboxylase (LDC) test and motility test.

Furthermore, handling practices at individual home level were assessed through questionnaire methods. The questions were adopted from WHO and assessment of the conditions of household water containers was obtained through observation checklist (8). Then, the results of bacteriological analysis (number of coliforms and thermotolerant coliforms) were compared with the standards set by WHO (11) and Ethiopian Ministry of Water Resource (12). Finally, data entry and analysis was done by using SPSS ($16^{th}$ version) computer package system and summarized by aid of descriptive statistics and multivariate linear logistic test methods.

## 3. Results

In this study, a total of 126 water samples were collected from main source, reservoir, private pipes and household containers in three rounds to determine bacteriological quality of drinking water. According to **table-1** and **Fig. 1**, 1(100%) of both main and reservoir water samples had 0 cfu/100 ml of both total and themotolerant coliform counts. Whereas, 18(90%) and 2(10%) of tap water samples had total coliform counts ranging from 0 and 1-10 cfu/100 ml, respectively. While, 19(95%) and 1(5%) of pipe water samples also had thermotolerant coliform counts ranging from 0 and 1-10 cfu/100 ml, respectively. Analysis of household water samples also revealed that 20 (100%) had total coliform counts that range from 11-100 cfu/100 ml water. However, in the case of thermotolerant coliforms, 9(45%) and 11 (55%) of water samples had counts ranging from 0 and 1-10 cfu/100ml, respectively.

## 4. Discussion

Health is determined by many factors, including income, environmental conditions like access to adequate sanitation and safe drinking water supplies, behavioral change and availability of health services. Therefore, indicator bacteria such as total coliforms and thermotolerant/ faecal coliforms have been used to measure water quality and personal hygiene standards in a variety of settings (13).

In the present study, the average counts of total coliforms and thermotolerant coliforms from both main source and reservoir water did meet both international as well as national standard values for drinking water. However, some pipe water samples and almost, all household water samples were found above the recommended value of WHO (11) and Ethiopian Standards (12). Generally, the presence of indicator bacteria in pipe water could be attributed due to cross-contamination between the municipal water supply and sewer/soil, due to leaky/corrode pipes and lack of water pressure (14).

Table 1: Comparison of bacteriological results of pipe and household water with the recommended values of WHO (11) and Ministry of Water (12), Arba Minch, 2010/2011.

| Name of Coliforms | Recommended values (cfu/100 ml) | Pipe water (n=20) | Household water (n=20) | P- value |
|---|---|---|---|---|
| Total coliform | 0 | 18 (90%) | - | < 0.05 |
| | 1-10 | 2 (10%) | - | |
| | 11-100 | - | 20 (100%) | |
| | 101-1000 | - | - | |
| | >1000 | - | - | |
| | | Total = 20 (100%) | Total= 20 (100%) | |
| Thermotholerant coliform | 0 | 19 (95%) | 9 (45%) | < 0.05 |
| | 1-10 | 1 (5%) | 11 (55%) | |
| | 11-100 | - | - | |
| | 101-1000 | - | - | |
| | >1000 | - | - | |
| | | Total = 20 (100%) | Total= 20 (100%) | |

*Note:* 0 = Safe/Excellent water, 1-10 = Reasonable/acceptable water, 11-100 = Polluted water, 101-1000 = dangerous water and > 1000 = Very dangerous water ranges.

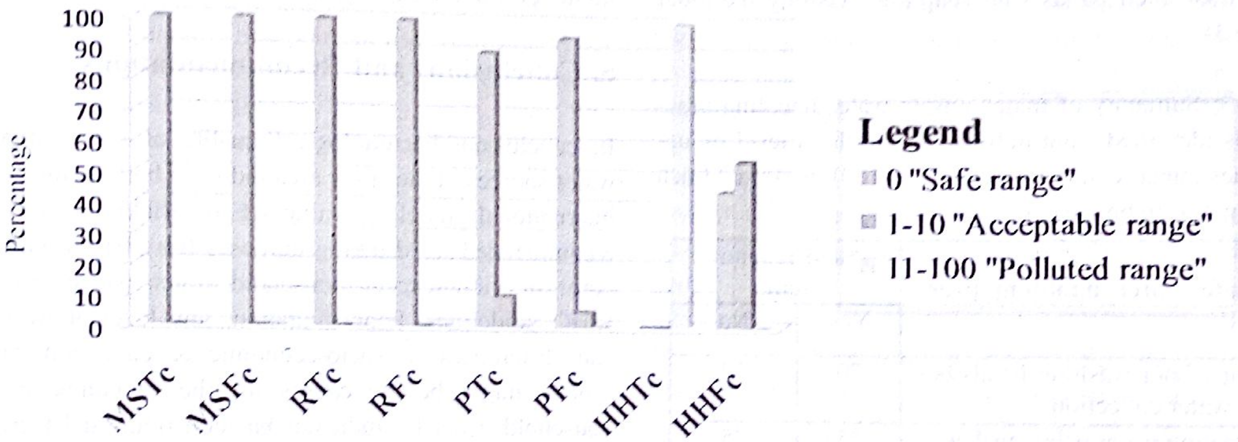


Figure 1: Ranges of Tc and Fc bacteria from main source, reservoir, pipe and household water.

| Sampling sites | Mean & S.E of Tc counts/100 ml | Mean & S.E of TTc counts/100 ml | P*- value |
|---|---|---|---|
| Main source | 0.00 ± 0.000 | 0.00 ± 0.000 | |
| Reservoir | 0.00 ± 0.000 | 0.00 ± 0.000 | |
| Pipe water | 0.75 ± 0.301* | 0.20 ± 0.100** | < 0.05 |
| Household water | 14.50 ± 0.952* | 2.68 ± 0.389** | |
| **Total** | 7.26 | 1.37 | |

The results of t-test showed that there were statistically significant differences between pipe and household water (P < 0.05) for total coliform and thermotolerant coliform bacterial counts. But, t-test can't be computed for main source and reservoir water. This is because of their standard deviation is zero and therefore, not statistically significant (**Table-2**).

*Note:* 1) S.E= Standard Error. Tc= Total coliforms & TTc= Thermotolerant coliforms
2) * Mean and S.E of Tc counts from pipe & household water
3) ** Mean and S.E of TTc counts from pipe & household water
4) * P = t-test for significant differences between the mean of pipe and household water

The results of questionnaire survey on water handling practices at individual home level in the study area revealed that 70 (70%) of the households responded that they don't wash their hands before water collection. 75 (75%) use bucket for water collection and storage process and 80 (80%) also reported that they store water in their home for at least more than 2 days. Again, 75 (75%) responded that they practice dipping method to transfer drinking water from storage containers. 55 (55%) answered that they have a habit of placing/putting water drinking utensils on floor and 45 (45%) replied that they don't wash their hands with soap after visiting the toilet (Table 3).

Table 3: Summary of major unsafe water handling practices as identified from individual household level by using questionnaire survey method (n=100) at Arba Minch town in November, 2010.

| Unsafe water handling practices | % of respondents | |
|---|---|---|
| | Yes | No |
| Habit of not washing hands before water collection | 70 | 30 |
| Collecting water using bucket | 75 | 25 |
| Storing water at home more than 2 days | 80 | 20 |
| Transferring water using dipping method | 75 | 25 |
| Placing water drinking utensils on floor | 55 | 45 |
| Habit of not washing hands after visiting toilet with soap | 45 | 55 |

When the mean values of total coliform and thermotolerant/faecal coliforms counts were compared between water sampled sites, household water had high mean value ($P<0.05$) as compared to other sites particularly that of source and pipe water. This is in agreement to the study done in another part of Ethiopia which showed that water stored inside household container had often a worse bacteriological quality than water from other sources (15, 16).

This high contamination of household water by total and thermotolerant/ faecal coliform bacteria may have arisen because of water drawing cups placed on the ground prior to being dipped in to the storage container, water could be contaminated during collection, transportation, storage in open vessels, or in vessels that are not washed regularly and immersing dirty (soiled) hands when drawing water might be the possible reasons for the significant difference in total and themotolerant coliforms in household water (17).

In the present study, the sanitary survey at individual home level was able to indicate the condition of water handling practices in relation to socio-economic background, education level, family size and occupation. The situation in most cases was very poor as compared to the studies that were conducted in other parts of Ethiopia particularly in North Gonder and South Wollo (15, 18). This might be due to poor health awareness, poor personal hygiene, differences in socio-economic & education background and having different family size among individual home level in the study area.

## 5. Conclusions and Recommendations

In conclusion, bacteriological quality of most sampled water sources in the study area did meet both national and international guidelines value set for drinking water and recommended for drinking purposes from bacteriological point of view except household water which crossed WHO guidelines. Poor sanitation, low level of hygiene and differences in socio-economic & education background might be the causes for the contamination of household water by indicator bacteria (total and thermotolerant coliforms). Therefore, training of local people to look after the water supply system, extension of hygiene and health education on sanitation could have a notable impact for the provision of safe water supply both at community as well as at household level.

## Acknowledgments

The author highly acknowledge Arba Minch Regional Laboratory, Arba Minch town Water Supply Enterprise and Gamo Gofa Zone Water, Mineral & Energy Department for providing Laboratory and other facilities to do this study. The author also wishes to thank Addis Ababa University, Faculty of Medicine, Department of Microbiology, Immunology and Parasitology (DMIP) for financial grant.

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# Estimating runoff in ungauged catchments using parameter regionalization methodologies to ungauged sub-basins of the Omo Gibe River Basin, Ethiopia

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## Abstract

*The main objective of this study was to estimating runoff in ungauged catchments using parameter regionalization methodologies to ungauged sub-basins of the Omo Gibe River Basin. HBV light, Arc GIS 9.3, Climate Forecast System Reanalysis (CFSR) global climate data and excel spread sheet has been applied. To solve problem of limitation of climate data evaluate areal average CFSR gridded global climate data with station areal average precipitation. The evaluated results of gridded CFSR and station precipitation data are very good for all evaluated 9 sub catchments of the basin. Bar graph of CFSR precipitation is best fit to station precipitation and scatter plot of $r^2$ is greater than 0.6 for all evaluated sub catchments.*

*Using gridded climate data and HBV Light rainfall-runoff model automatic calibration was done to 9 gauged catchments. The model was calibrated for period from 1979-2008. The performance of the model was evaluated on the basis of performance efficiency (Reff), efficiency using weighted errors (Reff weighted), efficiency using ln(Q) (log Reff), coefficient of determination ($r^2$),mean difference (mean diff). The overall performance of the model appears good. The $r^2$ is greater than 0.6. The hydrograph fit between the estimated and observed is also adequately represented. By using parameters of these 9 sub-catchments parameter regionalization is done to ungauged catchments. After catchment parameterization was done flow was predict for 15 ungauged sub catchments of Omo gibe river basin. The results of this study can provide solutions to limitation of climate and flow data in ungauged catchments of Omo gibe river basin.*

## 1. Introduction

### 1.1 Background

In nature, the water of right quality in right quantity is usually not available at the right place and at the right time. Sometimes, it is available at the wrong place and at the wrong time and its quality and quantity are not what they should be. Although in nutshell, this is the main point of the problem, this seemingly innocuous, albeit naughty interplay of words fails to convey the gravity and the magnitude of the problems that are caused by the mismatch between the availability and the demand of good quality water. Nature can indeed be very harsh and ruthless at times. However, a positive outcome of this mismatch is the development of a wide range of tools and techniques for water resources systems planning, development, operation, and management. All over the world that water resources of a river basin have to be developed and managed by systematically integrating socio-economic, environmental, political and engineering considerations (Jain and Singh, 2003).

In most international river basin systems, the runoff variability of upper basins caused by natural or anthropogenic factors is a serious concern in water resources management of all riparian countries. The Omo Gibe River Basin, which situated in the southern part of the Country, is a typical example. The Omo Gibe River Basin annually contributes about 90% of runoff to Lake Turkana. The Omo Basin is Ethiopia's second largest river system, accounting for 14% of Ethiopia's annual runoff, and being second only to the Blue Nile in runoff volume (Avery, 2010). Since the Omo-Gibe Basin is one of the significant surface Water Resources of Ethiopia, reliable runoff information from this basin is of great importance in the sustainable management of water resources. As in most developing countries, runoff information is limited in the Omo Gibe River Basin of Ethiopia.

The prediction of the hydrologic response of ungauged catchments is a deep-seated problem in hydrology. Regionalization is one of the ways where a conceptual model is applied to a representative number of gauged catchments and statistical relationships are derived between model parameters and catchment characteristics to predict ungauged basins. This has so far been done to Omo Gibe River basin with success.

To apply the model for ungauged catchments, it is necessary to first relate model parameters to the physical and/or climatic characteristics of the catchments. For this study catchment parameterization scheme is developed and the model parameters were estimated for each catchment. Finally, after catchment parameterization done flow is predict to ungauged catchments.

## 1.2 Objectives of this study

### 1.2.1 The main objective

The main objective of this study was to estimating runoff in ungauged catchments using parameter regionalization methodologies to ungauged sub-basins of the Omo Gibe River Basin.

### 1.2.2 Specific objectives

The Specific objectives of this study were:-

- To evaluate satellite gridded Climate Forecast System Reanalysis (CFSR) data to Omo Gibe River Basin
- To identify the physical variables that affect the rainfall-runoff transformation, and then to look for a regression relationship between model parameters and physical characteristics.
- To develop catchment parameterization scheme and to estimate the model parameters for each catchment.
- To predict flow to ungauged catchments.

## 2. Study are and hydro-meteorological data

### 2.1 Study area

Omo Gibe River Basin Located in the southern part of Ethiopia between 4°'N&9°22'N latitude and b/n 34°44'E&38°24'E longitude. The Basin area is 79,000km$^2$. At present, river flows are measured at different points in the basin. The basin is sub-divided into 30 sub-basins based on the major rivers in the basin and its tributaries (Richard Woodroof and Associates, 1996). But 64% of upper part of the basin, 27% of middle part of the basin and 9% lower part of the basin flow is measured. Generally most part of central and lower of the basin is ungauged. To solve this limitation of data and to generate baseline flow data to ungauged catchment of the basin this research is done.

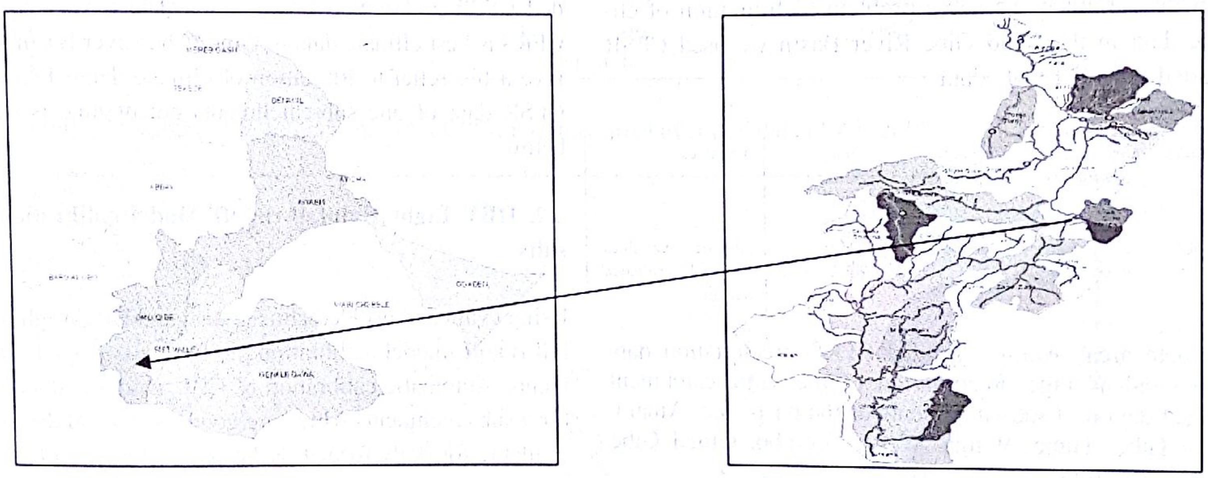

Figure 1: Omo Gibe River Basin

### 2.2 Hydro-meteorological data

Secondary hydrology and meteorology data are collected from Ministry of Water and Energy (MoWE) and National Meterological Agency (NMA). In upper part of the basin flow and meteorological data is almost available for long period of time but for central part of the basin flow data is available only for 3 sub-catchment and meteorological data is available for some catchments but for some stations the data is not long period. Lower part of the basin in some catchments meteorological (RF) data is available but is it not long period data. Flow data except Neri River near to Jinka lower Omo is not gauged.

Daily satellite gridded global climate data (Precipitation, maximum and minimum temperature, relative humidity, wind speed, net radiation… etc) from 1979 to 2010 were collected from IWMI staff. For this study slope, aspect, flow direction, flow accumulation is calculated by using DEM 90x90m and arc hydro and Arc GIS 9.3.

Raster annual rainfall, topographic witness index. NDVI and Soil data were collected from IWMI staff and IWMI GIS department. Annual PET raster data download from web site of http://www.cgiar-csi.org/data/global-aridity-and-pet-database.

Digital Elevation Model, together with the above developed raster file, was used to determine the different catchment characteristics. The different catchment characteristics, like average, slope, average aspect, average elevation, median flow direction, average flow accumulation, average annual rainfall, average topographic witness index, average Soil Bulk density, average soil available water content and average soil permeability, average NDVI and average annual PET were computed with the help of zonal statistics in spatial analyst tool of Arc GIS 9.3.

## 3. Methodology

### 3.1. Evaluation of Climate Forecast and Reanalysis System (CFRS) data

Meteorological stations in most parts of the basin are very sparse and most watersheds are un-gauged. Climate records are incomplete; high percentage of missing data and relevant variables. To solve problem of limitation of climate data in the Omo Gibe River Basin we used CFSR gridded global climate data.

| Product | Spatial Resolution | Temporal Resolution | Time Horizon | Variables |
|---|---|---|---|---|
| CFRS | 0.312 degree (~38km) | Hourly, Daily | 1979 – 2012 | Climate variables, and Hydrological quantities |

Evaluate areal average gridded CFRS precipitation data with areal average precipitation of the same catchment gauged data to 9 sub-catchments of the basin (i.e. Amara, Great Gibe, Tunjo, Walga, Wabe, Grombo, Gilgel Gibe Gojeb, and Guma).

### 3.2. Parameter estimation and regionalization methodologies

To apply the model for ungauged catchments, it is necessary to first relate model parameters to the physical and/or climatic characteristics of the catchments. The method classically used to regionalize the model parameters consists of establishing correlations of this kind. The aim here is to identify the physical variables that affect the rainfall-runoff transformation, and then to look for a regression relationship between model parameters and physical characteristics. The model parameters were then linked to these basin characteristics by regression and optimization methods. Finally, a catchment parameterization scheme is developed and the model parameters were estimated for each catchment. The catchment parameterization equations for parameters FC, LP, BETA, PERC, Alpha, K1, K2 AND MAXBASS. The general equation used in the regression analysis has the form:

$$X = I + a*A + b*B + c*C + d*D + \ldots$$

Where ,

I is intercept, a, b, c, d, are the coefficients of the regression equation and A, B, C, D are the catchment characteristics

## 4. Results and Discussions

### 4.1. Evaluated results of gridded CFSR and station precipitation data

Bar graph of CFSR precipitation is best fit to station precipitation and scatter plot of $r^2$ is greater than 0.6 for all evaluated sub catchments. The evaluated results of gridded CFSR and station precipitation data is very good so CFRS is best climate data to Omo Gibe River Basin and it give a big relief to limitation of climate data. Evaluated CFSR data of one sub-catchments out of nine is shown below.

### 4.2. HBV Light Rainfall-runoff Model calibration results

Using evaluated gridded climate data and HBV Light rainfall-runoff model calibration is done to gauged catchments. Automatic calibration of HBV model is done only for 9 sub catchments which are good results and data's are available for daily format. HBV parameters used for calibrations are FC, LP, BETA, PERC, Alpha, K1, K2 and MAXBASS. The model was calibrated for period from 1979-2008. The performance of the model was evaluated on the basis of performance efficiency (Reff), efficiency using weighted errors(Reff weighted), efficiency using ln (Q) (log Reff), coefficient of determination ($r^2$), mean difference (mean diff). The overall performance of the model appears good. The $r^2$ is greater than 0.6. The hydrograph fit between the estimated and observed is also adequately represented. The hydrograph of one sub-catchments out of nine is shown in Figure 4.

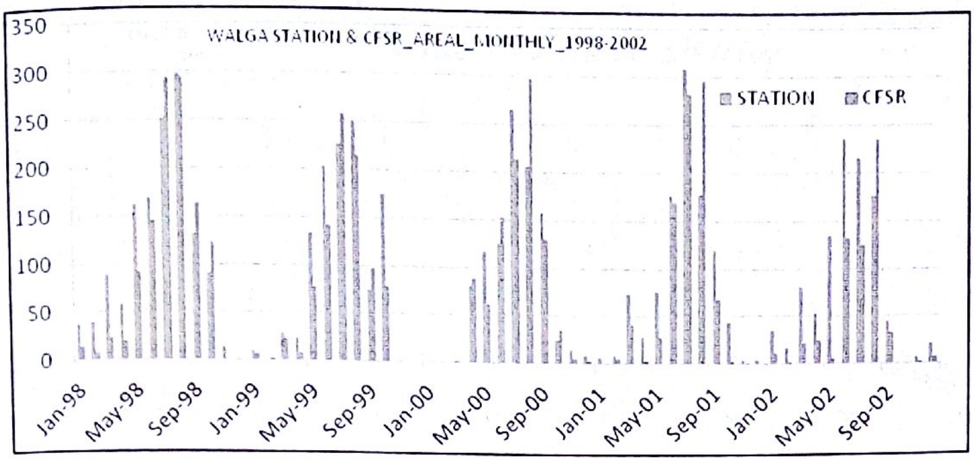


Figure 2: Walga station and CFSR montgly areal average (1998-2002)

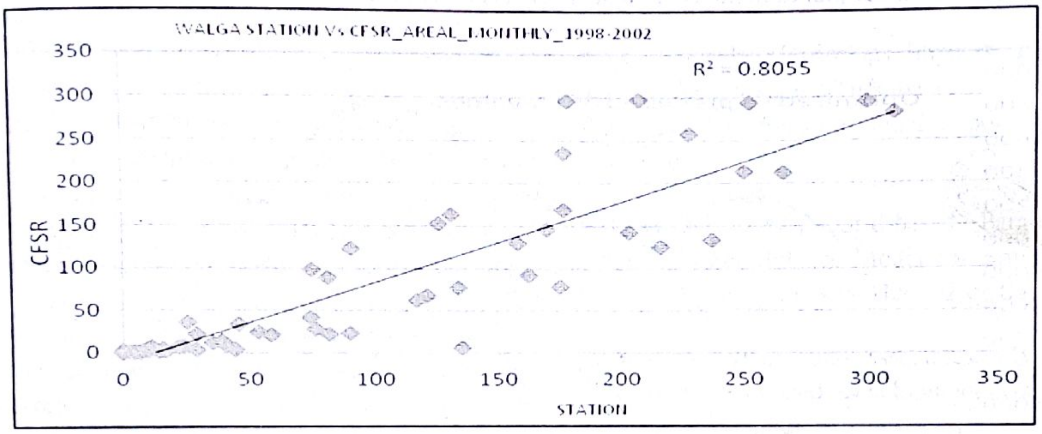


Figure 3: Scatter plot Walga station Vs CFSR monthly areal average data (1998-2002)

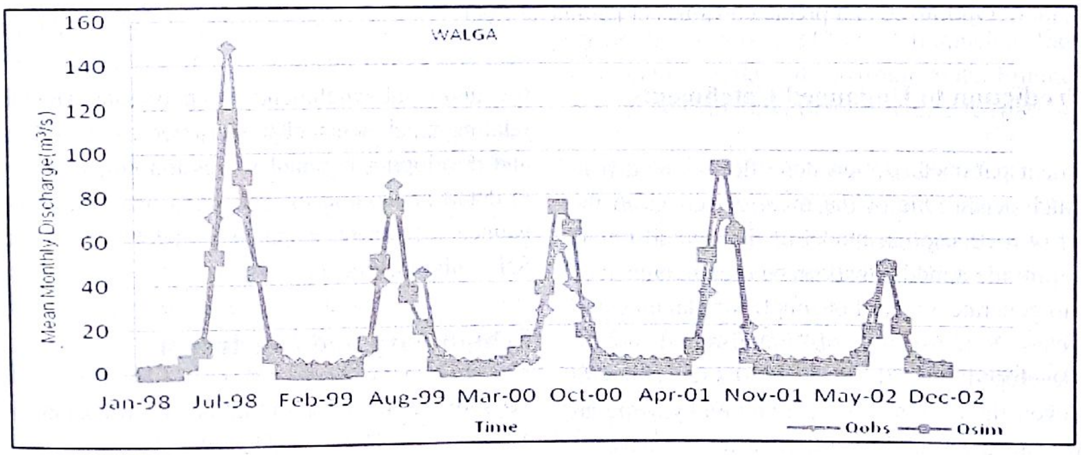


Figure 4 Calibration of observed and simulated flow hydrograph of Walga (1998-2002)

**4.3 parameter estimation and regionalization methodologies**

Catchment characteristics used to parameter regionalization are average slope, aspect, elevation, flow accumulation, annual rainfall, topographic witness index, Soil Bulk density, soil available water content, soil permeability, NDVI and annual PET and median flow direction. One sample of optimized and predicted values of parameter Beta is shown below.

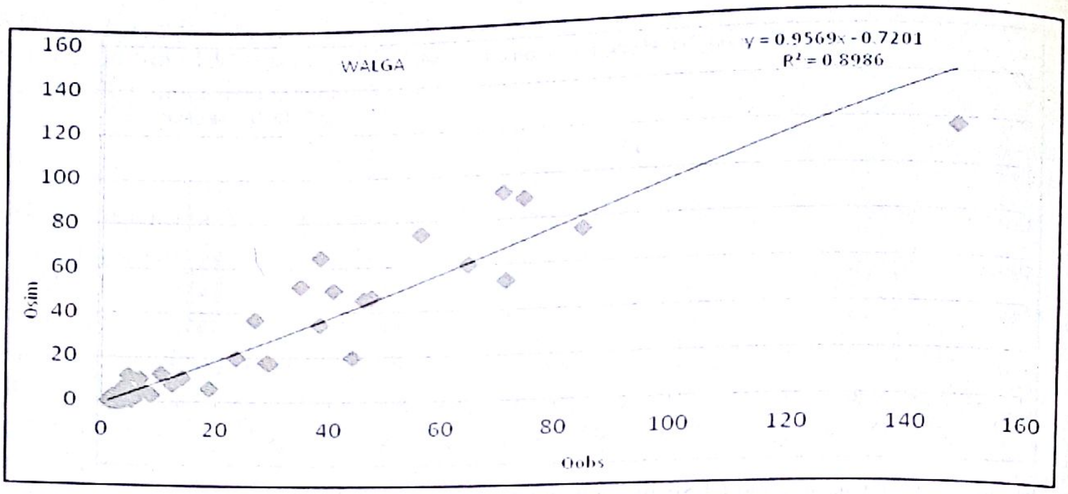


Figure 5: Scatter plot of monthly simulated versus observed flow of Walga (1998-2002)

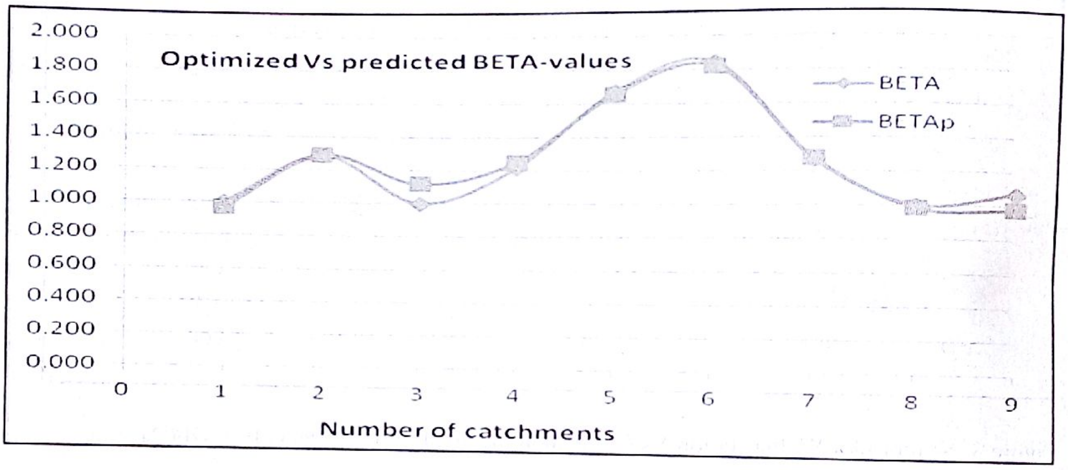


Figure 6: Optimized and predicted values of parameter Beta

### 4.4 Flow Prediction to Ungauged Catchments

After catchment parameterization done flow is predict to ungauged catchments. One of the main objectives in the development of a conceptual model of the rainfall-runoff process is to provide a model that can be used in ungauged catchments to generate a record of runoff for planning and design purposes. Various kinds of rainfall-runoff models have been developed since the early 1930's (K. Birhanu, 2009) However, the need of prior calibration by using an available stream flow record of sufficient length makes it difficult to apply existing models to ungauged catchments. It is therefore appropriate to emphasize the study of correlating model parameters to measurable physical catchment characteristics and in order to apply the model at ungauged sites.

In this study 15 sub catchment was chosen as ungauged sub-basin as it has 9 sub-catchments has no gauging station and 6 sub-catchments has poor data. The task of correlating catchments characteristics to model parameters and developing regional regression equation is described in detail above and the predicted hydrograph for the ungauged catchments using the model is shown below for Soke sub-catchments.

## 5. Summary and conclusion

To solve problem of limitation of climate data evaluate areal average CFSR gridded global climate data with station areal average precipitation. The evaluated results of gridded CFSR and station precipitation data are very good for all evaluated 9 sub catchments of the basin. So CFRS is best climate data to Omo Gibe River Basin and it gives a big relief to limitation of climate data in the basin. Using gridded climate data and HBV-Light simple rainfall-runoff model simulation is done to gauged catchments.

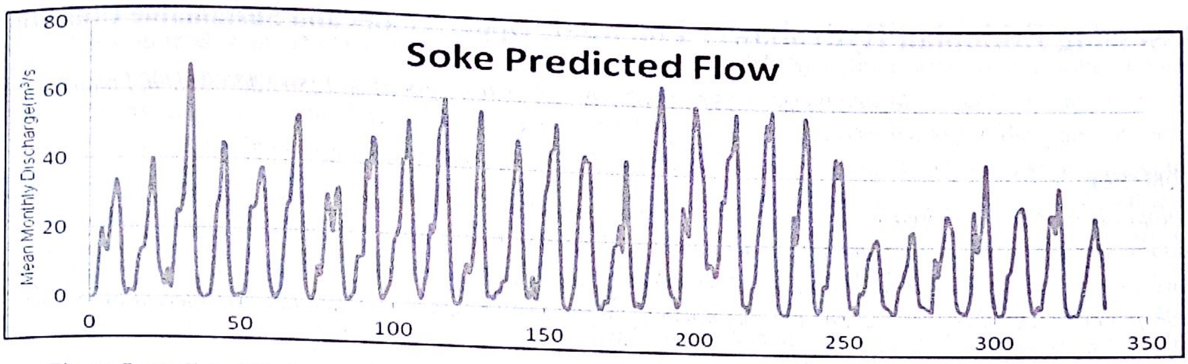


Figure 7: predicted discharge of Soke sub- catchment outlet

Automatic calibration of HBV model is done only for 9 sub catchments which is good results and data's are available for daily format. By using parameters of these 9 sub-catchments parameter regionalization is done to ungauged catchments. The HBV outputs results are good.

To apply the model for ungauged catchments relate model parameters to the physical and/or climatic characteristics of the catchments. The method classically used to regionalize the model parameters consists of establishing correlations of this kind. Identify the physical variables that affect the rainfall-runoff transformation, and then look for a regression relationship between model parameters and physical characteristics. The model parameters were then linked to these basin characteristics by regression and optimization methods. Finally, a catchment parameterization scheme is developed and the model parameters were estimated for each catchment. After catchment parameterization done flow is predict to 15 ungauged sub catchments of omo gibe river basin.

Once the amount of water available in the Basin is estimated for future, it will give an important clue for planners, decision makers, water users and other stakeholders in managing the water resources for efficient use of water for various purposes like hydropower, large scale commercial farms, environmental flows, residential, industrial, livestock. ecology and catchment conservation will promote, effective management and utilization of natural resources, planning of sustainable development projects and ultimately creation of economic development in the Basin and its people Finally the outcome of this study is giving a big relief to limitation of climate and flow data to ungauged catchments of Omo gibe river basin. Therefore this could contribute its own contribution to the millennium development goal of the country.

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# Assessing Ethiopian Hydropower Potential: Opportunities and Sustainable Utilization

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## Abstract

*Ethiopia is a nation endowed with enormous hydropower potential. Yet, its energy sector is highly dependent on traditional fossil fuels plus biomass and only about a third of the nation's population has access to electricity. In recent years, however, the country has engaged itself in unprecedented multibillion dollar energy projects. In this work the Ethiopian hydropower potential is assessed and the social, environmental and economic implications of different hydropower projects are discussed. The conclusion of this work shows that if Ethiopia uses its hydro potential efficiently, it can not only meet its energy demands but also be a giant energy supplier to east African nations in a few years. It is also concluded that while the current giant hydropower projects are of vital importance to the nation's development, small and medium scale hydropower plants are the best options for the nation.*

*Keywords: Sustainability, Renewable energy, Hydro*

## I. Introduction

### A. Foreword and Research Motivation

For centuries, our use of energy for different purposes has created massive impacts on the environment putting the ecosystem under enormous pressure. Consequently, replacing our conventional fossil fuel dependent energy systems with sustainable energy sources has received worldwide attention in the past few decades. As a result, the quest for sustainable energy sources seems reaching its maxima. Many countries have managed to reduce their dependence on traditional energy sources through new innovations and improved infrastructure while others still depend largely, in some cases almost entirely, on fossil fuels.

Ethiopia, located in the horn of Africa, is a country blessed with huge amounts of hydro, wind, geothermal and solar power potentials. However, only a small portion of these resources has been utilized so far. For instance, while its hydropower potential is estimated to be up to 45GW (DFIP, 2009), only about 2% of this potential is exploited so far. The nation's energy sector is rather imported oil dependent and over 90% of the population depends on biomass, such as burning of wood, animal manure and crop waste.

The consumption of energy in the form of imported petroleum and burning of wood poses many environmental problems: as air pollution, biodiversity loss, soil erosion, etc. The use of wood in rural areas has also social concerns as it usually causes smoke related health problems, burnings, etc. It also poses an economic challenge to Ethiopia. As a result it is very important for the nation to shift to socio-economic-friendly energy resources.

### B. Aim of the Study

Given the aforementioned social, environmental and economic concerns of our time and the need to a profound energy development in Ethiopia, the aim of this work is to investigate the hydropower potential of the country. It also analyzes the socio-economic and implications of current and future hydropower projects in Ethiopia.

### C. Methodology

To achieve the goal of this study, a comprehensive literature review was conducted. Different articles, books and scientific journals were used as main sources and different energy policies of Ethiopia were investigated. The study was analyzed based on three guiding concepts: economic, social and environmental sustainability.

## II. Ethiopian Hydropower Potentials and Current Status

### A. Ethiopian Energy: A Brief History & Current Status

Ethiopia is a country of diversity in its climatic, biophysical as well as in its socio-economic settings. The nation's climate ranges from equatorial rainforest with high rainfall and humidity in the South and Southwest to Afroalpine on the summits of the Semien Mountain and the Bale mountain chains and desert like conditions of the Northeast.

East and Southeastern lowlands. Similarly, the temperature varies from up to 60°c in the Dallol Depression of Ethiopia to freezing temperatures at Ras Dashen in the Semien Mountains; causing a rainfall variation of from about 3000 mm/year in the Baro-Akobo basin to as low as 200 mm/year in the Ogaden and Aysha basins (MoWR, online). The nation's socio-economic setting is also unevenly distributed with urban areas being well connected to each other while some rural areas are barely reachable (Ibid.).

In recent years, however, in its effort to change the nation's socio-economic arena, the Ethiopian government has committed itself to the improvement of infrastructures in the energy, telecommunication and transportation sectors. For instance, massive hydropower projects have been built in recent years and many more are underway. A successful completion of the undergoing challenging but yet promising projects would provide a huge percentage of the country's population with a cheaper and environmental friendly energy.

Ethiopia is one of the countries that suffer a very low consumption of electricity. Until as recent as 2007, only 22% of Ethiopians had access to modern electricity. This figure was down to 16% at the end of 2005 (Besha, et al., 2009) and only 13% in 1999 (Teferra, 2002). While more than 86% of urban residents have access to electricity, the consumption is as low as 2% for rural residents (Hathaway, 2008). According to a report by the Ethiopian Electric Power Corporation (EEPCo), the electric energy access of the country has reached 32% as of mid 2009 (EEPCo, online).

The birth of modern electricity in Ethiopia dates back to the late 1890's when King Menelik II of Ethiopia acquired the first generator to light his palace (Ibid.). Nearly three decades later, in the occasion of King Haile Selassie's coronation ceremony in 1930, the supply of electricity was extended to light the streets of Addis Ababa (EEA, online). Since then, the nation's energy sector has undergone through several developments and restructuring. Today, the state-owned Ethiopian Electric Power Corporation controls the power industry and is solely engaged in the generation, transmission and distribution of electric power.

## B. Ethiopia's Hydropower Potential

Ethiopia has enormous hydropower potentials that is estimated to be between 30GW - 45GW (EEPCo, online; DFIP, 2009; Dalelo, nd). The nation has generally 12 major basins; 8 river basins, 3 dry basins and the last one is lakes basin (MoWR, online). Most of the water basins have very special nature due to the landscape of the country. In many cases it is possible to use the water of these basins for hydropower in the highlands and use the same water for irrigation in the lowlands. Another special feature of Ethiopian rivers is that many of the major rivers are sourced in the central part of the country and stream to all directions with some of the river basins covering very large areas. Wabishebelle River, for instance, covers an area of more than 202,000km² (Ibid.).

While there are more than 300 different spots in the different basins where hydroelectric power generating stations could be installed, the basins have the irrigation potential to change the nation's rainfall dependent agriculture drastically. Figure 1 presents the main water basins in Ethiopia and their distribution across the country.

The Nile, Abay in Amharic, is one of the two main tributaries of the Nile, often considered to be the longest river in the world. The Blue Nile is the source of most of the water of the Nile and the transported sediment. Combined with the Tekeze and Baro-Akobo rivers, it contributes to about 90% of the water with the Blue Nile contributing about 60% of the total water (Beyene et al., 2010). About 96% of transported sediment by the Nile River also comes from the Blue Nile. The available minerals and deposits in the basin are believed to be over 265 of which 190 are metallic including (gold, iron, copper, zinc, etc) and over 75 are non metallic including limestone, marble, lignite, silicas, etc (MoWR, online).

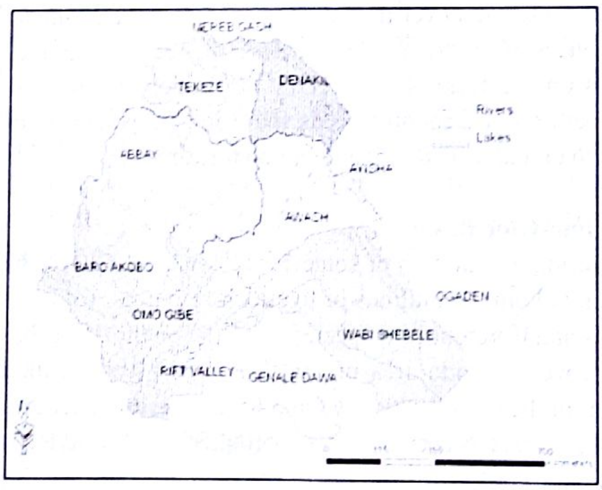


Figure 1: Ethiopian water basins (Awulachew et al., 2005)

This basin is probably the most important river basin in the country as it covers 20% of Ethiopia's land area, about 50% of the nation's total average annual runoff which emanates from the Ethiopian highlands, 25% of its population and more than 40% of the agricultural production (Awulachew et al., 2005). Its overall hydropower potential is estimated to be up to 78,820GWh per year (Ibid.).

Despite these facts, this resource has been underutilized. Until recently, there were only two operational hydropower plants built on the Blue Nile River. Tis Abbai I HPP, commissioned in 1964, has a total installed capacity of only 11.4MW while Tis Abay II HPP was commissioned in 2001 with a total installed capacity of 74MW (EEPCo, online). However, different hydropower plants are built in recent years. Tekeze hydropower project, inaugurated in November 2009 with an installed capacity of 300MW, is developed on Tekeze River, tributary of Blue Nile River. Similarly, the recently inaugurated Tana Beles project with installed capacity of 460MW is the largest hydropower plant in the country and is built using the Tana River, a tributary of the Nile River. This project is unique among other hydropower plants in the country as the discharged water is used for downstream irrigation purposes. The Grand Ethiopian Renaissance Dam commenced in 2011 is also under construction on the Blue Nile River which will have an installed capacity of 6000MW when completed.
A proper utilization of the river's potentials could bring vast opportunities for the nation. However, in addition to its underutilization, this basin has also been a center of controversy and has created some political suspicions and regional tension over the fair share of the resource among countries of the basin. Nevertheless, the recent mega projects on the Blue Nile River by the Ethiopia show how desperately the country needs the available potentials of the river and its determination to go forward.

**ii. Omo-Gibe Basin**

Covering a total area of some 79,000km2, the Omo Gibe basin is home to millions of livestock resources, wild animals and different bird species (MoWR, online). This basin covers a wide area of forest as well as agricultural land. In the early 1980s the Omo River (the lower reaches of the river) has been affirmed as UNESCO's World Heritage Site, following the discovery of the earliest known fossil fragments of Homo sapiens. This culturally and socially rich basin has immense potentials to offer if appropriate irrigation, energy, tourism and fishery projects are executed with caution. This Basin has an estimated small scale hydropower potential (5-30MW) of about 86MW and large- scale hydropower potential (above 30MW) of well over 2,497MW (Ibid.).
In recent years a huge investment fund has been allocated by the Ethiopian government for projects on this river. The Gilgel Gibe cascaded projects, Gibe I-V, are believed to boost Ethiopia's electricity production to an export level once completed successfully.
Located on the Gilgel Gibe River, the construction of Gilgel Gibe dam, the first of the five cascaded power plants, was started in the mid 1980s but mainly built between 1997 and 2003 and became operational in 2004 generating 183MW of power to the grid on its completion (HyPower, 2006). The completion of this power plant has increased the country's electricity supply significantly. The Gilgel Gibe dam is used both for Gibe I Gilgel Gibe II hydropower plants. Gibe II, inaugurated in January 2010 with a generating capacity 420MW of electric power, doesn't need a dam to be constructed. It rather uses the discharged water from Gibe I that is channeled through a 26km tunnel to Omo River Valley.

Gibe III, a very controversial project, is the third phase in the cascaded Gibe projects that uses the same river to build the third power plant which is located at about 150km downstream of the Gibe II outlet. When completed in 2013-2014, the plant is expected to generate 1,870MW of electric power, the largest ever in Africa. While Gibe IV and V with a capacity of 1,472MW and 560MW of electric power respectively are planned to be built, the currently underway Gibe III project has raised controversy over its social and environmental impacts (CRBM & CEE, 2008; Hathaway, 2009; ARWG, 2009). However, the social and environmental impact assessment conducted by EEPCo concludes that the project is feasible and labeled its potential adverse environmental impacts to be short term compared to the multidimensional benefits that the completion of the project could offer to the region, the society and the country at large (EEPCo & CESI SpA, 2009). Generally, while the controversy over the construction of dams on this basin is eye catching, the construction of well studied projects and a wise use of the resources could be a turning point to the country that faces multidimensional social and economic problems related to lack of adequate energy.

**iii. Other Basins**

Other major basins with substantial hydropower potentials include Baro-Akobo, Genale Dawa, Wabishebelle and Awash basins.

While Wabishebelle has a total hydropower potential of 7,457GWh/year. Genale Dawa has 9,270GWh energy potential per year, among others (MoWR, online). A combination of those basins is one of the biggest resources that the nation has and appropriate utilization of these resources is vitally important. The hydropower potentials of the main river basins of the country are summarized in Table 1.

Table 1: Ethiopian hydropower and Irrigation potential (Source: MoWR, online; Kloos & Legesse, 2010)

| No | River basin | Hydropower potential (GWh) | Potential hydro sites |
|---|---|---|---|
| 1 | Blue Nile | 55000/78820* | 132 |
| 2 | Omo-Ghibe | 26026/36560* | 23 |
| 3 | Baro-Akobo | 19826 | 39 |
| 4 | Genale Dawa | 9270 | 23 |
| 5 | Tekeze | 8384 | 15 |
| 6 | Wabishebelle | 7457 | 18 |
| 7 | Awash | 5589 | 43 |
| 8 | Rift Valley Lakes | 12240/800* | 6 |
| 9 | Mereb | na** | na |
| 10 | Aysha | na | na |
| 11 | Denakil | na | na |
| 12 | Ogaden | na | na |
| | *Total* | *166,706** | *299* |

* Different data from different references: both values are put whenever the difference is considerable

** na: data not available

### C. Ethiopian Energy Status

While the Ethiopian electricity system has a total installed capacity of about 1,965MW from its hydropower plants as of 2011, generally there are two power supply systems in the country: the ICS or the interconnected system and the SCS or self connected system. The earlier consists of major hydropower plants and the later consists of diesel generating units and small hydropower plants that operate in remote areas (Hailu, 2000). As of 2009, there are some three hydropower plants in the SCS system with an installed capacity of 6.15MW and isolated diesel power plants with an installed capacity of 30MW (EEPCo, 2008/09). Table 2 summarizes the total installed electricity capacities in the country.

As can be seen from table 2, in addition to its main 12 hydropower plants and a single geothermal plant, Ethiopia uses some diesel power plants to supplement the supply. For the landlocked country the use of the diesel generators has two big disadvantages: the economic drawback of importing expensive fuel and the environmental concerns of using fuel. As a result, it is very essential to avoid the use of these energy systems by moving towards better alternatives.

As can be seen from table 2, in addition to its main 12 hydropower plants and a single geothermal plant, Ethiopia uses some diesel power plants to supplement the supply. For the landlocked country the use of the diesel generators has two big disadvantages: the economic drawback of importing expensive fuel and the environmental concerns of using fuel. As a result, it is very essential to avoid the use of these energy systems by moving towards better alternatives.

### D. Ethiopian Energy Development Plans and Sustainability Concerns

#### i. Sustainable Development and Poverty Reduction Program

In 2002 the Ethiopian government launched an ambitious 15 years plan entitled Sustainable Development and Poverty Reduction Program (SDPRP) for the period of 2002 to 2016 where the government planned to carry out different development programs to achieve its goals.

Table 2: Total Installed Generating Capacity of Ethiopia (Source: EEPCo website)

| No | Plant | Installed Capacity (MW) | Year of Comm. |
|---|---|---|---|
| | ***Hydropower*** | | |
| 1 | Koka HPP | 43.2 | 1960 |
| 2 | Tis Abbai I HPP | 11.4 | 1964 |
| 3 | Awash II HPP | 32 | 1966 |
| 4 | Finchaa HPP | 134 | 1973 |
| 5 | Awash III HPP | 32 | 1974 |
| 6 | MelkaWakena HPP | 153 | 1988 |
| 7 | Tis Abbai II HPP | 74 | 2001 |
| 8 | Gilgel Gibe I | 210 | 2004 |
| 9 | Tekeze | 300 | 2009 |
| 10 | Gilgel Gibe II | 420 | 2010 |
| 11 | Tana Beles | 460 | 2010 |
| 12 | Fincha Amerit Neshe | 97 | 2011 |
| | ***Diesel*** | | |
| 1 | Kaliti | 14 | 2004 |
| 2 | Dire Dawa | 38 | 2004 |
| 3 | Awash 7 | 35 | 2004 |
| 4 | Nazareth Diesel | 30 | rented |
| 5 | Debre Zeit Diesel | 30 | rented |
| *6* | *Standby (different sites)* | *25.3* | *1958* |

In view of this, the ministry had put resource development priorities to the different available resources. Consequently, the priorities that the Water Resources Management Policy has put include (MOFED, 2002):

⇒ Expanding irrigated agriculture to the maximum possible extent;

⇒ Meeting hydropower generation capacity needs arising from electricity demand in the economic and social sectors;

⇒ Providing water for the industrial development;

⇒ Utilization of the resource for fishery, tourism and transportation purposes;

As presented above generation of electricity from hydropower has been set as one of the priorities. The recent boost in the energy sector is following the ambitious plan set at the beginning of the century.

Since then, a number of projects have been carried out and about eight years later, in a recent message to the UNFCCC, the Ethiopian Environmental Protection Authority handed the mitigation actions and development plans of the Ethiopian government in line with the COP15 accord, presenting brief developmental action plans of different infrastructures including energy and transportation for one decace. Accordingly, the energy plans together with the countries energy potential and existing capacity are analyzed here based on three guiding concepts: their societal implications, environmental and economic implications.

**ii. Energy Boost and Environmental Concerns**

Despite a continuous opposition from different groups around the world of some hydropower projects, the recent energy plans of Ethiopia focus highly on boosting the energy supply from its water resources. The Ethiopian government plans the installation of 10 hydropower plants with an installed capacity of 11,172MW to be completed on or before 2018 and another 8915MW hydropower projects under study. These projects are tabulated below.

Table 3: Future Ethiopian Hydropower projects (Source: EPA, 2010, EEPCo, website

| No | Project | Installed Capacity (MW) | Year of Commissioning |
|---|---|---|---|
| 1 | Gibe III | 1870 | 2013 |
| 2 | Fan Project | 100 | 2013 |
| 3 | Genale III | 258 | 2014 |
| 4 | Halele Werabesa | 422 | 2015 |
| 5 | Chemoga-Yeda | 278 | 2015 |
| 6 | Gibe IV Project | 1472 | 2015 |
| 7 | Genale IV | 256 | 2015 |
| 8 | Geba I and II | 366 | 2015 |
| 9 | Gojeb Project | 150 | 2015 |
| 10 | Hidase Project | 6000 | 2018 |
| | ***Total*** | ***11,172*** | |

This huge energy development and the constructions of dams and substations together with the installation of transmission lines, however, have been criticized by many including:

Table 4: Hydropower projects that are under study (Source: EPA, 2010)

| No. | Project | Installed Capacity (MW) |
|---|---|---|
| 1 | Beko Abo Project | 1600 |
| 2 | Dabus Project | 425 |
| 3 | Tams Project | 1000 |
| 4 | Tekeze II Project | 450 |
| 5 | Boarder | 1200 |
| 6 | Mendeya | 2000 |
| 7 | Gibe V | 600 |
| 8 | Wabi Shebele | 460 |
| 9 | Birbir Project | 467 |
| 10 | Lower Dedessa | 613 |
| 11 | Genale Dawa V | 100 |
| | *Total* | *8915* |

International Rivers, Survival International, Friends of the Earth, etc. The Gibe III project is on the top of the list. The different bodies condemn the construction of the highest dam in African, Gibe III, for being socially and environmentally destructive. Survival International, for instance, argues that the construction of the dam will impose enormous negative impacts on the ecosystem due to seasonal flooding of the Omo River and also as decrease its downstream volume considerably (Survival International, online). It is also underlined that at least 100,000 people will be facing food shortages (Ibid.). Similarly, a 2008 report published by CRBM & CEE entitled "The Gilgel Gibe Affair" argues that the construction of the dam together with the other Gibe projects, will probably have a significant negative impact on the whole ecosystem surrounding the area including the tribal based local population that depend on the traditional use of natural resources (CRBM & CEE, 2008).

However, in its in-depth social and environmental impact assessment report, EEPCo has presented that while the benefits of the dam and that of the hydropower plant is a great asset to the nation's economy, the environment and the society, the impact of the project in terms of population displacement and that of the ecosystem are minimal and proposed that possible measures should be taken to avert the effects of the negative impacts (EEPCo & CESI SpA, 2009).

## iii. Discussions

### A. Discussion: Energy Projects & their Implications

#### Societal Implications

The social benefits of modern energy systems extend from health condition improvements to family safety and from economy improvements to better quality of life. While the majority of the socially diverse but economically poor East African nation's population has no access to modern energy, many experience the negative consequences of using firewood and different fossil fuels. One of the main socially devastating impact of using wood as a source of energy in rural households is in connection with the burning of children, housewives and properties (in many cases the house itself). Whereas the frequency may vary from region to region depending on the type of wood consumed, the type of stoves used, etc. the incident is rather common in many parts of the world. For instance, according to a study conducted by Courtright et al. (1993) based on samples from 16 different communities with a total population of about 10,180 in Gurage-Chaha region rural Ethiopia, some 271 burn inpatients were recorded for the 7 year period the research considered. The article pointed out that most burns are in the domains of women. Another study in Mekelle town in northern Ethiopia showed that the annual incident in burns is 1.2% in the town with children of less than 5 years old being the highest victims of the incident (4.8%) (Nega & Lindtjorn, 2002). Smoke is also another problem that might cause pneumonia, eye infections etc.

Children and housewives usually travel long distances to gather firewood and the time they spend to accomplish a specific task using this traditional energy system is also a burden to many countryside villagers. Similarly, while the use of fossil fuel for cooking is relatively cleaner and faster means of energy with less risk of fire, it is usually unaffordable to many households.

Generally, the majority of the population in the country desperately needs a safer, cleaner and cheaper energy. As a result, the recent rapid energy development in the country plays a decisive role in unloading the burdens to many rural residents. However, in spite of its many social benefits that the development of the sector offers, the associated negative social impacts of different projects are also substantial and often controversial. In one hand, the construction of dams and transmission lines cause the relocation of thousands of people and costs them their land and social tie.

For instance, the Social and Environmental Impact Assessment report by EEPCo & CESI SpA (2009) concluded that Gibe III project affects some 355 households. On the other hand, the construction of dams together with water diversion usually leads to food security and clean water scarcity issues, among others.

### ii. Economic Implications

Probably economic advantage is the most important benefit that the country secures from the ongoing and planed projects. First, the nation will be relieved from the burden of petroleum import and secondly, the export of electricity to neighboring countries will also offer an economic advantage. About 200 fuel tanker trucks enter the country daily carrying 45,000 liters of oil each. Consequently, the development of the energy sector is of vital importance to the nation's poor economy as it will liberate the country from oil import burden.

### iii. Environmental Implications

The environmental implications of the projects can be seen from different perspectives. The long term implications might be of great importance to the environment than the short term ones. Ethiopia is a developing country with high population and the nation will engage itself in different industrial, agricultural and other energy demanding sectors in the decades to come. As a result promoting clean energy supply is of vital importance for $CO_2$ reduction and other fossil fuel related emissions that have a global impact. The Gibe III project, for instance, produces only about 90,000t of $CO_2$/year compared to 4,500,000t of $CO_2$/year which an equivalent thermo power plant would produce (EEPCo & CESI SpA, 2009).

In the short run, however, there are many controversies that circle the different projects specially that of the Gibe III project. Its impact on the entire Omo-Turkana ecosystem has been criticized by many (International Rivers, 2009; CRBM & CEE, 2008; ARWG, 2009; Survival International, online). However, the EEPCo social and environmental impact assessment report presents that while many of the potential adverse environmental impacts are short term impacts, they could be controlled within acceptable limits for as long as appropriate mitigation and compensation measures are adopted. Generally, even though it is difficult to quantify some of the environmental impacts that the ongoing projects cause (both negative and positive), such as soil erosion, ecosystem imbalance, $CO_2$ reduction, etc. the negative impacts seem short term while the major environmental benefits are in the long run.

## B. Design and Construction of Hydropower Plants

While the recent energy boost in Ethiopia seems very promising in many aspects and quite necessary to the betterment of the nation's societal needs, its economy and the environment, there is room for improvement as such aggressive development plan might also backfire.

Ethiopia is not in a position to construct huge projects that cost hundreds of millions of dollars and see them fail after sometime. Projects of that type should be carefully studied, highly engineered and well reliable in their construction to minimize their social, economic and environmental impacts and failures. As a result, EEPCo should make an in depth analysis of the projects prior to investing huge money and resource. The projects should be constructed in a way that they function at least for the period they are designed for. However, some projects are showing poor performance. For instance, while the Gilgel Gibe I dam was designed to be operational for at least 70 years, a recent study by Devi et al. (2008) showed that the volume of the dam will be reduced by half within 12 years and estimated to be completely filled with sediments and eutrified within 24 years. The main reason for this is that nearly 37.5 x 106 $m^3$ of sediment is deposited in the dam annually (Ibid.). This shows that about 4.4% of the dam's capacity is filled with sediments each year. From engineering perspective, however, if the sediment deposition potential is greater than 1% to 2% of the original capacity of the dam, an immediate remedy is necessary. Similarly, a 2008 report by International Rivers presented that the existing dams in Ethiopia have experienced heavy sedimentation over the years and pointed out that the problem is a real risk to the lifespan of new hydro dams and also dams for other purposes such as irrigation and water supply (Hathaway, 2008).

The rainy season of the year 2000, for instance, had seen Addis Ababa suffer power outages after siltation caused the closure of Koka Dam (Ayalew, 2002). The author also noted that a number of dams that were built in the past including Angereb and Melka Wakena have been greatly affected by siltation and recommends that due consideration should be given while constructing huge dams and reservoirs (Ibid). Sedimentation doesn't only affect the lifespan of reservoirs but also downstream ecology and aggravates downstream erosion (Hathaway, 2008).

Generally, most of the underway and planned hydro projects in Ethiopia are huge projects including the cascaded Gibe projects, where the failure of one dam has a direct

It is not unclear that the failure of any of the projects to function in their full capacity would cause social, financial and environmental crisis to the area and the nation at large. As a result a due consideration should be given prior to the development of such projects.

## Iv. Summary, Conclusions and Recommendations

Ethiopia, a socially and climatically diverse country, has a population of over 88 million inhabitants and a growth rate of 3.208% (CIA World Factbook, online). Located on the horn of Africa, the country has one of the lowest economies in the world. Agriculture, mostly traditional, is the backbone of the nation's economy accounting for 85% of the total employment and 45% of GDP but the sector faces a continuous challenge due to drought (Ibid.). However, recent developments have showed a dramatic shift towards industrialization leading to an increasing demand for energy. Consequently, recent developments in the energy sector show a promising start to meeting the demand.

While the nation's energy sector is largely fossil fuel dependent, the government has launched different ambitious energy projects in recent years. The projects are intended to provide electricity access to the majority of the Ethiopian population and improve its coverage from the current 32%. Some of the production is also expected to support the nation's economy by exporting power to neighboring countries. While many hydropower projects are underway, the sustainability of some of the projects has been questioned. However, EEPCo has given the projects the green light to carry on as the social and environmental impact assessments conducted by the corporation show that the projects are rather beneficial.

Never the less, this desk study assess the energy development projects from sustainability (social, economic and environmental), reliability as well as urgency point of view. Consequently, the following conclusions and recommendations are drawn to get the most out of the available natural resources and consequent energy projects:

- Ethiopia is endowed with enormous amount of hydropower potential. If this potential is correctly used, the nation has the potential to supply clean energy not only to itself but to its neighbors.
- The construction of hydropower projects need a serious attention in all phases: design through construction - to post construction management of the projects and failure of dams are not affordable as the effects are devastating and might be very costly to fix them once a failure occurs.
- While the different negative social and environmental impacts of many, if not most, hydropower projects are unavoidable, the long term benefit of the projects should be the main guiding factor. The EEPCo social and environmental impact assessment report lacks objectivity since it gives less attention to the negative impacts. However, while building different projects that affect thousands of people, cover a big ecosystem and cost hundreds of millions of dollars, different critical issues such as health, food security and displacement issues, ecosystem imbalance, cultural and aesthetic values, economy and others must be studied in-depth both for their short and long term implications and benefits to the society that they are built for.
- Equally important to developing new hydropower plants, EEPCo should also find a solution to problems that reduce the lifespan of the existing dams and a timely remedy is critical. As discussed earlier, the Gilgel Gibe I dam might be totally filled with sediments in less than 25 years compared to the 75 years service time which it was designed for. Many other dams are also in critical condition and immediate and appropriate actions to reduce the sediment levels play a critical role in avoiding the risk of failures. Erosion reduction and sediment flushing are recommended as alternative solutions.

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# Soil Moisture Assessment Using Hyperspectral Remote Sensing

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**Abstract**
*Soil moisture plays an important role in taking many decisions in water management. As soil moisture is a highly dynamic entity, exhibiting substantial variation in both time and space, rapid acquisition of spatial and temporal information on soil moisture remains vital to the precision of agricultural and other environmental studies. Due to the limitations of conventional approaches, hyperspectral remote sensing has been known to provide reliable information on soil moisture determination. The objective of this study was to discriminate soils at their various moisture levels and assess moisture content quantitatively from hyperspectral reflectance data by the help of field spectroradiometer (350 to 2500 nm, ASD, Fieldspec³). A set of 80 sampling points of six soil series were selected and a total 240 soil samples were collected taking three samples from each point(0-15cm, 15-30cm, and 30-45cm). Spectral measurement was conducted for both fresh and oven dry samples. Samples were divided into calibration and validation data sets. Spectral analysis showed that spectra variation for surface soils was much higher than subsurface soils and high correlation values were shown in the strong absorption bands at about 1400nm, 1900nm and 2200nm wavelength regions. It was found that the spectral reflectance at the NIR wavelength is more sensitive to the soil moisture variation than visible region and bands in this range were considered for developing empirical models for soil moisture estimation. The stepwise regression method and principal component analysis (PCA) approaches provided good estimation of moisture content ($R^2$=0.799) and ($R^2$=0.805), respectively.*

**Key words:** *Soil moisture, Hyperspectral remote sensing, Spectroradiometer, Stepwise regression, PCA*

## 1. Introduction

Soil is the base for all life processes. As soil water is a highly dynamic entity, exhibiting substantial variation in time and space, rapid acquisition of spatial and temporal information on soil moisture remains vital to the precision of agricultural and other environmental studies (Liu *et al.*, 2009, p.532-540). The amount of moisture in the soil, therefore, is important for recognized need of soil moisture information to support many types of applications such as timely sowing of crops, deciding spatio-temporal water requirement, irrigation scheduling, drought management.

Quantitative estimation of soil moisture in the surface layer of soil has been most successful using the Visible and Near Infrared regions as soil moisture. Mouazen *et al.*, (2006, p.1295-1302) quantitatively and qualitatively evaluated soil water content through Spectroradiometer applying partial least square (PLS) regression method for soil samples taken from single and multiple fields. Soil samples taken from single field provided better prediction ($R^2$ = 0.98) than multiple-field sample sets ($R^2$=0.88). Sahoo *et al.*, (2005,p.17-24) developed a numerical one dimensional index called "total information content index" from spectral data of soil in 400-1100nm range and evaluated in estimating soil moisture of different soil types of India. Petrone *et al.* (20004, p. 41-52) states that understanding of the soil moisture balance, its spatial and temporal variability, is instrumental in quantifying the linkage between a region's hydrology, ecology and geology at a variety of scales.

Soil, being a non-ideal system and chemically and mineralogical more complex than 'pure' system, is often studied using traditional laboratory procedures which are expensive, costly and impractical for assessing variability in larger areas. It has been a major concern for soil scientists and environmental managers to search rapid and inexpensive techniques. Although remote sensing is handy when mapping conditions at regional, continental and even global scales and possibly on a repetitive basis (Schmugge *et al.*, 2002, p.1367-1385), ground based method of soil moisture measurement provide high quality data at a point. Reflectance spectroscopy, specifically designed for field environment remote sensing to acquire Visible -near-infrared and short-wave infrared (350-2500nm) spectra, is precision instrument used to make proximal sensing measurements of the reflectance spectra of materials under study.

Reflectance data have been successfully used for prediction of numerous soil properties, such as soil moisture and organic matter in laboratory studies (Dalal and Henry, 1986, p.120-123; Ben-Dor and Banin, 1995, p. 364-372; nitrogen content (Vagen et al., 2006, p.281-294), soil colour (Mathieu *et al.*, 1998, p.17-28), soil moisture content (Carlson *et al.*, 1995, p.191-205), and the presence of swelling soils (Kariuki *et al.*, 2004, p.455-469).

The extensive use of remote sensing techniques has introduced a new era for soil resources assessment and monitoring in terms of information quality (Mermut and Eswaran, 2001, p. 403-426) and created tremendous potential in assessing soil moisture. Bogrekci *et al.* (2005, p.1307-1317) showed the soil moisture effect in predicting Phosphorus concentration in soils and observed better results with ($R^2$= 0.951) after removing the moisture effect on absorbance spectra of phosphorus. The objective of the study was aimed at quantitatively assessing soil moisture content from VNIR hyperspectral reflectance data.

## 2. Material and Methods

### 2.1 Study site

The research was conducted at Indian Agricultural Research Institute (IARI) farm, New Delhi. The farm is located between latitudes 28°37' – 28°39' N and Longitudes 77°9' – 77°11' E and lies at the end of the western flank of the remnants of the Aravilli hills. The total cultivated area of the farm is 243 ha. The relief is nearly level with almost uniform inclination of low gradient ranging from 1-3% and little more than 3% in the upper piedmont plain, with elevation ranging from 217 to 241m above mean sea level (masl), semi-arid climate, soil type ranging from sandy loam to clay loam, temperature range varies from 43.9°C to 45°C and annual rainfall of 708.6mm.

The Directorate of All India Soil and Land Use Survey established six soil series: Mehrauli, Palam, Nagar, Daryapur, Holambi and Jagat (Ingle *et al.*, 2009, p.45-48). Mehrauli soils are well drained, very deep, sandy loam to loam soils, dark yellowish brown to yellowish- brown color (Ustochrepts family); Palam are well drained, sandy loam to loam soils of yellowish brown to dark yellowish brown colors (Typic Ustochrepts family); Holambi are moderately well drained to well drained, very deep, loamy (fine) soils of dark brown to dark yellowish brown color (Typic Ustochrepts family); Daryapur are moderately well drained to well drained, very deep, calcareous, loam to silt loam soils of yellowish brown to dark yellowish brown colors (Ustifluvents family); Nagar are moderately well drained to well drained, very deep, sandy loam over loam soils of yellowish brown to dark yellowish brown color (Typic Ustochrepts family); and Jagat are moderately well drained to well drained clay loam over loam soil of dark yellowish to yellowish brown (Typic Ustochrepts family).

### 2.2. Soil samples

A total of 240 soil samples from 80 sampling points, three samples from each point up to 45cm using augur sampler and each sampling points were labelled in to three depths (0-15cm, 15-30cm, and 30-45cm) from November 23 - Dec. 2, 2009, were selected over the farm of 243ha area. And each sampling ppoint was marked using a differential Global Positioning System (DGPS) into its longitude and latitude. Gravimetric moisture content was, then, determined from the soil samples.

### 2.3. Hyperspectral reflectance measurements

After optimizing with a white reference radiometric panel (spectralon) for correction of raw soil spectra to reflectance value, the reflectance measurement was made for each fresh and dry samples using ASDFieldspec handheld Spectroradiometer with calibrated source of light in dark room condition without allowing any stray light which may act as noise while doing spectral measurement. Spectral readings were taken in the spectral range of 350-2500 nm at 25° Field of View (FOV) and 0.1nm spectral resolution which was nadir looking over approximately 45cm of the sample surface. An ASD Pro Lamp light source of 14.5 Volt 50 Watt that is tripod mountable was in a direct contact with the optical measurement unit situated at 0.70 meter from the soil sample provided almost collimated rays over the sample area and was connected to a regulation device to avoid possible variation of electrical power supply. Within the optical unit, the light illumination and reflectance fiber are collected together at constant angle of 45°. Then immediately after spectral reading in the laboratory, the wet soil samples were kept in oven for 24hrs at 105 °c till samples would dry up and attain a constant weight and the moisture of each soil was determined gravimetrically.

### 2.4. Data processing and statistical analysis

For processing reflectance data, different mathematical pre-processing techniques have been applied to raw reflectance and absorbance spectra to remove noise within spectra originating from effects of illumination or non-homogeneous distributions of particle sizes.

The reflectance data were translated from binary to ASCII and exported in batches using ViewSpec Pro (Analytical Spectral Devices, Inc., Boulder, CO). Then the 10 sequential reflectance readings obtained from each sample (240 scans) were averaged using Microsoft Office Excel 2007, producing a master data file with one representative reflectance spectrum per soil sample. Spectral data were transformed with first and second derivatives. Multivariate Statistical methods - Multiple Linear Regression and Principal Component - were used in calibrating soil reflectance to individual gravimetric soil moisture for the fact that these methods are important in dealing with high dimensional multicollinearity in the data set (which is the case of in soil spectral data). The statistical analysis and model development was done using SPSS statistical software and principal component analysis (PCA) followed by multi-linear stepwise-regression analysis (MRA) used to examine the relationship between the reflectance measurements and the soil moisture.

### 2.5. Selection of optimum band

The optimum number of variables used for regression was determined by comparing their correlation values of raw, first and second derivatives of reflectance and absorbance values of the spectra. The first derivative of the surface reflectance spectra was chosen for it was the one having highest correlation. Two approaches were used to develop the regression model: a) correlation approach - MRA was done by taking highly correlated bands to soils moisture contents through comparing the correlation values between each band and moisture contents; b) PCA - for the calibration data set, a total of 180 samples were expressed as a linear function of their spectral reflectance (for 40-bands) with the following Multilinear regression equation:

$$Y_i = a_1{*}X_1 + a_2{*}X_2 + ... + a_nX_n$$

Where, $Y_i$ are the $i^{th}$ number of observations (dependant variable, in our case soil moisture) to be predicted; b0 is constant; $a_1, a_2, ..., a_n$ are the coefficient values computed by the model; and $X_1, X_2, X_3 ...... X_n$ denote n-number of independent variables used in the regression model. In this case, what the model does is that the highly correlated original variables (in this case, bands, independent variables) were transformed to a new set of uncorrelated variables by multiplying the variables with their respective component score coefficients called 'principal components', which in definition are linear combinations of the original variables and are derived in decreasing order of importance so that the first principal component accounts for as much as possible of variations in the original data set. Finally, the stepwise regression method was used to develop regression equation and model predictability model ($R^2$) was evaluated.

### 2.6. Development of prediction model

Best 23 and 40 bands were selected from the first derivative of reflectance spectra for correlation and Principal component approaches respectively for predicting soil moisture content. The $R^2$ (coefficient of determination), which is the proportion of variance in the dependent variable which can be predicted from the independent variables, was used for evaluating the ability of model's predictability of soil moisture. The $R^2$ values of two approaches were compared and the spectral data set with highest Adj. $R^2$ was taken for selecting the model and the optimum number of bands (independent variables). Taking Adj. $R^2$ is important because it attempts to yield a more honest value to estimate the $R^2$ for the observations. Stepwise regression procedure in SPSS statistical software was used for development of parameter prediction model.

### 2.7. Prediction accuracy

The ability of Visible and near-Infrared techniques to predict soil moisture was evaluated using the $R^2$ of measured and predicted values of samples.

## 3. Results and Discussion

### 3.1. Soil reflectance

Soil reflectance was generally lower in the visible range and higher in the near infrared with specific absorbance bands around 1400, 2200 and 2400 nm. These are strongly associated with $OH^-$ features of free water at 1400 and 1900 nm and clay lattice $OH^-$ features at 1400 and 2200 nm (Fernando, 2003). Correlation coefficients between soil moisture and reflectance spectra showed both positive and negative correlations at various wavelengths across the spectrum.

### 3.2. Optimum band width for developing relationships with soil moisture

#### 3.2.1. Correlation approach

The correlation with soil moisture contents and reflectance data was computed and plotted against wavelength. The highest correlation for raw spectra, first and second derivatives of reflectance and absorbance with their respective wavelength regions.

### 3.3.2. Development of regression model using correlation approach

This approach involves reduction of the bulk volume of raw spectral data to new spectra data sets developed through spectral averaging at every 10nm successive bands; and the raw spectra of both reflectance and absorbance spectra with their respective first and second derivatives were tested for selecting best bands chosen to have the most fitting prediction of soil moisture. Thus, the first derivative of the surface reflectance spectra with maximum correlation values containing 23-independent variables were selected to develop regression model (with probability of F—to-enter 0.05 and remove 0.10).

Table 1. Spectral models developed for soil moisture and model predictability

| Parameter | Regression model | Adj. $R^2$ |
|---|---|---|
| $Y_{mc}$ | $= 126.219*R'_{1975} - 441.069*R'_{1435} + 634.974*R'_{2235} - 801.426*R'_{1225} + 485.272*R'_{1025} + 337.154*R'_{1035}$ | 0.943 |

R' indicates first derivative of reflectance used in developing the regression model

### 3.3.3. Development of regression model using principal component analysis

Multivariate regression modelling, one of the most commonly used approach in soil spectral analysis of soil properties prediction (Shi and Huang, 2007, p.393-407), was applied for selecting best data set for studying soil moisture contents. The first derivative of the reflectance spectral data was also selected and two new set of uncorrelated independent variables called 'principal components' (PCs) were transformed from the highly correlated original set of variables which are accounting for by a total of 95.5% variation in the original data set. Then, those identified two PCs were used to develop prediction models through stepwise regression and the equation is shown below:

Table 2. Spectral models developed for soil moisture and model predictability using PCA

| Parameter | Regression Model | Adj. $R^2$ |
|---|---|---|
| $Y_{mc}$ | $= 136.352\ PC_1 - 361.422PC2$ | 0.906 |

Where, PC1 and PC2 are principal component 1 and principal component 2.

In the above two equations of the model, the Adj. $R^2$ values indicate that 94.3.9% and 90.6% of the variances in moisture content can be predicted from the independent variables respectively. Note that this is an overall measure of the strength of association, and does not reflect the extent to which any particular independent variable is associated with the dependent variable.

### 3.3.4. Validation of prediction model

A total of 60 samples were used for validation of the first derivative of the reflectance spectra with gravimetric soil moisture contents. Soil moisture was predicted good ($R^2 = 0.799$) when the bands of high correlation values were used and the predictability better for principal component analysis ($R^2 = 0.805$) with Adj. $R^2 = 0.906$. It was found that the model.s predictive ability was found to be good with $R^2 = 0.799$ in predicting moisture contents of 60-samples used for validation.

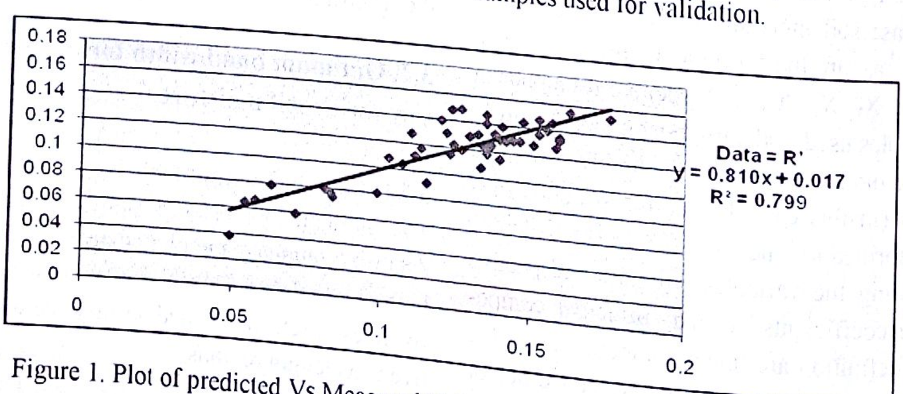


Figure 1. Plot of predicted Vs Measured Values of moisture content

## 4. Conclusions

Development of new spectra data sets from the bulk volume of raw spectral data (which was at 1nm width) through resampling at 10nm helps to minimize the dimension of data set thereby suppressing the bands in visible regions which do not contribute for moisture study. The chosen first derivative of the raw reflectance spectra was the best among other spectral parameters to develop the most fitting prediction model of soil moisture. Once the soil moisture is sufficient to cover most of the particle surfaces, additional water that fills large pore spaces will have small impacts on spectral reflectance. In contrast, absorption of water at wavelength greater than 1000nm causes any water added to have important effect on the reflectance. Although the moisture contents are less than the value where increase in moisture content will have no significant effect, the results observed from the spectral curves showed that the spectral reflectance at the NIR wavelength is more sensitive to the soil moisture variation.

Thus, the soil moisture was quantitatively analyzed based on the reflectance at NIR region which are of strong absorption bands. Thus, the regression model developed by using 180- samples in calibration data set and 60 samples for validation showed good performance of the model with coefficient of determination ($R^2 = 0.799$) using stepwise regression method and better result ($R^2 = 0.805$) was found using PCA approach. The study has scope to take up for other soils having large variation in soil moisture and other soil properties both at ground and satellite level for suggesting suitable bands and model for soil moisture estimation both at local and regional scale.

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# Evaluation of Rural Water supply and Sanitation system in Dendi woreda Oromiya Region

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**Abstract**
*The United Nation General Assembly stated that having safe and clean drinking water and sanitation is a human right. However, provision of sustainable water supply and sanitation is a serious problem in Ethiopia in vast and in Dendi woreda in particular. Therefore, this study was conducted to evaluate the sustainability of rural water supply and sanitation system in Dendi Woreda. A multistage sampling technique was used to select the Kebeles. A total of 240 questionnaires were administered in eight sampled Kebeles. Both quantitative and qualitative data were generated from primary and secondary sources through questionnaires, observation checklists, key informant interview, focus group discussions and document review. The largest (Workagara) water supply distribution system was analyzed using engineering software EPANET-2. In addition, Arc GIS software was used to generate water supply access map. The data from households were analyzed using descriptive statistical techniques and triangulated with the discussions. Fourteen water samples were also collected and analyzed using standard procedures. In addition, a cross-sectional sanitary risk assessment using a standardized format was carried out to identify risks for contamination with faecal bacteria and to see the association with water quality result. The sampled water supply schemes were from hand dug wells, shallow wells, springs and bore holes. The result indicated that higher non functionality rate was observed in boreholes (60%) and the remaining faced frequent interruption due to poor design and construction, low operation and maintenance and lack of spare parts. Inappropriate pipeline route selection and excess pressure was observed in the largest spring (Workagara). The capacity of WASHcos to manage the existing water schemes was limited. Community, especially women's participation, was ignored. The study indicated that 63.32% of the respondents pay 10 birr per m3 for water fee. However, the community consumes 9.43lcd and is found to be below the Ethiopian and WHO standards of 15 and 20 lcd with in 1.5km and 1km radius, respectively. The collection and transportation of water was done by mothers (52.92%) and daughters (43.75%). Most of the physicochemical parameters considered were with in WHO guideline for drinking water but turbid water was observed in Bete ejersa lafo (16.3FTU) and Ashene (10.3FTU). The fecal coli form indicator was found from nil to 104 cfu (coliform forming unit) per100 ml. and total coliform was from nil to too many to count. Almost all publicly used water sources were glossily polluted of fecal coli form. The result of cross-sectional sanitary risk assessment was significantly and positively correlated with water quality (r = 0.64*). Presence of animals nearby the well, poor drainage, cracked drainage canal, missing of fence and collection of spilt water in the apron area were among the identified risk factors. The respondents have traditional pit latrine type (41.3%) and the availability of latrines were strongly associated with sanitation education (r = 0.75*). Hence, the literates have better exposure toward pit latrine availability. It was observed that 57% of the respondents dispose dry wastes in open fields and 64% splashed liquid wastes any where or in their backyards. This study found that the status of water supply and sanitation system of the Woreda is poor. Thus, the donors and the municipality should give priority attention to improve the water supply and sanitary conditions. It is recommended that reevaluation of the design and construction of water supply schemes and regular disinfection of drinking water sources needs to be run. In addition, the sanitation practice should shift from drop and store/do nothing approaches to Ecological sanitation.*

***Key Words:** water supply, sanitation, water quality, sanitary survey, Dendi Woreda*

## 1. Introduction

The UN General Assembly declared the period from 2005 to 2015 as the international decade for action, "Water for Life". Most recently, the UN General Assembly again affirmed safe and clean drinking water is essential as human right to the full enjoyment of life (WHO, 2011).

This is because water and sanitation are widely recognized as an essential component of life since health and well being of a population is directly affected by the coverage of water supply and sanitation (Mengesha et al., 2004).

Despite various efforts by governmental departments and non-governmental organizations on the development of water schemes of the area like Intermon Oxfam Workagara large gravity Water supply, sanitation and hygiene promotion project, there is still a critical problem of sustainability of the water supply scheme because of poor operation and maintenance, low construction quality, low water quality, low hygiene and sanitation practice and poor design in distribution systems.

Most of the recently constructed water supply schemes are not functional as a result of frequent break down and large gaps have been observed in the sustainability of water supply and sanitation system of the Woreda. According to MoWR (2006) estimates 33% of water supply schemes in Ethiopia are non-functional at any time, with negative impacts on coverage and universal access due to lack of funds for operation and maintenance, inadequate community mobilization and commitment and lack of spare parts (Moriarty et al., 2009).This gap about sustainability issue is thus bottle neck to provide water in sustainable manner.
Currently, there will have no hesitation that the need for such study in Africa and specifically in Ethiopia, targeting to evaluate water supply and sanitation systems have paramount importance during pre and post-project phases. This research work therefore, specifically investigates about the existing water supply system in the study area, the physicochemical, bacteriological and sanitary risk assessment of the water supply system and the existing sanitation system in the study area.

## 2. Materials and Methods

### 2.1. Description of the Study Area

Dendi Woreda is one of the 20 Woredas in West Showa Zone of Oromiya Region. Dendi is the second largest Woreda next to Gindebert (2.369 km2) in West Showa Zone with a total area of 1411 $km^2$. The geographical location of Dendi district is 8° 55′ 0″ Latitude North and 38° 10′ 0″ Longitude East. In addition the highest and the lowest elevation of the district are 3270m and 1500 m, respectively.

#### 2.1.2. Data Collection and method of analysis

Table 1 below summarizes the data collection and methods used to analyse them. The schematic representation of sampling selection followed is given in Figure 1.

Table 1: Brief description of data collection and Method of analysis

| Input Data | Methods of analysis | Output |
|---|---|---|
| • Elevation, Diameter, Length and Roughness coefficient<br>• GPS reading of water supply schemes<br>• Fourteen water samples from different water supply schemes | • EPANET 2.0 based on the<br>• Arc GIS 9.3<br>• Membrane Filtration (for Bacteriological) and Atomic absorption Spectro photo metric (for Physisco chemical water samples | • Pressure at junction<br>• Water supply access map and water quality sampling points<br>• Water quality |
| • Sanitary inspection records | • The score was summed and changed to percentage | • Risks for contamination by fecal bacteria was identified |
| • Percentage of HH response, Water quality and sanitary Inspection result | • STATSTIX 8.0 | • Correlation |
| • Key Informant Interview | • Qualitative | • Qualitative Information |
| • Focus Group Discussion | • Qualitative | • Qualitative Information |
| • Secondary Data | • Document Review | • Understanding of the condition |

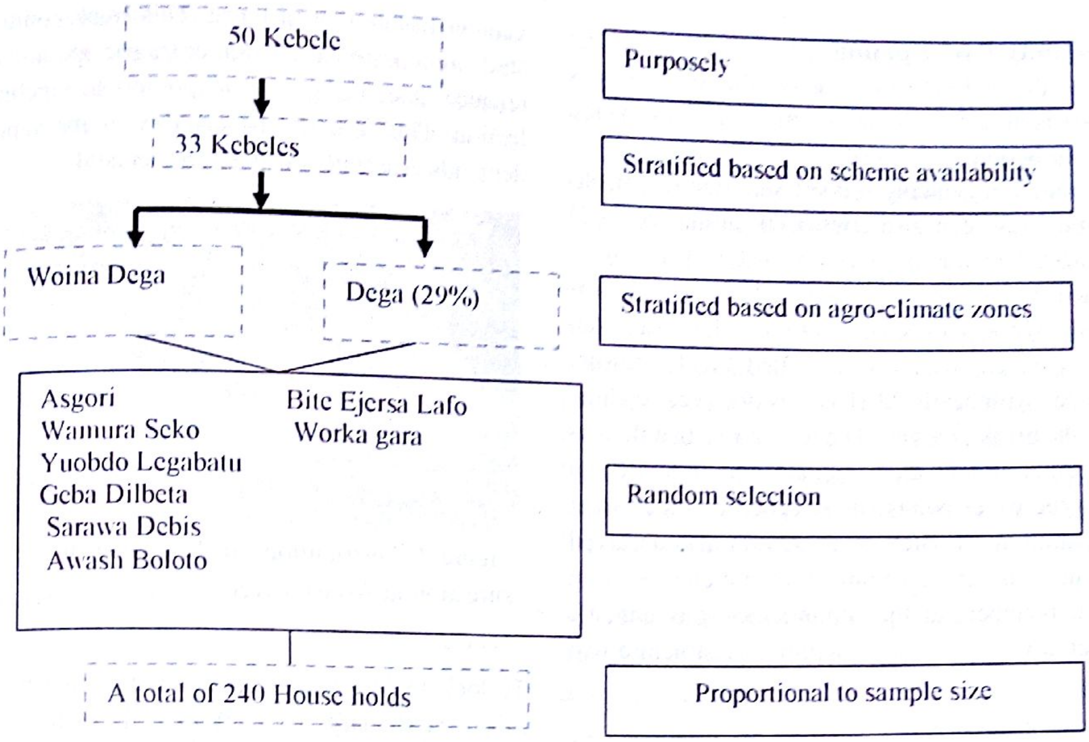


Figure 1: Schematic presentation of sampling design

## 3. Status of Water Supply Schemes

Of the constructed water supply schemes most of them are not functional for many reasons. For the major problems identified, as the causes for scheme breakdown mainly in hand dug well was flood intrusion, ground water draw down, collapsing of the well, poor committee performance, pump failure and pump taken by river. These could be the result of inappropriate site selection, poor design and construction and poor committee participation. As per the report, from the then Water Desk Officer sixteen hand dug wells were constructed in summer 2006 and the water table was found at shallow depth. However, the wells got dried soon in the winter season. Regarding the non functionality of the water points, it was reported that it was due to the failure of fittings like Couples, Gate valve, Union and Check valve.

Table 2: Functionality of water supply schemes of Dendi Woreda (Woreda Water office)

| Type of water sources | Number of total schemes | Number of functional schemes | Number of non functional schemes | Percent of non functional schemes |
|---|---|---|---|---|
| Hand dug well | 78 | 60 | 18 | 23% |
| Motorized spring | 3 | 3 | - | - |
| Medium/Shallow well | 12 | 9 | 3 | 25% |
| Bore hole | 5 | 2 | 3 | 60% |
| Gravity spring | 6 | 5 | 1 | 16% |
| On-spot spring | 8 | 5 | 3 | 38% |

### 3.1 Community Participation

According to the findings of the survey, the community is mainly participating through labor and local construction material contribution.

The participation in planning and site selection was negligible and this has been also confirmed during the FGD meeting where the participants complained that they were not consulted during site selection. One best example was the case with Workagara Kebele conflict with Water Action. The villagers who reside around break pressure "wake village" with nearly 23 HHs was observed fetching water from the break pressure. The reason was that there is no water points around there vicinity and they are not agreed with the water points site selection and they were not participating at all. Brett et al., (2007) also observed that with out considering communities preferences from the different members of the communities it is unlikely that an externally chosen water supply infrastructure will sustain longer.

### 3.2 Continuity of water supply

When the water is not available in the tap for different reasons almost 50% (n=120) of the respondents said that, they use lake water and 37% (n=89) utilize from unprotected spring. This happens especially when the scheme is non functional or when there is discontinuous supplies due to different reasons. This implies that when the water supplies is irregular, house holds are forced to use other alternative sources probably less water quality but more convenient in terms of distance. This weak continuity in the study area occurs as a result of fragile operation and maintenance, poor design and inappropriate pipeline route selection. This leads to the inability of the supply to meet demands especially during peak demand.

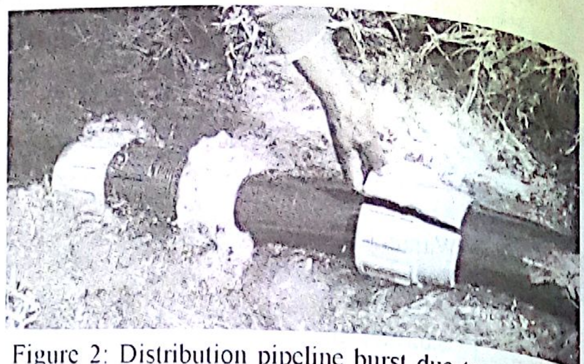

Figure 2: Distribution pipeline burst due to excess pressure around Awash River

To look for the exact problem of frequent break down of pipelines, the largest i.e. (Workagara spring) water supply distribution network was evaluated for its pressure in the nodes using EPANET-2 software based on the design document (Water action, 2006). The result shown in figure 3 indicates that the low pressure nodes are normally those at relatively high elevations (labeled in blue color). The node with red color indicates that the pressure in the pipeline is above 100 m head.

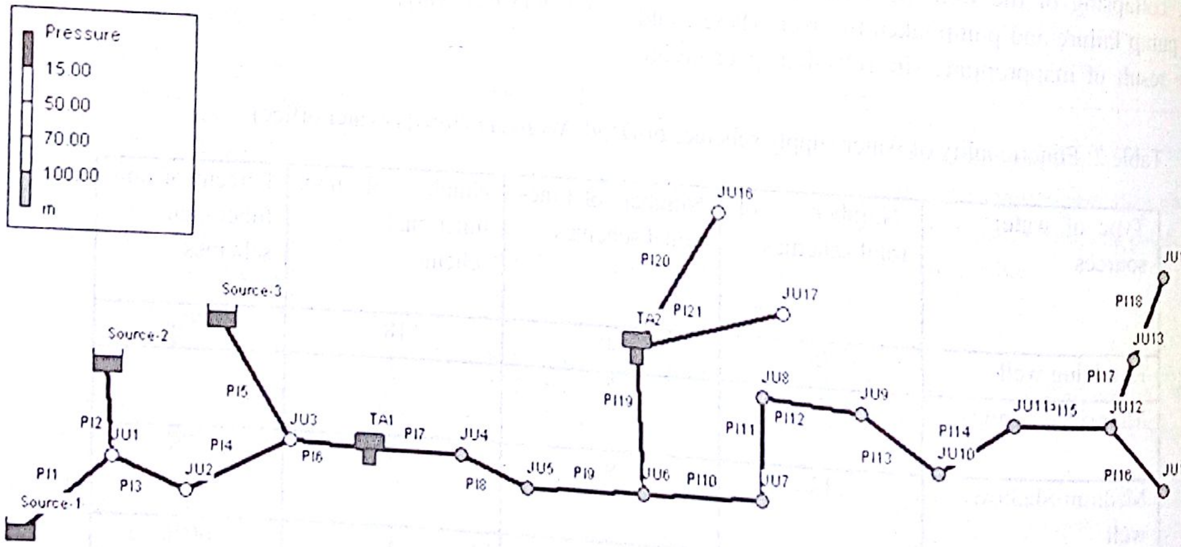


Figure 3 Workagara water supply distribution network of Dendi woreda

The Ethiopian guideline criteria for the minimum and maximum operating pressure value in the distribution network are 15 m and 70m respectively (MoWR. 2006). However. the pressure in most the distribution system was much more than 200m head for example the actual free head was 363m. while. the pipe has capacity of 100m head (10PN). Other than the incomparability of pipe rating and pressure head. the design also lacks proper material specification which can tolerate the adverse condition at this specific point. In this respect Abreham (2012) and Tizazu (2012) has observed that the main cause of water supply interruption for Hawassa and Yirgalem town was not of excess pressure. rather it was due to water shortage from the source and lack of maintenance.

### 3.3 Water consumption

The average water consumption of the total households were calculated and it was found that. on average 16.52 % ( n=40) of the households were found to use 20lit. 20.74% (n=48) of the households 40 lit. 22.62 %( n=54) of the households 60 lit and the rest 40.12 %( n=96) of the households use 80 lit of water per day. The average is about 50 lit per day. The average value of the per capita water use for the sampled Kebeles with average sampled size of 6.75 is 7.41lcd.

One of the possible reasons for the low values of daily per capita water use is that the distance to the scheme is not convenient and frequent interruption of supply. When it is compared to WHO (2003) standard. the households are below basic access (i.e. 20 lcd) and below Ethiopian rural water supply standard (i.e 15lcd) (MoWR. 2006). The volume of water used is primarily a function of proximity and it has been shown in a number of studies that once the source of water is located outside the home environment. the volume of water used decreases significantly (Howard. 2002).

### 3.4 Conveniences

The average distance people's travel to fetch water is about 1km (50 minutes). As per the JMP (2006). if the distance from the source is more than 30 minutes. people collect less water than they need to meet their basic needs. Since a large number of households are using public sources due to inconvenient location and longer waiting time. most of rural households had to go out to fetch their drinking water.

### 3.5 Water cost and willingness to pay

As per the investigation about willingness to pay for the service 63.32% (n=152) of them respond that they pay for the water while the rest don't. It was observed that. in areas where they don't pay for water fee. the scheme is less repaired when break down occurs. Since. the annual maintenance cost is covered from water fee. In areas where the community pays. they report that they pay 20 cent per 20 litter Plastic tanker which means 10birr per $m^3$. In areas where shower facilities are available i.e. in case of Intermon Oxfam target Kebeles they pay 50 cents per person mostly to stay taking shower from 20 to 30 minutes. But. the users don't pay for their cattle's. Regarding the understanding almost all respondents are willing to pay as far as they get better services.

### 3.6 Operation and Maintenance

The data shows that. 57.02% (n=136) of the water supply schemes are with water point operators. Nevertheless. the operators have not received adequate training and necessary tools to operate and maintain their system. It was found that 87% (n=288) of the respondents in the Woreda did not believe the operation and maintenance trainees had the capacity to maintain the scheme. based on the trainees' performance. About the system maintenance. emergency type maintenance is practiced. It is carried out usually when major schemes break down. Whenever a break down occurs there is no an immediate measure taken. Rather. it takes in average 2-3weeks especially when fittings are failed.

The frequent maintenance could be the result of poor design and sound construction. Other problems encountered are lack of ownership. lack of spare parts available near around. lack of capable manpower. lack of evaluation and monitoring. lack of transport. ignorance of local bodies and insufficient water fee collected.

From table 3 it is observed that the highest fecal coliform number (i.e. 104/100ml) was found in hand dug wells. In addition all of the hand dug wells were E-coli contaminated. Therefore. the result from the present study reveals that most of the people in the area are prone to water born diseases such as Typhoid. Diarrhea and the like. The people also reported that Typhoid 31 %( n=74) Intestinal parasite 48.85 %( n=117) and Diahrra 6.75 %( n=16.2) are the major diseases facing in the Worde.

## 4 Water Quality and Sanitary

### 4.1. Water Quality results

The water quality parameters of selected water supply schemes are as presented in Table 3.

Table 3: Bacteriological Water Quality of Sampled Water supply Schemes.

| No | Kebele | Site | Source | Sampling point | No. of Total colforms/100 ml | Number of Fecal coli form (cfu /100 ml) | Remark |
|---|---|---|---|---|---|---|---|
| 1 | Wamura Seko | Samonenya | HDW | HDW | TNTC | 88 | Non-potable |
| 2 | >> | Ashane | HDW | HDW | 97 | 38 | Non-potable |
| 3 | >> | Dagoye | HDW | HDW | TNTC | 104 | Non-potable |
| 4 | >> | Dugingi | HDW | HDW | 120 | 68 | Non-potable |
| 5 | >> | Dagoye | Spring | Public stand pipe | 74 | 10 | Non-potable |
| 6 | >> | Aba Kebede | Spring | Public Stand Pipe | 107 | 27 | Non-potable |
| 7 | Warka Gara | Wake | spring | Pressure break | NIL | - | Potable |
| 8 | Worka Gara | Andenya Mirt | spring | Public stand pipe | NIL | | Potable |
| 9 | Awash Boloto | Sotalo | spring | Water point | NIL | - | Potable |
| 10 | Asgori | Asgori | BH | Water point | 26 | 2 | Non-potable |
| 11 | >> | >> | BH | Reservoir | 45 | 4 | Non-potable |
| 12 | Sarawadebis | Kore | SHW | SHW | NIL | | Potable |
| 13 | Bite Ejersa Lafto | Bete Christian | SHW | SHW | TNTC | 1 | Non-potable |
| 14 | Ihud Gabaya | Ihud Gabaya | BH | Water point (private) | NIL | | potable |
| | | Note:-TNTC=Too numerous to count ,CFU Colliform forming unit, BH bore hole, SHW, shallow well, HDW, hand dug well | | | | | |

Among the hand dug wells the minimum value of fecal Coli form was found in Ashene (38/100ml) and the maximum number was counted in Degoye(104/100ml). This high level of microbial contamination was probably because the wells are located near to river, poor design and poor sanitation condition around the well. Whereas, the number of fecal colifrm count in workagara spring ranges from nil at the break pressure where the three springs (Guduru, Gogola and Harbu) meet together to 27 fecal coli form counts at the fringe water points. This is most likely due to frequent maintenance in the water distribution pipeline and intrusion of contaminants through the loosen joints. The results of the physical and chemical parameters were within the acceptable guide line limits of WHO standard for drinking water but turbid water was observed at Biteejersa lafo shallow well (16FTU) and Ashene hand dug well (10FTU).

### 4.1 Sanitary risk assessment

Table 4 describes the sanitary risk assessment scores recorded. Except the shallow well found in Sarawadebis, the rest studied water sources were at risk of contamination with bacterial fecal organisms.

The qualitative aggregate risk score varied from low to very high. Specifically, 66% of the schemes had a very high risk score (81-100%), while 16% had a medium risk score (31-50%), another 16% had low risk score. No hand dug or shallow well attained a risk score of either nil (0%).

The common risks identified were presence of animals nearby the well, poor drainage, cracked drainage canal, missing of fence, less cement around top of the well, collection of spilt water in the apron area, cracks in the cement floor, absence of diversion ditches.

The correlation of fecal coli form counts with the sanitary risk score was (r=0.63*) thus, the correlation of fecal coli form counts with the sanitary score showed that, it is a consistent with water quality result. According to lloyd and Bartman (1991) finding in a number of developing countries, the contamination in water supply schemes was significantly associated with the sanitary condition around the well.

Table 4: Hand dug and medium/shallow well sanitary inspection result

| Kebele | Name of hand dug well/ shallow well | Risk observed | Percent risk score | Qualitative risk profile |
|---|---|---|---|---|
| Wanura Seko | Samonenya | 3,4,5,6,7,8,9,11,12 | 90 | Very High |
| | Ashane | 3,4,5,6,7,8,9,10,11,12 | 100 | Very High |
| | Dagoye | 3,4,5,8,11 | 50 | Medium |
| | Dugingi | 3,4,5,6,7,8,9,10,11 | 90 | Very high |
| Sarawa debis | Kore | 3 | 10 | Low |
| Bite ejersa lafo | Bete kirestian | 3,4,5,6,7,8,9,11 | 80 | Very high |

Regarding the house and environmental sanitation in the Woreda, the result from the survey shows, there is no proper way of disposing for both dry and liquid wastes. The community simply disposes wastes in open fields indiscriminately. More than half of the dwellers 57% (n=137) in the Woreda dispose in open fields. The other 32 %( n=77) dispose in open refuse fields and 1 %( n=2) dispose in closed refuse pit and the rest 10% (n=24) burnt in open field.

This implies that most of the disposal (refuse) sites are not fenced off to prevent access by scavenging animals and degrades both the quality of the life of the community and the environment as well. Because, the solid waste which is decomposed can be used as manure, it will be supportive to encourage and teach the community about the modern sustainable sanitation system i.e. Eco San (Ecological sanitation) of decomposition of solid waste and its use as fertilizer.

According to the data, 36% (n=86) of the respondents pour the grey water in to waste pit, 38 %( n=91) splashing in to their back yard and the rest simply splash any where in their surrounding.

Among the visited households 33.16% (n= 80) disposes feces of children in side the toilet, whereas 35 %( n=84) of them dispose in the forest. Thus, the majority doesn't dispose it properly; mainly they throw it arbitrarily at their homestead. This shows that, their attitude and awareness toward the proper use of latrines is not good. Most of the respondents believed baby feces were harmless while it has been reported that baby feces that is not properly disposed might put household members at risk of diarrhea (Tumwine et al., 2003).

### 4.2. Types of latrine constructed and level of utilization

Most of the latrines constructed in the rural Kebeles are mainly water independent traditional pit latrine (TPL). The visited latrines are between 2 to 3 meters depth and they are not in a good condition.

Some of them are attached with the main house and don't have proper ventilation and lightening. Some of them don't have also properly constructed wall and roof and they are only covered with plastic sheet. However, the toilet has culturally accepted and there is no any prohibited problem in regards to the custom of the latrine.

In all Kebeles there were three types of latrines observed these are open pit latrine/without house, pit latrine with walls but without roof, and pit latrine with closed wall and roof (Table 5).

In regards to the utilization of toilet, it is difficult to estimate the utilization rate, as because day to day observation and record are required to evaluate the utilization rate. However, the house hold inspection revealed that in most of the rural Kebeles, feces were observed in the surroundings of the toilets. There was also smell around the toilet. This was in agreement with the house hold survey in which 38.88%of the toilets bowl was not covered and in most of the toilets there was no water container.

Table 6: Types of latrine constructed

| | Percent | N |
|---|---|---|
| Simple dug with out house | 17.1 | 41 |
| A house with wall and roof | 57.5 | 138 |
| A house with wall but without roof | 25.43 | 61 |
| Total | 100 | |

As per the discovery of the study 41.3% (n=99) of the interviewees constructed their own latrine. However, the latrine availability does not mean that the peoples used it regularly. Among the reasons they raise for not using the latrine regularly were due to bad smell around the compound 16.67%(n=40) feeling uncomfortable in using the latrine 27.78% (n=67), and large distance between agricultural fields and their home and latrine 55.56%(n=133). This may be due to many of the respondents were males 65%(n=156). Generally, the approach on sanitation in the study area relies mainly on two categories "Open defection" (Do nothing approach) and "Drop and store (Pit Latrines)" approach.

### 4.3. Impact of sanitation education

According to the result, 70% of the respondents in workagara Kebele have pit latrine. This may be because 68 % ( n=156) of them got sanitation education. The lowest number of pit latrine availability was observed in Biteejer-salafo. Among 34 %( n=81) who got sanitation education, only 14.7 %( n=35) have pit latrine.

The sanitation education was significant associated with pit latrine availability (r) 0.75 this implies sanitation education is the prominent factor for the existence of pit latrines in the study area. The present study was in agreement with the study conducted in Bangladeshi in which the sanitation condition was poor as a result of low level of education about sanitation (IWSC, 1989).

## 5. Summary and Conclusions

This study was aimed to evaluate the sustainability of rural water supply and sanitation system of Dendi Woreda. It focused on water supply system, sanitation system, water quality and sanitary inspection and hygiene behaviors in the study area. Dendi Woreda is mainly served by hand dug wells (78) and spring with distribution network to water points (above 56) and 12 shallow wells. However, there is a high rate of scheme and water point breakdown, which has harshly affected water service delivery. High rate of non functionality rate was observed in Boreholes. In addition, 27%of water points are not functional.

Dendi Woreda is mainly served by hand dug wells (78) and spring with distribution network to water points (above 56) and 12 shallow wells. However, there is a high rate of scheme and water point breakdown, which has harshly affected water service delivery. High rate of non functionality rate was observed in Boreholes. In addition, 27%of water points are not functional.
The cause for frequent break down was due to inappropriate site selection, poor design, poor committee participation, lack of fence and ownership. Couples, Gate valve, Union and Check valve were indentified as part of distribution system which fails frequently.

When scheme breakdowns occur, the speed of maintenance is slow and emergency type maintenance is practiced. Maintenance is carried out usually when major schemes break down. Even tough 57.02 %( n=137) of the water supply schemes are with water point operators, the operators have not received adequate training and necessary tools to operate and maintain their system. As a result, 87 %( n=208) of the respondents in the Woreda did not believe the operation and maintenance trainees had the capacity to maintain the scheme.

Most of the water points are not placed at a reasonable distance to serve the majority of the community. A number of households reported that the locations of alternate water sources are more convenient for them. About 28.5 % of the water supply schemes are found in distance greater than 2 km.

The burden of searching for water is done by Mothers 53 %( n=127) and daughters 44 %( n=105).

In general, the schemes do not provide enough water to meet the demand. The per capita consumption for the total households with average family size of 5.9 is 8.47lcd, which is less than 20 liters recommended by WHO as a minimum requirement for respecting the human right to water. It is also lower than the standard set in Ethiopian guideline to access 15 liters of water per capita within a 1.5km radius.

The pipe line route selection and installation for the largest gravity spring (Workagara) is not appropriate. Some part of it was laid on gullies and to overcome the problem neither erosion protection measures nor other mechanism was taken. It also lacks appropriate trench depth and backfilling. In addition to this, the river crossing structure was taken by flood. So that, it is afraid that the water supply system will sustain for long time unless measures are taken.

The weak continuity in the study area occurs as a result of fragile operation and maintenance, poor design and inappropriate pipeline route selection. The result of analysis of distribution system for Workagara spring shows that the pressure in the pipe line was much higher (363m head) than the pipe capacity (100 m head). This leads to frequent bursting of pipes and couplings.

Regarding the water fee almost all of the respondents are willing to pay. But, currently 63.32 %( n=152) of them responded that they pay 0.2 birr per 20litter Plastic tanker or 10 birr per $m^3$ for water fee.

Generally, sustainability of water supply system in the study area is clearly being undermined due to less community participation, in proportion of women in the WASH committee, poor design and construction, low capacity of caretaker's, less availability of spare parts and unreliable of water supply in the Woreda.

The major sanitary risk factors recognized in the study area were cracks in the infrastructure, leaks, unsanitary conditions around the source, additional potential source of pollution closer to the water, animal access to the water source, and poor drainage system. Hence, the use of local knowledge in addition to scientific methods is advised in the sitting of dug wells. There is positive co relation between water quality and sanitary inspection (r =0.63) this means, the poor sanitary condition at the well deteriorate the water quality in it.

The result of water quality at the source of the spring (Workagara) for both fecal and total coli form was within the WHO guideline of drinking water quality but, it becomes below the standard while it was tested at the users water points. This happens because the distribution pipe lines fail frequently. In general, from 38 to 104 of fecal coliform and from nil to too many to count of total coliform was observed in the water supply schemes. From the sampled sources 75% of public water sources have presumptive bacteria count above permissible limit for drinking water. This implies the potability and safety of these sources were questionable. The results of the physical and chemical parameters were within the acceptable guide line limits of WHO standard for drinking water but turbid water was observed at Biteejersa lafo shallow well (16FTU) and Ashene hand dug well (10FTU).

According to the observation made, the contamination was mainly due to lack of proper care for the water supply systems. Furthermore, lack of regular supervision, lack of disinfection and proper maintenance were the reasons for contaminating protected water sources. In this regard, the Woreda personnel raised the problem vehicle as one major obstacle they faced to make regular monitoring of the water supply systems in the Woreda.

According to the data regard to sanitation practice, 57% (n=137) of the respondents dispose dry wastes in open fields, 36 %( n=86) of the respondents pour the grey water in to waste pit, 38 %( n=91) splashing in to their back yard and the rest simply splash any where in there surrounding. From the visited households 33.16 %( n=80) of them dispose feces of children in side the toilet, whereas, 35% (n=84) of them dispose in the forest. Thus, the result from the survey reveals that dry and liquid waste handling and disposal practice in the study area is poor.

As per the finding of the survey about 41 %( n=98) of the community owns pit latrine. Most of them were with in Workagara WASH project target Kebeles. However, the level of utilization was not significant. The output of the sanitary survey also shows that there is direct relation between the availability of latrine at households and their exposure for sanitation education (r) 0.75 was significant. This shows Kebeles which are exposed to the Workagara water supply and sanitation project have more exposure to get sanitation lessons and owns latrines than others does. In general, the sanitation system in the study area falls in to two categories those are "Do Nothing" and "Drop and Store" Approach.

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# Mapping Climate Change Vulnerability: A Case Study of Selected Districts in Upper Awash River Basin, Ethiopia

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## Abstract

*Assessment and mapping of vulnerability to climate change is the first task for identifying vulnerability hotspots and then informing the development of site specific adaptation options. The present study was conducted in 11 selected districts (Dendi,Ejere, Walmara, Berehana aleltu, Akaki, Dawo, Ilu, Becho, Tole, Kersana Kondaliti and Alemgena) in Upper Awash river basin with the objective of assessing vulnerability to climate change, and producing vulnerability map that identify vulnerability hotspots. Vulnerability to climate change was analyzed using integrated vulnerability assessment approach using proxy indicators of biophysical and the socioeconomic factors. In this study, 17 biophysical and socioeconomic indicators were used to reflect the three vulnerability components: Exposure, Sensitivity and Adaptive capacity. Indicators in exposure components of vulnerability, frequency of drought was analyzed from gauged rainfall data of more than 30 years using Standard Precipitation Index (SPI) while the future climate projection, ensemble of four GCMs (CGCM3, HADGEM, MK3 and ECHAM5) data under A1B emission scenario was used to analyze the change in temperature and rainfall in 2050s from base period. The values of all indicators were normalized by considering functional relationship between the indicators and vulnerability, and expert judgment was also used to assign weights to all indicators. Using GIS environment, the aggregated vulnerability index map was produced using the weighted sum of all indicators in the three sub-indices map of Exposure, Sensitivity and Adaptive capacity. The preliminary vulnerability sub-indices result revealed that Dendi, Dawo and Welmera districts are highly exposed to the risk of drought and future change in temperature and rainfall. While, Dendi and Dawo are highly sensitive to the adverse impacts of climate change due to high human environmental interaction caused by the combined effects of large agricultural land owned by smallholder farmers, high dependency on agricultural activities and topographically slope area. Dawo and Tole districts have a higher adaptive capacity that averts the negative consequence of climate change. This is mainly due to the combined effect of high level of literacy, crop productivity, farm asset, and use of credit services. The overall vulnerability index map which is a composite of the three sub-indices maps revealed that Dawo districts is relatively highly vulnerable to the impact of climate change while Alem gena and Kersana kondaltiti are less vulnerable. The rest of districts are under relatively medium level of vulnerability to the impact of climate change. The vulnerability mapping is an important tool that helps to take effective response actions to the adverse impacts of climate change through identification of vulnerability hotspots. In line with this, the knowledge of vulnerability to climate change can assist decision makers in recommending adaptation measures and prioritizing resource allocation for specific areas as well as determining investments for adaptation measures to future impacts of climate change.*

**Key words:** *Climate change, agriculture, vulnerability, exposure, sensitivity, adaptive capacity*

## 1. Introduction

Climate change has been one of the current issues that cause severe impact on agricultural sectors: It has the potential to hold back economic progress, or reverse the gains made in Ethiopia's development and could exacerbate social and economic problems (CRGE, 2011). Besides, it will have multidimensional effect on humanity in terms of several socioeconomic parameters like agriculture, human health, sea level rise, disease prevalence etc.

Agriculture plays a great role in the livelihood of rural communities in many African countries. In Ethiopia, agriculture is the dominant sector in national economy. However, it is highly vulnerable to the impact of climate change which is manifested by recurrent drought and variable rainfall. According to the Intergovernmental Panel on Climate Change (IPCC), (2007), the worming of the climate system is unequivocal, and climate change increases the likelihood of extreme weather events such as droughts, floods, sea level rise and heat waves as well as more gradual changes in temperature and rainfall.

The predicted changes in temperatures and rainfall patterns, as well as their associated impacts on water availability, pests and disease occurrence are all likely to affect substantially the potential of agricultural production. This makes particularly small scale farmers vulnerable to the adverse impacts of climate change. Rural poor communities which are vulnerable to the adverse impact of climate change have only limited capacity to protect themselves from environmental hazards, in particular from extreme events such as drought and flood. They also bear the brunt of the consequences of large-scale environmental change, such as land degradation, biodiversity loss, and climate change. According to Temesgen et al., (2008), the impact of climate change is substantially affecting on poor people in rural areas where livelihoods of the majority depend directly on natural resources in general and agriculture in particular. This implies that climate change could have a significant adverse impact on agricultural production, which would have important implications for the wellbeing of small scale farmers unless proper adaptation options are implemented.

Assessment of the vulnerability to climate change is the base for the development of site specific adaptation options that reduce the risks associated with climate change. According to Houghton et al., (2001) and McCarthy et al., (2001), vulnerability to climate change is defined as the degree to which a system is susceptible to, or unable to cope with the adverse effects of climate change, including climate variability and extremes. Vulnerability has different meaning in different disciplines. Liverman (1990) noted that vulnerability has been equated to concepts such as resilience, risk, marginality, adaptability, and exposure. This diversity of conceptualization is due to the fact that the term vulnerability has been used in different policy contexts, referring to different systems exposed to different hazards.

Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (McCarthy et al. 2001). Luers et al. (2003) proposed a method for quantifying vulnerability based on its three components: exposure, sensitivity, and adaptive capacity. Exposure can be interpreted as the direct danger, and the nature and extent of changes to a region's climate variables (e.g., temperature, precipitation, extreme weather events); Sensitivity describes the human–environmental conditions that can worsen the hazard, ameliorate the hazard, or trigger an impact, and Adaptive capacity represents the potential to implement adaptation measures that help avert potential impacts. In order to develop site specific adaptation options, identification of vulnerable hotspot to climate change is the first task to be done. The level of vulnerability of different areas to climate change is determined by both socioeconomic and environmental factors. The socioeconomic factors include the level of technological development, infrastructure and institutional linkage (Kelly and Adger 2000; McCarthy et al. 2001) while the environmental attributes are climatic conditions, quality of soil, and availability of water for irrigation (O'Brien et al. 2004). The variations of these socioeconomic and environmental factors across different social groups are responsible for the differences in their levels of vulnerability to climate change. Besides, the degree to which climatic risks affect an agricultural system and make it vulnerable depends on a wide variety of factors, including the types of crops or livestock produced, the scale of the farm operations, the quality of the natural resource base, and human resources. In general the poor rural people who do not have access to different livelihood options, infrastructure, and institutional setups are known to be the most vulnerable. The degree of vulnerability is mediated by availability of different technologies, human and financial capital and management capabilities.

Approaches to vulnerability assessment attempt to explore questions about who and what are vulnerable, to what extent are they vulnerable, their degree of vulnerability, the causes of their vulnerability, and what responses can lessen their vulnerability (Downing et al. 2001). Despite many challenges that exist in quantifying vulnerability, several quantitative and semi-quantitative metrics have been proposed and applied. Amongst them, the indicator approach is the one widely applied to quantify vulnerability based on selecting biophysical and socioeconomic indicators and then systematically combining the selected indicators to indicate the levels of vulnerability (Cutter, et al., 2003). The indicator approach is the most common method adopted for quantifying vulnerability in the global change community. Hebb and Mortsch (2007) also expressed that indicator approach is used to develop a better understanding of the socioeconomic and biophysical factors contributing to vulnerability.

Vulnerability map are needed for practical decision-making processes, such as to provide policy makers with appropriate information about where the most vulnerable areas are located. In line of this, the present study was carried out with the objective of identifying different level of vulnerability to climate change and producing vulnerability map that helps to determine site specific adaptation options to the current and future impacts of climate change.

## 2. Materials and Methods

### 2.1. Description of the study sites

A study was conducted in eleven selected districts in delineated watershed (Fig.1) which is found in Upper Awash River Basin. The districts are Dendi. Eje Walmara. Dawo. Ilu. Becho. Tole. Kersana Kondaltiti. Alemgena. Berchana Aleltu and Akaki.

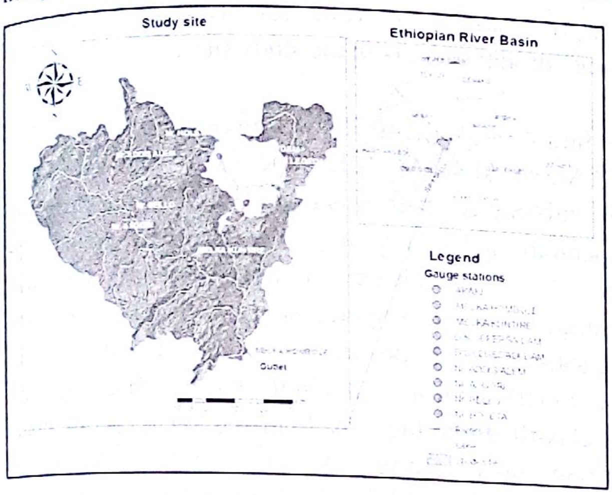


Figure 1: Location map of the study area

### 2.2. Data collection

Biophysical and socioeconomic data used for vulnerability analysis were collected for study sites. After defining the biophysical and socioeconomic vulnerability indicators (Table 1). primary data such as frequency of drought and change in rainfall and temperature was generated through analysis while. the secondary data was collected from various sources: National Meteorology Agency (NMA). Central Statistical Agency (CSA). CCAFS GCM data portal and International Food Policy Research Institute (IFPRI). Vulnerability is understood as a function of three components: exposure. sensitivity and adaptive capacity. which are influenced by a range of biophysical and socio-economic factors (TERI. 2003). Thus. in this study. 17 biophysical and socioeconomic indicators were identified and used to reflect the three vulnerability components: Exposure. Sensitivity and Adaptive capacity (Table 1).

Table 1: List of identified indicators and their relationship with vulnerability by vulnerability components

| Vulnerability components | Indicators | Description of indicators | Relationship with vulnerability to climate change |
|---|---|---|---|
| Exposure | Extremes Climate events | Frequency of drought | Increasing |
| | Change in climate variables from the base year | Change in Maximum and Minimum temperature; Change in Rainfall | Increasing |
| Sensitivity | Rural population density | Total population per $Km^2$ | Increasing |
| | Dependency ratio | Percentage of unemployment | Increasing |
| | Proportion of Household fully engaged in Agriculture | Agricultural household heads | Increasing |
| | Crop diversification index | Percentage of area under a major crops | Decreasing |
| | Access to water sources | Percentage of population to proximity to water source | Decreasing |
| | Topography | Percentage of sloppy area | Increasing |
| Adaptive capacity | Literacy rate | Proportion of agricultural population aged 15 years and older who can read and write | Decreasing |
| | Farm organization | Percentage of farmers utilizing advisory services | Decreasing |
| | Access to credit | Percentage of farmers utilizing credit service | Decreasing |
| | Crop production per unit area | Amount of Yield per hectares | Decreasing |
| | Land area under smallholder farmers | Percentage of total land area | Increasing |
| | Access to market ` | All weather road density | Decreasing |
| | Farm asset | Total value of farm asset | Decreasing |

## 2.3. Data analysis

Vulnerability to climate change was analyzed using integrated vulnerability assessment approach using proxy indicators of biophysical and the socioeconomic factors that reflect the three vulnerability components: Exposure, Sensitivity and Adaptive capacity.

The socioeconomic and biophysical indicators mentioned in table 1 were used to measures the level of vulnerability by computing sub-indices of exposure, sensitivity and adaptive capacity and come up with an aggregate vulnerability index. In order to standardize, and ensure that the value of all the indicators are comparable (Vincent 2004), normalization was computed using the formula (Equ.1&2) by considering functional relationship between the indicators and vulnerability to climate change.

If the indicator is hypothesized to increase vulnerability, then .

$$VI = \frac{AcV - MinV}{MaxV - MinV} \qquad (1)$$

Whereas, if the indicator is hypothesized to decrease vulnerability, then

$$VI = \frac{MaxV - AcV}{MaxV - MinV} \qquad (2)$$

Where, VI= vulnerability index; AcV=actual value; MinV= minimum value; MaxV=maximum value

After normalizing, expert judgment (Brooks et al. 2005; Moss et al. 2001) was used to assign weights to all indicators in order to ensure that large variation in any one of the indicators would not largely dominate the contribution of the rest of the indicators.

Exposure components of vulnerability, frequency of drought and change in rainfall and temperatures were analyzed using Standard Precipitation Index (SPI) and GCMs outputs, respectively. Mckee et al. (1993) noted that SPI is the most widely used index for quantifying the frequency of drought events. Thus, the frequency of drought event was calculated using SPI index using the following equation:

$$SPI = \frac{(Xij - Xim)}{\sigma} \qquad (3)$$

Where, $X_{ij}$= is the seasonal precipitation and, $X_{im}$ is its long-term seasonal mean and σ is its standard deviation.

SPI was calculated using seasonal rainfall data from the stations found in and around the study sites which have 30 and more years of rainfall data. An inverse distance weight (IDW) interpolation technique was used to interpolate the value of rainfall data of the area where meteorological stations are not found. In this study, the frequency of drought having SPI value less than -1.5 was used to indicate drought events in the study sites.

The future climate projection, ensemble of four GCMs (CGCM3, HADGEM, MK3 and ECHAM5) data under A1B emission scenario was used to analyze the change in temperature and rainfall in 2050s from base period. Finally, the climate change vulnerability index map was produced using the weighted sum of all indicators in the three sub-indices: Exposure, Sensitivity and Adaptive Capacity in GIS environment. On the basis of index, districts were classified into high, medium and low level of vulnerability to climate change. Medium level of vulnerability was defined as an index within one standard deviation unit of the whole districts index mean. While High and low level were greater than and less than 1 standard deviation unit above or below the whole districts index mean, respectively.

# 3. Results and Discussions

## 3.1. Analysis of vulnerability using vulnerability components

### 3.1.1. Exposure index

The future climate projection, ensemble1 of four GCMs (CGCM3, HADGEM, MK3 and ECHAM5) data under A1B emission scenario revealed that there would be a change in rainfall and mean temperature by 2050. The spatial trends in Fig 2 shows that change in seasonal rainfall ranges from -5- 3.7 percent while average seasonal mean temperature from 1.2 – 3.3°C. This result was used as a proxy indicator for measure of exposure to future climate change in vulnerability analysis.

The exposure index is related to the frequency of climate hazards. The preliminary result indicated that Dendi, Dawo and Welmera districts are highly exposed to the risk of drought and future change in temperature and rainfall (Fig. 3), while Ilu and Keresana kondoltiti districts have relatively less exposure. The remaining districts are moderately exposed. In view of the result, the current and future exposure to adverse impacts of climate change helps indicate the likely occurrence of climate related hazard and their impacts in wide economic sectors.

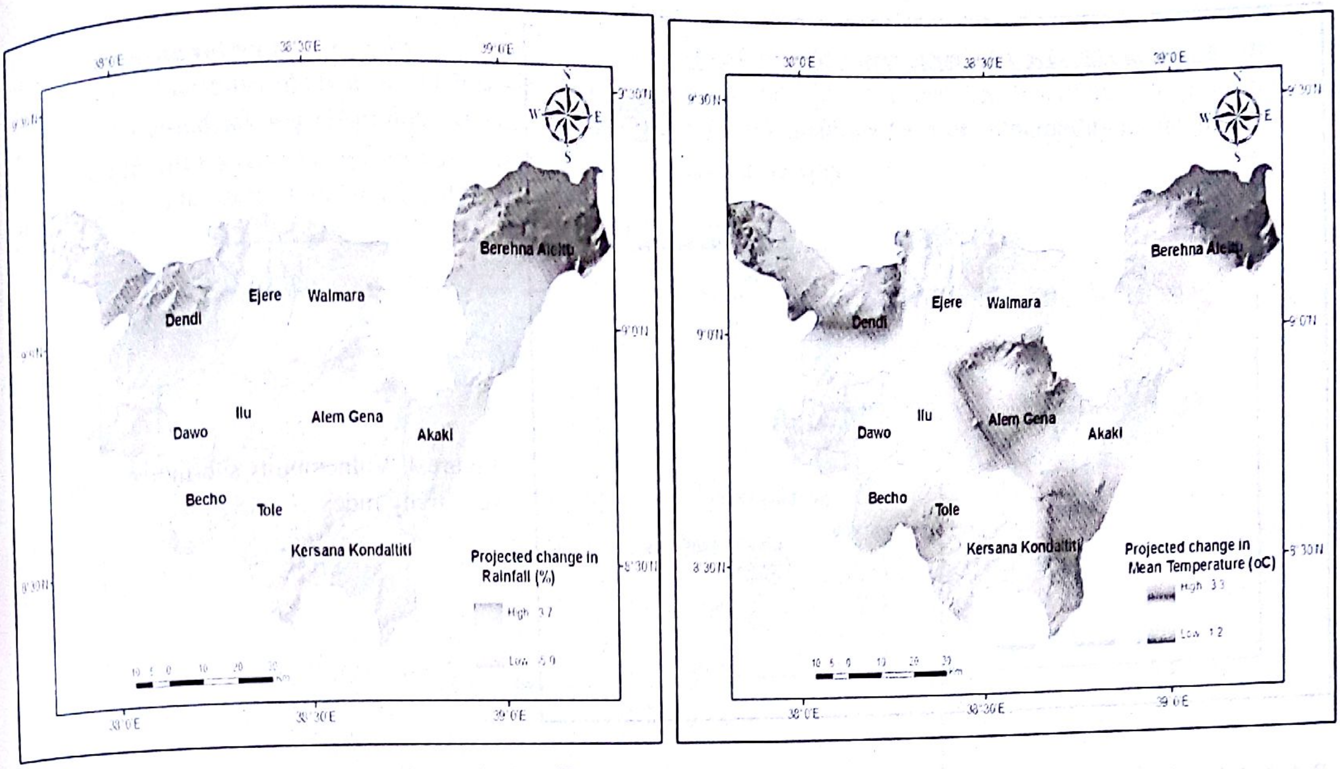


Figure 2: Projected Change in Rainfall and Mean Temperature

### 3.1.2. Sensitivity Index

Results from the sensitivity analyses revealed that Dendi and Dawo districts were relatively highly sensitive to the adverse impacts of climate change due to high human environmental interactions (Fig.4) caused by combined effects of large agricultural land owned by smallholder farmers, high dependency on agricultural activities and topographically slope area. The least sensitive districts are Ilu and Alem gena districts. From the result, the overall sensitivity index holds higher weight on livelihood sensitivity except for crop diversification and accessibility to water source as the result of which the impact of climate change on the livelihood of the farmers is expected to be more severe.

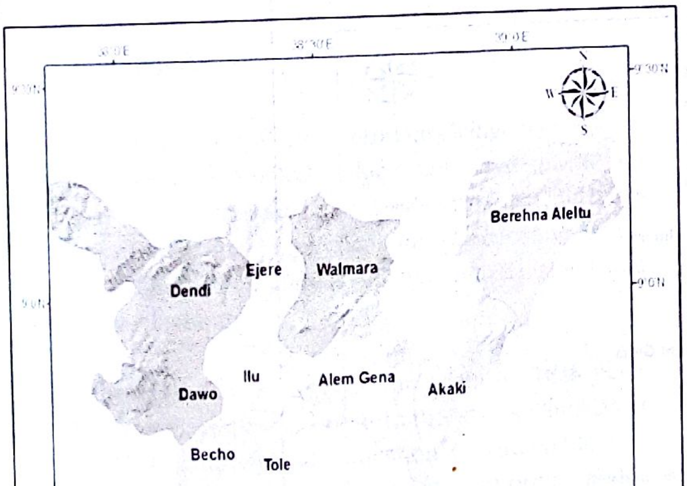


Figure 3: Vulnerability sub-indices map: Exposure index

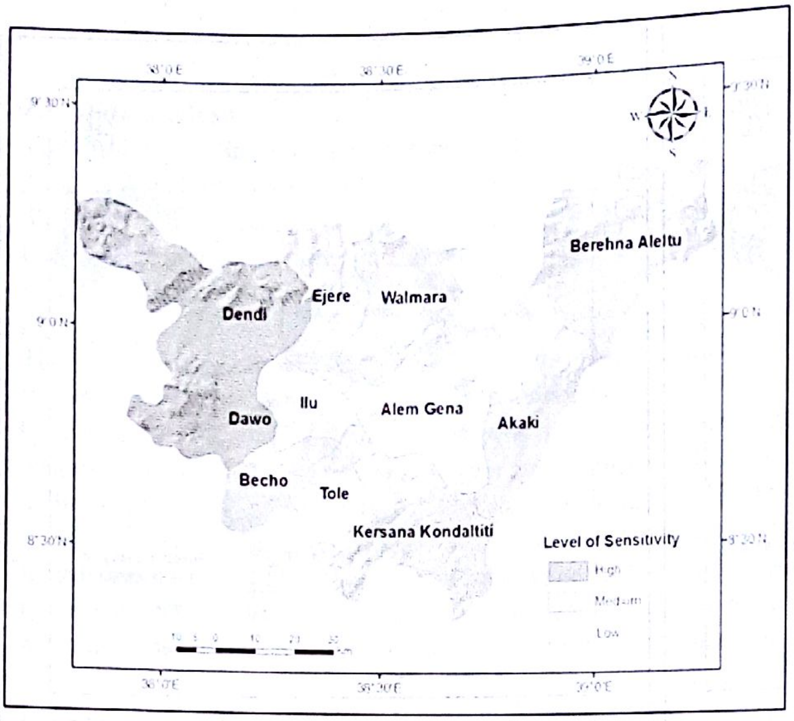


Figure 4. Vulnerability sub-indices map: sensitivity index

### 3.1.3. Adaptive capacity Index

The analyses of adaptive capacity sub-indices shows that majority of the districts have medium level of adaptive capacity that could avert the negative consequence of climate change. Dawo and Tole districts have relatively higher adaptive capacity (fig.5). This is mainly due to the combined effect of high level of literacy, crop productivity, farm asset, and use of credit services. Ejere, Alem gena and Kersana Kondaltiti districts have relatively lower adaptive capacity, while the rest of the districts showing medium level adaptive capacity. The result implies that both socioeconomic and infrastructural asset distribution makes the majority of the area to build capacity to respond to the climate risks.

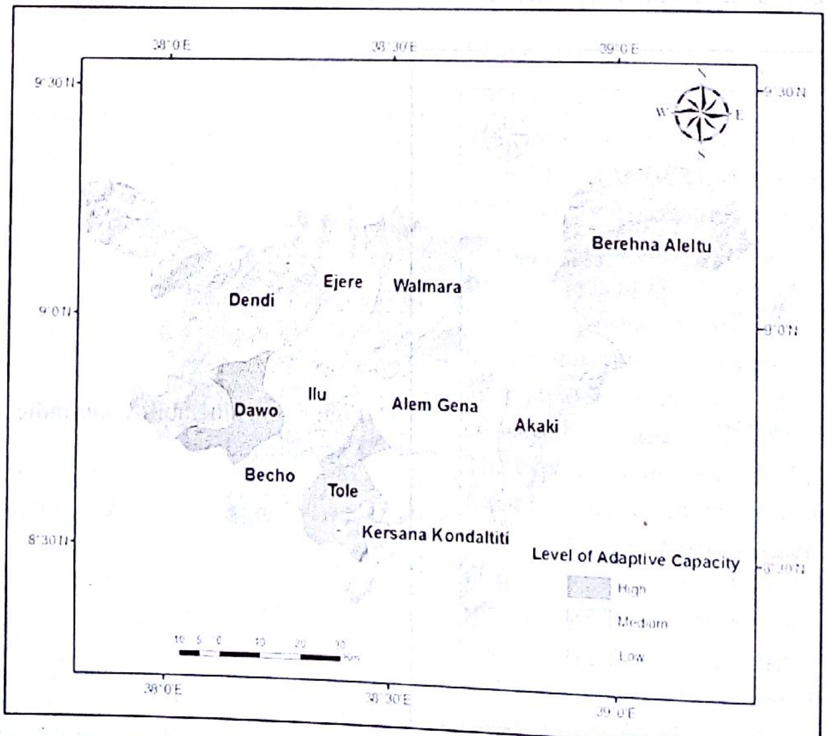


Figure 5. Vulnerability sub-indices map: Adaptive capacity index

### 3.1.4. Aggregate vulnerability index

The overall vulnerability index map which is a composite of the three sub-indices map (Exposure, Sensitivity and Adaptive capacity) revealed that Dawo district is relatively highly vulnerable to the impact of climate change (Fig.6.) while Alem gena and Kersana kondaltiti districts are less vulnerable. The rest of districts are under relatively medium level of vulnerability to the impact of climate change.

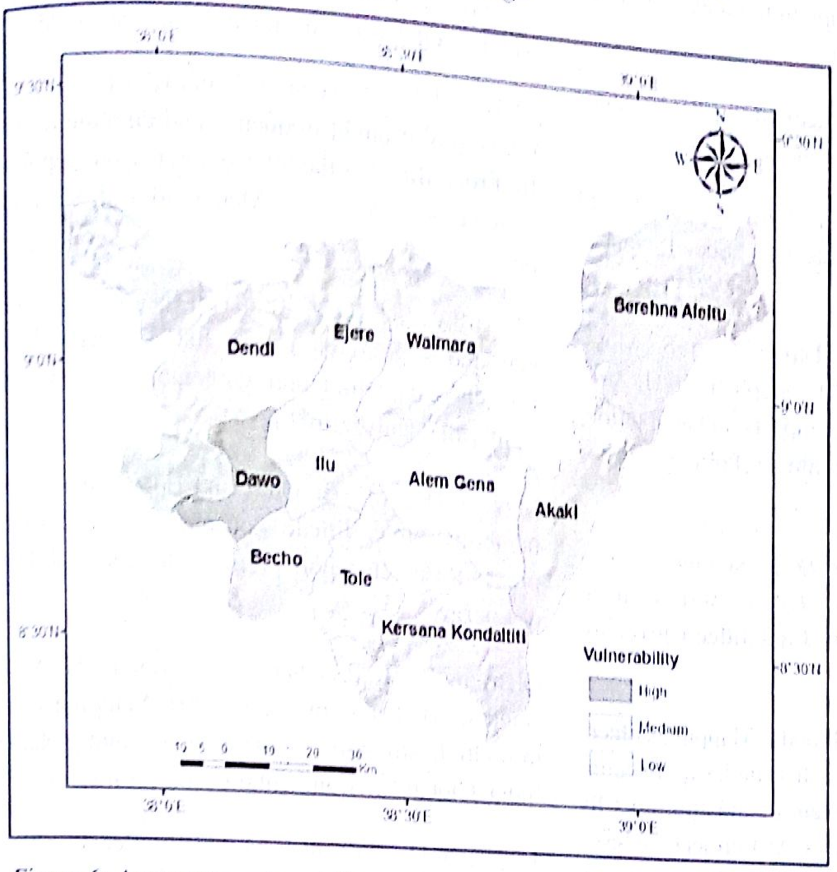


Figure 6: Aggregate vulnerability map

## 4. Conclusions

Assessment of vulnerability to climate change using proxy indicator based integrated vulnerability assessment approaches are paramount importance in order indentify hotspots of integrated biophysical and socioeconomic vulnerability for further climate change impact study and adaptation planning.

The vulnerability mapping is an important tool that helps to take effective response actions to the adverse impacts of climate change through identification of vulnerable hotspots. This also helps to generate baseline information that helps to conduct further impact study in real time situation and the future for generating different adaptation options within relatively large geographical area.

The knowledge of vulnerability to climate change can assist decision makers in recommending the existing adaptation measures and prioritizing resource allocation for specific areas as well as determining investments for adaptation to future impacts of climate change. Besides, the need for further site specific impact and adaptation studies should be made based on such identification of risk levels of specific locations.

## Acknowledgments

The authors acknowledge North, East, West and South West shewa zone agricultural and rural development offices and their respective Woreda offices, International Food Policy Research Institute (IFPRI), National Meteorology Agency (NMA), Central Statistical Agency (CSA), and CCAFS for their cooperation in providing all necessary information. The authors also gratefully acknowledge Melkassa Agricultural Research Center based Biometrics, GIS and Agrometerology support process researchers for their valuable comments on the draft manuscript.

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# A review Paper on Smallholder Traditional Farmers' and Indigenous Peoples' Strategies for Climate Change Mitigation

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## Abstract

*The world is now facing a new era of climate change and the impacts of climate change are already being felt everywhere, particularly in the developing countries and small islands. The local knowledge systems and agricultural practices and techniques adopted by local people remain the dominant form of coping mechanisms/responses to climate change. Lessons from the past show that thousands of traditional farmers in many rural areas have evolved and adapted to ever-changing environments by developing diverse and resilient farming systems in response to different opportunities and constraints faced over time. Many of these agricultural systems around the world serve as models of sustainability that offer examples of adaptation measures that can help millions of rural people to reduce their vulnerability to the impact of climate change and to maintain ecosystem goods and services. Some of these adaptation strategies include: use of locally adapted varieties/species exhibiting more appropriate thermal time and vernalization requirements and/or with increased resistance to heat shock and drought; enhancing organic content of soils through compost, green manures, cover crops, etc., thus increasing water holding capacity; wider use of local knowledge and practical means to "harvest" water and conserve soil moisture (e.g., crop residue retention and mulching), and more effective use of irrigation water; managing water to prevent water logging, erosion, and nutrient leaching where rainfall increases; use of crop diversification strategies (intercropping, agro forestry, crop-sequencing, etc.) and integration with other farming activities such as livestock raising; preventing pest, disease, and weed infestations via management practices that enhance biological and other natural regulation mechanisms (antagonisms, allelopathy, etc.), and development and use of varieties and species resistant to pests and diseases; and using climate forecasting to reduce production risk.*

## Introduction

THE threat of global climate change has caused concern among scientists as crop growth could be severely affected by changes in key climatic variables (i.e., rainfall and temperature) and agricultural production and food security could be affected both globally and locally. Although the effects of changes in climate on crop yields are likely to vary greatly from region to region, anticipated changes are expected to have large and far-reaching effects predominantly in tropical zones of the developing world with precipitation regimes ranging from semiarid to humid (Cline 2007). Hazards include increased flooding in low-lying areas, greater frequency and severity of droughts in semiarid areas, and excessive heat conditions, all of which can limit crop growth and yields. The Intergovernmental Panel on Climate Change (IPCC) in its fourth Assessment report (IPCC 2007) warns that warming by 2100 will be worse than previously expected, with a probable temperature rise of 1.8°C to 4°C and a possible rise of up to 6.4°C. As temperatures continue to rise, the impacts on agriculture will be significant (Doering et al. 2002). These impacts are already being experienced by many communities in countries of the Southern hemisphere. There will also be an increase in droughts and heavy precipitation events, which will further damage crops through crop failure, flooding, soil erosion (including wind erosion). An increase in intense tropical cyclone activities will cause crop damage in coastal ecosystems, while sea level rise will reduce cropping areas and will salinize coastal aquifers. Pacific islands and large deltas are already being affected by these phenomena. The adverse effects of climate change will be felt most acutely by populations particularly in developing countries who have contributed least to climate change but who are already in *vulnerable situations*, owing to factors such as geography, poverty, gender, age, indigenous or minority status and disability.

- gradual changes like melting of snow and ice, thawing of frozen ground, and shrinking of sea ice;
- sea-level rise and higher water temperatures;
- increased frequency of hot extremes and heat waves;
- increases in heavy precipitation events and droughts.

- increased intensity of sudden impacts in the form of weather-related disasters such as tropical cyclones, hurricanes, and floods;
- increases in heavy precipitation events and droughts.

Undoubtedly, the livelihoods of thousands of smallholder/traditional family farming communities and indigenous peoples in the developing world will be severely impacted by climatic changes. It is therefore critical that implications of climate change for food security are explored and understood not only at global and national levels but also at local level. It is also imperative to have a better understanding on how to sustain and combine indigenous agricultural knowledge systems and scientific knowledge, and how to translate this into decision- making processes that provide the necessary support to the local peoples. Lessons from the past show that thousands of traditional farmers in many rural areas have evolved and adapted to ever-changing environments by developing diverse and resilient farming systems in response to different opportunities and constraints faced over time. Many of these agricultural systems around the world serve as models of sustainability.

Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history. Between 1960 and 2005, the demand for ecosystem services grew significantly as the world population doubled to over 6 billion people and the global economy increased more than six fold. To meet these growing demands, food production increased by roughly two-and-a-half times, water use doubled, wood harvests for pulp and paper production tripled, and timber production increased by more than half (Stockholm Environment Institute 2007).

Agriculture is an essential component of societal well-being and it occupies 40 percent of the land surface, consumes 70 percent of global water resources and exploits biodiversity at genetic, species and ecosystem levels. At every point of production, agriculture influences and is influenced by ecosystems, biodiversity, climate and the economy. Destabilization of long-established production systems via stresses such as water shortages, salinity, aridity and heat has increased, in the light of a growing demand for food which poses serious challenges to humankind. Furthermore, the expected increase of bio-fuel monoculture production may lead to increased rates of biodiversity loss and genetic erosion. A key challenge will be how to safeguard biodiversity for food and agriculture for future generations as well as maintain a broad gene pool which ensures ecosystem resilience.

### *Impacts of Climate Change on Smallholders Family Farming Communities*

Apart from the landless and urban poor, small farmers are among the most disadvantaged and vulnerable groups in the developing world. The share of surveyed smallholder households falling below the poverty line is close to 55 percent in most continents. Most climate change models predict that damage will be disproportionately borne by small farmers, particularly rain-fed agriculturalists in the Third World.

In some African countries, yields from *rain-fed agriculture* – the predominant form of agriculture in Africa – could be reduced by 50 percent by 2020. Additionally, agricultural production in many African countries is projected to be severely compromised especially in dry lands. About 70 percent of Africans depend directly on dry and sub-humid lands for their daily livelihoods.

Jones and Thornton (2003) predict an overall reduction of 10 percent in maize production in the year 2055 in Africa and Latin America, equivalent to losses of $2 billion per year, affecting principally 40 million poor livestock keepers in mixed systems of Latin America and 130 million in those of sub-Saharan Africa. These yield losses will intensify as temperatures increase and rainfall differences are less conducive to maize production. It is obvious that climate-related environmental stresses are likely to affect individual households differently compared to more market-oriented farmers. Some researchers predict that as climate change reduces crop yields, the effects on the wellfare of subsistence farming families may be quite severe, especially if the subsistence component of productivity is reduced. Changes in quality and quantity of production may affect the labor productivity of the farmer and negatively influence his/ her family health (Rosenzweig and Hillel 1998).

Models on plant diseases indicate that climate change could alter stages and rates of development of certain pathogens, modify host resistance, and result in changes in the physiology of host-pathogen interactions. The most likely consequences are shifts in the geographical distribution of host and pathogen and increased crop losses, caused in part by changes in the efficacy of control strategies.

Altered wind patterns may change the spread of bacteria and fungi that are the agents of windborne plant diseases. The limited literature in this area suggests that the most likely impact of climate change will be felt in three areas: in losses from plant diseases, in the efficacy of disease management strategies and in the geographical distribution of plant diseases. Climate change could have positive, negative or no impact on individual plant diseases, but with increased temperatures and humidity many pathogens are predicted to increase in severity.

| Box 1. Possible impacts of climate change on agriculture, forestry and ecosystems<br>Affected Potential Impacts Region | |
|---|---|
| Africa | By 2025, approximately 480 million people in Africa could be living in water-scarce or water stressed areas. By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50 percent. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition. |
| Asia | By the 2050s, freshwater availability in Central, South, East, and Southeast Asia, particularly in Large river basins, is projected to decrease. |
| Latin America | By mid-century increases in temperature and associated decreases in soil water are projected to lead to a gradual replacement of tropical forest by savannah in eastern Amazonia. Semiarid vegetation will tend to be replaced by arid-land vegetation. Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones, soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase. |

Source: FAO (2008), based on information from IPCC (2007)

The possible increases in pest and disease infestations may bring about greater use of chemical pesticides to control them, a situation that may enhance production costs and also increase environmental problems associated with agrochemical use. Of course, this may not be the case with farmers who use poly-cultures, agro forestry or other forms of diversified cropping systems that prevent insect pest buildup either because one crop may be planted as a diversionary host, protecting other, more susceptible or more economically valuable crops from serious damage, or because crops grown simultaneously enhance the abundance of predators and parasites which provide biological suppression of pest densities (Altieri and Nicholls 2004).

*These agro ecosystems that are of global importance to food and agriculture are based on cultivation of a diversity of crops and varieties in time and space that have allowed traditional farmers to avert risks and maximize harvest security in uncertain and marginal environments, under low levels of technology and with limited environmental impact. Such biodiversity farms are endowed with nutrient-enriching plants, insect predators, pollinators, nitrogen-fixing and nitrogen-decomposing bacteria, and a variety of other organisms that perform various beneficial ecological functions.*

By properly assembling a functional biodiversity (that is, a collection of organisms that play key functions in the farm), it is possible to promote synergy which enhances farm processes such as the activation of soil biology, the recycling of nutrients, the enhancement of biological pest suppression, etc., all important in determining the performance of agro ecosystems.

Recent observations, studies and research suggest that many farmers cope and even prepare for climate change, minimizing crop failure through increased use of drought-tolerant local varieties, water harvesting, extensive planting, mixed cropping, agro forestry, opportunistic weeding, wild plant gathering and a series of other traditional farming system techniques.

These points lead to the need to re-evaluate indigenous technology as a key source of information on adaptive capacity centered on the selective, experimental and resilient capabilities of farmers in dealing with climate change. Observations of agricultural performance after extreme climatic events in the last two décades have revealed that resiliency to climate disasters is closely linked to levels of farm biodiversity.

A survey conducted in hillsides after Hurricane Mitch in Central America showed that farmers using diversification practices such as cover crops, intercropping and agro forestry suffered less damage than their conventional neighbours using monocultures. The survey, spearheaded by the Campesino a Campesino movement, mobilized 100 farmer-technician teams and 1,743 farmers to carry out paired observations of specific agro ecological indicators on 1,804 neighboring sustainable and conventional farms. The study spanned 360 communities and 24 departments in Nicaragua, Honduras and Guatemala. It was found that sustainable plots had 20 to 40 percent more topsoil, greater soil moisture and less erosion and experienced lower economic losses than their conventional neighbours (Holt- Gimenez 2001).
The 1991/92 drought had a crippling effect over much of Southern Africa, with many countries in the region having seasonal deficits of up to 80 percent of normal rainfall.

There were unprecedented crop failures. The region, usually a food exporter, had to import 11.6 million tons of food worth over US$4 billion. Regional grain production fell some 60 percent short of expected levels. The drought led to widespread hunger and malnutrition with loss of cattle and crops. Farmers' responses to the effects of the drought were varied. In Zimbabwe, farmers, especially women in Nyanga, Chipinge, Mudzi, Chivi and Gwanda districts, undertook many actions to mitigate drought and these resulted in at least some level of food security. The following are some of the measures employed:

⇒ *Permaculture*: Helps farmers prepare for drought through land use designs that enhance crop diversity and water conservation.

⇒ *Water harvesting*: Farmers harvest water from rooftops and divert water from natural springs into tanks. This ensures that they have a substantial amount of water stored up. In case of a drought, the stored water will be able to sustain them for about five months depending on the volume of the tank. The water is also used for supplementary irrigation of vegetables and crops.

⇒ *Infiltration pits*: Some farmers dig infiltration pits along contours. Water collects in the pits during the rainy period. When the weather becomes dry, as in the case of a short period of rains, the water infiltrates underground and is used by the plants. Crops can grow up to maturity by using this conserved moisture. Farmers' experience shows that even if there are only five days with rain in the whole rainy season, the crops will reach maturity using conserved and harvested water in the pits.

⇒ *Granaries*: Most farmers store food to be used in case of a drought. They have a specific granary stocked with grain (sorghum, millets, and maize for a shorter period of time), especially those resistant to post-harvest pests.

⇒ *Drought-tolerant crops*: Many farmers prefer the use of traditional grains such as millets and sorghums that are more drought-resistant than maize and therefore give a good yield even with very little rain. Farmers also prefer specific crop varieties for drought seasons, such as an indigenous finger millet variety (chiraufe), a cucurbit (Nyamunhororo), as it ripens fast, and an early maturing cowpea (*Vigna unguiculata*) variety.

These examples are of great significance as they point the way for resource-poor farmers living in marginal environments, providing the basis for adaptive natural resource management strategies that privilege the diversification of cropping systems which lead to greater stability and ecological resiliency under climatic extremes.

### *Coping Mechanisms and Strategies to Enhance Resiliency to Climatic Variability*

In many areas of the world peasants have often developed farming systems adapted to the local conditions, enabling farmers to generate sustained yields to meet their subsistence needs, despite marginal land endowments, climatic variability and low use of external inputs (Wilken 1987; Denevan 1995). Part of this performance is linked to the high levels of agro biodiversity exhibited by traditional agro ecosystems, which in turn positively influence agro ecosystem function (Vandermeer (ed.) 2002). Diversification is therefore an important farm strategy for managing production risk in small farming systems.

In general, traditional agro ecosystems are less vulnerable to catastrophic loss because they grow a wide range of crops and varieties in various spatial and temporal arrangements. Examples of the coping mechanisms and strategies used by smallholder traditional/indigenous family farming communities to enhance resiliency against climatic variability are:

## A) Multiple cropping or poly-culture systems

By employing multiple cropping or poly-culture systems, traditional farmers can adapt to local conditions, and sustainably manage harsh environments and meet their subsistence needs without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science. Indigenous farmers tend to combine various production systems as part of a typical household resource management scheme. Natarajan and Willey (1986) examined the effect of drought on enhanced yields with poly-cultures by manipulating water stress on intercrops of sorghum (*Sorghum bicolor*) and peanut (*Arachis* spp.), millet (*Panicum* spp.) and peanut, and sorghum and millet. All the intercrops over yielded consistently at five levels of moisture availability, ranging from 297 to 584 mm of water applied over the cropping season. Quite interestingly, the rate of over yielding actually increased with water stress, such that the relative differences in productivity between monocultures and poly-cultures became more accentuated as stress increased. These types of ecological studies suggest that more diverse plant communities are more resistant to disturbance and more resilient to environmental perturbations (Vandermeer (ed.) 2002).

## B) Agro forestry systems and mulching

Many farmers grow crops in agro forestry designs and shade tree cover to protect crop plants against extremes in the microclimate and soil moisture fluctuation. Farmers influence the microclimate by retaining and planting trees, which reduce temperature, wind velocity, evaporation and direct exposure to sunlight and intercept hail and rain. Lin (2007) found that in coffee agro ecosystems in Chiapas, Mexico, temperature, humidity and solar radiation fluctuations increased significantly as shade cover decreased; thus, it was concluded that shade cover was directly related to the mitigation of variability in the microclimate and soil moisture for the coffee crop. Clearly, the presence of trees in agro forestry designs stands out as a key strategy for mitigation of microclimate variability in smallholder farming systems.

### *Use of local genetic diversity*

In addition to adopting a strategy of inter-specific diversity, many resource-poor farmers also exploit intra-specific diversity by growing, at the same time and in the same field, different cultivars of the same crop. In a worldwide survey of crop varietal diversity on farm involving 27 crops, Jarvis et al. (2007) found that considerable crop genetic diversity continues to be maintained on farm in the form of traditional crop varieties, especially of major staple crops. In most cases, farmers maintain diversity as insurance against future environmental change or to meet social and economic needs. Many researchers have concluded that variety richness enhances productivity and reduces yield variability, but as Di Falco et al. (2007) found in their study of wheat genetic diversity in the highlands of Ethiopia, the richness must reach a certain threshold level, as apparently reduced yield variability only occurs at high levels of genetic diversity.

The existence of genetic diversity has special significance for the maintenance and enhancement of productivity of small farming systems, as diversity also provides security to farmers against diseases, especially pathogens that may be enhanced by climate change. By mixing crop varieties, farmers can delay the onset of diseases by reducing the spread of disease-carrying spores, and by modifying environmental conditions so that they are less favorable to the spread of certain pathogens. This aspect was well demonstrated by researchers working with farmers in 10 townships in Yunnan, China, covering an area of 5,350 hectares. The farmers were encouraged to switch from rice monocultures to planting variety mixtures of local rice with hybrids. The enhanced genetic diversity reduced blast incidence by 94 percent and increased total yields by 89 percent. After two years, it was concluded that fungicides were no longer required (Zhu et al. 2000).

### *Conclusion*

The local knowledge systems and agricultural practices and techniques adopted by local people remain the dominant form of coping mechanisms/responses to climate change. Many of these agricultural systems around the world serve as models of sustainability that offer examples of adaptation measures that can help millions of rural people to reduce their vulnerability to the impact of climate change and to maintain ecosystem goods and services.

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# Potential impact and response of vegetation dynamics to climate variability at different time scale: A Case study in Gojam, Ethiopia

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## Abstract

*Agriculture is the backbone of Gojjam, Ethiopia economy as it mainly depends on seasonal characteristics of rainfall. This study analyses the components of regional climate variability, especially La Niña or El Niño Southern Oscillation (ENSO) events and their impact on rainfall variability and the growing season normalized difference vegetation index. The temporal and spatial distribution of temperature, precipitation and vegetation cover have been investigated statistically in two agricultural productive seasons for a period of 9 years (2000–2008), using data from 11 meteorological station and MODIS satellite data in Gojam, Ethiopia. The normalized difference vegetation index (NDVI) is widely accepted as a good indicator for providing vegetation properties and associated changes for large scale geographic regions. Investigations indicate that climate variability is persistent particularly in the small rainy season Belg and continues to affect vegetation condition and thus Belg crop production. Statistical correlation analysis shows strong positive correlation between NDVI and rainfall in most years, and negative relationship between temperature and NDVI in both seasons. Although El Niño and La Niña events vary in magnitude both in time and space, ENSO analyses shows that two strong La Niña years and one strong El Niño years. ENSO analyses result shows that its impact to the region rainfall variability is mostly noticeable but it is inconsistent and difficult to predict all the time. The NDVI anomaly patterns approximately agree with the main documented precipitation and temperature anomaly patterns associated with ENSO, but also show additional patterns not related to ENSO. The spatial and temporal analyses of climate elements and NDVI values for the growing season shows that NDVI and rainfall are very unstable and variable during the 9 years period. ENSO /El Niño and La Niña events analyses show an increase of vegetation coverage during El Niño episodes contrasting to La Niña episodes.*

## 1. Introduction

### 1.1. Background and justification

The interaction between climatic elements, vegetation dynamics and sea surface temperature anomalies are not well defined, and there are differences from region to region all over the world. According to many previous studies, the climate parameters and the normalized difference vegetation index (NDVI) have a positive relation in some region (Nicholson et al., 1990); while, it is negative in other regions depending on geographical position, geomorphology, vegetation type, climatic condition and other factors (Zhong et al., 2010). Vegetation condition is dependent on soil type, moisture of soil and type of vegetation in the region; besides, climatic elements such as temperature, rainfall and sea surface temperature. Among those many factors of vegetation dynamics the climatic elements are very unpredictable and variable in a very short period of time, spatially and temporally. Precipitation is much more variable in both time and space than other climatic factors. All other factors of vegetation dynamics are most likely dependent of climatic factors and they don't vary temporally in a very short period of time like temperature and rainfall. This spatiotemporal variation of climatic elements has great influence on the vegetation dynamics and seasonal agricultural productivities.

In the Gojam region, Ethiopia, the majority of the population depends on rainfall based agriculture and agricultural related activities for their livelihood. Nowadays, the seasonal rainfall is not coming on time and is decreasing in amount (UNFCCC 2010). Rainfall fluctuation has significant long and short term impacts on natural resources particularly forests, lakes, wetlands and rivers. The Gojam people economy is mainly based on rain-fed agriculture. Regardless of the presence of surface and groundwater resources, the failure of seasonal rains seriously affects the region's agricultural activities that leads to food insecurity and other hardships.

However, in the present time climate variability has changed and unseasoned rainfall is often observed (Conway et al., 2005). High population growth, deforestation, very traditional agriculture techniques and improper use of land have resulted in massive land degradation with losses of fertile soil. Today, many rural families can barely make their living from agriculture. The basic climatic elements such as rainfall and temperature show seasonal or annual fluctuations somewhat different from normal expected climatic conditions, which are very important to agriculture productivity in the area. Ethiopians are facing the consequences of rapid deforestation and degradation of land resources. The increasing of population has resulted in extensive forest clearing; for agricultural use, overgrazing, and exploitation of existing forests, for fuel wood, fodder, and construction materials (Bishaw, 2001). Understanding the impact of vegetation dynamics to climate variability and response of vegetation on climate variability at the inter-annual to decadal time scales are desirable.

The El Niño and La Niña events result from the tropical pacific Surface Ocean and atmospheric interaction in the tropics. Although El Niño originates in the Eastern Pacific, its warming effect is rapidly spread by the winds that blow across the ocean altering the weather patterns in more than 60 percent of the planet's surface (Kandji et al., 2006). Some of the major disasters associated with El Niño events include floods, droughts, heavy snowfalls, devastating effects in fish industry and frosts. El Niño and La Niña have positive or negative influence in the timely coming of rainfall.

Therefore, the rainy season in Gojam, Ethiopia, depends on El Niño and La Niña events occurring in the tropical Pacific Ocean; besides, the Indian, and Atlantic oceans and other factors. Analyzing El Niño/La Niña-Southern Oscillation ENSO episodes together with other climatic parameters would be helpful for agriculture management. The El Niño and La Niña event are the main causes of Ethiopian climate variability, including the Gojam region. Changes are rapidly occurring in earth surface relating to climate variability and vegetation conditions.

Therefore, understanding the interaction between climate elements and vegetation condition in response to climate variability and change in global or regional scales would have great scientific importance. Geostatistics and remote sensing could be helpful for analyzing the El Niño and La Niña events together with other climatic elements and vegetation responses.

## 1.2 Objectives

The main objective of this study is to analyze time series of seasonal, monthly and yearly NDVI vegetation indices, climatic elements for short and long rainy seasons (Belg and Kiremt) and Sea surface temperature (SST) anomalies, which is the main cause of climate variability in Gojjam, Ethiopia. Belg has a short and moderate rainy season from February to May and Kiremt has the main rainy season from June to September, which is related to the revenue of agricultural activities. It is clear that statistical analyses of climatic elements and vegetation characteristics would help to assess crop production and the vegetation cover in Gojam, Ethiopia.

This study also aims at investigating the statistical relationship between climate parameters, normalized difference vegetation indices (NDVI) and Sea surface temperature anomalies. The analyses will be based on time series of vegetation Indices, ENSO and climatic elements for nine years (2000–2008) and also aims to predict vegetation condition and agricultural products. The study will also assess the ENSO impacts on the spatial and temporal distribution of rainfall and vegetation in Gojam, Ethiopian.

To achieve these objectives spatial interpolation of climatic elements and NDVI analyses will be performed. Unpredictable and very variable atmospheric circulation patterns, lack of complete data and different topography are some of the limitations that the study will have to face for getting accurate gridded data for climate variability and vegetation dynamics analyses in Ethiopian high land, particularly Gojam.

## 1.3. General methodological framework

The general methodological framework followed during the study is presented in Figure 1.

## 1.4 Gridded datasets derived from climate data

Monthly mean maximum, minimum temperature and rainfall data were collected from National Meteorological Agency of Ethiopia. These data were also recorded from 15 Meteorological station placed in the study area for agricultural or rainy seasons (February -September) during the period 2000-2008. Three variables are analyzed in this study: mean monthly, seasonal and yearly rainfall, maximum and minimum temperature. The meteorological stations were irregularly distributed over the study area and doesn't represent the whole region well. There were a few data gaps and removed by averaging data from the nearest neighbor stations.

Preparation of gridded climate maps was made by interpolation of these records based on the longitude, latitude and elevation of the weather stations. Use of elevation as secondary information for modeling gridded maps was not that much important but the relief or topography of study area has a bit influence on the spatial patterns of climate parameters.

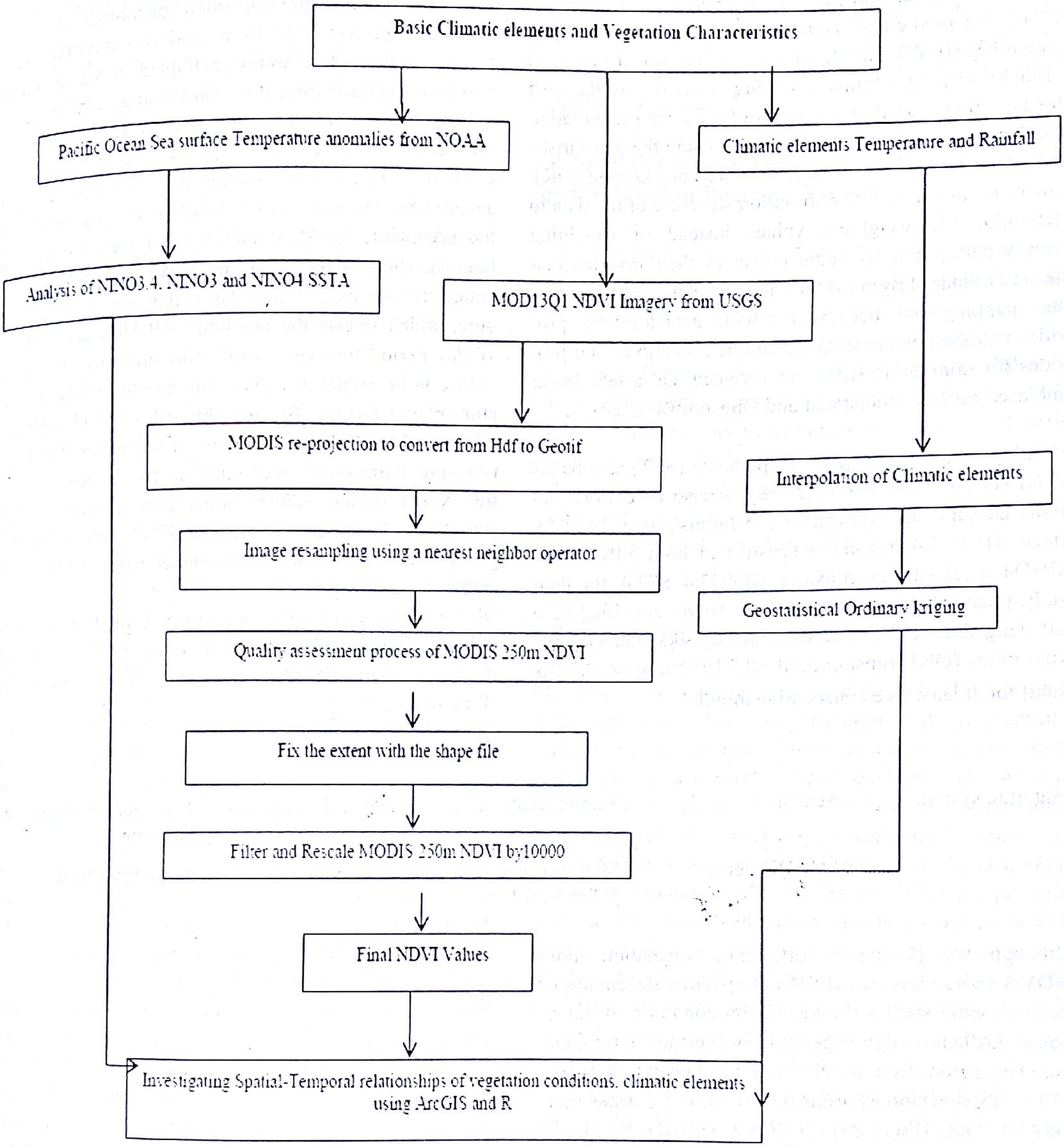


Figure 1: General methodological framework of the study

The magnitude of elevation ranges from 639 m to 4038 m. The general increase in precipitation with elevation is well known, it is due to fact that hills are barriers to moist air-streams, forcing the airstreams to rise and they act as high-level heat sources on sunny day.

Different interpolation methods were tried in order to increase the prediction accuracy such as inverse distance weighting (IDW), simple kriging, Universal kriging and ordinary kriging. Ordinary kriging method was the best for this study and all raster maps of seasonal precipitation for the study region were constructed using the geostatistical interpolation method known as ordinary kriging (OK). OK relies on the spatial correlation structure of the data to determine the weighting values instead of weighting nearby data points by some power of their inverted distance. Ordinary kriging is an effective spatial interpolation and mapping tool, because it honors data locations provides unbiased estimates at unsampled locations, and provides for minimum estimation variance, i.e. a best linear unbiased estimator (Jantakat and Ongsomwang, 2011).

Monthly mean sea surface temperature (SST) anomalies of NINO3.4, NINO3, NINO4 region also used from National Oceanic and Atmospheric Administration (NOAA). Since NINO 3.4 has characteristics of both NINO3 and NINO4 most studies consider NINO3.4 SSTA for their study (Babu 2009; Zaroug 2010). To be classified as a full-fledged El Niño and La Niña episode the Oceanic Niño Index (ONI) must exceed +0.5 [El Niño] or -0.5 [La Niña] for at least five consecutive months.

## 1.5 Gridded datasets derived from satellite data

The multi-temporal images used were acquired from the NASA Terra (AM-1) satellite's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor. The MODIS 250 m NDVI product (MOD13Q1) 16-day composites provided the needed vegetation phenology data. The MODIS re-projection tool was used to convert HDf file to Geotif and images were resampled using a nearest neighbor operator from their native sinusoidal projection to geographic projection with datum WGS 84. Depending on the MODIS 250m NDVI Quality Assessment Science Data Set (QASDS) information and requirement quality assessment also processed. NDVI pixels that fell below the acceptable QASDS quality level were deleted and flagged. The 16-days composite NDVI data sets were generated using a maximum value composite (MVC) procedure, which selects the maximum NDVI value within a 16-day period for every pixel. This procedure is used to reduce noise signal in NDVI data due to clouds or other atmospheric factors. The monthly NDVI raster map and others such as maximum, minimum and mean NDVI values were extracted by averaging the 16-composite. Negative NDVI values indicate non-vegetated areas such as snow, ice, and water. Positive NDVI values indicate green, vegetated surfaces, and higher values indicate increase in green vegetation.

Digital terrain model also used from United States Geological Survey (USGS) for pre-processing of satellite data and the supplementary statistical analysis in the main part of the study .

| Satellite system | Sensor | Spatial resolution | Temporal resolution | Time-period/ Acquisition date |
|---|---|---|---|---|
| NASA | MODIS Terra | MOD13Q1 250m NDVI | 16 day composite | From 2000-2008 |

Although the Normalize difference vegetation index (NDVI) value classification is not specific, depending on previous some studies the vegetation condition of the region classified as High vegetation (values above 0.5), medium vegetation (from 0.292 - 0.5), low vegetation (0.166-0.292), no vegetation ( from 0.1 -0.166) and water body (USAID, 2006; USGS 2011; USGS & USAID, 2005).

## 2. Results and Discussion

### 2.1. Spatial and temporal variation of Mean monthly NDVI for Belg and Kiremt season

Generally, there is high vegetation coverage in Kiremt season (June, July, August and September) than Belg (February, March, April and May) from the period 2000 to 2008 due to good amount of rainfall in Kiremt season for plants or crop to grow. Relating to the altitude there is better vegetation coverage in the central part of the region, around choke mountain (the highest plateau of the region) in both seasons. In the other hand, there is less vegetation coverage in the eastern periphery of the region while, better vegetation coverage in the western part of region

From seasonal quantitative analysis of vegetation coverage in both seasons as shown in Figure 1 there is 77.14 % highest high vegetation coverage class in the year 2002 Kiremt season. Yearly Kiremt season high vegetation coverage class from highest to lowest 2002 (77.14 %) and 2003 (66.59%) consecutively. Highest Kiremt season medium vegetation coverage class is in 2003 (23.24%) while, lowest medium vegetation coverage class and low vegetation coverage is in 2002 (12.74%).

In the Belg season the highest high vegetation coverage class year is 2007 (2.55%) and lowest high vegetation coverage class year is 2004(0.48%). The highest medium vegetation coverage class year is 2000 (58.15%) while, the lowest year 2003 (26.69%). The highest low vegetation class also in 2003 (61.91%).

The result of pacific ocean sea surface temperature anomalies analyses show that 2000 and 2008 are strong La Niña years, but the National Oceanic and Atmospheric Administration (NOAA) includes 2001 and 2007 as La Niña or close to La Niña year as well. In the other hand, 2002 is strong El Niño year and NOAA also includes the years 2003, 2004, 2005 and 2006 (NOAA, 2010). So that, there was a decrease in vegetation coverage in 2000 and 2008 particularly in first two months (February and March) of Belg season due to La Niña episodes and decrease of rainfall amount( Figure 1 and 2 ). But the total vegetation coverage of Belg season and La Niña episodes is not decrease because of the rest April and May vegetation coverage and rainfall amount increase (Figure 1). The highest vegetation coverage is in 2002 is due to El Niño episodes. The El Niño episode increase the amount of rainfall in Belg season while, decrease the amount of rainfall in the late Kiremt season. Hence, due to one or two months lag time vegetation coverage increment after the fall of rainfall the vegetation coverage is increase in 2002. The spatial and temporal distribution of rainfall and vegetation coverage have similar pattern that is, maximum vegetation coverage and rainfall amount in the east and north east part of region while, decreasing of vegetation and rainfall west, south, north west and south west part of region (Figures 1 and 2).

### 2.2 Spatial and temporal variation of mean seasonal rainfall in Belg and Kiremt

Ordinary kriging considered to be the best methods, as it provided smallest RMSE and ME value for nearly all cases. Since the distribution of sample data points is uneven and sparse IDW interpolation techniques quality is very less and doesn't cover the whole study area. Ordinary kriging was selected for this study based on how well it has performed on prior years data and because the statistical characteristics of the data in 2002 and 2003 make Ordinary Kriging the appropriate choice of Exponential and stable type of models are used for ordinary Kriging interpolation of seasonal rainfall data.

## 3. Conclusions and Recommendations

The relationship between precipitation and NDVI is very strong and predictable when observed at the appropriate spatial and temporal scale. The phenology of vegetation in all formations closely reflects the seasonal cycle of rainfall. Within the period 2000–2008 there is considerable monthly, seasonal or year-to-year variation in precipitation and NDVI throughout the region of Gojam. The yearly correlation coefficients between NDVI and precipitation are very high, while the correlation between NDVI and temperature are low. The total growing season analyses show that the general temporal or spatial distribution of NDVI in the whole study area corresponds directly with the spatial pattern of average monthly or annual precipitation. Belg season NDVI coefficient of variation analyses shows high instability or variability in both fully strong El Nino or La Nina episodes in 2000 and 2002 but the Kiremt season NDVI coefficient of variation is more highly variable in the whole years. Gojam is a region in the tropics or in monsoon region, so that tropical pacific ocean circulation effect, that is ENSO/ El Nino or La Nina episodes, has a great impact in the seasonal rainfall variability.

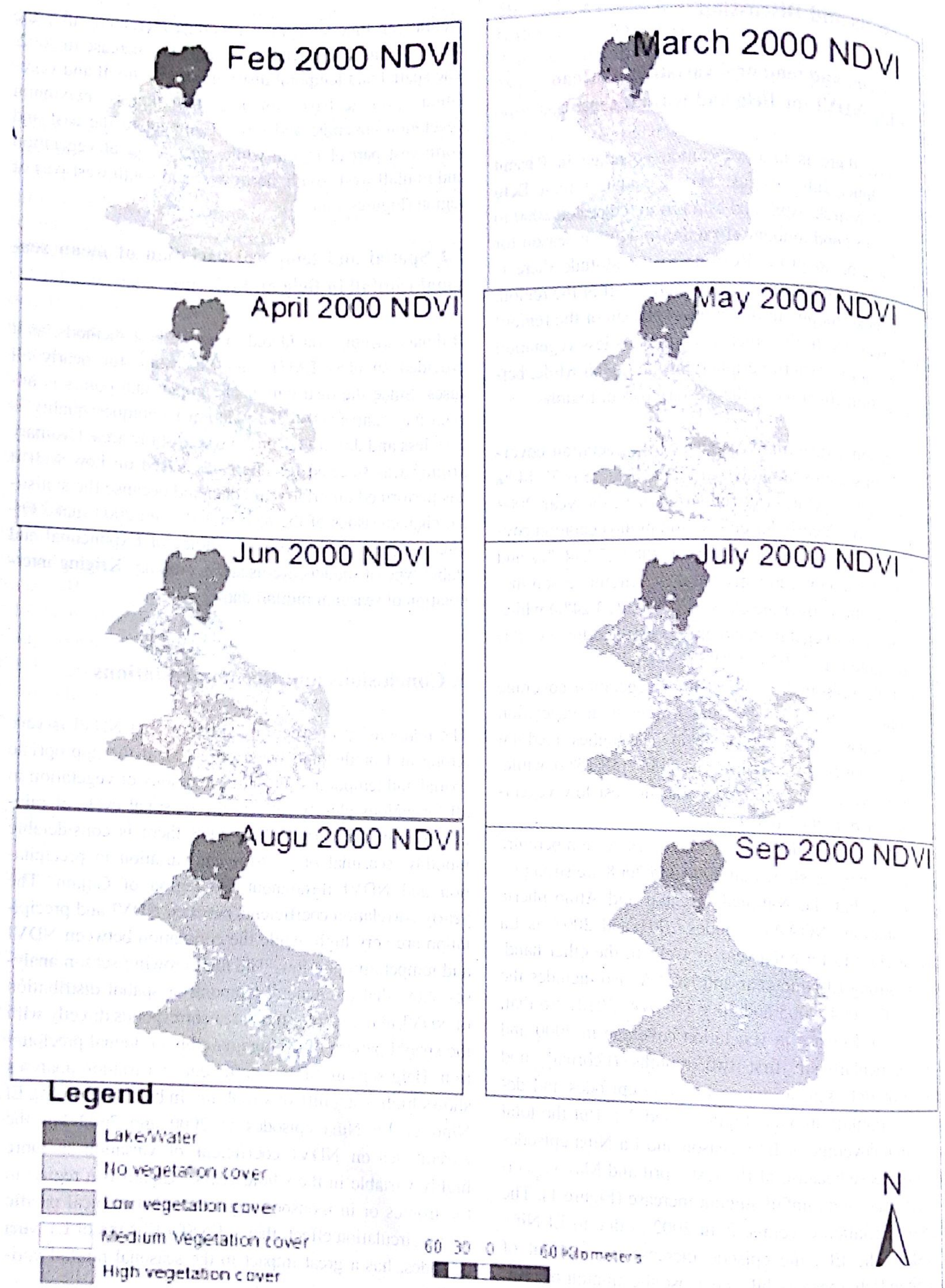


Figure 1: Illustration maps of mean monthly NDVI in rainy season for 2000 La Nina years

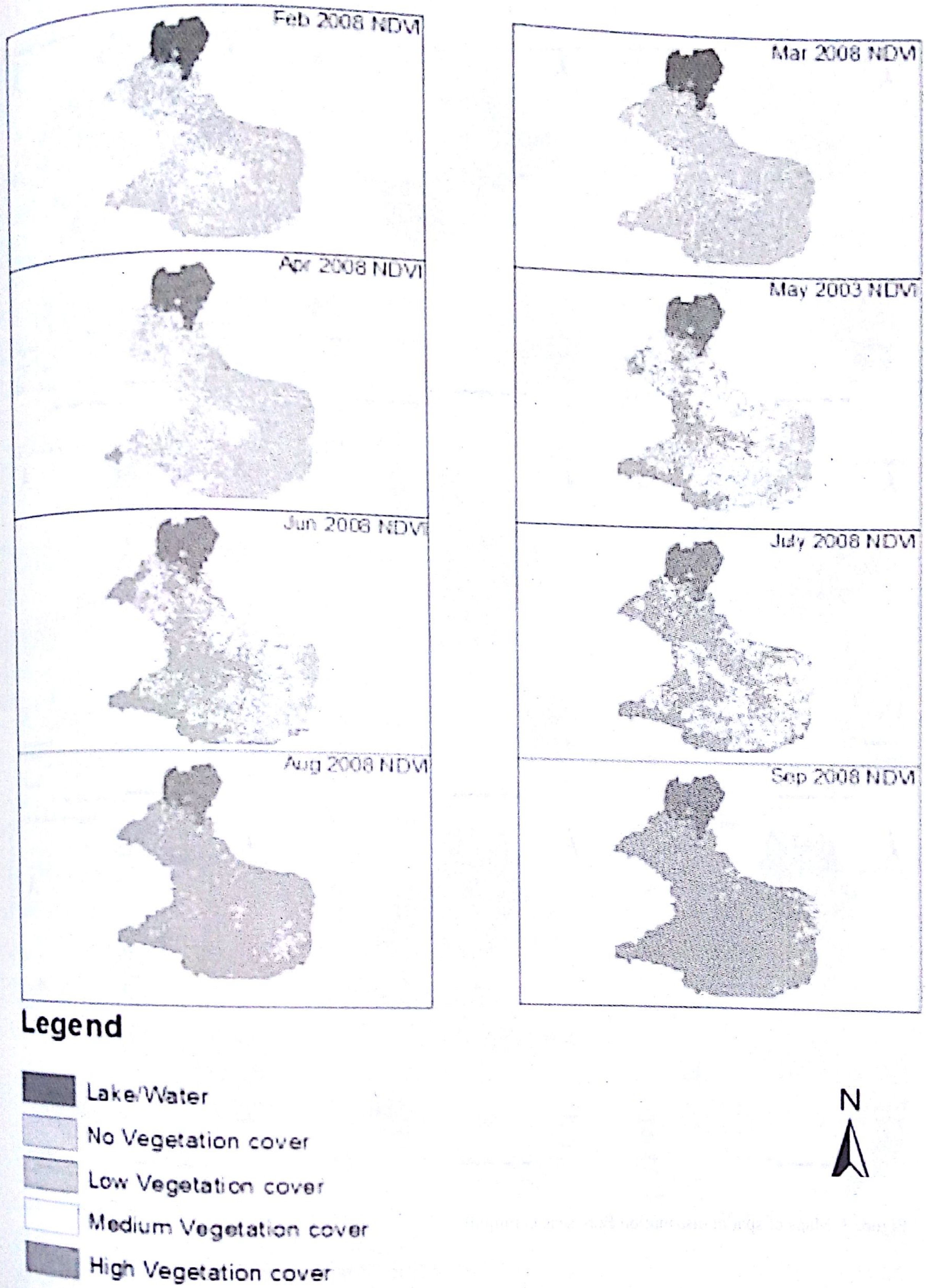


Figure 2 Illustration maps of mean monthly NDVI in rainy season for 2008 La Nina year

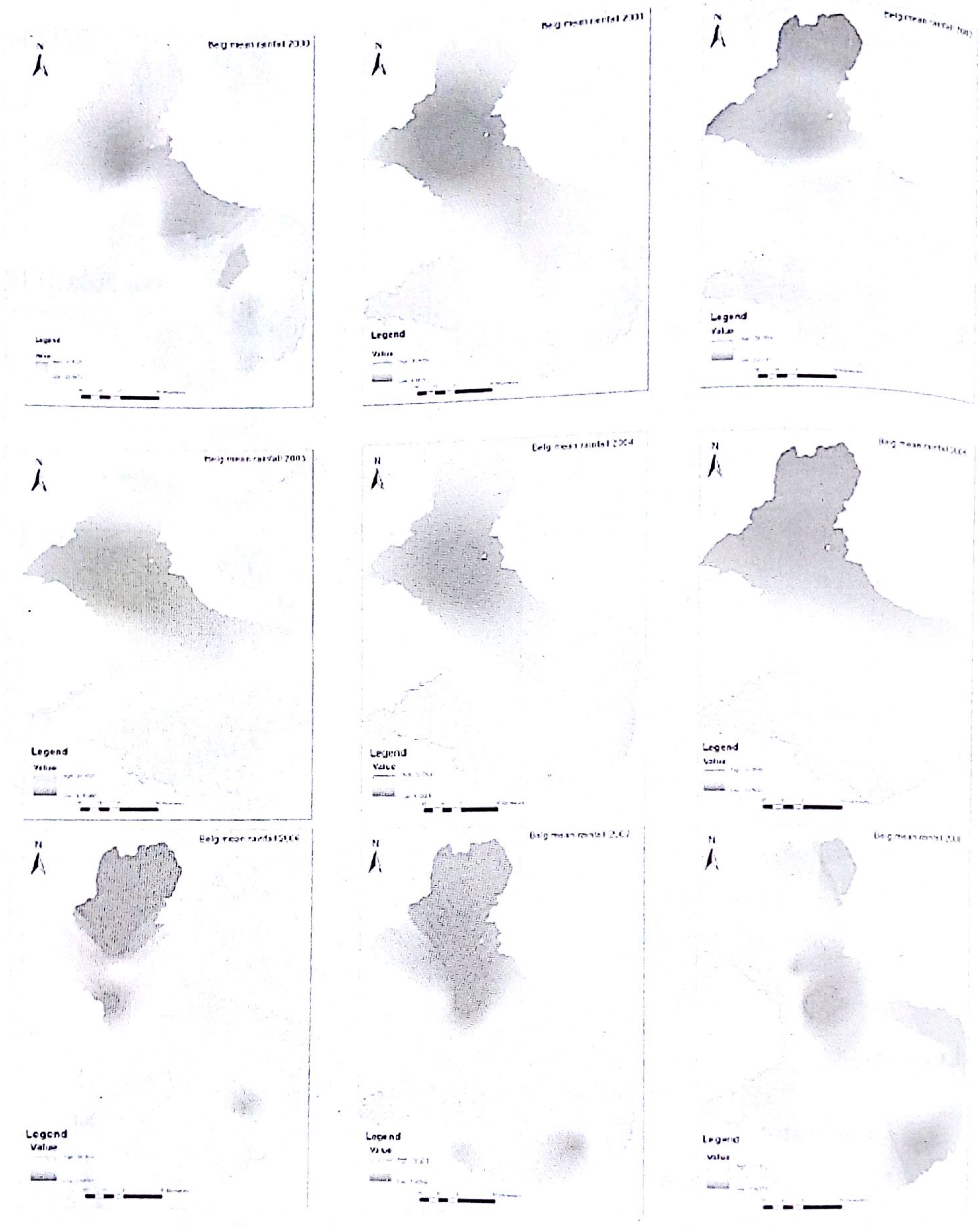


Figure 3: Maps of spatial distribution Belg season rainfall

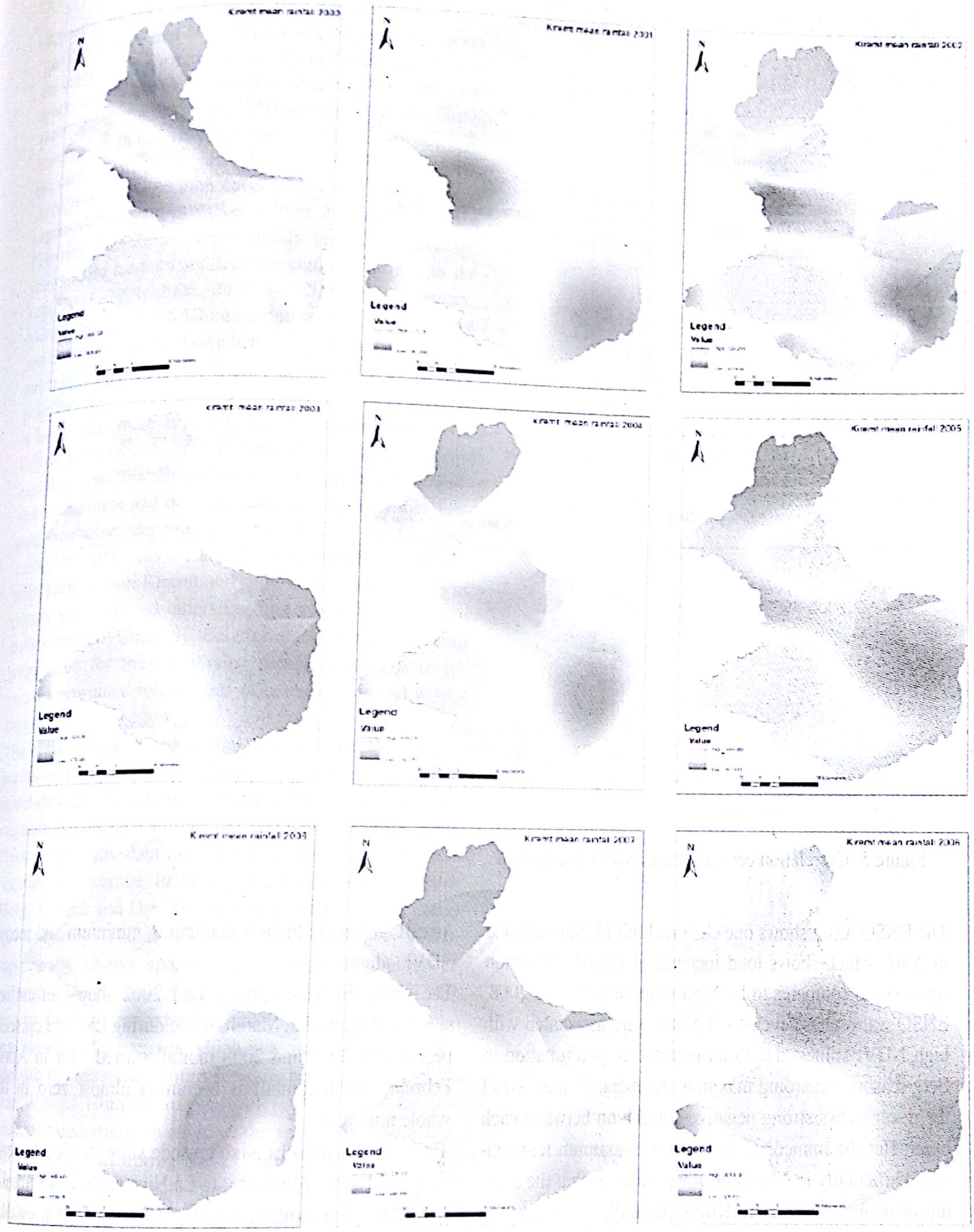


Figure 4: Maps of spatial distribution of Kiremt Season rainfall

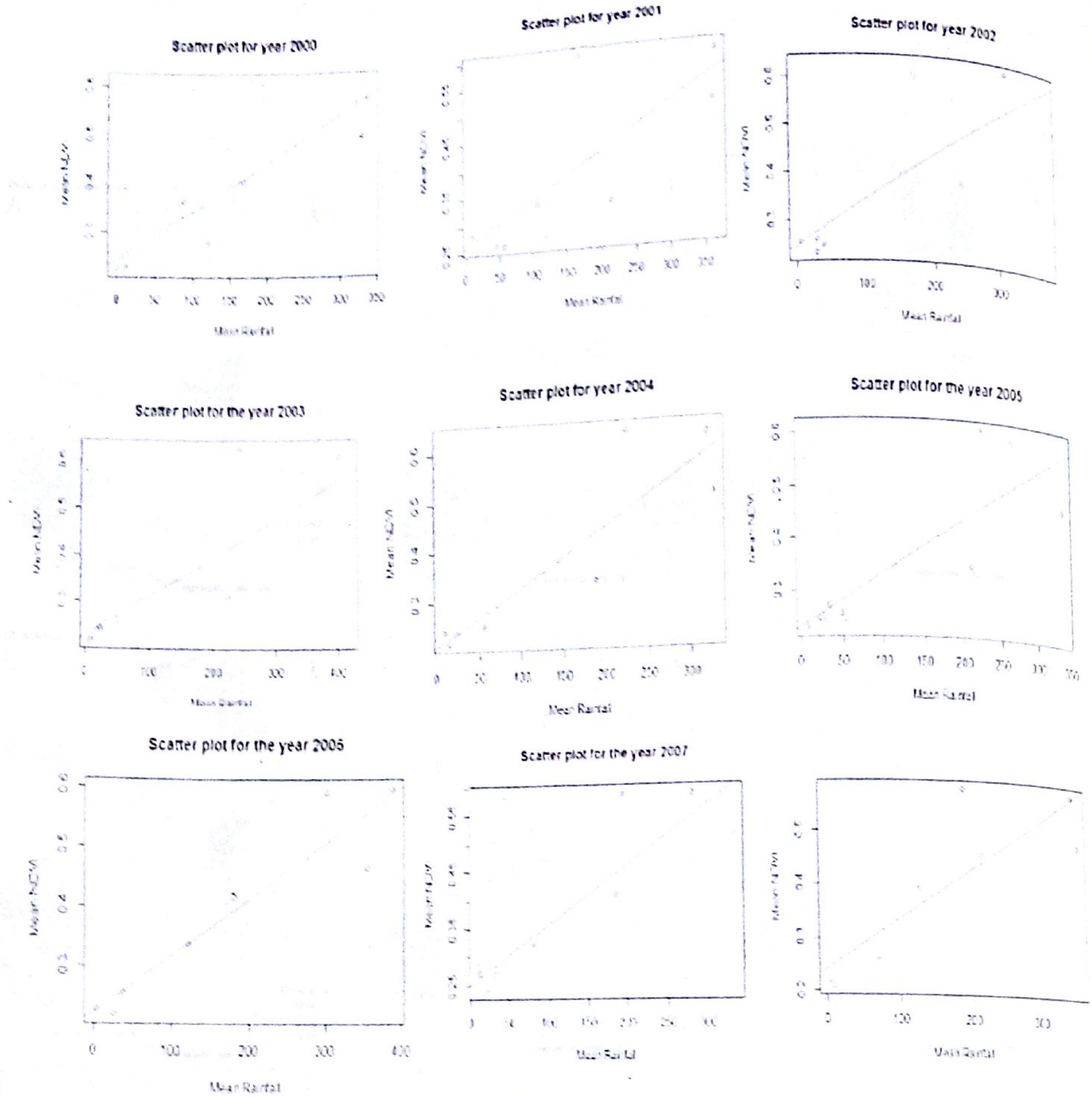


Figure 5: Correlation between mean NDVI and rainfall

The ENSO result shows one clear and full El Nino episode in 2002, which shows total increase of spatial vegetation coverage as compares to La Nina years of 2000 and 2008. ENSO warm phase events (El Nino) were associated with high NDVI values, due to an increase of precipitation in Belg season. Regarding maximum temperature and NDVI the result shows strong negative correlation between each other. But the immediate decrease of maximum temperature, particularly in March or May, indicates that the starting of main rainy season, Kiremt rainfall, and increasing of vegetation growth in almost the whole years. Spatio-temporal analyses of NDVI shows lowest maximum, minimum and mean vegetation coverage in February and March in almost all the years or months, while July and August shows the highest maximum, minimum and mean NDVI values.

The strong El Nino episode year 2002 shows an earlier starting of rainfall in March, while during La Nina episode period year 2000 and 2008 rainfall started later in April. February mean rainfall is becoming almost zero in the whole nine years.

The Kiremt season El Nino episode show earlier decrease of rainfall as we compare it to La Nina episode. Generally, year 2003 shows increasing or good amount of rainfall in both seasons, while 2005 and 2007 show decreasing amount of rainfall in both seasons.

February monthly vegetation coverage analyses shows that 2001, 2002 and 2007 have better medium vegetation coverage in the eastern and central part of the region than other years. March vegetation coverage analyses also shows good (but less than February) medium vegetation coverage in those areas and more vegetation coverage in the central part in the years 2001, 2002, 2003 and 2007. April monthly vegetation coverage shows better medium vegetation coverage in the years 2000, 2002 and 2007 than February and March. May monthly vegetation coverage shows more medium and high vegetation coverage in the year 2000, 2001, 2006, 2007 and 2008 than February, March and April. All Kiremt months (June, July, August and September) have shown better high and medium vegetation coverage except some parts of the region in the west peripheries.

It seems that there is a possibility to predict rainfall in Gojam if the SSTAs and El-Nino events could be forecasted in good time ahead. So that it would be very important for farmers and other agricultural sector as they prepare themselves depending on the seasonal rainfall forecasts. The *Belg* rains are used for land preparation for the main rainy season Kiremt and some crop products such as potato, sorghum and others used to sow if the Belg rain comes earlier. Untimely Belg rainfall means poor land preparation for the main rainy season that leads to increased unwanted infestations of certain pests and reduction of crop production.

The total temporal and spatial analyses of climatic elements and vegetation characteristics of the region shows instability or variability of both climatic elements and vegetation coverage during the study period from 2000-2008. Long year data analyses of climatic elements and vegetation coverage including the whole three seasons (Belg, Kiremt and Dry) would be important to understand the variability. The detail observation of the vegetation map clearly shows spatial and temporal variability of greenness due to rainfall variability of region. ENSO El Nino or La Nina episodes has great influence in the seasonal rainfall of the region which may weaken, increase or dislocate the seasonal rainfall spatially or temporally.

Generally, El Nino warm phase of ENSO shows the increase of vegetation coverage in the region due to earlier starting of rainfall during the El Nino episode. La Nina, the cold phase of ENSO, shows decrease of vegetation coverage in the region due to the late starting of rainfall in the region. The monthly trend analyses of NDVI and rainfall also shows that how those two variables are highly variable from year to year during the analyzed nine years.

## References

# Irrigation Water Management in Small-scale Irrigation Schemes: the case of the Ethiopian Rift Valley Lakes Basin

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## Abstract

*Appraisal of irrigation water management scenarios in irrigation schemes is crucial in project performance monitoring. A comprehensive irrigation water management study has been conducted on four SSI irrigation schemes in the Ethiopian rift valley lake basin. It is observed that from 147 irrigators, 68% faced irrigation water supply unreliability, 79.1% encountered unfair distribution of water and 66 % undergone through timeliness problem in water distribution occasionally. All the schemes investigated witnessed a weak (50 % of all scheme users noted poor) organization of irrigation scheme administration. The WUA2s lacks a clear laws / by-laws and strategies to lead small or major canal operation and maintenances. Without strong WUA, it is impossible to think of filling farmer's skill gap, to have a working maintenance strategy, fair distribution of irrigation water, reliable irrigation water supply and timely delivery of irrigation water.*

## 1. Introduction

There are mixed perceptions about the contribution of irrigation in general and SSI interventions in particular for poverty reduction and food security improvement. In Ethiopia, although irrigation has long been practiced at different farm levels, there is no efficient and well managed irrigation water practice (Dessalegn, 1999). The reason could be little efforts made to investigate irrigated land management and water use in the country. Even some research results found out that no difference is observed sometimes between rainfed and SSI user smallholders in their food security status (Peden et al., 2002). The world major grain exporters such as USA, Canada, France, Australia and Argentina produce grain on very productive rainfed agricultural lands while major grain importers depend on irrigation to produce grain (De Fraiture et al., 2009). According to Shah *et al.* (2002), SSI development should result in substantial improvement in household food security and poverty reduction through low cost of maintenance and better institutional support for its sustainability and national economic benefit. A review of several empirical studies by Hussain and Hanjira (2004) indicated a strong linkage between irrigation development and poverty reduction through improving level and security of productivity, livelihood diversification as well as creating employment and income opportunities. Out of 200 sampled irrigator and non irrigator households in a particular area of Oromia region, only 45 % of them were food secure and more than 70 % were irrigators (Tesfaye et al., 2008). A study by Brabben *et al.* (2004) and Angood *et al.* (2002, 2003) concluded that irrigation development resulted in considerable rural livelihood, food security, and nutritional improvement among the beneficiaries in Nepal and Bangladesh. In addition, a study by Gebregziabher *et al.* (2009) using survey of beneficiaries of a selected SSI schemes in Tigray region of Ethiopia revealed that household income of irrigation users is higher than non irrigators by about 50 %.

With all these facts on hand and even water resources development for agriculture as a policy priority, poorly planned and managed irrigation schemes undermines efforts to improve livelihoods and exposes people at risk in Ethiopia. Much of the increase in irrigated area had come because of expansion of small-scale irrigation in the country. Yet, the existing irrigation development in Ethiopia, as compared to the resource the country has, is negligible (Mintesinot et al. 2005).

Agriculture is the backbone of the country's economy earning a livelihood of more than 85% of the total population. The country grows a wide variety of irrigated crops including cereals, pulses, cash crops such as *chatt* and different variety of root crops. The vast irrigation land and abundant surface as well as ground water resources are mostly found in the lowlands of the country, which accounts 56% of the total agro-ecological zone. Irrigation has been developed in the country by farmers, Governmental Organizations and Non Governmental organizations. Those irrigation structures developed by farmers are traditional ones, constructed using local knowledge and labor.

country along with the establishment of state farms since 1977 to produce plantation crops such as cotton, tobacco & others. All these schemes were medium ones constructed and owned by the government.

To achieve sustainable production from irrigated agriculture it is apparent that the management of important resources in irrigated agriculture, water and land, must be improved. Crop responses to different inputs including fertilizer application depend on the level of water availability (Pala et al., 1996). Application of fertilizers not only increases plant shoot and root growth (Brown et al., 1987), but also increases ET and hence metabolism through a large root system and greater extraction of stored water (Cooper et al., 1987). In addition, a large and earlier canopy cover resulting from the application of fertilizers can reduce soil water evaporation and improves field water utilization (Zhang et al., 1998). Hence it is clear that irrigation and fertilizer are the most important inputs for high crop production and better water management. Generally in the country and specific to the Rift Valley Lake Basin, several irrigation projects have failed or have had limited livelihood impacts and have been unsustainable because of different limitations such as less integration of the socio-economic, existing local community water management practices, institutional, technical and policy weaknesses. (IFAD.2005).

The questions "how is irrigated agriculture managed with limited water and land resources?" have not been yet satisfactorily answered. Availability of irrigation water management information on farmer fields is not common. Thus, this study have been focusing on evaluating the irrigation scheme water management condition of small scale irrigation schemes in the Ethiopian Rift valley lake basin taking four small scale irrigation schemes as a sample. The minor objectives could be:

- Evaluating the management of different irrigation schemes to learn a lesson from the bettered ones.
- Identification of specific management elements that makes a difference is irrigation schemes managements.
- Identification of scheme management problems and their causes in respective to schemes actual condition.

According to MoWR (2001), it was planned to expand irrigated agriculture area by more than 470,000 ha between 2002 and 2016 out of which 48 % will be SSI schemes. Undertaking water management assessment of the existing SSI schemes in this regard is vital to make appropriate decision between implementing new interventions and improving the existing ones to enhance the performance and contribution to advance food security and cash incomes of smallholders.

## 2. Methods

### 2.1 The study area

Ethiopia has about twelve river basins with a potential to irrigate an estimated area of 3.5 million ha, out of which only 190,000 ha (4.3 %) is actually under irrigation (Makombe et al., 2007; Tesfaye et al., 2008). Rift Valley Basin (RVB) is one of the major basins having an area of 52,739 Km2, covering parts of the Oromia, Southern Nations and Nationalities peoples (SNNPR) regions (Fig 1).


Figure 1: The study sites

The basin extends between latitude of 07°00' and 08°30' N and between longitude of 38°00' and 39°30'E. The total mean annual flow from the River Basins is estimated at about 5.6 BMC (Awulachew et al. 2007). It has substantial areas of productive rain-fed agricultural land, good rangelands and also irrigation lands due to the great demand for economic and social development. Irrigation development is growing in the basin where about 10% of the estimated irrigation potential of 139,300 ha of irrigation land is under irrigation, out of which about 4627 ha is provided by small scale irrigation schemes.

For this study, four diversion irrigation sites namely Gedemso 01, Argeda, Bedene Alemtena and Eballa located within the basin were selected; of which the former two are located in the Oromiya and the latter two are located in the SNNP Administrative Regions. The reasons for the selection of thesschemece sites were: accessibility, scale, management type, agro ecological similarity and similarity of market outlet.

**Gedemso 01 SSI scheme,** constructed in 2001 by Oromiya Regional Government is located in West Arsi zone in Arsi Nagelle district, Buku Woldaya Kebele, 30 kilometers to the East of the district capital, Arsi Nagelle and 224 kilometers to the south East of Addis Ababa, Ethiopia. The scheme has a potential to irrigate 180 hectares (BoA, 2009/10); out of which 80 hectares are located in Gedemso 01 (BoA, 2009/10; Awulachew et al., 2007), and the remains 100 hectares is located in Gedemso 02.

**Argeda SSI scheme**, constructed by Oromiya regional government in 2004 is also located in West Arsi Zone in Arsi Nagelle district in Argeda Shaldo Kebele, 39 kilometers to the east of Arsi Nagelle and 233 kilometers to the Southeast of Addis Ababa, Ethiopia. The potential irrigable land of the scheme is 80 hectares (Awulachew et al., 2007).

**Bedene Alemtena SSI scheme** is located in SNNP administrative region in Halaba special Woreda. The project is located 12 kilometers from the Woreda capital, Halaba Kulito town. The scheme was constructed by CoSAERSAR to irrigate 200 ha (Awulachew et al. 2007).

**Eballa SSI scheme** is located in SNNP administrative region in Kembata Tembaro Zone in Hamido Goforo kebele. It is located at a distance of 120 kilometres to the Northwest of Hawassa, the regional capital. The scheme was constructed by CoSAERSAR in 1997 to irrigate an area of 120 hectares (Awulachew et al. 2007; Mihret et al., 2013). The planned beneficiaries of the scheme are 627 households. Both schemes use similar diversion structures to guide the water into a gravity water distribution system.

## 2.2 Data collection

### 2.2.1. Document Review and Secondary data collection

Relevant project documents have been reviewed during preparation of field data collection tools and thoroughly reviewed during the preparation of the report. The reports include performance report, midterm review, baselines, beneficiary assessment, inventory, project completion report and others. Secondary data were also collected from each sector offices at Woreda and Kebele level.

### 2.2.2 Focus Group Discussion (FGD)

Focus group discussions were made with community representatives and Das with special attention to the water management indicators listed above. In all irrigation schemes, focus group discussions with organized groups were the main sources of information on the water management of SSI projects.

### 2.2.3. Field Visit and Observation (transect walk)

Field investigation and site observation together with Scheme users were the major approach of the study. The field visits was made to each irrigation schemes plot-by-plot to visually observe the current water management situations in the schemes. Observations into various schemes helped in knowing their status and identify constraints in sustaining the services of the schemes to the targeted communities. On the spot discussions with the scheme management committees and scheme users were conducted so as to have first hand information.

Direct observation was exercised starting from the head-work to farm level by selecting representative section of the scheme. The structured walk through the schemes helped to assess particular indicators (water availability, maintenance status, soil type, soil characteristics, type of crop, homestead, grazing land, type of livestock, watershed status etc). It provided a good first overview of the irrigation scheme and plot use.

### 2.2.4. Household Survey (HH)

Household survey in the four irrigation schemes was conducted using structured questioner regarding the water management of irrigation schemes in the community. Farm households who are directly using irrigation schemes were surveyed to see water management of the irrigation schemes. Primarily, purposive sampling based on performance and convenience were employed
to select the four irrigation schemes; in the second stage, each selected scheme was purposively divided into three strata based on their relative location with respect to the diversion structure as head, middle and tail reach. This stratification helped in classifying schemes into smaller areas that are homogenous in terms of access to water and irrigation infrastructure. A probability sampling method involving simple random sampling technique was used to select the respondents. Proportional sampling was used to select the respondents. Proportional sampling was employed to pick female headed HH and male headed households from each strata. For irrigation water management investigation 147 irrigation scheme user households were involved.

## 2.3 Sampling protocol

Number and distribution of sample households with respect to scheme, their location in the scheme and sex are given in Table 1 below.

Table 1: Distribution of samples at each irrigation scheme

| Name of scheme | Total sample | | Location within the scheme | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Female HH | Male HH | Head | | Middle | | Tail | |
| | | | Female HH | Male HH | Female HH | Male HH | Female HH | Male HH |
| Argeda 01 | 7 | 28 | 1 | 5 | 4 | 13 | 2 | 10 |
| Gedemso 01 | 8 | 34 | 1 | 5 | 3 | 19 | 4 | 10 |
| Bedene Alemtena | 6 | 21 | 1 | 2 | 3 | 9 | 2 | 10 |
| Eballa | 7 | 34 | 2 | 3 | 3 | 20 | 2 | 11 |
| Total | 28 | 117 | 5 | 15 | 13 | 61 | 10 | 41 |

## 2.4 Indicators selected and data collection

The indicators presented in Table 2 were used to assess water management in SSI projects. These indicators were selected according to the context of this investigation (focusing on irrigation water management), and the cost of data collection and processing (Biswas, 1984, 1985).

Table 2: Indicators used for investigation

| Indicators | Method of Data collection |
|---|---|
| Fair distribution of Irrigation water | Household survey to investigate Fair distribution of Irrigation water |
| Reliability of Irrigation Water Supply | Household survey to investigate Reliability of Irrigation Water Supply (survey) |
| Timely delivery of Irrigation water | Household survey to investigate Timely delivery of Irrigation water (Survey) |
| WUA Organization | Presence of a water user organisation including men and women and strength.( HH survey) |
| Information and education | Acquired irrigation systems management skills (Survey and FGD). |
| Status of irrigation services | Presence of organised maintenance strategy (Survey, FGD, KII) |

## 3. Results and Discussions

For the rapidly expanding small scale irrigation farms in the area, there are very few or no information regarding appropriate management of irrigation water and crop management practices in the four irrigation projects investigated. Knowledge about irrigation water management practices are very crucial to improve the productivity of irrigated agriculture through the application of scientific and modern irrigation water management technologies with ultimate goal of improving livelihood of smallholder farmers in the respective irrigation schemes without any adverse effect on the social and environmental arena. Employing the aforementioned methods, irrigation water management parameters like fairness in irrigation water distribution, timely delivery of irrigation water and reliability of irrigation Water Supply in the four schemes were investigated. Each of these findings has been presented in this section.

### 3.1. Fair distribution of Irrigation water

In all irrigation schemes (mean of 79.1%), occasionally in their field experience (Figure 2) they faced unfair distribution of irrigation water. In Gedemso 01 irrigation project for instance, unfair distribution of irrigation water is a serious problem due to illegal water users and weak water users association. In all other schemes the unfairness is attributed to corrupt water users association and vested interest of head water users.

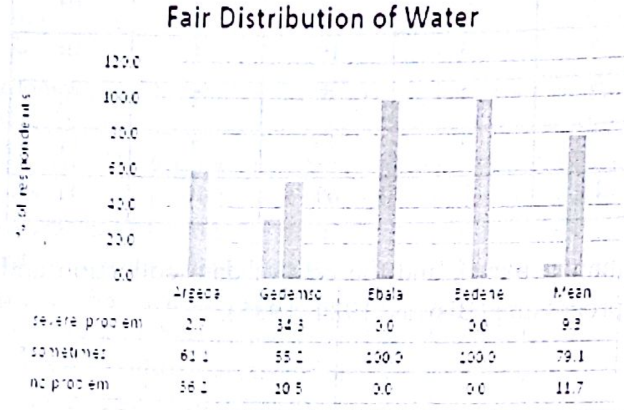


Figure 2: Irrigation water management - Fair distribution of water

### 3.2. Reliability of Irrigation Water Supply

Unreliability of irrigation water supply due to poorly functioning irrigation infrastructure and night illegal water users (vandalism) are sometimes observed by 68 % of irrigation schemes users (Figure 3). Unauthorised water users, seepage, canal blockage for washing cloths and herds of cattle drinking from the canals may also contributed for supply unreliability.

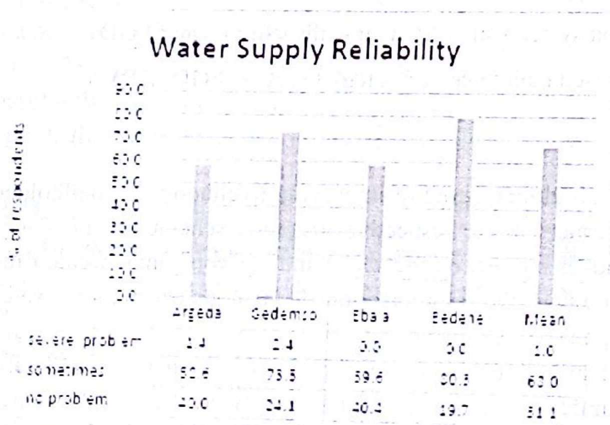


Figure 3: Irrigation water management - Water supply reliability

### 3.3. Timely delivery of Irrigation water

Irrigation is an essential component of agricultural water management where greater production of food and fiber is required under severe constraints of water resources. Humanity is challenged to increase production using existing resources mainly land and water efficiently. Plants are efficient in sensing water stress and respond it accordingly. Untimely delivery of water has a significant impact on crops performance. In all irrigation schemes, 66 % of irrigation water users sometimes in their practical irrigation life they experienced a problem of timely water delivery according to their schedule (Figure 4). The problem mainly attributed to poorly functioning irrigation canals, seepage, illegal water users and canal blockage to use the water for other purposes.

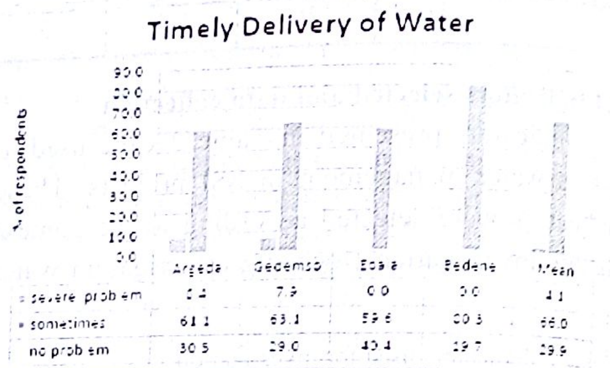


Figure 4: Irrigation water management – timely delivery of water

### 3.4 Participation

#### 3.4.1 WUA Organization

Effective organizational structure of water users association in irrigation schemes create the ability to facilitate working relationships between various entities and improves the working efficiency within the organizational units. Without efficient Water Users Association (WUA), thinking of efficient irrigation scheme management is impossible. By strengthening the management capacity of WUA, legal and smooth handover of schemes after construction are critical to sustain performances. With this case study it is observed that there is a positive correlation between schemes which have an established WUA and better water management. Even though technical aspects contributes, most weak and poor water management in irrigation projects are derived from poor management of schemes. Organizational strength is critical in hampering the precedense of most water management related problems.

65.2% of household farmers in Argeda and 74.7% in Gedemso 01 irrigation schemes appreciated the organizational structure and performance of their WUA (moderate and well organized). While, 59.6 % of household users in Eballa and 80.3% of household users in Bedene Alemtena irrigation projects complained about the poor performance and bad organizational structure of their WUA (Figure 5).

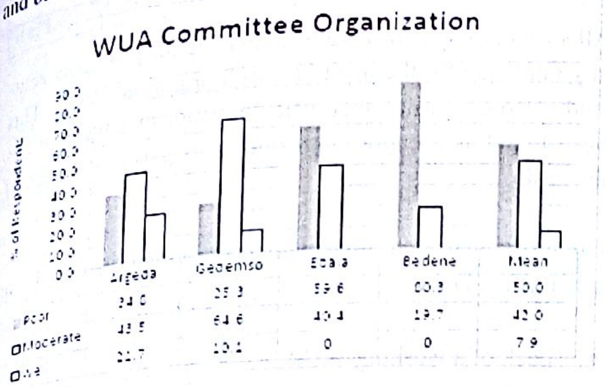


Figure 5: WUA structure and performances

### 3.4.2 Information, education and communication

Except Gedemso 01, majority of the households in the irrigation schemes do have sufficient knowledge about irrigation. But during the FGD it was observed that the proportions of WUA members who have taken the training are different. Figure 6 below provides the percentages of respondents who have and have not sufficient knowledge about irrigation.

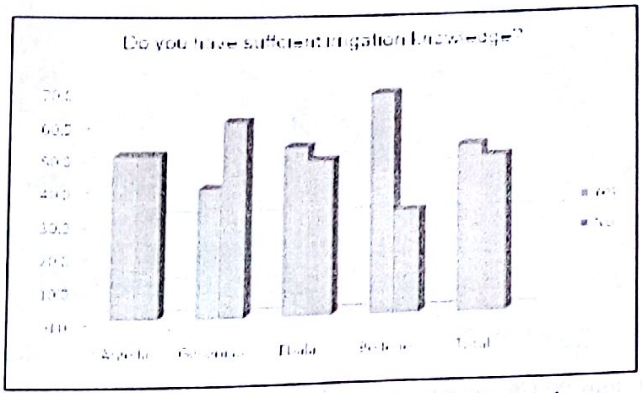

Figure 6: Irrigation knowledge of users in each scheme.

Table 3: Members of WUA who have taken different training in percentage

| Types of training taken | WUA members who have taken different training (%) | | | |
|---|---|---|---|---|
| Kinds of training attended | Argeda 01 | Gedemso 01 | Bedene Alemtena | Eballa |
| Irrigation scheme administration | 50 | 55.6 | 62.5 | 83.3 |
| Irrigation scheme O&M | 62.5 | 44.4 | 62.5 | 66.7 |
| Irrigated crop production and management | 62.5 | 44.4 | 87.5 | 66.7 |
| Irrigation scheme administration | 62.5 | 55.6 | 87.5 | 83.3 |
| Average (%) | 59.4 | 50 | 75 | 75 |

Relatively lower percentages of participants have attended the training from Argeda 01 and Gedemso 01 irrigation schemes (Table 3). Institutional support towards establishing better irrigation management through training would play an inevitable role in enhancing the effect of irrigation schemes on the sustainability of local economic development.

## 3.5. Canal Maintenance Strategy

Canal maintenance is the major task of farmers that takes much of their time and labour. Prolonged de-siltation season posed major difficulties on their crop selection options and forced them not to stick with crops that can suffices their market opportunity. All the schemes investigated lack a clear canal maintenance strategy. 94.5% of the respondents in all schemes believe that their canal maintenance strategy is not good (Figure 7).

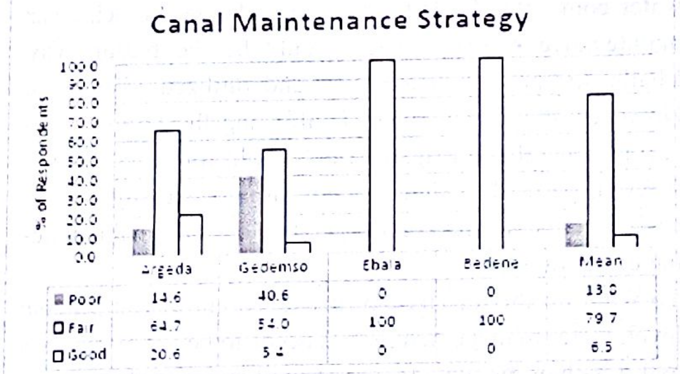


Figure 7: Presence of clear canal maintenance strategy in each scheme.

In all the schemes observed, canal cross-section and gradient were deteriorated, frequent unwanted canal obstructions and blockage either by foreign materials or due to growth of vegetative coverings was observed (Figure 7). Proper canal crossing at a logical location lacks in all schemes creating cattle's to jump over or walk through the canals breaching canal profile.

Figure 8: Canal crossing made from abandoned log and flow obstruction in Argeda SSI.

In most farm lands of the basin, the landholding is declining to support decent livelihoods. The old practices of fallow cropping which used to be upheld in the area are being eroded. In irrigation fields it is impossible to think of such practices. The only option is to maintain irrigation infrastructures and sustain the fertility of fields through natural or artificial ways. The recent invasion of eucalyptus along the main canals in irrigated fields made maintenance activity frequent and costly, which calls for the attention of policy makers to enforce strict regulation in land use. The community in Eballa and Bedene Alemtena irrigation schemes indicated that most of absentee-land owners who live in the near by villages/town plant eucalyptus trees in fertile lands as it doesn't need much supervision and labour input. Poor/weak organization of the water committee leads to irrigation schemes to lack clear maintenance strategy. These could be the reason why Eballa irrigation scheme was underutilized (Table 4). However, this development is affecting the farming system in general and irrigated field's utilization and productivity in particular. Non resident farmers actually are not easily accessible and non cooperative during canal maintenance operations.

To wind up this discussion, it is apparent that at scheme level, water management issues needs to be led by WUA's and it is their mandate to operate and maintain the system.

Figure 4: Irrigated field Utilization (%) (average of five years, 2009-2013)

| | Scheme type | Command area (ha) | Irrigated area (ha) | Utilization (%) |
|---|---|---|---|---|
| Argeda 01 | Diversion | 80 | 78 | 97.5 |
| Gedemso 01 | Diversion | 80 | 96 | 120.0 |
| Bedene Alemtena | Diversion | 120 | 85 | 70.8 |
| Eballa | Diversion | 200 | 276 | 138.0 |

All irrigation schemes water management problems actually implicate for the need of a well organised WUA. This study also confirmed that efficient water management has been found as a major challenge in irrigation schemes of the basin.

Organizational and management problem especially at scheme level observed were:

- Lack of a working WUA;
- Water management problems like equitable water use, high water loss due to seepage as a result of poor maintenance strategy, uncontrolled water use, vandalism and water theft;
- Scheme management issues like lack of structural maintenance, lack of proper operation of structures and lack of ownership sense are the major constraints in all schemes.

Poor irrigation scheme water management has been an appreciated problem on the four irrigation schemes regardless of scheme design and operation. Due to non coordination of scheme management, water management problems have been manifested on designed crop calendar, proposed cropping pattern, and weak production and productivity.

## 4. Conclusion

The need for production and productivity improvement to alleviate the challenge of food insecurity in the country obligates the use of irrigation particularly in water deficit areas. However, production gain from irrigated agriculture is below the expected value due to inefficient scheme water management. Generally, water supply unreliability (68% of all scheme users' observation), unfair distribution of water (79.1% of all scheme users' opinion) and timeliness of water distribution (66 % of all scheme users' remark) are major problems in all schemes investigated.

All the schemes witnessed a weak organization (50 % of all scheme users noted poor organization) of irrigation scheme administration. The WUAs lacks a clear laws/by-laws and strategies to lead small or major canal maintenances. In all schemes, there is no any documented administration matters dealt with any time in the past. No scheme auditing done throughout the life of the schemes. All actions have been dealt spontaneously and farmers use their personal judgment in selecting the cropping pattern. As a result they have been facing overlapping of crop seasons (irrigated crops harvesting season overlapping with rainfed season) , market elasticity and post harvest handling problems. Most of these water management issues shall be sorted out by having an organized WUA. Without strong WUA, it is impossible to think of filling farmer's skill gap, to have a working maintenance strategy, fair distribution of irrigation water, reliable irrigation water supply and timely delivery of irrigation water.

## Acknowledgements

The authors would like to thank UNESCO-IHE (the University Water Sector Partnership- Demand Driven Action Research project) for financing this research, and Arba Minch and Hawasa Universities for providing the necessary facilities like office and vehicles. Our special thanks will be for Oromiya Water Mines and Energy bureau, Southern Nations Nationalities and Peoples Regional States Irrigation Development and Scheme Administration Agency. We are also highly indebted to Dr. Flip Wester, Dr. Frank van Steenbergen, Mrs. Susan Graas, Mr. Yohannis Geleta, Mr. Tadele M, Mr. Roba, Mr. Adunga E., Dr. Mekonen A., Mr. Gezahegn Wejebo for their all round support to realize this research.

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# Environmental dynamics and Challenges of Sustainability in southern Ethiopia - A Case Study of the Chencha and Arba Minch Areas

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## Abstract

*Environment has undergone unprecedented changes in Chencha and Arba Minch areas, Southern Ethiopia, during the last century. Yet there exist well-established land-use systems and a wealth of local experience in maintaining and managing environment. The major objective of the study is to explore the dynamics of environment in a chronological and spatial order to identify trends, driving forces and impacts of land use systems, land cover and landscape structures during the last century in Chencha and Arba Minch areas. The methods used in the study include detailed field and lab investigations including $C^{14}$ dating, satellite image interpretation, interviews and group discussions. The results of satellite image analysis (images from 1972, 1984 and 2006) show that cultivated land was expanded by 39 % from 1973 until 2006, but farming land per capita decreased enormously. In the same period of time, grassland as the main fodder resource for livestock shrank by 69 % – thus causing a huge decrease in livestock. Similarly, forest cover shows a 23 % decline from 1972 until 2006, with the most significant change from 1986 to 2006. Cultivated land scarcity and fragmentation can mostly be related to demographic pressure, which was exacerbated by government policy, the land tenure system, and the nature of subsistence agriculture. Farmland scarcity has already caused farmers to cultivate marginal land areas and fragile ecosystems. This coupled with deforestation and cattle grazing in the remaining forestland, resulted in a decline in soil fertility and an increase in soil erosion by water. Gullying is one of the common and widespread processes of erosion in the area. Gully systems are characterized by the cyclic succession of phases of entrenchments with aggradations and with stability and soil formation. The farmers, however, were resourceful and gathered a wide range of experience and developed skills over millennia to cope with the problems associated with population density and scarce resources. Despite the recent disruptions, they have used intensive cultivation systems, integrating crop-livestock practices and cultivated diversified crops such as "demographic" (very productive) and drought tolerant plants. Moreover, terraces were built along contours, and used – as radiocarbon dating proves – over the last eight centuries, particularly in Dorze-Belle, Chencha. These indigenous terraces are thus dubbed a success story to manage the environment over generations and as a survival strategy for life on the steep mountains. Moreover, the people of the area have long had rules and regulations to maintain the sacred forests, woodlots and stands of trees around the homesteads and in the farm fields. However, these traditional land use activities and land management practices have been deteriorating recently. Farmers have been forced to cultivate steep slopes, wetlands, and grasslands, whereas the practice of fallowing and the application of manure have declined. Land use planners and environmental managers should take local knowledge and innovation into account in order to make sound decisions for the future.*

## 1. Introduction

Agricultural landscapes and forestland in Ethiopia underwent unprecedented changes (particularly during the last century) due to the dynamics of political, demographic, socio-economic, and cultural factors (Zewde 1998; Hurni 1993). However, the type, direction and rate of the changes have to be investigated in detail.

Governmental awareness and recognition of the problems of land degradation in Ethiopia started with the 1970s famine. There was a general consensus in the government that the famine event was associated with deforestation and soil degradation. As a response, massive soil water conservation activities were carried out to mitigate land degradation, with the assistance of international organizations (Admassie 2000; Alemneh 2003; Bewket, 2003). Was the soil water conservation program with a top-down approach and a low level of involvement of the farmers in planning and implementing soil conservation measures effective and successful? Have the farmers of Ethiopia been aware of the problems of land degradation, even before the government recognized the problem? Did the farmers use measures to halt soil degradation and to manage forest resources over generations? These are important research questions that should be addressed.

Landscape development and human activities have also been rapidly changing during the last century in Chencha and Arba Minch areas in Southern Ethiopia. As a result soil degradation is prevailed in the area and becomes one of the most serious threats in terms of agricultural production, food insecurity and development challenges. Hence, an historical investigation of landscape development, which took place during this period of time, is of a paramount importance to provide valuable information for decision makers, land use planners, and environmental managers who need to make sound decisions. During the past century in particular, there has been a very significant development of agricultural landscapes. During this period, three different political regimes emerged and deployed different ideologies and differing agricultural land utilization and land policies. The regime changes were radical and the impacts were reflected in resource utilization and management. Furthermore, population growth was very rapid. The last century was therefore a period of dynamic socio-economic and political changes, which played an immense role in modifying landscapes.

On the other hand, farmers have developed and practiced various traditional mechanisms to cope with the challenges of population pressure, environmental degradation, and food insecurity (low productivity) over a long period of time. However, the agricultural system and the mechanisms against adverse conditions have not gained attention and appreciation by planners and researchers. For instance there is an important lack of studies, which investigate the importance of terracing in the area.

Thus, the study of the long-term landscape dynamics has multifold significances such as adding scientific knowledge about land uses, landscape structures and land management. The long-term perspectives of the landscape management are also guiding efforts towards sustainable land management systems. Moreover, the present investigation is important since today many cultural landscape practices are on the verge of disappearance due to cultural assimilation and integration, coupled with the high dynamism of the political and economic conditions. Furthermore, the investigated area is marked by a high diversity of physical and socioeconomic environments. For example, the altitude ranges within a short horizontal distance of only 20 km from 1,100 m in the rift valley to 2,300 m above sea level in the highland. I.e. there exists an enormous diversity in topography, climate, soils and vegetation in the research area. Moreover, there is also a spatial variation on types, magnitude and severity of soil degradation. On the other hand, there is a strong linkage between land use, landscape structure and the people. This is also an important premise to investigate site specific and spatial interlinking of landscape dynamics.

## 2. Objectives and Research Questions

The major objective of the study is to explore the dynamics of landscapes in a chronological and spatial order to identify trends, driving forces and impacts of land use systems, land cover and landscape structures during the last century in Chencha and Arba Minch areas, Southern Ethiopia.

**Specific Research Questions addressed were:**

1. What are the trends and patterns of the dynamics of land use systems, land cover and landscape structure and their driving forces?
2. Why is the recent rate of landscape change so high? Were there comparable rates of changes in the past?
3. To what extent do people perceive the problems of soil degradation (sheet, rill and gully erosion, soil fertility)?
4. How have farmers responded to the effects of the dynamics of land use systems, land cover and land structure?

## 3. Description of the Study area

Chencha (6° 15' N, 37° 34' E) is situated in the south-western highlands of Ethiopia, about 600km south of Addis Ababa (Figure 1). It is bounded by Lake Abaya in the Great Rift Valley and Arba Minch in the east and south respectively. The elevation in the area ranges from 1,100 to 3,200 m a.s.l. Chencha is characterized by diversified topography, consisting of the rift valley escarpment, high plateaus topped by hills and mountains, plains, and river valleys. The rift valley escarpments and the upper foot slope of the mountains in the highlands above are very steep and marked by undulating and rugged surface features. Mountaintops are mostly gentle to almost flat. The valleys of the perennial rivers (Kulfo, Hare and Baso) are steep in the upstream area and flat in the rift valley. The highlands are well settled and have long been used for cultivation, while the rift valley escarpments and bottom of the rift valley have not been used because of the rugged topography and harsh environmental conditions, namely a hot climate and the presence of malaria.

The monthly average maximum temperature in Chencha is 15 $^{0}$C (occurring in February) and the monthly average minimum temperature is 13 $^{0}$C (occurring in October), based on the meteorological measurements taken from 1970-2009 by the meteorological station at Chencha town, at an elevation of 2,800 m a.s.l. The mean annual precipitation for Chencha was measured as 1,255 mm. During the measuring period mentioned above, the annual precipitation varied from 756 to 2,353 mm, showing the high inter-annual variability. The precipitation pattern is of a bi-modal type. The first precipitation season, locally known as *gabba,* occurs from March to June and the peak monthly precipitation of 185.4 mm was measured in May. The second precipitation season, locally known as *silla,* occurs from August to November. The highest proportion of annual precipitation (75%) occurs in the *silla* season. Similarly, the precipitation variability within the seasons is also high, with particularly extreme variability occurring in *gabba* season. The agricultural activities of the areas follow the seasonal patterns. As a result, there are two cropping seasons in the area, also referred to locally as *silla* and *gabba*. In silla season, land is ploughed in June/July and crops are planted in July/August and harvested in November/December. However, in *gabba* season land is ploughed in January/February and crops are planted in February/March and harvested in June/July. *Silla* is the dominant agricultural season; it accounts for 65 -75% of the total yields in the area. This is attributed to the occurrence of a sufficient amount of precipitation over the required period of time. Additionally, the warm temperatures that come after the planting periods also enhance the fast growth and ripening of crops. In contrast, *gabba* is marked by high variability of precipitation that exerts various adverse impacts on agricultural productivity. The heavy shower at the onset of a rain event erodes the uncovered ploughed soil and washes away the seeds. Furthermore, the ripening and harvesting of the crops of this season coincides with the heavy rain of *kirmet* (the main rainy season) which promotes the occurrence of crops diseases, also resulting in damping-off conditions.

There are four soil units in the Chencha area: Acrisols, Alisols, Fluvisols and Leptosols (FAO, 1997). Among these, Acrisols and Alisols are dominant. They are formed on rolling mountains mainly in foothill positions with slope gradients that range from 5 to 14 %. The parent material of the soils is predominantly basalt colluvium. Good texture, plus high organic matter and total nitrogen characterize the soils, which are widely used for cultivation. However, the reaction of the soils is often acidic as a result of the leaching by high rainfall. They are also marked by low cation exchange capacity (CEC) and base saturation. The cultivation of the soil also causes lowering of the available nutrients, which are the main constraints for cultivation. Acrisols in particular are marked by very low CEC and consequently the soil has a low potential for producing high yields. Leptosols occur on upper slopes of the mountains and on the summits, which are significantly subjected to accelerated erosion. Leptosols are marked by shallow depth and acidity – both are constraints for crop cultivation. Fluvisols occur in the river valleys, which are situated in the semi-arid rift valley. They are deep and consequently they promote moisture and nutrient storage and release. This situation is strengthened by the loamy texture. Fluvisols are friable so easy to cultivate. Moreover, their reaction is slightly alkaline, which is suitable for the growth of most cultural plants.

The population of the *worada* of Chencha in 2005 was 127,193 (CSA, 2006). The density is estimated at roughly 336 persons per square kilometre. Scientific investigations prove that the area has been settled since at least 3360 years cal B.P. (Arthur *et al.*, 2010). The area is in the centre of the region GamoGofa, which is divided into 40 *dere* (small discrete political units). Olmstead (1975) estimated that 5,000 to 35,000 people were living in the area at the end of the nineteenth century. *Dere* were governed at that time by general assemblies which were represented by the high priests, known as *Kao*. At the end of the nineteenth century, however, the region was incorporated into Ethiopia. The main economic activity of the area is subsistence agriculture. People mainly cultivate enset, barley and wheat. To a lesser extent they also grow maize, teff, peas, beans, potatoes and tree cabbage. Enset is the staple food in the area and central to the subsistence agriculture. Raising livestock is also an integral part of the economy. Off-farm activities include weaving and small-scale trading. The traditional house is made from the stems and leaves of bamboo and looks like an upturned basket

## 4. Methods (Overview)

Multi- and interdisciplinary research methods and a holistic analysis have been involved in collection, organization and analysis of both the historical and contemporary data on the land use systems, land cover and landscape structure from geoarchives, laboratory analysis, remotely sensed images, public, agencies and documents. Detailed field investigations and measurements on soil erosion and deposition processes in a chronological and spatial order have been carried out. Charcoals samples have been analyzed and dated.

Satellite images of the different periods of time have been used to analyze the magnitude and rate of land use and land cover dynamics. In depth semi-structured interviews were carried out with 120 households. To cover the different agro-ecological zones, areas that belong to the highlands, middle altitudes, and lower elevations were selected. Group discussions with key representatives were also held to document the causes of soil degradation, the perception and responses of the people to landscape dynamics.

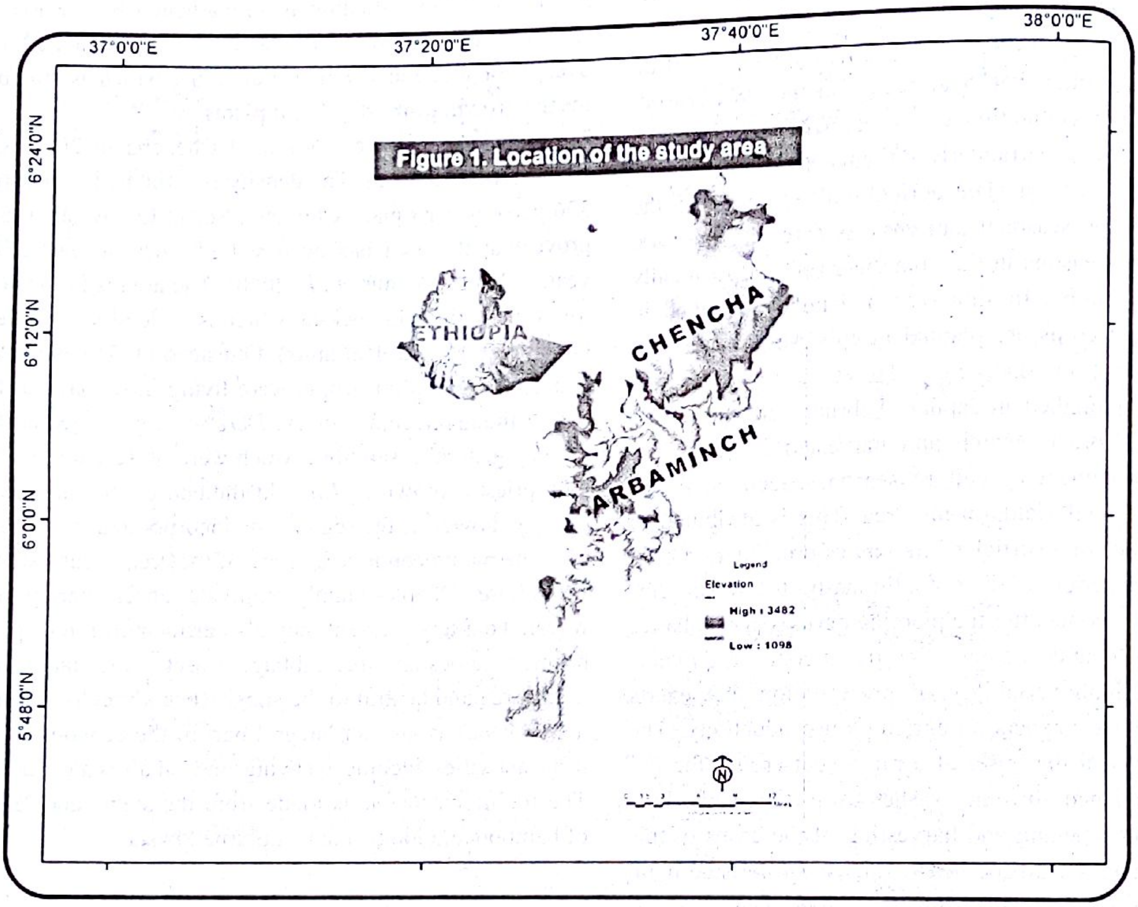


Figure 1: Location map of the study area

## 5. Results and Discussion

### 5.1 Forest and agricultural landscape dynamics

*Trends of deforestation since the 1970s*

The result of satellite image interpretation depicts that forest accounted for 32%, 24%, and 9% of the investigated area in the years 1973, 1986 and 2006 respectively. The downward trend in forest cover is a widespread phenomenon in subsistence agriculture, characterized by an increase in the demand for cultivation land and for fuel wood. This result is also in line with the reports of various studies which were undertaken in different parts of the country. For example, Dessie and Carl (2008) have demonstrated a decline in forest extent in the Awassa region, southern Ethiopia, from 16 % to below 3 % from 1972 until 2000.

Zeleke and Hurni (2000) have revealed a considerable decline of natural forest extent in Denbecha, Gojam region, from 27% in 1972 to below 1 % in 1997.
However, the pattern of decrease in forest cover in our study area was not uniform over time and space. The lower annual decline in the first period (from 1973 to 1986) compared to the second (from 1986 to 2006 ) period is explained by the massive afforestation program that took place in the area during the late 1970s and early 1980s. This plantation program has contributed to the forest cover and thus lowered the deforestation rate. However, in other parts of Ethiopia the forest cover was increased and deforestation was even reversed due to the plantation of trees that took place in the same period (Woldetsadik ,1994; Bewket, 2003).

The high rate of deforestation from 1986 until 2006 is explained by a particular episode in Ethiopian history – the political upheaval of the 1990s. During this time, there was a radical government transition: the present government took over from the Derg (1974-1989). According to the informants of the current study, this transition time was accompanied by a massive destruction of forests. The principal reason for the clearance of forests was the demand for land for cultivation. Trees were also felled on a large scale for firewood and timber production. At this time, there were only loose institutions and government legal frameworks to control the forests. This massive forest clearance was also an expression of the farmers' dissatisfaction with the afforestation program which took place during the Derg regime.

Larger-scale forest clearance took place in the lowlands compared to the highlands. This was attributed to the recent movement of people to the lowlands for settlement and cultivation. In the past, settlement in the lowlands was inhibited due to the prevalence of malaria and trypansomasis, a disease that affects cattle. Improvements in health facilities and the decline of malaria and trypansomasis in the area were therefore the major factor for settlement and cultivation. Similarly, the agricultural land expansion and permanent settlement in the recent past in the Ghibe valley, southwest Ethiopia, was also due to the elimination of trypansomasis in the area (Reid et al. 2000). On the other hand, minor changes in the size of forests in the highlands since the mid twentieth century were caused by long-term settlement in the area that contained most of the forest land, which due to its suitability for cultivation and it already being at the disposal of farmers, led to its early transformation into cultivable land.

The changes of forest land in the highlands were marked first by the felling of trees using mainly axes from the adjacent areas of the forest boundary, followed by a select felling of trees inside the forest. Then the adjacent land to the forest was brought to cultivation or used for grazing. Select felling of the forest land caused a thinning of forests and ultimately this land was converted to grazing land and then to cultivation. They sometime set fire to get clear the land for cultivation and to get better grass for cattle grazing inside the forest. At present, this same process has also occurred at the middle altitudes, mainly on the escarpments. In the lowlands, forest land has been cleared since the 1970s and then cultivated, as reported by the informants.

***Trends of agricultural landscape***

Cultivated land has increased enormously over the last four decades. However, there was no continuous linear increase over this period of time (spatially and temporarily). Household holdings of cultivated land have decreased over time despite an increase of the extent of total acreage of arable land in the highland. A large number of fragmented landholdings is also a prevailing feature of the area. The average number of fields in fragmented cultivated land areas is estimated at about 5.0 in the upper highland, 4.6 in the middle highland, and 3.7 in the lowland. Moreover, the diversity of crop species and crop varieties in the area has also changed during the last decades. New varieties of crops were introduced while existing crops were modified or disappeared. The diversification of crops has also been reduced and in some cases has been replaced by mono-cropping. As to the trend of agricultural productivity in the highland, the majority of the farmers responded that there is a decline of productivity at a high rate compared to forty years ago. Similarly, there is a significant downward trend in forest cover change in the area since the 1960s. However, the pattern of decrease in forest cover in the study area was not uniform over time and space owing to various reasons.

## 5.2 Driving forces of landscape dynamics

The most cited factors that cause deforestation in the study area are agricultural land expansion, fuel wood demand and settlement. According to the informants in the highland, the main reasons for agricultural land expansion are low agricultural production and population increase. Population growth is among the main causes for the scarcity of cultivated land in the area.

The problem of land scarcity has been very acute over time, since the existing land was shared and distributed mainly to the male children. Fuel wood demand is another chief cause of deforestation since the fuel wood is also the main source of energy for the surrounding towns, namely Arbaminch and Chencha. The lowland was covered by forest till the mid-twentieth century. Agricultural practices in the lowland started in the recent past and resulted in intensive forest clearances. One of the main reasons for deforestation in the lowland is settlement, which in turn was caused by different factors such as the decline of malaria, high population density in the highland, government policy, and the expansion of commercial farming.

The lowland was covered by forest till the mid-twentieth century. Agricultural practices in the lowlands started in the recent past (Jackson 1972) and resulted in forest clearances. A small number of semi-settled farmers were growing crops using the alluvial soils along the river deltas since the 1950s, according to the informants. Furthermore, the farmers from the highlands moved to lower altitudes for cultivation practices during the day and returned to the highland during the night. They were mainly growing maize, which was sold to the highlanders and also used for their own consumption. The main constraints for permanent settlement in the lowland area were prevailing malaria and trypanosis.

Large-scale forest clearance in the lowlands was associated with permanent settlement that took place in the area from the 1960s. According to the informants, about 150 people formed the first permanent settlers in the area in 1964.

These people came from the surrounding highlands as well as other locations. In addition, a fairly large number of people migrated to the area from 1975 for permanent settlement and to cultivate land. This settlement was enhanced by the reduction of malaria owing to improvements in the health facilities.

In the 1980s the then government launched a villegization program in the area. People in the highlands were coerced into settling in the lowlands. The main purpose was to ease the population pressure on the highlands. Upon arrival, the farmers grew maize, cotton, and potatoes; only later were different plants introduced and grown, such as bananas.

Figure 2: Sacred forest in Chencha area

## 5.3 Effects of landscape changes

Deforestation and agricultural land use dynamics are the main reason for the rampant sheet, rill and gully erosion processes in the area. The vegetation removal from steep slopes and the subsequent cultivation resulted in the lowering of soil resilience to erosion and has exacerbated soil erosion by water. In addition, the problem of soil erosion in our investigation area has also been exacerbated by cattle grazing in the remaining forestland, owing to the shortage of proper grazing land. The cattle tracks have caused soil sealing, which in turn reduces soil infiltration and subsequently high surface run-off rates occur during heavy precipitation events. A cattle grazing has also reduced vegetation cover density in forestland. Further, farmers have been cultivating the shallow soils, sometimes saprolite, as observed during the field investigations, which has also enabled an acceleration of surface run-off rates.

Gully systems in the investigation area are characterized by the cyclic succession of phases of entrenchments with aggradations and with stability and soil formation. Gullies are highly modified and altered landscape elements, which in turn have immense implications on the environment and livelihood of the people. Gullies caused stripping of large amounts of soils from the highland and also water availability in the soil for plant growth. In addition, siltation of irrigation channels and weirs at the lowland is one serious obstacle for agriculture. Frequent flooding that is triggered by gullying has also affected the town of Arba Minch during the last few decades. Blockage, cutting of the side of roads and sediment deposits on the roads is another adverse effect of gulling in the area. More than five decades ago gullies were confined only at a few places, as reported by the farmers. The extension of areas that are affected by gullying has dramatically increased over the last five decades owing to the dynamics of the social, economic and demographic conditions.

Deforestation has also exerted significant impacts in terms of the decline, modification and change in the biodiversity of the area. Indigenous trees, which were common in the area in the past, are now endangered due to deforestation. Farmers reported that *Cordia africana* is one of the tree species under threat of disappearance. This tree has diverse functions, namely for making coffins, as roof supports, for building sheds on the agricultural fields, and as raw materials for timber production. The latter use of the tree has led in particular to over-exploitation and is resulting in the threat of disappearance. Bamboo is mainly used for house construction, as well as the establishment of fences. Additionally, it has spiritual significance (Cartledge, 1995).

Despite this, bamboo is currently declining rapidly in the investigation area, in terms of both extent and in the size of the individual trees. In the past bamboo was allowed to grow for long period of time, while at present early felling is common. This has also caused a change in the type and shape of houses. Due to a lack of bamboo and grasses, rectangular houses constructed with corrugated iron are replacing the upturned basket form of traditional houses. Similarly, the dominant species of swamp and shore vegetation along the lakeshores.

## 5.4 Perception of landscape deterioration and Traditional knowledge

Nevertheless, the majority of the farmers have a wealth of experience in identifying the severity, dynamics and causes of soil erosion and soil fertility decline. Farmers were also aware of the seriousness of problems of grazing land deterioration, which affect the raising of livestock. Nearly all surveyed farmers mentioned feed problems as a result of increasing grazing land shortage. The majority of the respondents are aware of the problem of forest decline. Despite the recent disruption farmers have developed a wide range of local strategies as a response to demographic pressure and scarce resources. These include cultivating drought resistance plants (such as enset), growing diversified crop varieties, integrating crop-livestock practices, agroforestry husbandry, and the recent practices of cash crop cultivation. Enset is a drought resistant plant and provides a higher amount of food per unit area than most other cereals. There are about 48 plant species, which are used as food for humans. Intercropping (growing of different crops on the same field in the same season) is one of the systems to grow these crops. Intercropping has been practiced in the area due to the various advantages that overweigh mono-cropping systems in small holding agriculture. Livestock tending is the main integral part of the agriculture system in the area. It has played an important economic and ecological role for a long period of time. Beside crop growing and livestock tending, very few households are engaged in various off-farm activities. These activities would enable them to generate a complementary income and would serve as a strategy to cope with resource constraints. Traditional forest management is also another salient feature of the land management practices.

Forests, woodlots, and stands of trees around the homesteads and in the farm fields, along with the cultivated land prevailed in the study area. Farmers integrated trees with crops in cultivated land as they are aware of the various economic, environmental and social significances for the people. Namely, they are important for daily diets (e.g. moringa), as sources of cash crops (e.g. coffee) and they also provide fuel wood. Trees are also important for bee-keeping (apiculture). These trees are also a source of income during crop failures; cash from the sale of wood is used as insurance. Along with their use as fodder for livestock, trees serve as shade during the high sun time when the land is used for pasturing. The people are also aware of the environmental significances of trees, such as maintaining soil fertility (e.g. Erythrina, Hagenia, and Crotone) and acting as barriers for surface runoff and soil erosion.

Farmers have developed and used various traditional management practices evolved over the course of time. The main practices for boosting soil fertility are manuring and crop rotation. These practices play vital roles in boosting macronutrients such as nitrogen, phosphorous and potassium in the soils of the area. Manure also contains additions to the minerals that are exported by crop harvest every year. Besides, organic matter is very important in maintaining the soil structure. Moreover, along with soil fertility management practices, farmers have also used indigenous terraces. Radiocarbon dating of a terrace from Chencha-Dorze Belle has provided evidence that the stonewall terraces have been part and parcel of long-lived agricultural activities in the region, over eight centuries. These terraces have various uses, such as runoff reduction, soil erosion control, and landscape alteration. The long term continuous usage of the indigenous terraces is attributed to social commitments, the structural features of the terraces and the farmers' responses to the dynamics of social and cultural circumstances. Farmers also acknowledged the advantages of the indigenous terraces compared to the introduced terraces. They suggested that the indigenous terraces are environmentally suitable, socially acceptable and economically feasible.

All these locally developed, long-term sustainable land use systems and land management techniques in the study area suggest that the agricultural system has been characterized by a high standard of land resource management, providing food and material resources to the inhabitants over centuries. Moreover, the local peoples practices of e.g. forest management and preservation show the people's identity and sense of place and their harmonious relationship with the forest. The significance and importance of indigenous land management such as the installation and use of terraces lies beyond their contribution to land productivity and economic significance.
It is dubbed a success story in which people invested their skills, labor, energy and knowledge in constructing the terraces in order to manage the environment over generations. The specific indigenous terrace systems are a major part of the cultural landscape, which is unique not only for the region and Ethiopia, but also on a global scale. Thus, there is a strong need to preserve and develop this important cultural heritage and example of sustainable land use and living. Thus these practices should be promoted and advanced.

On the other hand, there will be a loss of traditional land management practices, of the people's identity and their cultural heritage. The recent changes include reduction and abandonment of fallowing, modification of crop rotation and large-scale reduction of manuring. The resilience of the traditional practices for livelihood requirements is the main driving force for the changes. Furthermore, despite various attempts by government, sheet erosion and gully development remain rampant. The top-down of planning and the negligence of the traditional knowledge are the main drawbacks. The questions to be addressed are therefore how can soil degradation such as gullying be avoided or at least reduced drastically under the conditions of a densely populated and intensively used area with sensitive soils and steep slopes? Watershed management that is based on grass root level community participation from the conception phase to implementation and maintenance is recommended. Site-specific attempts to address the problem should also be considered. In the planning, along with soil and water conservation measures, there should also be some strategies to release population pressure and fulfilling the livelihood of the people. Therefore environmental and land-use management planning should not only consider the rehabilitation of land but also address the main attributes of local management resources, mainly their impact in raising agricultural productivity.

## 6. Conclusions

The downward trend in forest cover is mainly attributed to agricultural land expansion, as a response to the increase of population and the decline of agricultural production in the area, as expressed by the farmers.

Figure 3: Terraces of Chencha- Dorse Bele

The increase in the demand for fuel wood in the area and in the surrounding towns, which heavily depend on fuel wood for energy consumption, is another chief cause of deforestation. The recent settlement and cash crop farm expansion in the lowlands also resulted in the massive clearance of forests. Government upheavals, land tenure, and absence of continuity in forest policy have also compounded the factors for deforestation.

The dynamics of land management are also aggravated by land tenure systems and the government agricultural policy that banned sale and purchase of land. Since the land has been state property since 1974, farmers fear to invest in long-term soil water conservation measures, as the land might be taken by the government and redistributed to others. The top-down approaches towards soil water conservation design and implementation did not consider the significance of local land management knowledge and practices. The low attention paid to grazing land management, compared

In the study area, further research needs also to be carried out on past land uses and their impacts on soil degradation. The old gullies are visible in area indicating the past land use impacts. Moreover, it is important to investigate the impacts of old indigenous terraces on natural resources such as on soil properties, and carbon sequestration. Deciphering the role of climate or human induced impacts on long-term environment history will also play a significant role in determining the landscape development of the area.

## Acknowledgements

We are very grateful to all farmers and the enumerators who took part in the research. We would also like to thank the German Research Foundation (DFG) for financial support to the study. Thanks are also due to Nicole Taylor for proof reading of an earlier version of the manuscript.

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# Household Adaptation to Flood in Itang District of Gambela Region in Ethiopia

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**Abstract**
*Flood is the most frequently occurring natural disaster in Ethiopia. Climate change may further increase frequency and magnitude of floods across the country. However, flood has not received the research attention it deserves particularly compared to drought in Ethiopia. In this study, we assess people's perception of climate change and experiences of adaptation measures to deal with floods in the Itang district of Gambela region in Ethiopia. Itang is situated in the floodplain of Baro River which is a tributary to the Nile River. Data for this study was collected through quantitative survey of 431 households, focus group discussions and key informant interviews. Descriptive statistics were applied in this study to report results of the quantitative survey.Nine out of ten respondents believe that there is significant increase in flood duration, extent and frequency over the past two decades. As a result, many households experienced a severe decline in crop production over the past twenty years mainly due to recurrent flooding. Nearly half of the surveyed households faced food shortages every two years. To deal with floods, a considerable number of households practiced adaptation measures but mostly related to non-farm activities such as migration, selective herding of livestock and livelihood diversification. The measures were not effective to the desired extent in dealing with floods due to limits to households' adaptation capacity. External intervention is, therefore, necessary to increase households' resilience to climate change in Itang.*

## 1. Introduction

Ethiopia has been affected by recurrent flood and drought that jeopardized the livelihoods and well-being of millions of rural and urban dwellers. Flood is one of the most severe natural disasters that have occurred during the last century. It is comparable with drought in terms of frequency as well as impacts on people and economy. Flood is the most frequently occurring natural disaster in Ethiopia with 1.45 events per year, which is higher than the incidence of drought that account for 0.32 events per year (EM-DAT, 2010). Flood also represents the second severe form of natural disaster, being preceded only by drought, in terms of the number of people it affects and the economic damage it causes in the country. However, studies often deal mainly with drought (Conway 2011; Bryan et al., 2009), while paying little attention to the problems of flood. The problems of flood are multidimensional. It affects livelihood and economy by disrupting business activities and destroying crops and livestock. It affects well-being as it often leads to health deterioration. It also destroys valuable infrastructure, thereby retarding development.

Flood is affected by climate variability and change. Climate change is likely to alter flood frequency and magnitude. The findings of many Global Circulation Models (GCMs) suggest that the Eastern Africa region will likely be affected by changing climate in the future (IPCC, 2007). The climate change which is projected to affect the region is expected to occur not only in the form of changes in average climatic conditions but also in the form of altered climate extremes such as drought and flood. It is assumed that precipitation change, rising or falling precipitation magnitude, will happen in the Nile basin region. Studies indicate that average precipitation in the Nile basin may decrease by up to 22 percent or increase by up to 18 percent towards the end of this century (Beyene et al., 2010).

It is expected that the floodplain of Baro River may encounter a changing flood situation. The plain of Baro River which is located in the Itang district of Gambela region in south west Ethiopia is one of the flood prone areas. Studies focused on this basin suggest that a flood event with return period of 100 years in the base line period is projected to have a return period of 20 to 50 years in the 2080s time horizons (Haile et al., 2013). This shows that in the future the risks of flood will likely increase in the Itang district of Gambela, as it is situated in the Baro floodplains. This situation calls for the need to enhance our understanding of the impacts of flood and people's coping and adaptation mechanisms. This requires a careful examination of people's experiences with flood: - how flood has impacted people and how people have tried to cope with and adapt to such circumstances.

Understanding such experiences by examining the impacts of flood along with people's coping and adaptation measures is important to successfully deal with future flood events.

This study assesses people's perception of climate change and experiences of adaptation measures. It seeks to identify adaptation measures at household level. The study area is the Itang district of Gambela region in southwest Ethiopia. The study area is situated around the Baro floodplains. The people of Itang are exposed to recurrent flood due to overtopping of the Baro River and excessive rainfall that causes flash floods. The riverine flood in Itang occurs gradually and stays on the ground over a period of three to four months. On the other hand, the occurrence of flash floods is often sudden and short in duration. However, this incidence of flood involves a very severe impact. Increased severity of flood in terms of frequency, extent, depth and duration is causing the deterioration of the livelihoods of farmers and livestock keepers in Itang. For instance, such people are affected through loss of standing crops and death of livestock. It is particularly exacerbating the vulnerability of residents who are already in poor state of living condition. By examining experiences of adaptation measures vis-à-vis climate change impacts, the study will enhance the understanding of adaptation to flood at the household level. It will also contribute to efforts that seek to increase households' resilience to climate change.

## 2. Conceptual notes on preventive, coping and adaptation measures

Climate change exacerbates the severity and frequency of flood and this situation concerns many people due to its impact on a wide range of sectors. Changing floods can result in deterioration of health status, reduced productivity and threaten survival in different ways. Such impacts can be most severe at a household level, particularly for the poor with limited resources to deal with the impacts. People who reside in flood prone areas try to deal with impacts of flood through various preventive, coping and adaptation measures. Commonly, these measures are not fully effective because of limits to households' capacity. Preventive measures can include short term practices such as cleaning ditches as well as long term measures such as changing house construction styles and constructing dykes. However, protection structures usually give a false sense of security in that such structures may not withstand flood events induced by climate change and variability. Besides, such measures can become expensive for some areas such as extensive floodplains which are affected not only by riverine floods but also by flash floods.

Preventive measures are not always adequate to avoid flood impacts. This situation forces people to consider coping measures. Coping measures often involve short term response to unexpected events. Such responses may include selling assets, income diversification and changing consumption patterns. Coping measures are short time oriented in terms of dealing with impacts. But, resorting to unplanned coping measures can end up eroding household resources and exacerbate vulnerabilities (Opondo, 2013). At the level of the individual adaptation for many people is primarily a matter of survival strategies to deal with the effects of rainfall variability (Conway, 2005). Adaptation was defined by Warner et al., (2012) as longer-term responses to more gradual changes and therefore constitutes measures that are planned based on experiences. Households who have developed adaptation mechanisms through long-time experiences can adjust their situations in the face of adversities. Such households are equipped with better enabling strategies to deal with the ensuing impacts. Thus, adaptation provides a better enabling mechanism than coping to deal with the impacts of recurrent calamities.

The main objective of this study was to assess people's perception of climate change and identify adaptation measures at household level. The study will enhance the understanding of adaptation to flood at the household level, thereby contributing to efforts that aim to increase households' resilience to climate change.

## 3. Description of the study area

This study was conducted in Itang woreda of Gambella regional state (Figure 1). The Gambella People's Regional State (GPRS), located in south west Ethiopia, is bound by 6°28'38" to 8°34'00" North Latitude and 33°00'00" to 35°11'11" East Longitude. The region accounts approximately 2.7% of the surface area of the country. It is administratively divided into twelve woredas and one special woreda called Itang.

The Itang Special woreda encompasses 21 Kebeles with nearly all situated in the floodplain zones of Baro river basin. Itang covers an area of 2,188 km$^2$ with a total population size of about 42,000. The Itang town and most of other villages are located along the left and right banks of the Baro River which provides ecological importance and sources of livelihood to the inhabitants. During high flow period overbank flow from Baro River as a result of limited natural channel capacity, inundates major portion of the villages.

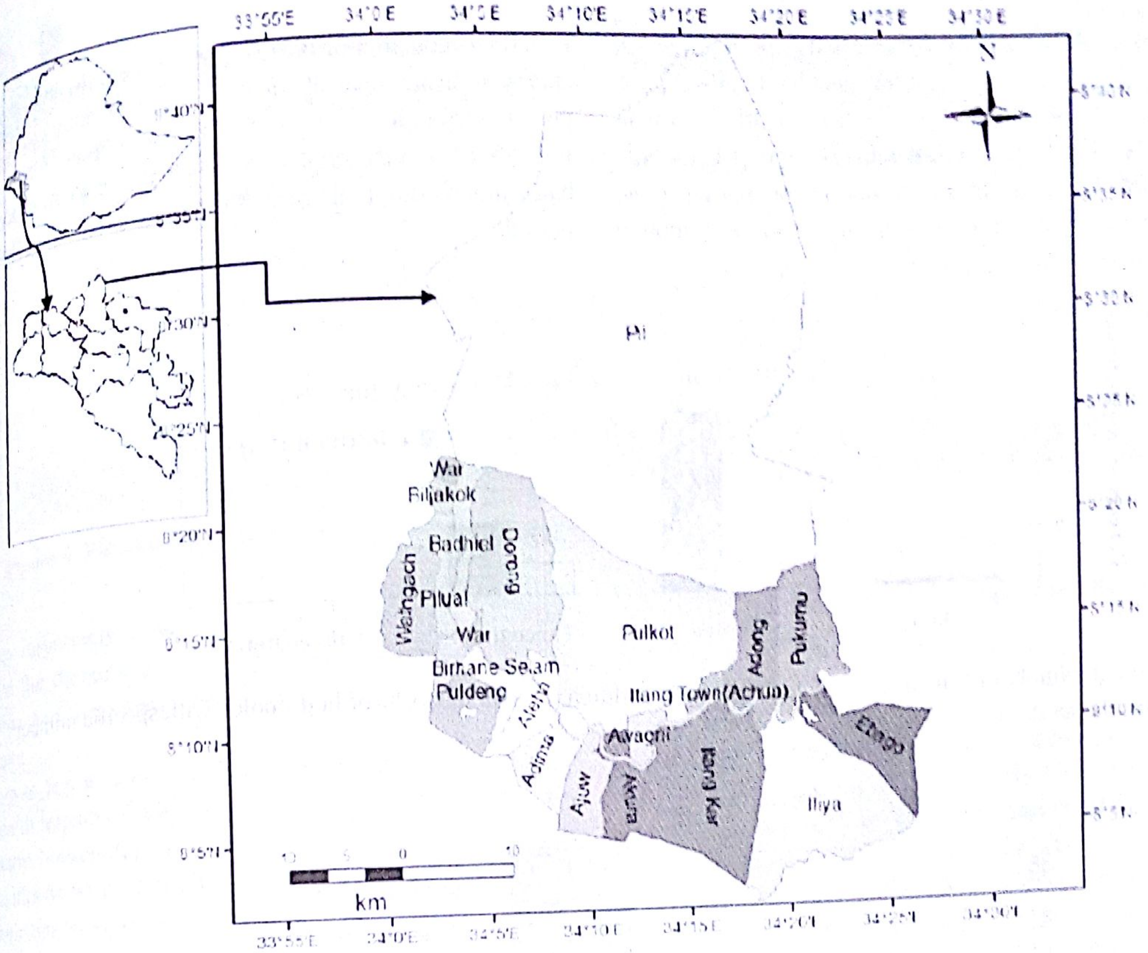


Figure 1: Map of the study area. The map on top of the left hand side is the country map, the bottom left map shows the region and the right hand side shows the Itang area. (Source: Haile et al., 2013)

## 4. Methods

The study was conducted using a combination of methods including Focus Group Discussions (FGD), Key informant interviews and Quantitative household survey. Four Focus Group Discussions (FGDs) were undertaken with various community members. FGDs for men and women were done separately as well as together. Discussions were also conducted with expert group consisting of teachers, health officers, woreda officials and others. The participants were selected from a wide range of age and economic group (petty business women, house workers, farmers, pastoralists, and agro-pastoralist) in order to enhance the debate. The discussion with each group was completed within 60 to 90 minutes.In total 20 Key informant interviews were conducted with elderly members of the community, flood affected people, and other stakeholders (governmental organizations and NGOs which are involved in flood related activities).

The total number of households surveyed in this study was 431. The households' distribution in each Kebele was fixed based on a set of criteria that include severity of flooding as measured by distance to the main river, surface area and size of population. Pill Kebele was entirely inundated during the household survey period. For this reason, it was not included in this study. Descriptive statistics are applied in this study to report results of the quantitative survey.

## 5. Results

Livelihoods in Itang involve challenges from a combination of climatic (such as flood, drought and heat waves) and non-climatic factors (heavy dependence on market, limited income generating options and meager subsistence crop cultivation). The crop production of many households is not sufficient to cover their own food consumption. Consequently, a large number of people depend on market supply for household food consumption.

The survey result indicates that nearly half of the surveyed households acquire 50 percent of their food consumption from the market. Buying food from the market, particularly for covering such considerable portion of household food needs is not an affordable option for many people. This situation often leads to reducing food consumption including reduction of meals. For instance, the household survey indicates that about 85 percent of adults and 70 percent of children in Itang eat only twice a day (see Figure 2). Such limited number of meals per day can exacerbate vulnerability to diseases such as malaria during flood periods.

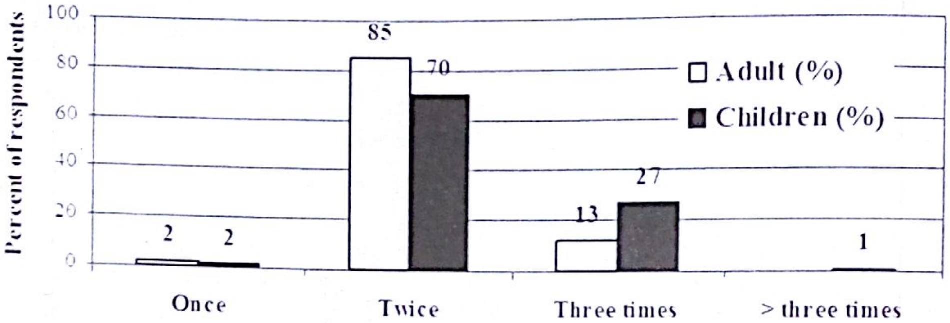


Figure 2: Number of meals per day for adults and children (Y-axis shows % of households with specific number of meals per day)

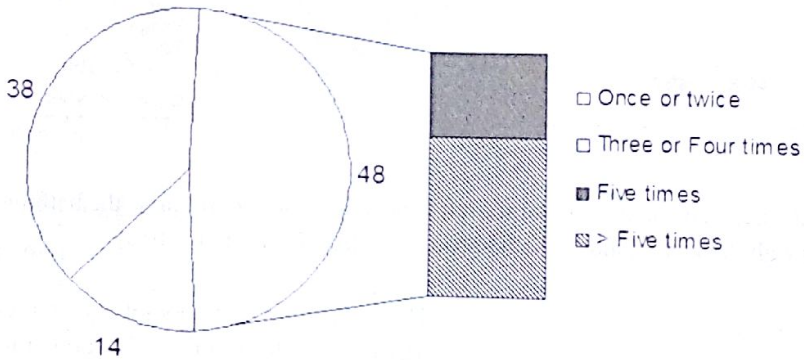


Figure 3: Percent of households that experienced specified number of years of food shortage in the past 10 years

Food shortage has been experienced by many people in Itang and respondents associated this problem with flood and drought events. Ninety six percent of the respondents stated that they experienced severe food shortage in the year 2011/12. They attributed this problem to prolonged and extreme flood events that hindered crop production. Food shortage has been a concern in terms of its impact on many people as well as its recurrence over the years. Almost all households have experienced food shortage in the last ten years (see Figure 3). Indeed there have been variations: some have experienced more or less shortage of food than others. Nevertheless, nearly half of the households faced food shortages every two years, i.e., five times in ten years. Our survey result shows that the main reason for such food shortages includes recurrent flood or drought due to variable weather condition, late onset of rainy season and prolonged rainy/dry season.

**Climate change**

Changes in climate along with ensuing impacts have been reported by people in Itang. Focus group discussion participants and key informants stated that the nature of flooding in Itang has substantially changed over the past twenty years. There is wider local perception regarding this changing situation. Data from the household survey also supports this local perception. Ninety percent of survey respondents perceive that there has been a significant increase in flood depth and extent, involving new areas which are inundated annually.

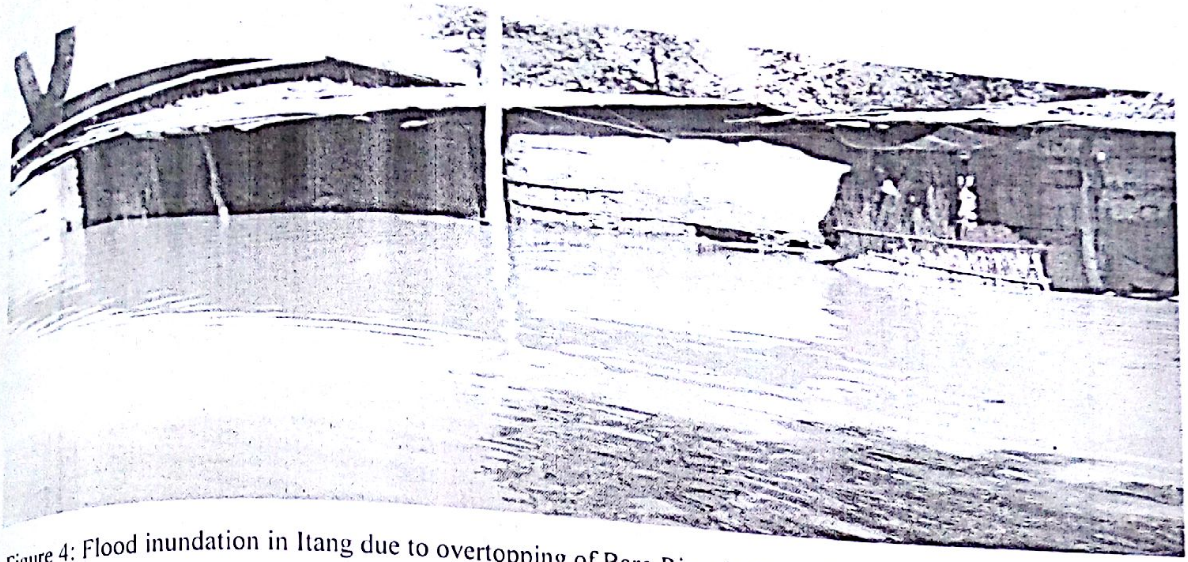

Figure 4: Flood inundation in Itang due to overtopping of Baro River in September 2012

Key informants as well as FGD participants also indicated that the duration of flood increased substantially and the impact of this change has been severely felt by people in Itang.

It was learnt from health professionals in Itang that the health impact of flooding is directly or indirectly affecting many households. This was also reflected in our survey results as 65 percent of respondent households stated that their health situation deteriorated due to changing floods. Common flood related diseases in the study area include malaria, diarrhea and skin diseases. The changing situation of flood has also involved economic impacts. . Ninety -one percent of the respondents who perceived changes in floods reported that their overall economic situation has continuously declined due to changing flood characteristics.

Recurrent flood in Itang is annually disrupting income generation activities as well. Large number of respondents (86 percent) experienced a severe decline in crop production over the past twenty years, as floods affected crop cultivation, repeatedly destroying standing crops and even damaging stored grains. Farmlands of some households are abandoned due to annual flooding.

Flood also affected livestock keeping in the area. More than 60 percent of the respondents that keep livestock in the area stated that increased flood depth and its long duration severely affected the practice of livestock keeping. According to FGD participants the impacts of flooding on livestock keeping include inaccessibility of grazing land, disease outbreak, loss of productivity and death of livestock. Although the impact on livestock is primarily felt by livestock keepers in the area, it can also affect the livestock economy in the country. This is likely when considering that Gambela is known as one of the livestock rich regions in Ethiopia.

## Adaptation

Households in Itang have variously attempted to adapt to the changing situation of flood. Fifty-six percent of the households involved in crop cultivation and perceived flood change stated that they have practiced at least one adaptation measure. Adaptation measures practiced by such households vis-à-vis climate change include increased involvement in new economic activity, expanding existing non-farm or non-livestock activity, increasing the number of household members engaged in economic activities, and seasonal migration to other areas. Despite the adverse impact of flooding on crops, only less than three percent of the respondents attempted to improve crop cultivation practice by changing crop type, applying irrigation or modifying farm techniques/inputs. On the other hand, temporary migration is found to be a common practice to adapt to changes in flood characteristics. Half of the surveyed households temporarily migrated out in every flood season. There have also been adaptation practices that involve changing house construction styles and constructing barriers in response to changing flood situation. People modified the construction of houses by elevating floor levels (see Figure 5) and constructing boundary walls for the house by using easy to maintain materials such as dried grass, bamboo or wood. Livestock keeping has also undergone some changes, involving selective herding. People who live close to river banks raise small animals which are easy to move during severe floods.

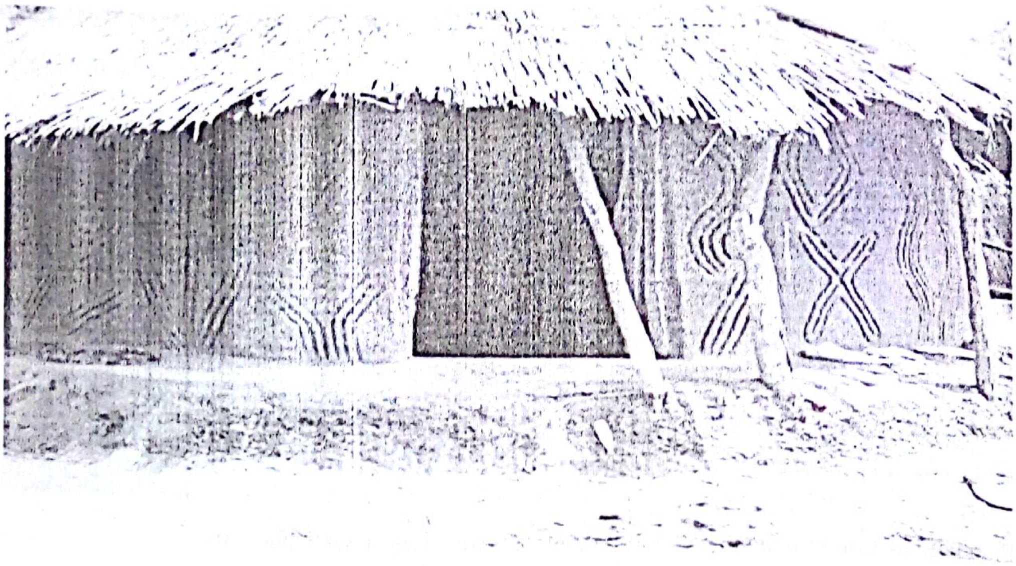

Figure 4: Elevated floor level to block floods from entering into a house in Itang woreda

The adaptation practices are not, however, sufficient enough to manage the problem of flood. A significant number of respondents (96 percent of who applied adaptation measures) expressed that the adaptation measures applied by their households were not sufficient to deal with impacts of changing flood. Several reasons were given for households' inability to develop adequate adaptation capacity to deal with increased flood severity. The most commonly mentioned reason was lack of financial means to implement adaptation measures. This was reported by more than half of the respondents. Insufficient labor force in the household was another reason mentioned by 24 percent of the respondents. Sixteen percent of the respondents indicated they believe that flooding is a natural process that cannot be prevented. This may be attributed to the low level of literacy in the study area.

It is commonly expected that households who attempt to adapt to changes will be involved in more economic activities than those who did not make any attempt.

However, our survey result shows the contrary. The households that took adaptation measures were involved in two income or food generation activities on average but the average number of economic activities for the households who did not apply any measure is slightly more (2.5).The dependency ratio is calculated as the ratio of number of economically inactive household members (<18 and >65 years old) to number of economical active members (18-65 years old).In the households that tried to adapt, the dependents were more than those who are involved in economic activities (dependency ratio is 1.3). However, the number of economically active members and the number of dependents is the same in the households that did not attempt to adapt (dependency ratio is 1.3). This suggests that the larger the number of dependents the more a household will be forced to apply adaptation measures to deal with impacts of changing climate.

## 6. Conclusions

We assessed people's perception of climate change and experiences of adaptation measures to deal with floods in the Itang district of Gambela region in Ethiopia. Our analysis was based on quantitative survey of 431 households, focus group discussions and key informant interviews. There is wider belief by respondents that flood magnitude, duration and frequency has increased in Itang as a result of climate change. Such changes are affecting livelihood and wellbeing of the people of Itang. Although the impact on livestock is primarily felt by livestock keepers in the area, it can also affect the livestock economy in the country since Gambela is known as one of the livestock rich regions in Ethiopia. Respondents said that crop production has substantially reduced over the past 20 years and they related this to increased flood severity. Almost all households experienced food shortages in the last ten years with half of them experiencing it every two years. Adults and children eat only twice a day as crop production is not sufficient to meet food consumption. Fifty-six percent of the households involved in crop cultivation and perceived flood change stated that they attempted to adapt to the changing floods.

The most common measures practiced by households in Itang include increased involvement in new economic activity, expanding existing non-farm or non-livestock activity, increasing the number of household members engaged in economic activities, and seasonal migration to other areas. Half of the surveyed households temporarily migrated out in every flood season in search of additional income or food. Selective herding is also practiced as people who live close to river banks raise small animals which are easy to move during severe floods. However, despite a wider perception of flood impacts on crop cultivation very few households applied farm-related adaptation measures (<3%). This suggests either lack of knowledge about such measures or limited resources.

More than nine out of ten respondents believe that the adaptation practices are not sufficient enough to manage the problem of flood. The commonly mentioned reason for households' inability to develop adequate adaptation capacity was lack of financial means, insufficient labor force and low level of literacy in the study area. This indicates the need to increase households' resilience to climate change in Itang by building their financial and human capacity.

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## A Saga of Status quo and Ethiopia's Contribution to Cooperation in the Nile Basin

**A power point presentation by Dr. Yacob Arsano**

**I. The Nile Basin: An overview**

- Encompasses Northeastern and Central Africa
- 1/10th of Africa
- Connects 11 riparian countries: Bu, DRC, Eth, Ke, Rw, Ta & Ug in upstream (7) Sudan, Eritrea & S. Sudan in mid-stream (3)

**Hydro-diplomacy**

- Management of relationship between nations:
- Skill in handling affairs without arousing hostility;
- Art and practice of conducting international relations, as in negotiating agreement, treaties, and salliances;

Hydro-diplomacy: a complex arena of interaction between riparian nations on the utilization, management and protection of shared waters.

**II. Unity of the Nile**

Permanent flow:

- the condition for the continuous flow: humidity, heat and precipitation in the upstream
- Change of state boundaries or political systems does not and cannot change the flow of the Nile
- The Nile is a permanent bond between upstream and downstream countries
- Any perception of exclusive possession of the Nile becomes futile and contrary to the unity of the Nile

Upstream

- little utilization to-date
- Increasing need and potential for Nile use
- Downstream

**III. The paradox of the Nile**

-Nearly total dependence on the Nile flow

-claim exclusive possession of the Nile waters

**The paradox of the Nile**: a challenge for the hydro- diplomacy?

**IV. Control and Hegemony on the Nile?**

Changing Hegemony

- Pre-colonial era: the Turco-Egyptian drive of conquest and control of upstream Nile: 1820s onword
- Colonial era: Nile as a factor in colonial diplomacy in their scramble for Northeastern Africa (eg. 1891, 1906, 1925)
- "historical & natural rights" (since 1929): A saga of hydro-diplomacy of the Nile
- Post-colonial hegemony: Sudan-Egypt "full utilization of the waters of the Nile" (1959)
- Untenable legacy of Hydro-diplomacy of the Nile

**VI. Status quo as obstacle to Nile cooperation**

- "Historical and natural rights": impediment for Nile cooperation
- "Full utilization of the waters of the Nile": contrary to unity of the Nile and shared ownership of the waters
- status quo : as negotiation position by Egypt & Sudan
- The Nile upstream nations: negotiate for equitable & reasonable

**VI. Upstream response against status quo**

**1. Ethiopia's rejection of status quo**

"We have already explained the plans are under construction to utilize our rivers as an essential step in the development of agriculture and industry, it is of paramount importance to Ethiopia, a problem of first order that the waters of the Nile be made to serve the life and needs of our beloved people now living and those who will follow us in centuries to come. However, generally, Ethiopia may be prepared to share this tremendous god given wealth of hers with friendly nations neighboring upon her, for the life and welfare of their people, it is Ethiopia's sacred duty to develop the great watershed which she possesses in the interest of her own rapidly expanding population and economy. To fulfill this task, we have arranged for the problem to be studied in all its aspects by experts in the field. Ethiopia has time and set this forth as her position regarding the utilization of the Nile waters". *(Ethiopia Observer*, II, No. 2, 1958 P. 93)

This is still a standing offer from Ethiopia's side

**2. Neyerere Doctrine**

- Tanzania would not inherit colonial agreements on the Nile
- Uganda and Kenya followed suit rejecting colonial agreements on the Nile

**3. Negotiation and signing of the CFA** as rejection of status quo

- Seven upstream nations have adopted CFA
- Six countries have signed
- Ratification process is underway

**4. Nile Basin Commission** is envisioned some time sooner

**VII. Recent developments against status quo in the Nile Basin**

Nile 2002 conference series (1993-2002)

- Agreed minutes of Dar es Salaam (February 1999): all inclusive "new deal"
- Establishment of NBI with two pillars:
    - Shared vision
    - Subsidiary action programs
- Joint multipurpose program (ENCOM, 2005)

A new trend in the hydro-politics of the Nile?

### VIII. Negotiations for CFA (Cooperative Framework Agreement)

Nine Nile countries negotiating

Stage one: technical committee

Stage two: negotiating committee

Stage three: ministerial committee

Stage four: seven countries adopted CFA – 2009

Stage five: extended negotiations ( to accommodate downstream requests with additional negotiators)

Stage six: Signing of CFA –(May 2010-May 2011)

- Six states , signed (2/3 majority)
- Ratification underway
- Downstream continues stand as opposed (ENTRO on halt)

### IX. Examples of international consensus towards cooperation on TBWB

- Helsinki rules (1966)
- UN Convention on non-navigational use of international water courses (1997)
- Berlin rules (2004)
- ICCON: Exemplary international support for Nile cooperation (2001)
- Agreed minutes of the Water Ministers of Basin states (Dar es Salaam, Feb. 1999)
- Numerous TBWB agreements globally

### X. Status quo untenable

- Antithesis for Unity of the Nile
- Status qou, no legal or political prospects
- Status quo, worst service to Egypt and Sudan
- Riparian nations are sovereign
- Egypt and Sudan have no clout to maintain it

### XI. Scenarios

Upstream stance

- Ratification of CFA in progress
- Establishing Nile Basin Commission is the next step

Downstream stance

- Holding to the Status quo?
- Unilateralism unabated

HAD, Toska canal, el-salam canal, Rosaries dam, Kashim el Ghirba, Merowe dam; others planned

- Upstream projects on the Nile

Grand Ethiopian Renaissance Dam - GERD launched (Feb. 2011); others planned

### XII. Ethiopia's New Diplomatic Initiative

- Ethiopia's initiative for IPoE (Eth.Su.Eg.) + International Panel of Experts
- ToR & Rules of procedure drawn and signed by the three countries
- Sudanese-Egyptian decision to resume ENTRO (Nov. 2012)
- The Republic of South Sudan to accede CFA

### XIII. IPoE, unprecedented contribution of Ethiopia to Nile cooperation

- Launch & 1st IPoE meeting in May 2012, Addis Ababa
- 2nd IPoE meeting in June 2012, Cairo
- 3rd IPoE meeting in October 2012, Addis
- 4th IPoE meeting in November 2012, Addis
- 5th IPoE meeting in March 2013Rosaries, Rosaries, Sud.
- 6th and Final IPoE meeting May 2013, Addis Ababa
- IPoE has completed its task on 31 May 2013
- Submitted to the three governments
- Outcome envisioned to enhance cooperation

### XIV. Keeping on cooperation track of the Nile

- Ethiopia's offer to remain on track of cooperation
- The role of Republic of South Sudan
- Statement from Africa Union Commission
- Statement of President Musebeni
- Sudan Republic's support for GERD Project
- Egypt's Foreign Minister in Addis Ababa

### XV. Downstream confusion on cooperation?

- Egypt/Sudan plea for extended negotiations (2009-2010)
- Egypt's 1st track diplomacy targeting GERDP (2011-2012)
- Egypt's public diplomacy (May 2011, Feb. 2012, 2013)
- Misinterpretation of IPoE report (May 2013)
- Declaration of subversive measures against Ethiopia
- Threat of war: 'a drop of blood for a drop of water

### XVI. The Prospects of Hdro-diplomacy of the Nile Basin, an Ethiopian Perspective

- Ethiopia's hydro-power potential: 45,000 MW
- Currently: +2000 MW harnessed
- In the pipeline: Gibe III; GERD; Ganale-Dawa
- Many more in the prospect: Mandaya, Mabil, Kara-Dobi, etc.
- Ethio-Djibouti power transmission
- Ethio-Sudan power transmission
- Ethio-Kenya power transmission
- 212 million persons will benefit from the Eth-Ken PT
- Prospects for wider power pooling

### XVIII. Challenges for Nile diplomacy

- The issue of water security (The downstream countries not willing to accept the equitable and reasonable basis for water use and management)
- Weak commitment for Joint multipurpose water development programs
- (the tripartite initiative for joint multipurpose projects (JMP) has been halted)

**Concluding remarks**

- Nile will for always remain as permanent bond between the riparian countries and communities
- There are numerous and compelling areas of cooperation in the Nile Basin which diplomacy can fix
- The aspirations for sustainable socio-economic development, peace and prosperity in the Nile basin in the 21st Century premise on the imperatives of environmental, economic, institutional and security imperatives of cooperation.
- Through cooperation the Nile riparian nations will not only overcome any historical and contemporary tensions but also make themselves permanent partners rather than misguided adversaries.
- There is no viable alternative to upstream-downstream cooperation
- A Nile cooperation can only be based on equitable and reasonable utilization of the Nile waters and sustainable benefit sharing