Water

Ethiopian Journal of Water Science and Technology

Special Issue

Proceeding of the 17th International Symposium on
Sustainable Water Resources Development
Held at Arba Minch University
from June 23-24,2017
Arba Minch, Ethiopia

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THEME FOUR
WATER SUPPLY AND SANITATION

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EMERGING CHALLENGES

FOREWORD

Arba Minch University organizes symposia on Sustainable Water Resources Development since the last Seventeen years. The objective of the symposium is to create a platform where professionals, researchers, practitioners and decision-makers come together and share ideas, communicate research results, good practices and innovations in that can enhance sustainable water resources development. This year the symposium marks the 17th cycle in the series. The organizing committee has received more than 150 papers in different thematic areas announced in call for papers. After review process, about 22 pares have been selected for oral presentation and 8 papers for poster presentation. This proceeding contains the full contents of presented papers. I believe 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.

Abdella Kemal, Ph.D
Director, Water Resources Research Center
Editor

Welcome Address

Dr. Damtew Darza, President of Arba Minch University

H.E. Dr. Michael Menkir , Delegate of Minister Ministry of Water Resources, Irrigation and Electricity
H.E Ato Abiti Getanhe, Research Director of Ministry of Water Resources, Irrigation and Electricity

Invited guests,
Ladies and Gentlemen,
It gives me a great pleasure to extend to you all a very warm welcome on behalf of Arba Minch University and myself.
Water is the primary life-giving resource. It is a source of great productive opportunities in agriculture, industry, energy, and transport, and it is vital for the health of both people and ecosystems. Therefore, the management of water resources is an important issue for societal health and well being. As world population continues to grow, a greater quantity and diversity of water needs will challenge water resource managers. Hence, water resources managers must recognize that they are dealing with complex problems-problems with no clearly defined boundary, multiple stakeholders, and an absence of a single satisfactory solution. These suggest that a holistic and integrated approach is required for sustainable management of water resources.

Ladies and Gentlemen,
Ethiopian water resources system is governed by 12 major river basins that generate about 124 billion cubic meters of water annually. There also several fresh and saline lakes which have storage capacity of about 96 billion cubic meters. The groundwater potential of the country varies from -----to ----billion cubic meters. Due to such immense physical water resources potential our country has been considered as the water tower of Eastern Africa. However, the contribution of these resources to the overall development of the country has been disappointingly low. One of the major problems is lack of technical and technological capacity for which human resources development is a key. We remain vulnerable to water related impacts of drought and flood as long as we are unable to manage and utilize these resources. The recent 50-years drought that affected more than ten million people and their livestock manifests that we are highly vulnerable to water related problems. Dependence of our economy on agriculture, which in turn is rainfall dependent, is the major source of our vulnerability to the effects of climate change and variability. Our country is taking progressive measures to build water storage infrastructures and industrialization.
Ladies and Gentlemen, Arba Minch University as a public university is committed more than ever to contribute its part to realize the county's development vision. Since its establishment as water Technology Institute in 1986, the University has trained substantial number of water professionals at certificate, diploma, and first and second degree level. To respond to the country's demand for highly qualified professional, the university has also launched PhD programs in Water Resources Engineering.

Arba Minch University further commits itself to capacity building and research which play a central role in developing skills, generating knowledge, and transferring technology useful for sustainable development of our water resources.

Ladies and Gentlemen, this annual symposium marks Arba Minch University's sustained commitment of creating and hosting scientific forum to enable researchers, practitioners, and decision-makers come together discuss on issues of sustainable development of water resources development have been received, reviewed and invited for oral and poster presentation. Presenters are also coming from different regions and organizations which represent a good opportunity to share ideas and experiences for further networking.

Finally, I would like to thank the organizing committee of this symposium to have worked hard to realize this gathering. I also acknowledge the Rift Valley Basin Authority for co-sponsoring this symposium.

Ladies and Gentlemen, with these few remarks, may I wish you success and fruitful deliberations on sustainable water resources development.

To make your stay here in Arba Minch a joyful, the organizing committee members and my colleagues are at your disposal and don't hesitate to consult them.

Thank you!

THEME ONE

HYDROLOGY AND INTEGRATED WATER RESOURCES MANAGMENT

An integrated approach for the spatial and temporal variability analysis of wetlands: A case of Central Rift Valley Lakes, Central Ethiopia

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Abstract

Alteration in the hydrological system and ecological situation within CER is highly seen from mid 1970s due to both anthropogenic and natural factors. Humans usually and very dramatically accelerate natural processes often unintentionally but usually in the course activities like agriculture, industry and urban development. An attempt has been made to assess and map the spatial and temporal variability of these changes with respect to driving forces and to determine water resource including wetland priority areas for conservation and management purpose based on tendency of the land use and direction of denudation using Remote Sensing and GIS techniques. Landsat satellite images having different sensors, meteorological data, hydrological data are possible data sources were used in order to accomplish the study. Satellite imageries of 1973, 1986, 2000 and 2011 were used to map LULC and change detection analysis. In addition to this, specifically delineation of wetlands and mapping of wetland types using criterion layers satellite imagery analysis has been adopted. The change detection shows a cultivated land is increased by 42% from 1973 to that of 2011, whereas wetlands/water bodies (small part of an area) are reduced by 4% which has great impact on ecological diversity and hydrology of the area. The major possible causes identified for destruction of wetlands, fluctuation of lakes level and its volume within CER are climate variability, poor land use system, imbalance of water inflow and outflow to/from the lakes, deforestation and overgrazing, diversion of river canals and water abstraction for irrigation purpose, water abstraction for soda ash extraction and sedimentation to the lakes. The result from an integration analysis showed that hydrological and ecological system is in a dynamic disequilibrium to which the outlook seems very bad. However, to alleviate these problems the best solution is to create awareness towards wetland ecosystem value for the resident communities and to formulate/regulate policy on wise use of water resources including wetlands for its protection and conservation.

Keywords: CER, Lake, LU/LC, Satellite imageries, wetland

A wetland is an area that has water at or near the surface of the ground during growing season (wetland hydrology). According to ***Ramsar convention*** (1997:2) wetland is defined as areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tides doesn't exceed six meters.

According to Maltby, 1986 wetlands are distributed all over the world and are estimated to cover about 6% of the earth's surface, some 5.7 million km^2 (WCMC, 1992). Although Africa is best known for its savannahs and hot deserts, 1% of its surface area (345,000 km^2) is covered by wetlands (Finlayson and Moser, 1991). But an estimate of over 50% of world's wetlands may have been altered or lost in the last of 50 years (Dugan, 1993).

Ethiopia is often referred to as the water tower of Africa mainly because of its wide variety of landforms and climatic conditions, creating an extensive wetland system throughout the country. General wetland ecosystem values range from tangible subsistence uses and direct benefits to intangible goods and services and the fulfillment of human needs (Dugan, 1990). The indirect uses of wetlands are their hydrological and ecological functions, which support various economic activities, life support systems and human welfare. As such, wetlands produce an ecological equilibrium in the environment by maintaining the integrity of life support systems for sustainable socio-economic development.

Wetlands are considered as one of the most productive and diverse ecosystems on earth; they play a key role in natural processes and have provided humankind with goods and services since early times. Despite this, wetlands in the study area (Zeway, Langano and Abiyata) are among the most threatened ecosystems and are subject to many pressures in the name of wrongly understood "development". Currently, they are continued to be depleted at an alarming rate.

In order to develop viable wetland conservation and management plan in the area great deal of effort has to put in understanding the causes and effects at desired spatial and temporal scales. To alleviate all the problems associated with the wetland loss it has been found that first to map and locate them in a landscape and know the actual causes and threats, rates and degrees of wetland lose.

Keeping the importance of wetlands in mind, attempts were made to assess and evaluate the spatial and temporal variability of wetland ecosystems around the Lakes using remote sensing, GIS and hydrological analysis. Special interests were placed on the spatial distribution and, rate and intensity of changes.

Objectives of the study

Is to assess the spatial and temporal change of wetland ecosystems and their properties and to propose wetland conservation sites for the sustainable management of the wetland ecosystem. Basically by considering

- Mapping wetland types, location its extent
- Analyzing changes on land use trends and assessing causes for change.
- Estimate spatiotemporal variability of factors affecting morphometric properties of lakes and to suggest possible measures to protect wetland ecosystems.
- To develop information systems that supports hydro-meteorological and related environmental systems of the wetlands.
- To assess the conservation status of the wetlands and to define priorities for conservation, for restoration and for sustainable use

Materials and Methods

Description of the study area

The study area is located in Oromiya region, southern part from capital city of Ethiopia, Addis Ababa. It covers an area of 4210.63 km^2. It consists of three lakes (ziway, langano, Abijata) which has an area coverage of 426, 230.8 and 128.69 km^2,respectively) and associated wetlands.

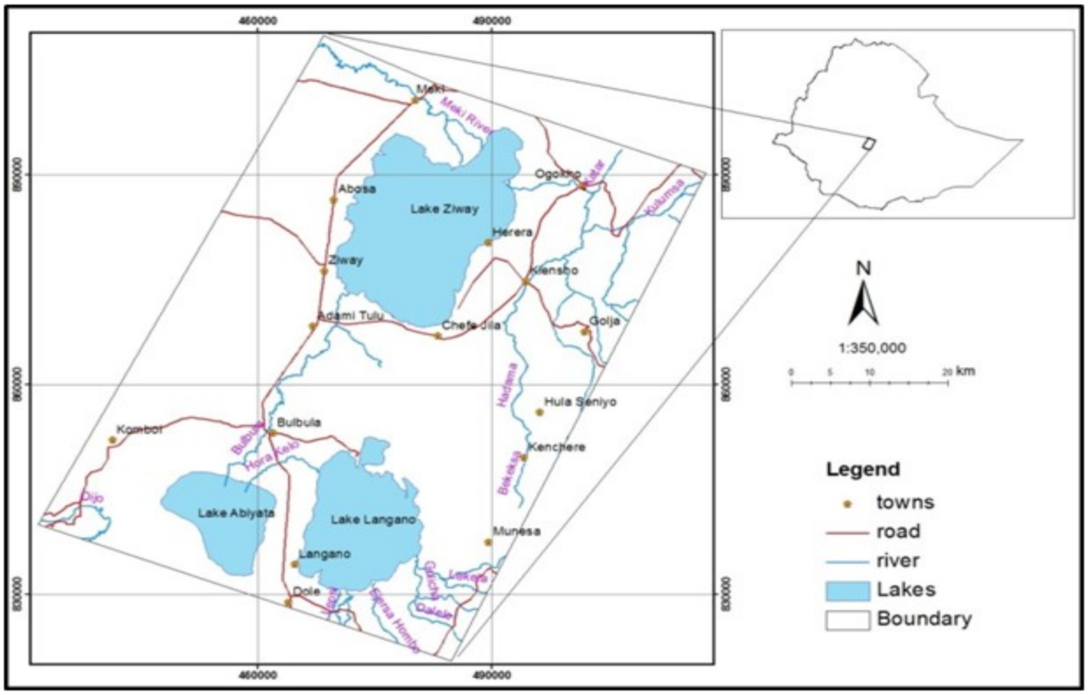


Fig.1 Location map of the study area

The CER falls in a semi-arid climatic zone with average annual rainfall and temperatures that vary substantially with altitude, ranging from 734 mm and 25º C near the lakes and 15ºC at higher altitudes. The area is laid down with a topographic position having an elevation value ranging from 1561 to 2598 m.a.sl. The lakes are found within the same hydrological system (Ziway-Shalla sub basin) in which change in one will have a significant impact on others.The area is highly covered with cultivated land and mixed cultivated/acacia and acacia woodlands.

Data and Material used

In this study, different data and materials were used. Soil map, land use map, hydrological (water level, flow, sediment concentration) data, meteorological (mean monthly RF, evaporation)data, time series Landsat image of 1973 with a path/row of 180/54&55 and 181/54&55 and image of 1986, 2000 and 2011 with a path/row of 168/54&55 and SRTM were used. GPS, ArcGIS, Erdas Imagine, Global Mapper are one of the commonly used tools to conduct the study.

Data collection and Analysis

Preliminary field survey, reviewing different literatures, GCP (Ground Control Point) collection and collecting appropriate and relevant satellite imageries and SRTM were the basic tasks of data collection. After data collection, Preprocessing of the image was carried out prior to usage of raw satellite images.

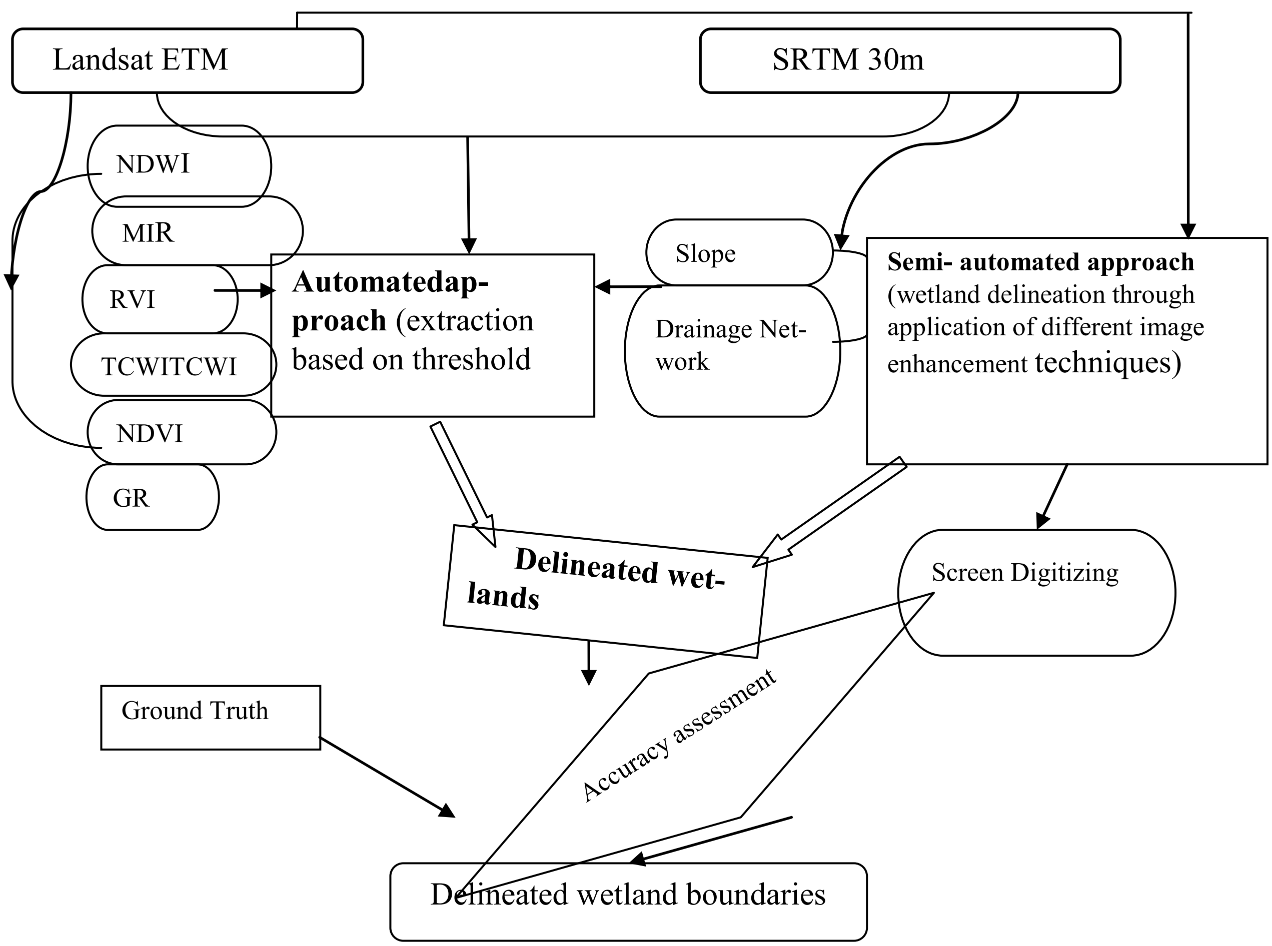


Fig. 2 wetland delineation workflow using automated and semi-automated approaches

Band selection, de correlation stretching, histogram matching and color balancing were carried out prior to main data analysis based on reflectance characteristics of wetlands and remote sensing technology. The band combination selected for identification and mapping of different land cover classes from Landsat MSS (1973) is the False Color Composite (FCC) (4, 2, and 1).

For case of both Landsat TM and ETM+ different True Color Composite (TCC) and FCC band combinations used in this research are FCC of 7-4-3, 7-4-2, 4-3-2 and 7-4-1.

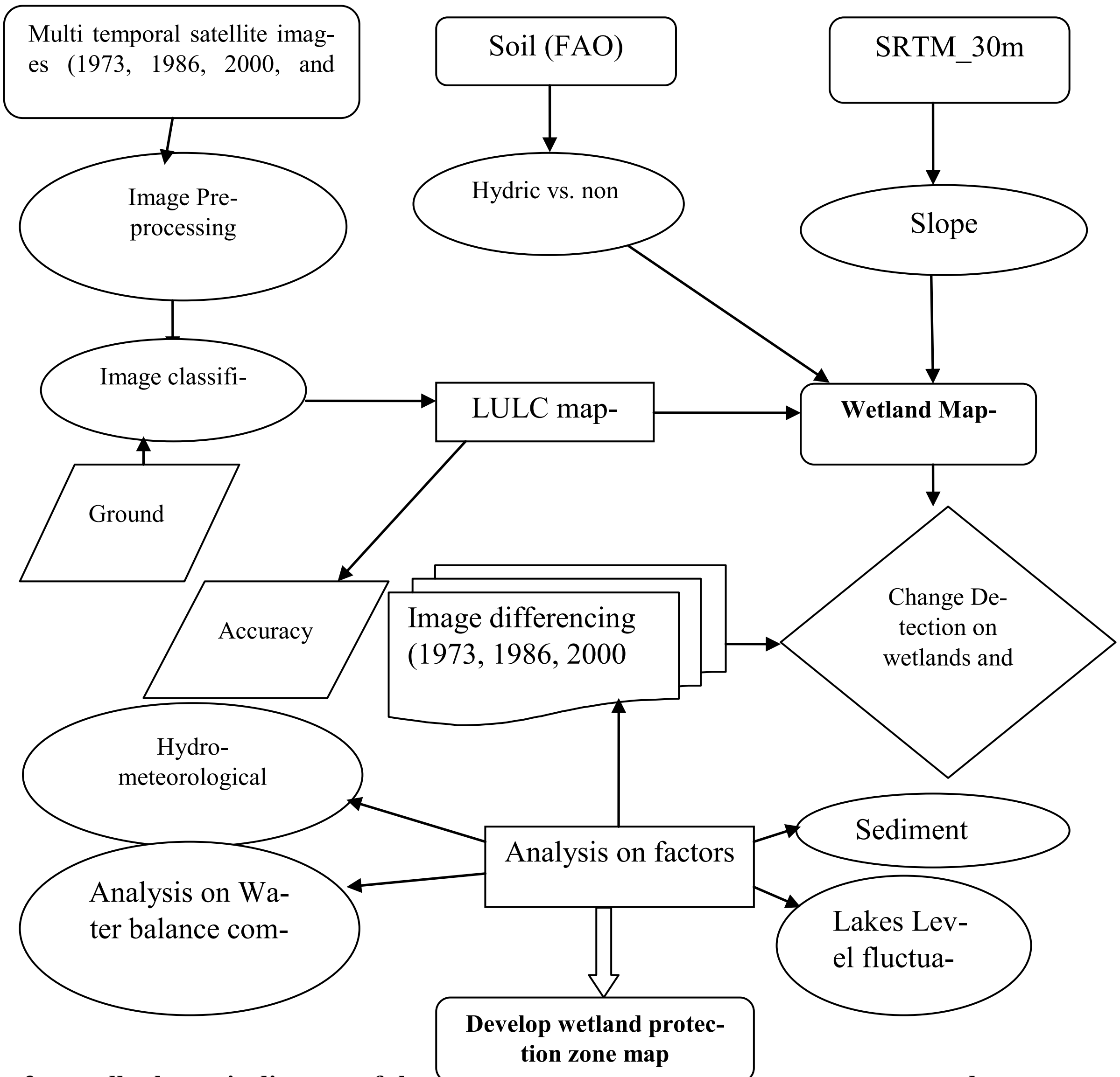


Fig. 3 overall schematic diagram of the study

Image transformation algorithms such as Normalized Difference Vegetation Index (NDVI), Tasseled Cap transformation (TCT), ratio of single bands (indices) and supervised classification techniques were utilized to identify and map wetland types.

Result and Discussion

Analysis on Land use Land cover dynamics

Land, water and ecosystems are main parts of the resource system on which to build a sustainable living. The transformation of LU/LC by human action can affect the integrity of the natural resource system and the output of the ecosystem of goods and services. Therefore, each part of the system needs to be followed up, monitored and accounted. In this study area wetlands, water bodies, cultivated lands, woodlands, forest and degraded savanna are common land use types were identified.

The current land use and historical trends was based primarily on Landsat satellite imageries of 1973 (MSS), 1986(TM), 2000(ETM) and 2011(TM).For land use mapping of year 2011, ground check were executed to verify the (2011) classification results and accuracy assessment were carried out. In 2011, more than 50% of an area was covered by intensive cultivated land. Forest and woodland destruction, reduction in surface water, destruction of wetlands is highly seen at this time.

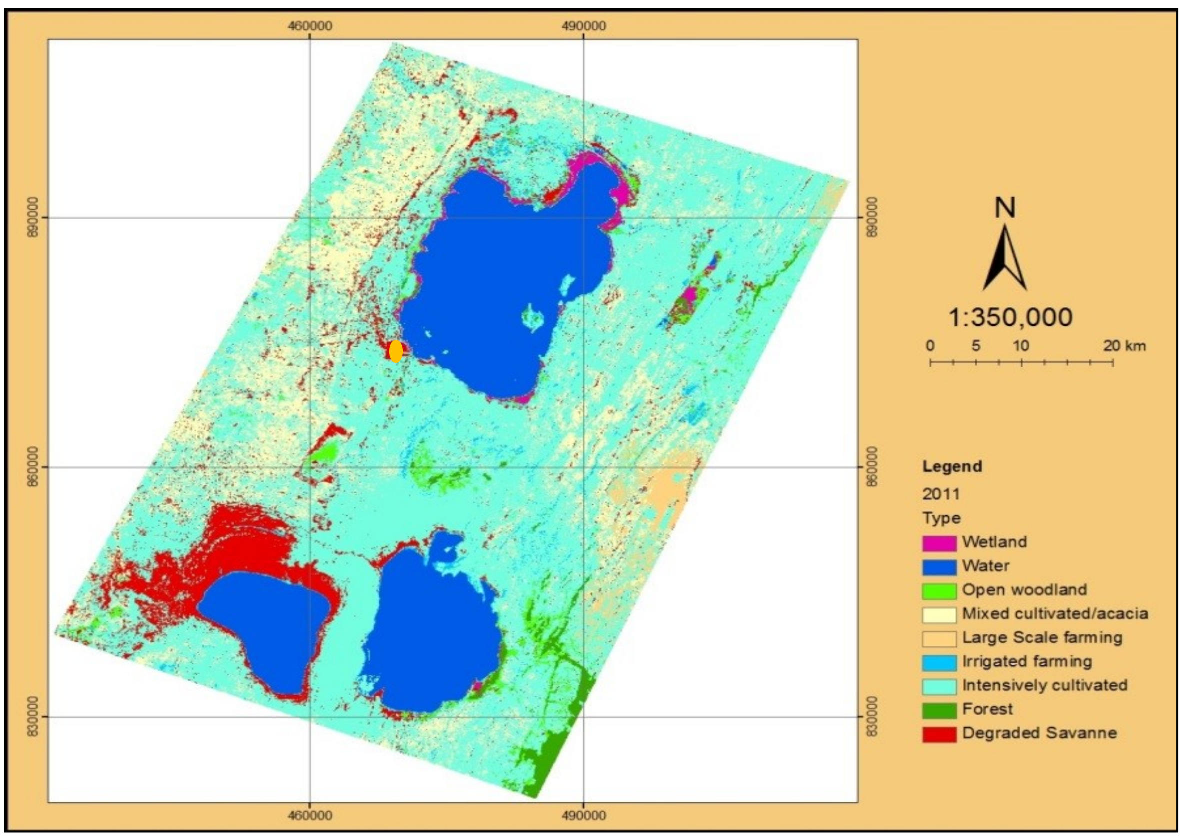


Fig. 4 land use land cover map of the study area in 2011

Table 1 Land use land cover trends measured in hectare from LULC developed using imageries

LU/LC Type	1973	1986	2000	2011
	Area(ha)	Area(ha)	Area(ha)	Area(ha)
Wetland	7485.4	4230.25	4791.63	3974.44
Water	85090	80321.53	81710.6	76321.98
Open woodland	40359.4	29574.75	15996.2	7964.1
Mixed cultivated/acacia	215868	190251.3	190587	70158.96
large scale farming			2411.73	9708.03
Irrigated farming				6107.67
Intensively cultivated	59319.6	87324.35	122320	227720.1
Forest	9040.99	18518.07	13179.2	5992.74
Degrade Savanne	21898.6	28291.39	7512.66	30612.78

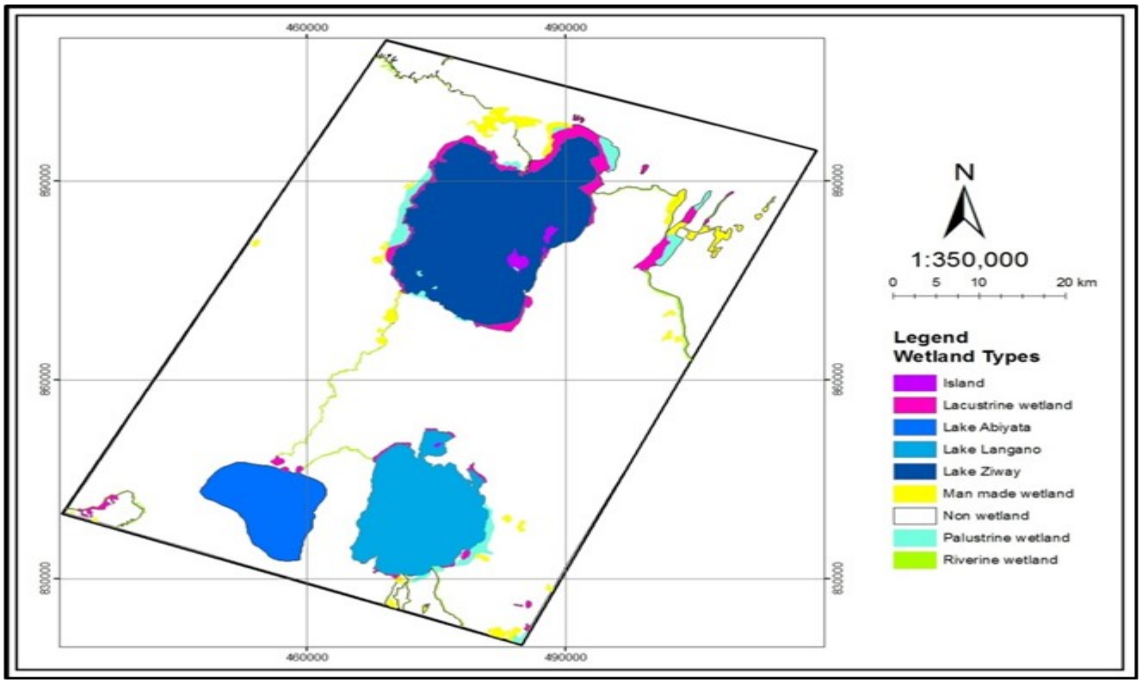
The land use map has been developed at an overall accuracy of 80.51%. From the result shown above forests, woodland, wetlands and water bodies are land use types which are decreasing gradually. Cultivation and irrigation activities plays great role in destruction and decrement of wetland ecosystem and biodiversity.

Wetland mapping

Explicit wetland delineation is needed besides LU/LC mapping because of inherent characteristics of wetlands in their distribution, status, type and location. In this study two basic methods were adopted to delineate wetlands.

The first method is based on the criterion layers that said, wetland occurs within an integration of three basic components; Water-logged (Hydric soil), Slope and hydrology. The second method is based on satellite imagery analysis using different image transformation and classification algorithms. As it is described in the methodology part, both automated and semi-automated approach of image analysis was used to delineate wetland boundaries.

The classification system of the wetlands is adopted from Ramsar wetlands classification. The "wetland" class was reclassified to primarily wetland system, which comprises palustrine wetlands (dominated by trees, shrubs, persistent emergent, emergent mosses and depth doesn't exceed 2m), lacustrine wetlands (situated in a topographic depression or dammed river channel and no trees or shrubs), riverine wetlands, man-made wetlands and lake water bodies.

Fig. 

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final wetland mapping using overlay method

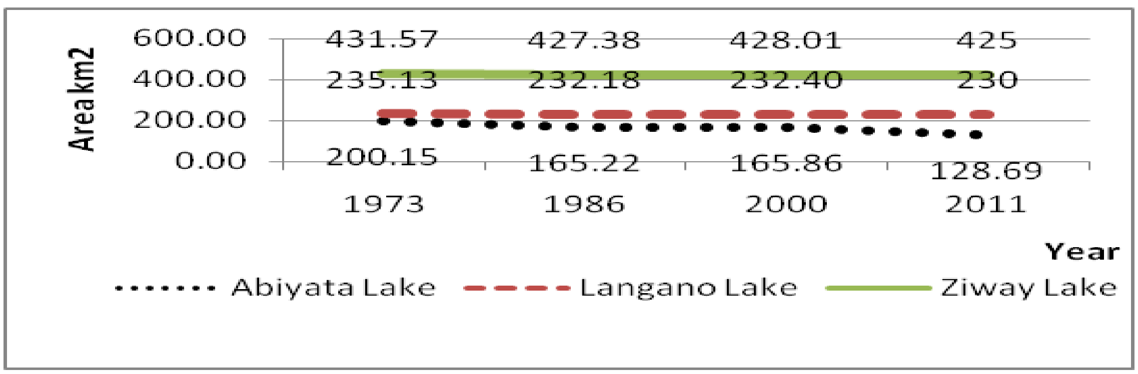


Fig. 6 Conventional method of lakes change detection from TCT image

Assessment of possible factors on wetland change

Any change in the land use will have an impact on the hydrological system of the catchment and on the available water resources. Much of pre-settlement results development of irrigation schemes on the surrounding Lake Ziway, along river canals on the upper stream (Meki River) and eastern part of the area and wet areas of lake zones have been converted to agricultural land use. This has induced reduction of large volume of water entering to the lake Ziway and indirectly affects Lake Abiyata by reducing inflow to via Bulbula River. It is therefore important to understand the impacts of historical trends in land use, to put ongoing modifications into proper context.

The increase in temperature over the years results in high evaporation and decrease in precipitation on the main catchments have resulted in the decrease of lakes and surface area of surrounding lakes. The basic factor for loss of waters from lake and water is evaporation which is natural phenomenon. The CER has the same climatic characteristics especially in temperature and evaporation to some extent but with slight difference in amount of rainfall.

As in other parts of Ethiopia, deforestation and over-grazing in the study area has resulted in increased erosion and runoff of rainwater, which may have affected the regional hydrology. From time to time population pressure has increased and the quest for new farmland has become predominant in the region.

The improper utilization of water and land resources brought about noticeable negative changes in the region, which have far reaching environmental implications. The most important withdrawals of water in the CER are for irrigation and soda ash production. The consequences created because of water abstraction for irrigation and soda ash extraction.

Lakes level fluctuation and trends in water balance components

The recorded water level of the lakes provides history and possible trends of the water contained in the lakes. The lake level data for Ziway, Abiyata and Langano on monthly basis has been compiled. Based on this the annual maximum, annual minimum and annual mean water level for each lake has been analyzed and presented. Lake Ziway has one gauging station near Ziway. Likewise, each Lake Abiyata and Langano has one gauging station.

Lake Ziway is slightly changed over the last three decades. However, after 2000 the changes have become pronounced owing to the increase in pumping for irrigation and slight decrease in precipitation over its catchment. It has a maximum level of 2.31m in September, 1974 and progressively decreasing in the consecutive years and reaches 1.12m in 2009.

Lake Abiyata has undergone drastic changes in size and level in the last few decades. Abiyata's shallower depth and terminal position makes it more susceptible to changes in climate and pumping.The current situation is shocking and most the lake area is converted to blowing sand plain. Soon after the commencement of pumping for soda ash production in the 1980s, pumping of Lake Ziway and diversion of Bulbula River resulted in reduction of the level and volume of Lake Level Abiyata. In addition to this, inflow from the lake Ziway has diminished from 210 mcm to 60mcm resulting in reduced inflows to the lake in 1994 and the year that followed

The level of Lake Langano is more stable compared to other two lakes. The stability of the Lake is related to a large groundwater flow from springs and seepage through large faults.

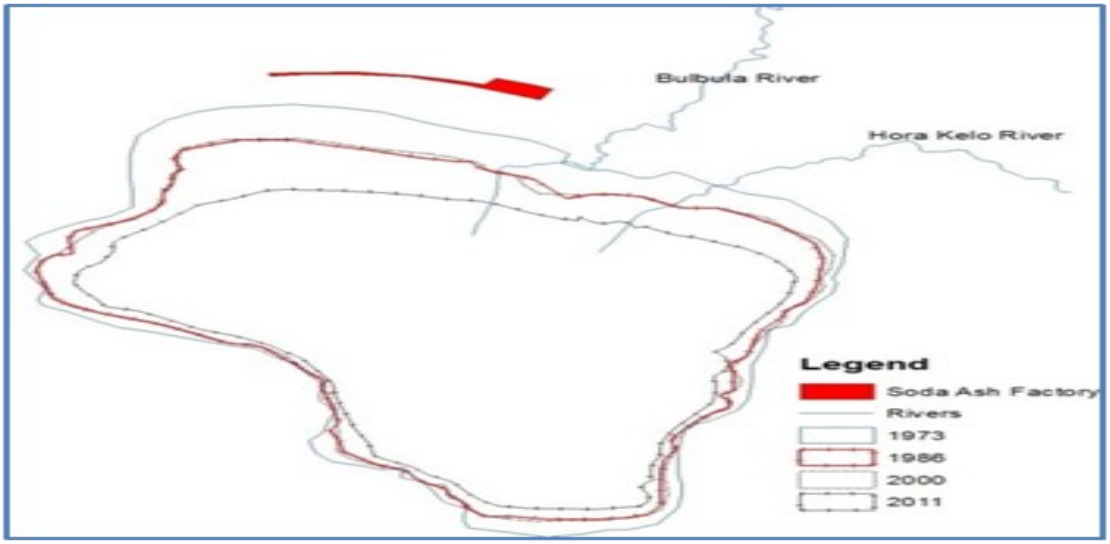


Fig. 7

Temporal variations on size of Abiyata Lake

Rainfall versus Lakes level

The mean annual rainfall is plotted against mean annual lake level. The correlation is based on an approach that, if the amount of water entering to the lakes increased beyond a certain level. However, the lake level fluctuation and precipitation to the lakes are correlated poorly. For instance, the correlation of water level of Lake Ziway, Abiyata and Langano with amount of rainfall to the lakes is 5%, 2% and 0.07% respectively. This indicates impact rainfall variability on reduction of lake levels is seen very minimal.

Trend analysis on water balance components

In this section, recharge and discharge through tributaries for the three Lakes is discussed. The flow to Ziway Lake has reduced gradually. The maximum flow recorded for Meki River in 1998 is about 493.48mcm and it reaches about 3.3mcm in 2006.The mean annual water flow from Katar River laid down to 35.05mcm which become drier and drier and will result in seasonal River like Meki River.

Water inflow to Lake Abiyata from both rivers is declining due to the diversion of rivers for irrigation purpose along Bulbula River and rainfall variability. The current annual water flow from Hora Kelo is 0.4mcm and that of Bulbula River is 41mcm which was 140.9mcm and 390.5mcm in 1996, respectively.

Water inflow to Lake Langano from Lepis River is relatively smaller when compared with that of Gedemso River. It has a maximum and minimum annual water flow of 58.31 in 1998 and 8.78mcm in 2005, respectively.

In general, the future life span of the lakes is questionable especially the inflow to that of Lake Abiyata is highly decreased and may result in severe problem (become saline) as that of Lake Haromaya.

Sediment load analysis

For CRV catchments an initial estimate of suspended sediment rating equation have been developed by equation:

$$SL = a\,Q^{b}$$

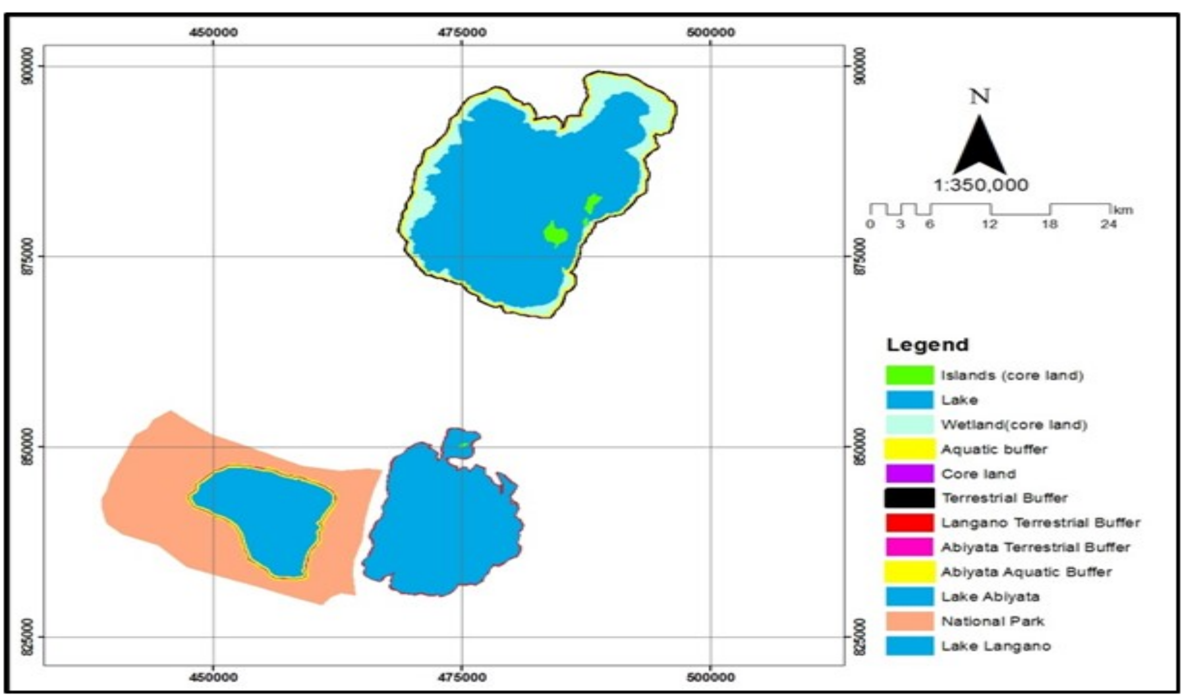
Where *SL is sediment load in (tons/day), Q is water discharge or flow in* m^3/s, ***a, b*** areconstant correlation coefficient values dependent on tributaries flow, depth and height.

The mean annual SL of Meki River is 7,460,609 tons/year (R^2=0.666) and mean annual SL of katar River is 709,354.385 tons/year

The mean annual SL from tributaries of Lake Abiyata is about 616,506.62 tons/year which is relatively small when compared with SL in the Ziway catchment. The flow coming from Lake Langano through Hora Kelo carries a mean annual SL of 30,232.32 tons/year whereas, that of Bulbula River has a mean annual SL of 586274.3 tons/year. The mean annual suspended SL of Langano is 210,591 tons/year with a corresponding sediment yield 214 tons/km^2/year.

Mapping Conservation Zones of Wetlands

Factors to consider in setting the designated use and developing a management strategy for a wetland include: wetland type, landscape position, surrounding land uses, cumulative impacts on the wetland.



Lake, wetland, island are considered as core lands. Again, core land is a transition line between aquatic buffer and terrestrial (upland) buffer. Aquatic buffer is an area along shoreline, wetland, or stream where development is restricted or prohibited. Whereas, terrestrial buffer is a transition boundary exist in a between core land and adjacent uplands. Therefore, for each lake the three zones were buffered based on the inherent characteristics of the wetlands and by considering adjacent land use types.

Conclusion

The extent to which water and wetland resources can potentially contribute to our country's development has barely been assessed. Wetlands and water resources in CER are currently being lost or altered by unregulated over utilization, including water diversion for agricultural intensification, pollution, urbanization, climate variability and other anthropogenic interventions.

The study comprises an integration of different analysis; namely LU/LC mapping and change detection, Mapping of wetland types, location and their distribution, Assessing possible causes (anthropogenic and natural factors) for reduction in water resources and degradation of wetlands, Variability analysis in water balance components, Lakes level fluctuation and possible causes, Sediment load analysis and finally, mapping conservation and protection zone map of Lakes and associated wetlands based on the degree of tendency of the land use.

Recommendation

Due to natural factors and human influences on the natural systems the integrity of the natural resource system and the output of the ecosystem of goods and services are affected. Therefore, each part of the system needs to be followed up, monitored and accounted. To safeguard the life of wetlands and water resources the following mitigation measurements are recommended to be carried out.

- The wise use of wetlands is impractical if the people who make use of them are not involved in one way or another. Therefore, creating awareness is important.
- The existing and expected future problems related to land and water resource uses demand a comprehensive water management and planning strategy.
- Protection of forests, acacia woodlands and afforestation along streams and on the shore of the lakes is essential; thereby they reduce soil erosion and rate of sedimentation.
- Environmental Impact Assessments should be carried out when any development intervention is planned.
- Future improvements in current wetland vegetation mapping could include the use of more recent and better geospatial data when it is available.

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Evaluation of Groundwater Potential Areas through the Integration of Multicriteria Decision Analysis and Geospatial techniques, a Case Study in Northern Ethiopia, Amhara Region, Gerardo River

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Abstract

This study was conducted in Gerardo River Catchment, Wollo, with the aim to spatially delineate the groundwater potential areas using geospatial tools and Multi Criteria Analysis (MCA). To do so, eight significant environmental factors like geomorphology, lithology, slope, rainfall, land use land cover (LULC), soil, liniment density and drainage density were considered and used as input in simulation of the model. The sources of these data were mainly satellite imageries, DEM, thematic maps and metrological data. Landsat image was used in ERDAS Imagine to drive the LULC of the area. While the geomorphology, soil, and lithology of the area were identified and classified through field survey and digitizing from existing maps using the ArcGIS software. The slope, liniment and drainage density of the area were derived from DEM using spatial analysis. The rainfall surface map was created using the deterministic interpolation, thiessen polygon interpolation. Finally, after preparation of these thematic maps, weighted value determination for each factor and its field value was computed. At last, all the factors were integrated together using the weighted overlay model and potential groundwater areas were identified. The finding depicted that most of the potential groundwater areas are found in the central and eastern part of the study area. While, the northern and western part of the Gerado River catchment has less potential of groundwater occurrence. This is mainly due to the cumulative effect of steep topographic and high drainage density. At last, once the potential groundwater areas were identified, cross validation of the resultant model was carefully carried out using existing data like dung wells and bore holes. The point data of dung wells and bore holes were overlaid on groundwater potential map and coincide with the expected values. Generally, from this study it can be concluded that RS and GIS with the help of MCA are good tools in monitoring and follow up groundwater resource availability.

Key words: Groundwater potential, Gerardo River, MCDA, Spatial information

Groundwater is one of the most valuable natural resources, which supports human health and economic development. Because of its continuous availability and excellent natural quality, it becomes an important source of water supplies in both urban and rural areas of any country (Todd & Mays, 2005). It helps in poverty alleviation and reduction, which can be delivered directly to the poor community far more cheaply, quickly and easily than canal water (IWMI, 2001). Of the total of freshwater estimated to be present on the earth, around 22% exists in the form of groundwater i.e. constitutes nearby 97% of all liquid freshwater available and use for human consumption (Foster, 1998).The excessive use and continued mismanagement of groundwater resource to supply ever increasing demand leads to water shortages and pollution (De Villiers, 2000; Tsakiris, 2004).

Consequently, unsustainable groundwater use is becoming increasingly evident and the key concern particularly in developing countries (Todd & Mays, 2005). Since water is a limited and vulnerable resource, it must be used efficiently and in an ecologically sound manner for present and future generations. Adopting advanced geospatial tools are very imperative to continuously assess and monitor the groundwater resource status periodically. Recently, satellite data can provide quick and useful baseline information about the factors controlling the occurrence and movement of groundwater.

Updated information on geology, lithology, geomorphology, land use/cover, drainage patterns, lineaments and others can easily accessed from satellite data (Bobbaet al., 1992; Meijerink, 2000).However, all the controlling factors have rarely been studied together because of the non-availability of data, integrating tools and modeling techniques.

Geospatial tools have emerged as an effective tool for handling spatial data and decision making in several areas including engineering and environmental fields (Stafford, 1991 & Goodchild, 1993). The combined use of RS and GIS tools for the analysis of voluminous hydrogeological data and for the simulation modeling of complex features (Watkins et al., 1996; Loague& Corwin, 1998; Goguet al., 2001; Gosselet al., 2004). In Developing Countries like Ethiopia most of hydrogeological investigations and groundwater potential evaluation have been done in the absence of RS & GIS application. In the study area, some studies had been conducted before for different purposes. The geo hydrogeological investigations and inventory of land slide susceptibility in the area were conducted by Ethiopian Geological Survey (Bayessa, et al. 2002) and AWDSE, 2002).

Dereje (2012) also carried out ground water potential assessment investigation in the study area. Of these conducted in study area, almost none of these studies didn't try to evaluate the potential groundwater of the area with the advance application of RS and GIS. Therefore, the present paper is an attempt to highlight geospatial technologies modelling and multicriteria analysis in groundwater spatial mapping in Gerado River, Northern Ethiopia. Such up to date and systematic information will be a great importance for the researchers, practicing hydro geologists and the concerned decision makers, particularly for new researchers on the field.

Study Area Description

The study area is situated in the Ethiopian Highland Plateau adjoining the Western Escarpment of the Rift Valley and found in the Abay River Basin (Figure.1). The general topography of the catchment is characterized by undulating hills, plane and valley. Its elevation ranges from 1965m to 3552mmasl and bounded within 552428 to 572576E and 1210451 to 1243825N (UTM/ ADINDAN) respectively. The annual average temperature of the study area is 17^{o}c.

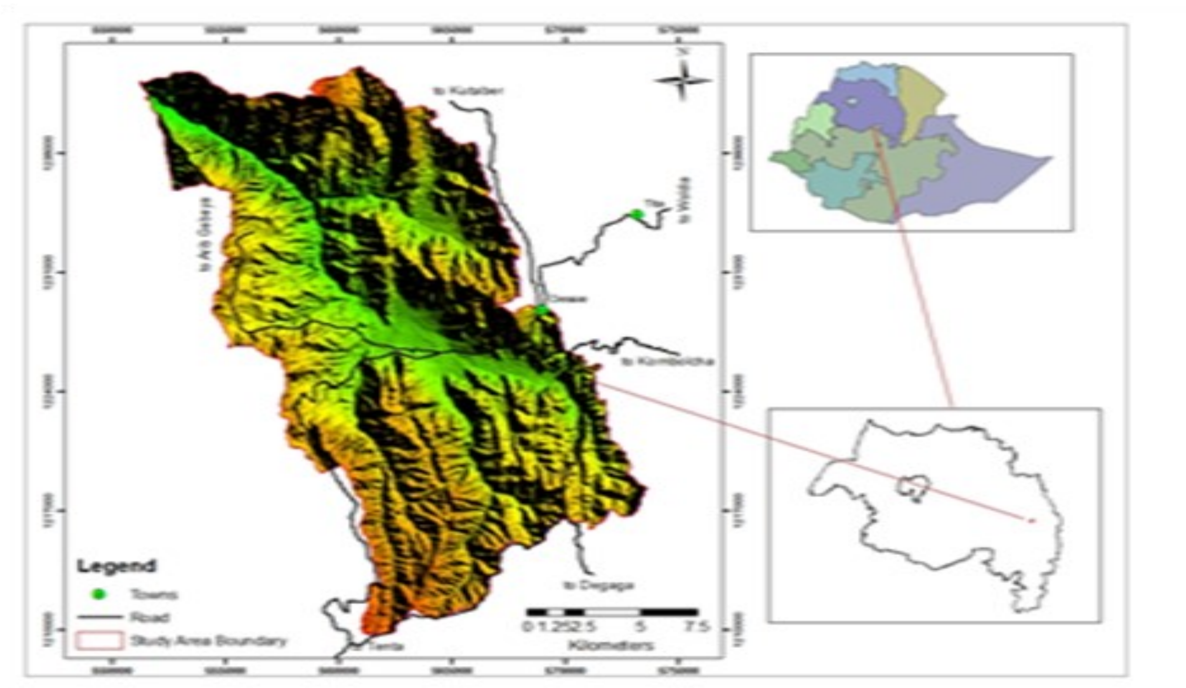

Figure 1 Study Area M

Methodology Adopted

Field Work Activity

The methodology designed for this research work consisted of three major phases; pre fieldwork, fieldwork and post fieldwork. In the pre field work, review of previous works on the study, reconnssiance survey area and other similar areas related to the topic has been carried out. Collections of appropriate data were done giving particular attention to the quality of documents. Geological and structural investigations were conducted in the fieldwork for identifying the major geological units and structural configurations in the study area. As a result geological map of the area was produced. Hydrogeological field investigation was done by giving more attention on differentiating the sediments and rock units of groundwater significance such as the degree of fracturing of the rock units, space between fractures and opening space of fractures in the rocks.

Thematic Map Preparation Using ArcGIS

In the post field work, data processing analysis of primary and secondary data obtaining from pre-field and fieldwork were the main activities. Some of the important activities were: delineating of the study area was initially done by extracting the catchment from topographic maps and DEM images using ArcGIS software and then finalized by taking GPS readings at different locations of the study area for ground checking. After delineating of the study area, base map preparation was undertaken by using topographic maps with a scale of 1:50,000, aerial photo and DEM 30m spatial resolution. In order to evaluate groundwater prospect of the area , identification and classification of the basic baseline maps of geomorphology, soil, liniment, drainage density, land use land cover, slope, lithology and rainfall of the catchment were done. Then, different thematic maps were produced.

To begin with slope preparation of the area, a digital elevation model (DEM) with 30m spatial resolution was used as in the Arc Map of ArcGIS, spatial analysis tool. Then, the study area's slope was classified in to four classes with lowest and highest value of 5degree and 60degree respectively. The flat and steep gradient areas of study area have significant impact on groundwater occurrence and movement. The other determinant factor controlling groundwater occurrence is drainage density. It was calculated directly in Arc map of ArcGIS, using spatial analyst extension using DEM with 30m spatial resolution. Accordingly, four drainage density categories were identified and mapped which important in controlling groundwater occurrence and movement.

Remote Sensing Activities

The land use cover of the area was done using the multi spectral band of Landsat satellite image of 2014, with 30m spatial resolution. The image was freely downloaded from USGS and it was geometrically and radio metrically corrected with the ERDAS Imagine 8.6. Then, supervised image classification was done for 2014 year and four classes were identified and mapped those which have different impact on groundwater occurrence.

Geostatistics Analysis

Rainfall measurement is a point observation and may not be used as a representative value for the area under consideration. Therefore, it is necessary to obtain effective uniform depth of rainfall of the catchment to get a more reliable and representative results. Areal depth of rainfall in the catchment was estimated by using simple arithmetic mean, Isohyetal and thiessen polygon methods. So, to create the surface map of the study area, ten years metrological data from Dessie, Kombolucha, Albuko and Kutabor Districts were used as input.

However, since those rainfall data were in point features, thiessen polygon methods interpolation was used. After all the baseline maps were identified and prepared, weighted value estimation for each factor and its field value was determined since all the factors have no equal importance in controlling groundwater occurrence.

And this was done using the multicriteria evaluation analysis and an IDRISI Software was used for this purpose. At last, all maps were added together to ArcGIS Software, and weighted overlay method was used to finally to stimulate the model. However, it needs further validation to cross-check whether the selected suitability classes are right or not. Accordingly, point data on water pump well and dungs were collected across the study area.

Result and Discussion

Evaluating Physical and Environmental Factors Controlling Groundwater Occurrence

Geomorphology: The main geomorphic units identified in the area are alluvial plain, mountainous area, plateau, and residual hills. As shown from figure 9, groundwater occurrence map, those suitable areas are found with geomorphic class of alluvia plain and plateau because of high infiltration rate. SoumenDey., 2014, also indicated that alluvial plain and plateau have more impact in occurrence groundwater while the mountainous area and residual hills and undulating upland, have shown less impact of poor groundwater.

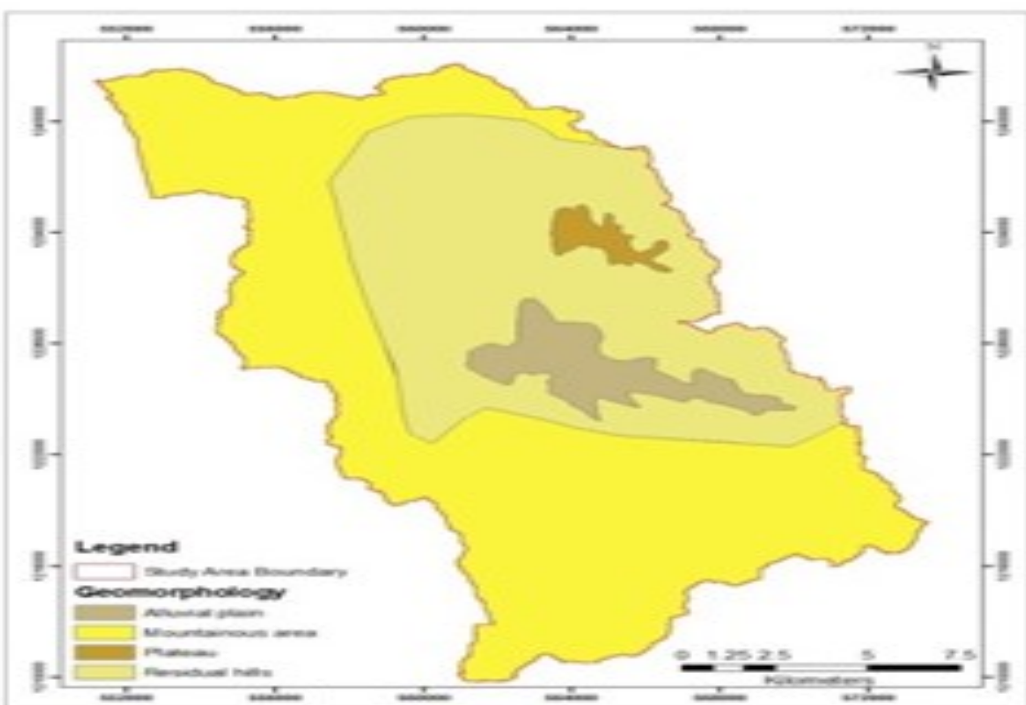

Figure 2 Geomorphology Map

Lithology: it is major factor controlling the quantity and quality of groundwater occurrence in a given area (Bhuvaneswaran, 2015).The area's lithology (Figure.2) is dominated by quaternary sediments and tertiary rocks and classified in to alaji rhyolite, aiba basalt, tarmaber formation and alluvial deposits. The lithology influences on both the porosity and permeability of aquifer rocks (Ayazi et al. 2010; Chowdhury et al. 2010).

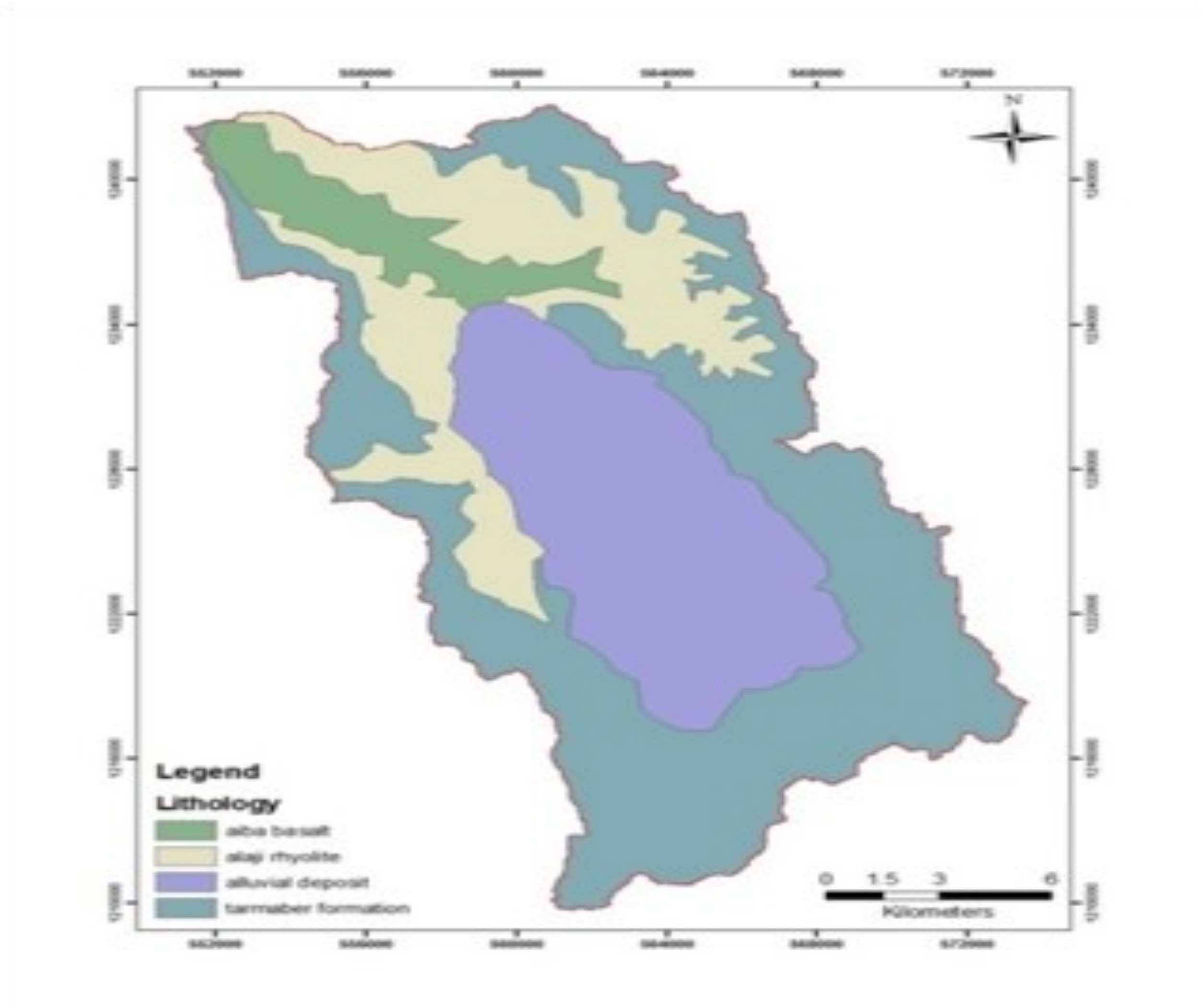

Figure 3*Lithology*Map

The most suitable groundwater potential areas are found in the lithology class of tarmaber formation and alluvial deposits as shown in figure because of good capacity of infiltration and water recharge. However, as each of those lithological units have no equal importance in determining and controlling groundwater. So, to determine the weighted impact of among those lithological units, IDRIS Software was used and accordingly the result are alluvial deposits >tarmaber formation >alaji rhyolite >aiba Basalt respectively.

Drainage Density: In the study area, four main drainage density categories have been identified and mapped as shown in (Figure.3). Very high drainage density is found in the northern part of the study area whereas high drainage density is found in eastern, western and central parts. Moderate and low drainage density concentrates in the southern and central part of the study.

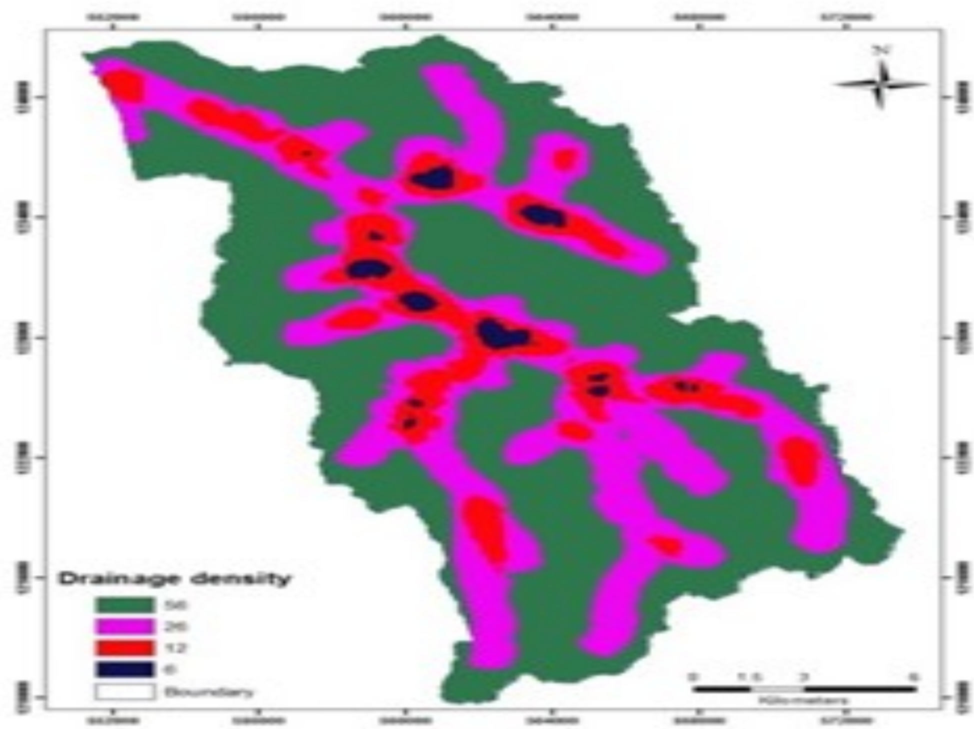

Figure 4:- *Drainage Density* Map

The coarse drainage texture indicates highly porous and permeable rock formations; whereas fine drainage texture is more common in less pervious formations (Waikar1 &Nilawar, 2014) structurally controlled drainage is normally seen in northern part of the study area. Drainage texture and patterns are controlled by different litho-units, structure and morphology. In the northern part of the area drainage pattern is sub-dendritic to sub-parallel. Groundwater potential is poor in areas with very high drainage density/course as it lost majority of the rainfall in the form of runoff.

On the other hand, areas with low drainage density allow more infiltration to recharge the groundwater and therefore have more potential for ground water occurrence. Murasingh, (2014)also noted thatlow drainage density region causes higher infiltration and it yields in better groundwater potential zones as correlated to a high drainage density region. In-contrast, high drainage density values are favorable for run-off, and hence indicates low groundwater potential zone (Agarwal et al. 2013).

Land Use Land Cover: It one the factors affecting groundwater occurrence. Supervised classification was conducted to identify the type of LULC and four classes identified namely cultivated land, slope, forest and shrub.

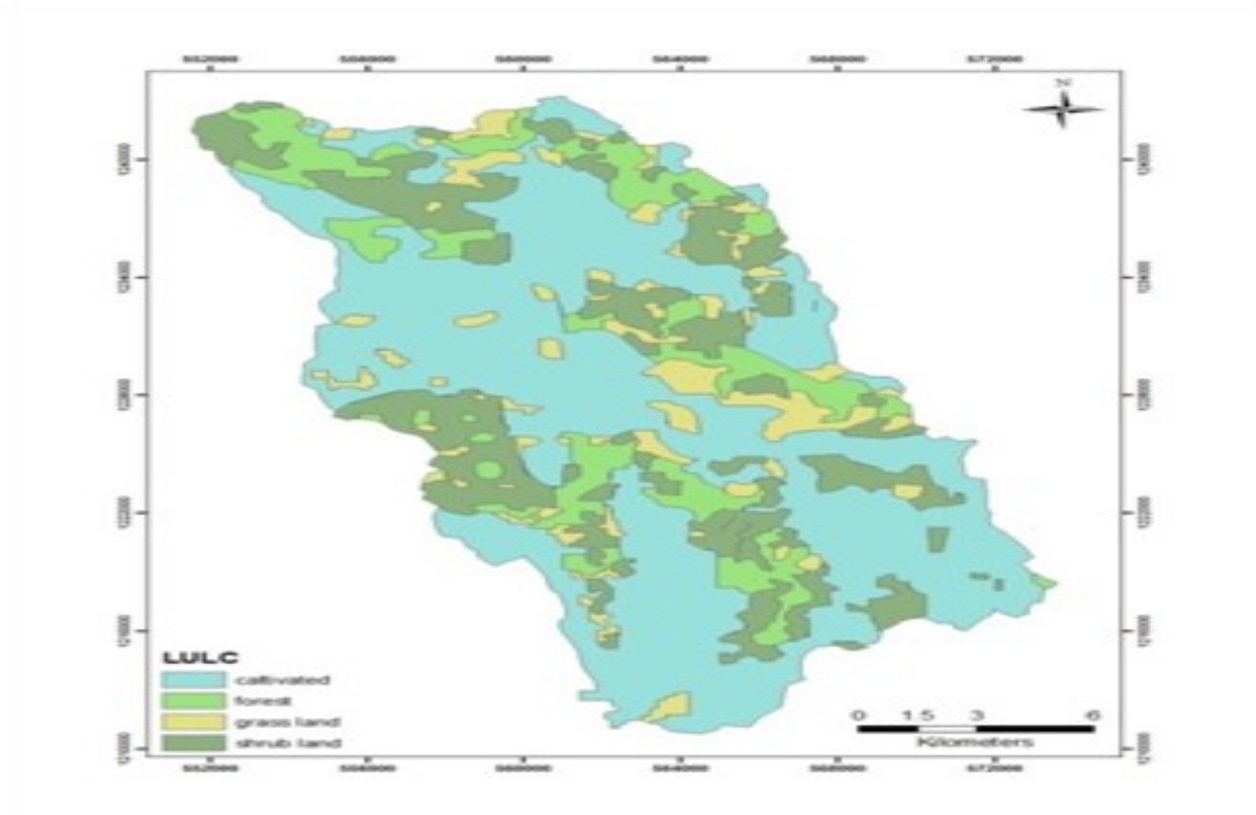

Figure 5:-Land Use Land Cover Map

According to Singh et.al, 2014, LULC information is an important factor in groundwater storage and recharge. For this research, the result of LULC on groundwater controlling in order of increment forest > grassland>cultivation-land. So, the most suitable areas are found within shrub land and grazing lands which have better infiltration as compare to cultivation lands.

Rainfall: Rainfall measurement is a point observation and may not be used as a representative value for the area under consideration. Therefore, it is necessary to obtain effective uniform depth of rainfall of the study area to get a more reliable and representative results. Areal depth of rainfall in the catchment was estimated by using simple arithmetic mean, isohyetal and thiessenpolygon methods (figure 5 below).

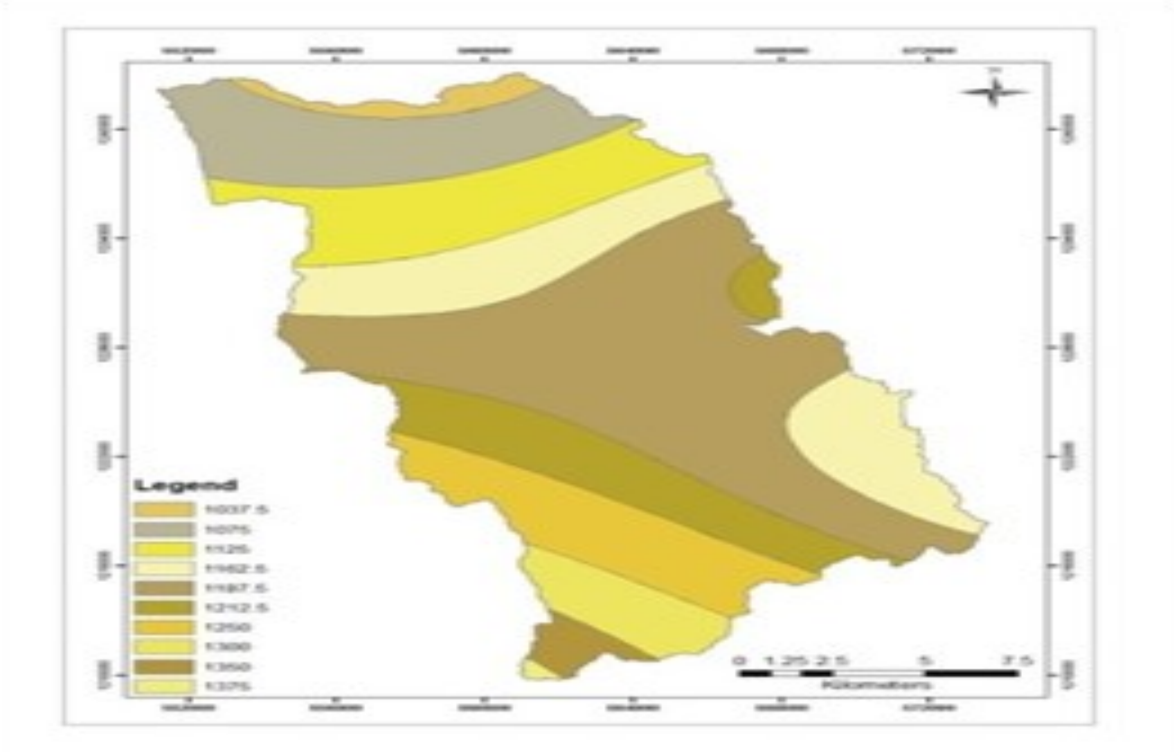

Figure 6:- Rainfall Map

To, determine the mean monthly rainfall of the study area, five meteorological stations meteorological stations were used. As a result, the mean annual rainfall of the catchment was found 1251.37mm. The annual total rainfall of the area is found 1307.76 mm per year. During the month of March and April, the area has got small rain which contributes more than 11% ; while July, August and September months have contribute more than 70% for annual rainfall or big rain (Kiremt Season) and the rest months contributes 18% are dry months (**Dereje, 2012).**

Rainfall is the major source of recharge. It determines the amount of water that would be available to percolate into the groundwater system (Agarwal et al. 2013).Gintamo (2015) also noted that rainfall is the primary input of the hydrologic cycle. It plays an important role in the hydrologic cycle which controls groundwater potential.

Slope: As shown from figure.6,the central part of the study area is highly covered by grazing and cultivating land that is flat having a slope degree value of 0°-5° and which is 69.62% of the catchment. The area with slope values of 5°-12°and12°-30° is classified as gentle and moderate that covers 97km^2 and 15km^2 which is 26.08% and 4.03% of the study area respectively which is covered by cultivation.

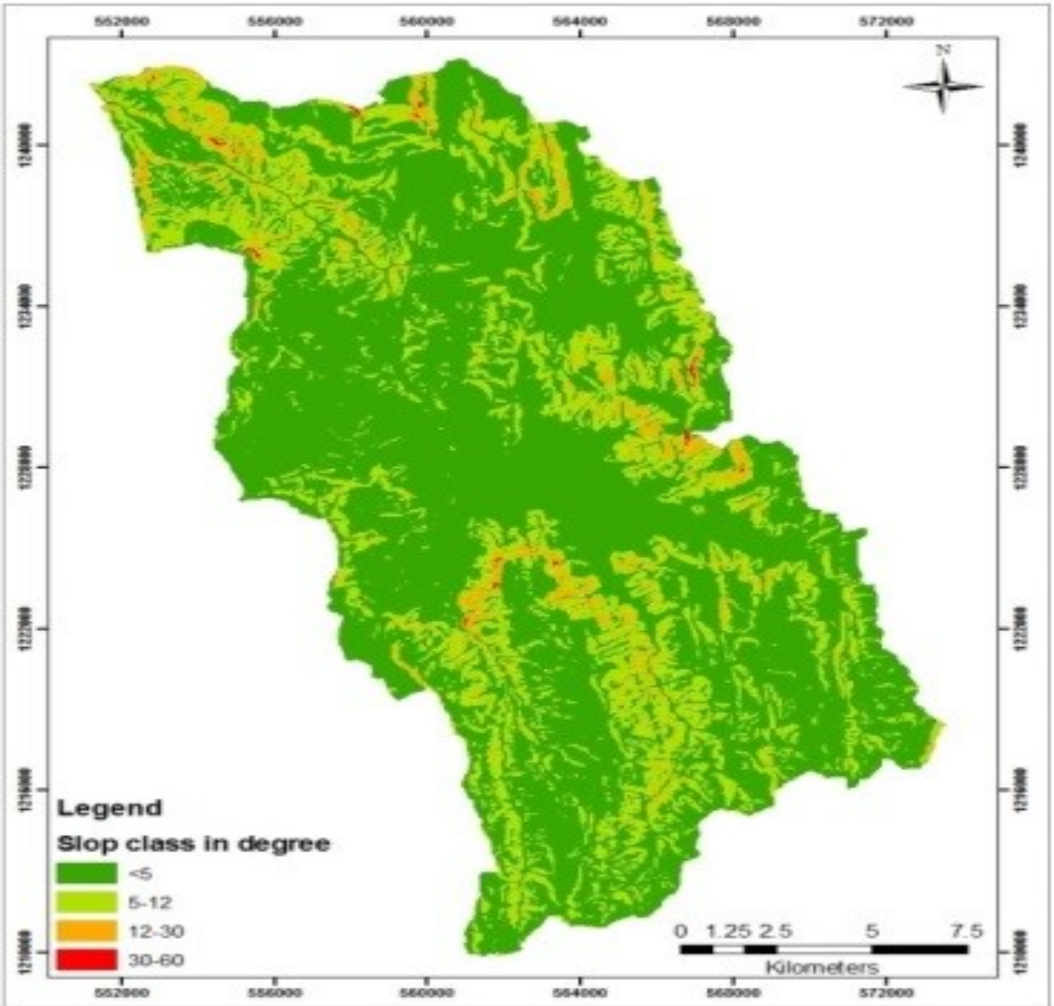

Figure 7:- Slope Map

The area around the south east and north part of the catchment is steep having a slope value of 30° -60° cover 1km^2 which is equivalent to 0.27% of the catchment and it is covered by shrubs and plantation. Slope is one of the most important factors controlling groundwater occurrence. Flat areas are capable of holding the rainfall and facilitate recharge to groundwater as compared to steep slope area where water moves as runoff quickly (SisayLibasse, 2007). The finding showed that slopes with flat (<5 $^{0)}$ and gentle areas (5-12^0) are more suitable for groundwater occurrence as compare to steep because gentle and flat slope areas permit less runoff have very good potential for groundwater. Topographic setting relates to the local and regional relief gives an idea about the general direction of groundwater flow and its influence on groundwater recharge and discharge (Tesfaye, 2010).

Soil: The characteristics, types and distribution of soil (Figure.7) for a certain area depend on geomorphology, geology, relief, time, and other factors.Soil properties influence the relationship between runoff and infiltration rates which in turn controls the degree of permeability, that determines the groundwater potential (Gintamo, 2015; Tesfaye, 2010). Soil texture is a medium that control the groundwater vulnerability which is an important in determining the intrinsic vulnerability (Colin etal, 2015).

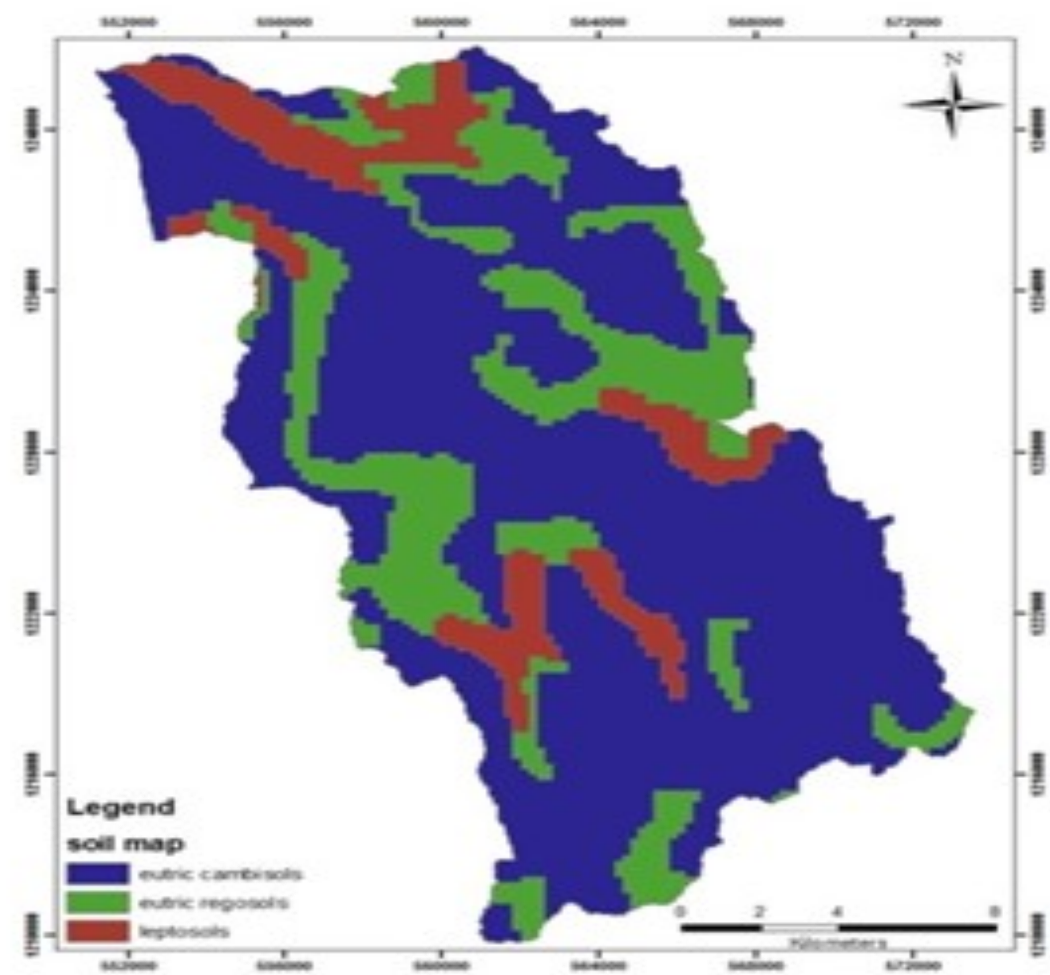

Figure 8:- Soil Map

In line with FAO and according to Ethiopian Ministry of Water Resource Soil Classification, the prevailing soil types in the study area was classified in to three major groups namely cambisols, leptosols and regosols as shown in figure7. Cambisols and leptosols soils are found the dominant in terms of area cover and more determinant in groundwater occurrence and movement as compare to leptosols.

Lineament Density: Areas with higher lineament density facilitate infiltration and recharge of groundwater and therefore have good potential for groundwater development (Bhuvaneswaran, 2015). Moreover, areas with gentle slope and permit less runoff and have very good potential for groundwater availability (Figure.8). The slope increases towards the south east and north part of the study area that facilitate high runoff and poor groundwater recharge.

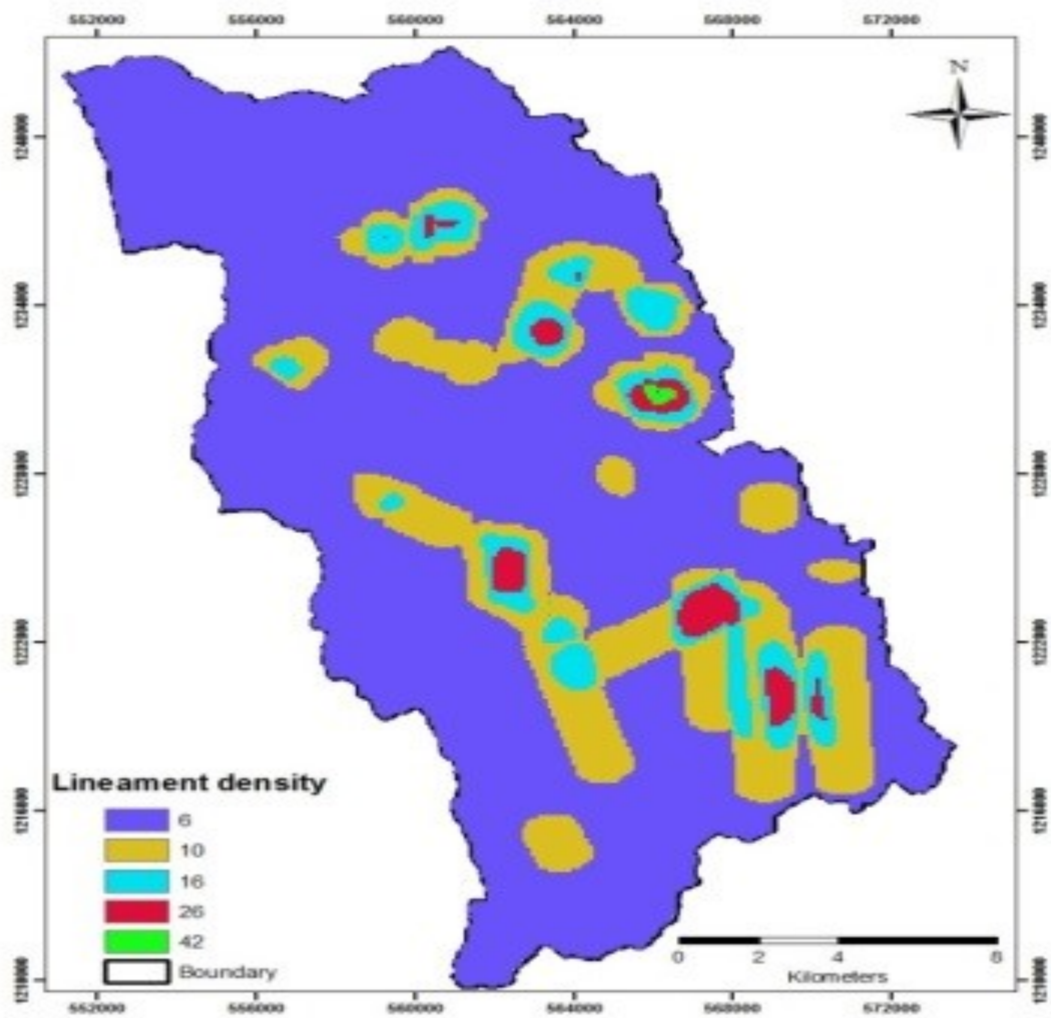

Figure 9:- Lineament Density Map

A high lineament length density infers high secondary porosity, thus indicating a zone with high groundwater potential (Abadi&Shamma'a, 2014). As shown from figure.9 the groundwater suitability map, most of the potential areas found with higher lineament density and gentle slope.

Groundwater Prospects Map and Validation

To identify groundwater potential zones, factors such as geological structures, lithology, geomorphology, slope, land cover, drainage and others are very important to integrate through RS and GIS modeling and MCA (Waikar&Nilawar, 2014);Ayele,etal,2014;Sisay,2007, Tewodros,2005, Abiy,2009, Gupta Dev Sen, etal, 2015, Mondal S, 2012, RS Suja rose, & N Krishnan , 2009). Groundwater occurs within different hydrogeological environment, geological formations and topographic settings that control the groundwater distribution and development for different purposes (Tesfaye, 2010).

For this research, the groundwater prospect map of the area was done by integrating eight thematic layers in ArcGIS by using weighted overlay method which are listed in table.1. Based on the multicriteria evaluation technique each layer and field value was assigned a rank and weighted (Arivalagan, et al, 2014**)**. This is because all those variables have no equal weight in determining groundwater occurrence and movement (Satty, 1980).

Where, LT: Lithology/Geomorphology/, LD: Lineament Density, GM: Geomorphology, SL: Slope, SOL: Soil, DD: Drainage Density, RF: Rainfall, LULC: Land use Land cover. For all thematic layers, the CR value is less than 0.1 and, hence, the judgments of the pair-wise comparison within each thematic layer are acceptable (Saaty, 1980). Table 1 show that the most three factors affecting groundwater occurrence were found lithology with (34.5%), lineament (23.4%), and geomorphology (15.5%) respectively.

On the other hand, the rest five least influencing factors were slope, soil, drainage density, rainfall, and land use/cover respectively. The final stage involves spatial analysis (weighted overlay) to combine all thematic layers based on rates for the classes in a layer and weight of thematic layers from the pair-wise comparison. The formula for computing the GWP map is shown below.

GWP=0.3456*LT+0.2339*LD+0.1548*GM+0.1033*SL+0.0689*SOL+0.0449*DD+0.0286*RF+0.0203*LUL---Equation (1)

Where:- GWP = Groundwater potential, LT = lithology, LD = lineament density, GM = geomorphology, SL = slope, SOL= soil, DD = drainage density, RF = rainfall, and LULC = Land Use Land Cover.

The groundwater prospect map produced by the weighted linear combination of the thematic layers and reclassified into four zones: namely, very good, good, moderate and poor. The very good groundwater prospect zones are mostly in the alluvial plains/valleys, with smooth and irregular plain geomorphological classes. And it coincides with flat to moderate slope classes. Groundwater zones produced are compared against borehole yield data to check the validity of the result. Olutoyin, 2013,&Singh et al, 2014,SoumenDey., 2014, stated validation of the groundwater potential zones should be done using existing data on dung wells and bores.

Thus, out of the collected and reviewed 60 water points, 57 have measured and estimated actual yield data. In general, the data indicated high yield (≥30 l/s) in the very good potential areas while very low yield (<5 l/s) in the very poor potential areas. Intermediate values appear in the zones between these extremes. Water points with yield 5-<12 l/s occur in the poor, with 12-17 l/s in the moderate, and 18.5-20 l/s in the good zones of groundwater potential.As shown from the figure.9 map, most of the suitable groundwater areas are found in the central and eastern part of the study area. In contrast, the northern and western part of the Gerado River catchment has less potential of groundwater occurrence.

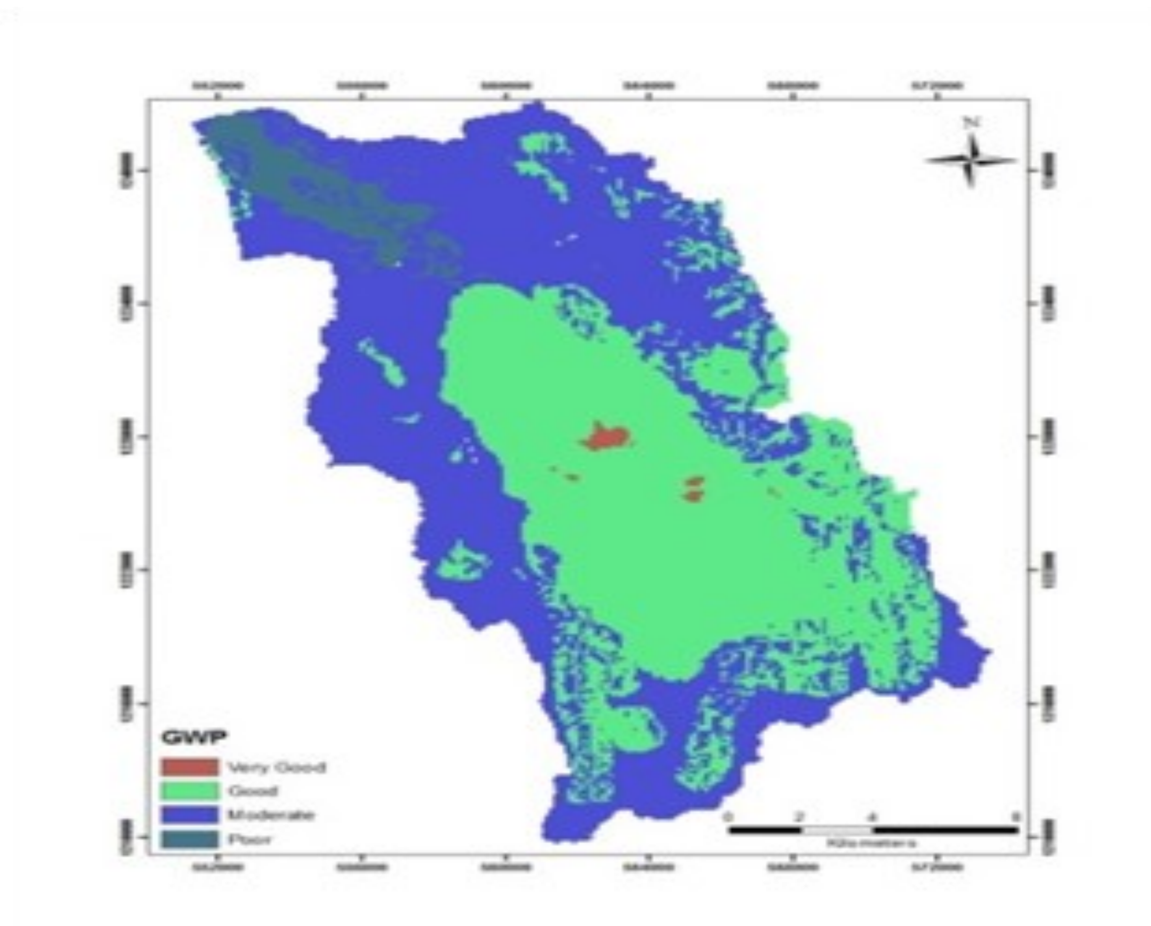

Figure 10:- Groundwater Potential Suitability map

Conclusion

Adopting advanced geospatial techniques in groundwater mapping is cost effective in terms of time and resource. This paper was an attempt to delineate and map out groundwater availability of Gerado River , Northern Ethiopia. The most important variables affecting groundwater controlling were considered namely, geomorphology, lithology, slope, soil, LULC, linment density, drainage density and rainfall. But, since all those factors have no equal impact in controlling groundwater, weighted value determination was done after all thematic maps were organized. Accordingly, lithology, linment density, geomorphology and slope were found the most significant factors with a weighted of value of 34%, 23%, 15% and 10% respectively. As shown from Fig xxx, the suitable potential groundwater areas are found with lithology, geomorphology and with flat slope and low LD. In contrast, the rest factors such as soil (6.89%), drainage density (4.5%), rainfall (2.86%) and LULC (2.03%) were found separately the least factors controlling groundwater occurrence. When looking to the spatial distribution of the GWP map, the less potential areas of GWP were found in western, northern and southern parts of the area.

And these areas are characterized by steep slope, high grainage density which facilitate run off creation and hence low potential GWP. In general, areas with very good and good class of groundwater map account for x% and y% respectively. Hence, it can be inferred that the area has little GWP as compete to its aerial coverage. Furthermore, geospatial techniques with the help of multicriteria analysis are good tools to investigate the relation ship among different geomorphological and environmental factors. Thus, these are good tools in planning and managing groundwater of a given area.

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Engaging citizens as scientists for generating hydrological data and information in ungauged watersheds

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ABSTRACT
National hydro-meteorological monitoring networks often do not cover the many upland micro-watersheds in which physical interventions are being introduced to improve livelihoods. Citizen science provides an opportunity to fill the existing gaps in hydrological data and knowledge for ungauged watersheds. Citizen science creates a two-way interaction between citizens and scientists: the public can increase awareness about the environment while scientists obtain data at low cost. In this study, we documented the process and findings of our effort to introduce citizen science and evaluated its scope in two micro-watersheds in Ethiopia. The first site is the Brante micro-watershed which is situated in the Upper Blue Nile basin near Dangila town. The second site is Wutame micro-watershed which is situated in the Omo Basin near Areka town. Focus group discussion was organized to generate hydrological knowledge regarding water availability at both sites for which no hydrological data was collected in the past. Citizens also became engaged in rainfall, shallow groundwater level and stream flow data monitoring. Data collection in Brante was started in 2014 to support improved management of shallow groundwater resources for small scale irrigation. Data collection in Wutame was started in 2017 to support an evaluation of the impact of sustainable land management interventions. Citizens' interest and understanding of their environment increased as they actively participated in site selection, instrument installation and data recording in both micro-watersheds. At both sites, citizens were willing to be engaged as scientists occasionally but they demanded attractive monetary incentives for regular engagement. We therefore suggest that future studies must explore how to make occasional engagement of citizen scientists more effective in Ethiopia. Additional research in other micro-watersheds is needed (i) to understand what motivates citizens to volunteer and (ii) to involve them as active participants in the research and not simply as data collectors.

Keywords: Citizen science, monitoring, hydrology, SLMP, micro-watershed, Dangila, Areka, Ethiopia

Introduction

Various interventions are being introduced in many upland micro-watersheds in Ethiopia with the aim to improve livelihood. For instance, shallow groundwater wells are dug by communities in Dangila district. In some villages, one in six households own hand dug wells while many households own multiple wells. The wells serve multipurpose including meeting irrigation, domestic and livestock demands. The local agriculture bureau is promoting shallow ground irrigation with a target of 0.125 ha land to be irrigated using hand dug wells by each household.

The Sustainable Land Management Program (SLMP) also introduced various physical interventions in selected upland micro-watersheds of Ethiopia. The interventions include, but is not limited to, hillside terrace, stone bund, soil pasted stone bund, and deep trenches. The expectation is that such physical interventions can reverse land degradation. It is also expected that the interventions will positively affect the hydrological behavior of the micro-watersheds thereby positively affecting the livelihood of the people. However, this is not far from speculation since there is no adequate scientific proof about the hydrological impacts of these physical interventions for Ethiopia.

The impact of both the physical interventions and increased groundwater abstraction on the hydrology of upland micro-watersheds of Ethiopia is not well documented. The lack of scientific evidence is mainly caused by hydrological data gaps to generate empirical evidence. The current hydro-meteorological monitoring networks, which are operated by the National Meteorological Agency (NMA) and Ministry of Water Irrigation and Electricity (MoWIE), cannot provide data on the hydrology of the micro-watersheds in which interventions are introduced. These micro-watersheds are too small and inaccessible to monitor with reasonable cost. In this study, it is found necessary to evaluate alternative data sources.

Citizen science refers to the participation of the general public (i.e., non-scientists) in the generation of new scientific knowledge (Buytaert et al. 2014). It provides opportunity for the public to participate in scientific research. Citizens' awareness about their environment increases while scientists obtain data at low cost. The generated data and knowledge contributes to an improved understanding of water resources (Starkey et al., 2018) which can serve as a base for decision making.

The main issues in citizen science include lack of guidelines to introduce it in new sites and the quality of citizen data. These issues are being addressed by recent scientific research (e.g. Tipaldo and Allamano, 2017; Everett and Geoghegan (2016); Aceves-Bueno et al., 2015;) but there remains large gap of scientific evidence on citizen science for hydrology. This article, therefore, contributes to filling the scientific gap regarding the scope of citizen science for the hydrology of upland micro-watersheds in Ethiopia. We documented the main steps and outcomes of our effort to introduce and test citizen science at two sites which are in Southern and North-western parts of Ethiopia.

Study areas

The study was carried in two sites as shown in Figure 1. The first site is Branti micro-watershed which is situated in the Upper Blue Nile basin near Dangila town. The second site is Wutame micro-watershed which is situated in the Omo basin near Areka town.

Branti is situated along the Addis Ababa-Bahir Dar road at about 80 km south west of Bahir Dar town. This micro-watershed is dominantly cultivated with some extensive grazing land and eucalyptus plantations. Many households own shallow groundwater wells to extract water for domestic, livestock and irrigation purposes.

Wutame micro-watershed is situated at 56 km from Sodo town with 31 km paved road and 24 km unpaved road. The micro-watershed is covered by Sustainable Land Management Program (SLMP2) to reverse land degradation. This program introduced physical interventions in Wutame in the form of terraces, bunds, trenches, etc.

Figure 1: Location of study sites

Methods

We implemented a set of activities to test the scope for citizen science in Ethiopia. These activities include various levels of consultation, training, site instrumentation, and data and information generation.

First, we met with various directorates of the Ministry of Agriculture and Natural Resources, the staff of the Sustainable Land Management Program (SLMP) and the Agricultural Transformation Agency. These meetings were important to understand gaps in data and knowledge on shallow groundwater, and impact of SLMP interventions and household irrigation. We, therefore, aligned our citizens science activities to fill current gaps in data.

We organized two national consultation workshops at an interval of about one year. The first workshop was organized at the start of the project for scoping the citizen science study while the second was organized after one year for reporting the study findings and identify future research topics. These workshops served as a starting point to establish a national platform to share experience and findings.

The criteria for site selection were defined after the national level consultations and the first workshop. These criteria include presence of shallow groundwater, household irrigation and SLMP interventions in the micro-watersheds. The final site selection was made after field visit to candidate watersheds.

We conducted a transect walk to confirm that there is large hydrological data and information gap in the selected micro-watersheds. The transect walk was also used to interact with the community and select gauging sites based on technical criteria. This was followed by a community consultation through focus group discussion (FGD) to identify volunteers, set incentives for observers, demonstrate monitoring instruments and discuss about the hydrology of the micro-watershed. Fourteen people participated in the FGD at each study site.

The identified volunteers or citizen scientists were trained on the basics of monitoring stream-flow, groundwater, springs and rainfall before their engagement as citizen scientists. Figure 2 shows the procedure which was followed in introducing and testing citizen science in the two study sites.

Citizen science involves engagement of volunteers. In this study, we identified the citizen scientists through a participatory approach. We first explained the criteria for engagement as citizen science to the FGD participants (Figure 3). These criteria are willingness, minimum education level of grade 10, residence in the proximity of the observation sites, strong commitment, limited mobility (the person should not be frequent traveler outside of the micro-watershed), and gender representation.

In addition, the rain gauge observer's compound should have adequate space which is clear

Figure 2. The process of engaging citizen scientists as applied in this study.

from tall trees and cattle interference and large enough to install a rain gauge. The stream flow observer should also reside in the proximity of the gauging site.

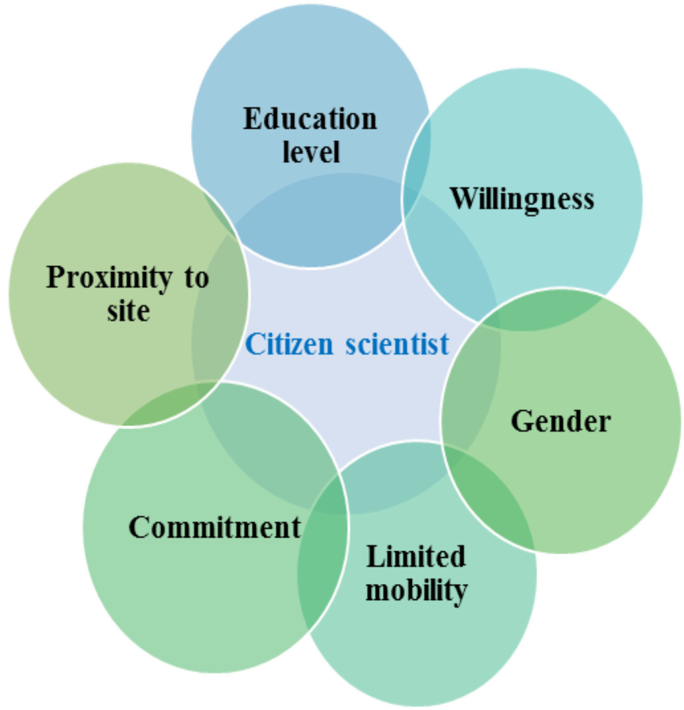

Figure 3. Criteria to engage volunteers as citizen scientists

Results

Water availability as described by citizen scientists

We evaluated water availability in the two study cites through the transect walk and the FGD. Residents of Wutame micro-watershed experience critical water shortage in the dry season. Women and girls often travel 30 to 60 minutes daily (commonly up to 3 times a day) to fetch water mostly from springs or rivers and seldom from public fountains. Men and boys spend up to 2 hours daily to take their cattle to water sources.

Lack of access to water is affecting the community's health, education and overall livelihood. The water shortage is making it difficult to keep even personal hygiene. Impact on educations is also felt as students are commonly late since breakfast is always delayed until water is fetched. Water shortage is somewhat becoming a barrier for irrigation in Wutame.

As such, crop cultivation is entirely rain-fed. Livelihood in Wutame micro-watershed is therefore very sensitive to any changes in rainfall amount or pattern.

About one in six households own a shallow groundwater well in Branti micro-watershed. Most well owners practice backyard irrigation to produce vegetables and fruit trees (e.g. mango, avocado) for market and their own consumption. Well owners save extra time that would have been used to search for drinking and livestock water. For none well owners, it takes about 30 minutes and 1 hour to fetch water for domestic and livestock purposes, respectively. In addition to an extra travel time, households who do not own wells rely on unsafe water sources.

Perception about citizen science

We evaluated citizens' perception in both micro-watersheds. The FGD participants in Wutame stated that hydrological monitoring is necessary to know how much of the rain water joins the river and ground water and can be utilized for irrigation development.

Well cleaning is done arbitrarily in Wutame without the use of data to inform the extent of cleaning required. Therefore, the FGD participants believe that monitoring of SGW water level will inform them about the range of water level fluctuation and hence the required extent of well deepening.

The FGD participants in Branti stated that the citizen science data can be used to determine appropriate groundwater lifting technologies in the micro-watershed. They also said that the data provides information on the impact of climate variability on groundwater and river water levels.

About 64% of the participants expressed willingness to engage as citizen scientists in both sites. The main reason for willingness to engage in citizen science was the believe that the citizen data can be directly used by the community to better utilize their water resources.

Some showed a reservation to engage in citizen science since (i) it adds burden (in terms of labor and time) to women who are already busy with too many responsibilities, (ii) some participants cannot read and write, (iii) they need additional information to be convinced about the importance of citizen science, and (iv) one of them stated that the administration office of Bolosso Bombe woreda promised him a rope and washer pump. However, the woreda did not keep the promise and as such the person decided not to be part of any volunteering.

In Wutame, citizens are willing to monitor streamflow once a month and to monitor rainfall and groundwater level more frequently, which is once a week (Table 1). In Branti, the participants agreed to frequently monitor hydrological variable that shows large temporal variation. They suggested to measure rainfall every day but measure groundwater and river water levels only once per week.

The FGD participants have every day commitments (e.g. on farm and off-farm work). Therefore, they demanded compensation for their time before committing themselves to frequent monitoring activities. The participants asked for monetary incentives to increase observation frequency. In Wutame, they suggested 20 birr (0.91 US dollars) per day as a reasonable incentive to monitor each hydrological variable at single station. In return, they are willing to monitor groundwater level every other day, rainfall every day, and streamflow twice per day. However, they suggested that proper training should be provided to them before starting the monitoring.

In Branti, the FGD participants suggested a daily incentive of 20 birr (0.73 USD) per day for river water level measurement. However, 10 birr per day incentive was suggested for rainfall and groundwater level monitoring. In return, they are willing to measure rainfall on daily basis, groundwater level every three days and river water level twice per week and once per week for rainy and dry seasons, respectively.

Table 1. Hydrological monitoring frequency as suggested by FGD participants

Hydrological variable	Branti		Wutame	
	Without incentive (Volunteer)	With monetary incentives	Without incentive (Volunteer)	With monetary incentives
Rainfall	Daily	Daily	Once a week	Daily
Stream flow	Once a week	Twice per week	Once a month	Twice per day
Groundwater level	Once a week	Every three days	Once a week	Every other day

4.3 Experience of citizen scientists in Branti

The citizen scientists of Branti micro-watershed were engaged in monitoring over the past four years. One of the challenges they faced was lack of support from groundwater well owners. The citizen scientists suggested to provide some incentives to well owners. This can be in the form of a training to raise their awareness so that they support observers.

Heavy floods as caused by poor access road made river gauging sites difficult to access, carried tree logs to frequently damage and even break the staff gauge and changed the cross-section at the gauging site. The citizen scientists also noticed that the observation frequency (twice per day) is not sufficient to capture extreme flood events.

The observers claim that the training that they received at the start of the project was not sufficient to interpret the citizen data and inform the community. Particularly, community members ask repeatedly about the major benefits they receive because of the data collection. It is suggested to frequently train and demonstrate the citizen scientists about the benefit of the collected data.

The citizen scientist who records both rainfall and groundwater level claimed that he noticed correlation between rainfall amount and well water level with some time lag. He also noticed that well water level in the area may increase even after the rainfall stops, probably due to sub-surface lateral flow. Comparison of current and past observations also helped him to identify the year and season as normal, dry or wet.

The citizen scientists who records groundwater level said that he advises the owners to increase or decrease their rate of water abstraction and even improve the well cover when he notices that the water becomes too turbid due to flood water entering the well. When the water stored in the well becomes extremely low he advises the owners to clean or deepen the well. He also stated that he explains to the community members about the effect of well diameter on water storage and groundwater potential for backyard irrigation.

We asked the citizen scientists if the community is now willing to volunteer for data collection. However, they said that they are not sure about this since the community members know that the current citizen scientists are receiving incentives. As such they may not be willing to volunteer unless they receive some monetary incentive. However, the current citizen scientists are willing to enhance their engagement without additional incentives.

Conclusion

Many citizen science initiatives remain undocumented in the scientific literature. Therefore, guiding documents are lacking to introduce citizen science for hydrological monitoring in new sites. In this study, we have documented the process of engaging citizen scientists in two micro-watersheds in Ethiopia. The article can serve as a spring board for future studies that aim at expanding the science to other sites.

This study demonstrates that there is a scope for citizen science to fill gaps in hydrological data and knowledge of upland micro-watersheds in Ethiopia. Previously unengaged citizens can easily be occasionally engaged as scientists. However, monetary incentives are required for regular engagement which makes expanding citizen science to other micro-watersheds very expensive. We therefore suggest that future studies must explore effective ways of occasionally engaging citizen scientists in Ethiopia.

Future research is needed on how to accommodate large number of citizen scientists to reduce burden on few participants, increase the data size and capture flood peaks. There is a need to less rely on the rigid observation time which is applied by the Ministry of Water, Irrigation and Electricity (twice per day observation at 06:00 A.M. and 06:00 P.M.) and apply flexible observation interval and timing of hydrological variables. Research is needed to evaluate how to achieve such flexibility so that citizen scientists can be engaged without affecting their other commitments.

In this study, we showed that water availability can be evaluated in previously unmonitored micro-watersheds through discussion with citizen scientists. This has twin benefits as citizens become empowered with enhanced knowledge about their environment and researchers obtain an important hydrological information about ungauged sites. Our study demonstrated that citizen scientists informally transferred the knowledge they gained to community members. To make this more effective, short term trainings on hydrological data collection and data interpretation must be regularly organized for the citizen scientists. Additional research in other micro-watersheds is needed (i) to understand what motivates citizens to volunteer and (ii) to involve them not simply as data collectors but also as active participants in the research.

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Analyzing the Mara River Basin Behaviour through rainfall-runoff modeling

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Abstract

Hydrological models are considered as necessary tools for water and environment resource management. However, modelling poorly gauged watersheds has been a challenge to hydrologists and hydraulic engineers. Research done recently has shown the potential to overcome this challenge through incorporating satellite based hydrological and meteorological data in the measured data. This paper presents results for a study that used the semi-distributed conceptual HBV Light Model to model the rainfall-runoff in the Mara River Basin, Kenya. The model simulates runoff as a function of rainfall. It is built on the basis established between satellite observed and in-situ rainfall, evaporation, temperature and the measured runoff. The model's performance and reliability was evaluated over two sub-catchments namely; Nyangores and Amala in the Mara River Basin using the Nash-Sutcliffe Efficiency which the model referred to as Reff and the coefficient of determination (R^2). The Reff for Nyangores and Amala during the calibration and (validation) period were 0.65(0.68) and 0.59(0.62) respectively. The model showed good flow simulations particularly during the recession flows, in the Nyangores sub-catchment whereas it simulated poorly the short term fluctuations of the high-flow for Amala sub-catchment. Results from this start can be used by water resources managers to make informed decision on planning and management of water resources.

Key words: Hydrological models, satellite data, HBV Light Model, Mara River basin

Kenya is characterized as water stressed country since the per capita water availability is at 792m^3 with a population of approximately 40 million people (UNEP, 2010). With the increasing population, expanding urbanization, modernised lifestyles, climate changes and other global changes, the pressure for sustainable planning and management of the finite water resources is more evident than ever.

This paper focuses on a study that was carried out in the Mara River Basin that cuts across Kenya and Tanzania. The Mara River Basin (MRB) covering a drainage area of 13,750km^2 is one of the catchments of Lake Victoria and forms part of the Upper Nile Basin. The Mara River (MR) which is about 395 km long is one of the Rivers supplying water into Lake Victoria throughout the year. The River originates from Mau Forest Complex which forms part of the upper basin. The Mara River Basin (MRB) is characterized by the extensive cultivated land and forested areas in the upper part, tropical savannah vegetation in the middle of the basin and one of the world famous Mara-Serengeti ecosystem towards the lower part of the Mara wetland form part of the extreme lower side of the Basin on the Tanzania side where the River drains into Lake Victoria.

The Mara River Basin faces numerous interactions that require effective management to ensure sustainability of its water resources since many livelihoods depend on it. The basin has undergone several changes over the last 50 years as a result of increased human population (Abwoga, 2012).

The flow regime in the Mara River has changed over the years due to catchment degradation. For instance, Melesse *et al.* (2008) in their study on Modeling the Impact of Land-Cover and Rainfall Regime Change Scenarios on the Flow of Mara River found out that there has been a decline in the dry season flow and increased peak flood frequency in recent years. In another study by Mati *et al.* (2008) where these researchers applied the USGS Geospatial Stream Flow Model in studying the impact of land use/ cover on the hydrology of MRB, it was found out that forests and savannah grasslands have been cleared and turned into agricultural lands. In addition, the long-term monitoring also identified several areas of concern in the upper catchment of the basin. For instance, the results showed that the Amala sub-catchment higher decline in average monthly flow levels over the last 15 years, transported higher sediment load per unit catchment area and had generally lower water quality than the Nyangores sub-catchment, suggesting land degradation in this sub-catchment may be responsible for declines in water quantity and quality in the Mara.

In order to effectively plan the water resource use and to protect it under the changing conditions, application of basin runoff models that can simulate flow regimes under different scenarios of change (Mango *et al.,* 2011) is required. However, the availability of long term spatial and temporal quality hydro-meteorological data has been a challenge in many river basins in Kenya. In order to overcome this challenge, this study used the satellite observed rainfall products and the 30m resolution Shuttle Radar Topography Mission (SRTM) DEM which were derived from open sources. The study applied a conceptual hydrological model, the *Hydrologiska Byrans Vattenavdelning* model (HBV Light Model) for run-off simulation of the measured rainfall.

Materials and Methods

The Mara River Basin which is a trans-boundary basin covers approximately 13,750km^2. It lies between South Western Kenya and North Western Tanzania at between longitudes 33° 47' E and 35° 47' E and Latitudes 0°28' S and 1°52' S. The Napuiyapui swamp in the Mau Forest Complex, is the source for the Mara River where it flows at an altitude of approximately 3000 metres above sea level (m.a.s.l) South West before draining into Lake Victoria in Musoma Tanzania at an altitude of 1134 metres above sea level (Mwania, 2014). The Nyangores and Amala Rivers are the two main perennial tributaries of the Mara River and their respective sub-basins form part of the Upper catchment. The other tributaries are; Talek, Sand and Engare Ngobit rivers on the Kenyan side and the Bologonja River on the Tanzania side (Figure 1). The amount of annual rainfall in the basin varies from 1,400 mm in the hills of the Mau Forest to 500–700 mm in the dry plains of north-west Tanzania (WWAP, 2012).

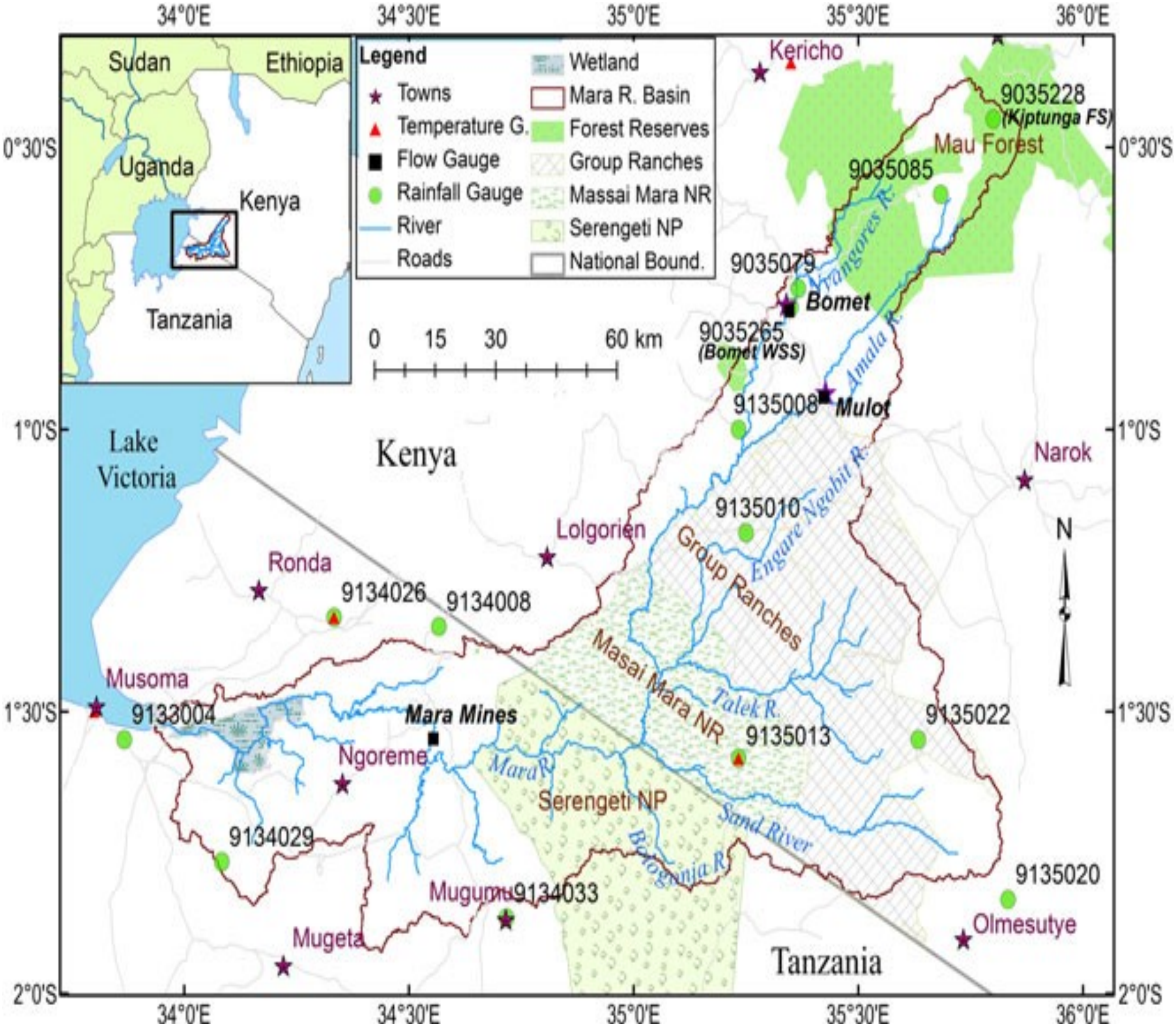


Figure 1:Site Map of the trans-boundary Mara River Basin, showing the Mara River with its tributaries. Source: (Melesse, 2012)

The study used the HBV model which simulates the daily discharge using input variables of rainfall, temperature and potential evapotranspiration (Bergström, 1976). The input data collected were checked for consistency as well as filling in the missing data gaps for precipitation, discharge and temperature datasets. The main approach used was the correlations between the three hydro-meteorological stations (Narok, Kericho and Kisii) data. Thereafter, multiple linear regressions were used to develop relationship equations which were then used to fill the missing data gaps.

The records of only three out of the thirty six hydro-meteorological stations on the Kenyan side as shown in Figure 2 were processed. The data was recorded daily at 0900hours and was expressed in millimetres per day (mm/day). The areal average precipitation P_{area} was calculated as weighted mean of precipitation stations in and around the catchment. This was achieved through use of the Thiessen polygons.

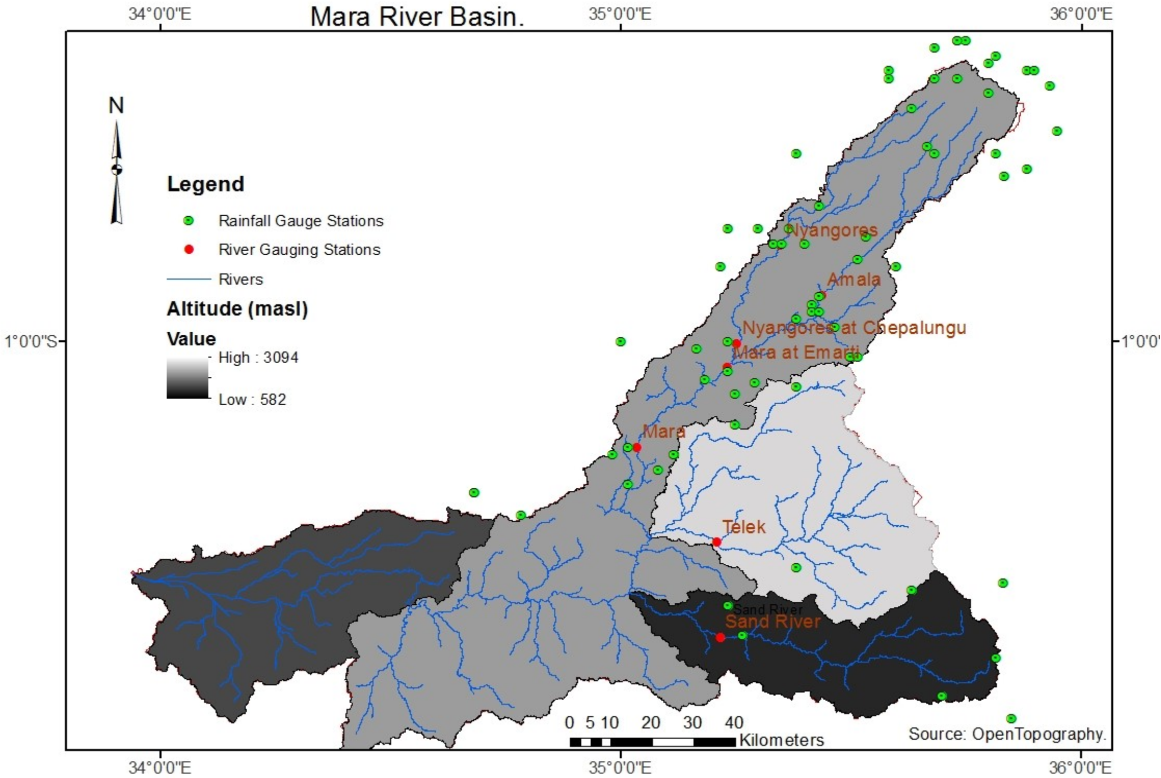


Figure 2: Processed SRTM DEM showing the Elevation, Rainfall gauging stations and the River gauging stations of the Mara River Basin

The temperature was calculated as weighted mean of the stations in and around the catchment after the missing data was filled using multiple linear regressions. The data was obtained from the Kenya Metrological Department. Compared to other rivers within the Mara River basin, Nyangores and Amala Rivers have long term daily discharge data records. Readings of water levels for the two rivers were taken twice each day daily in the morning at 0600hrs and in the evening at 1800hrs. Rating curves were then used to estimate daily average discharges.

Application of HydrologiskaByransVattenavdelning (HBV Light) Model

The HBV light model which is a semi distributed conceptual model was selected to simulate the rainfall runoff processes in the two sub-catchments. The model was selected because of its suitability that has been demonstrated under different hydro climatic conditions in the world (Bergstr¨om, 1995; Lindstrom *et al.,* 1996). The general structure and equations of HBV light model is summarized in Figure 3. The reservoirs are connected to each other by means of exchange fluxes which define the amount of water between the different zones. Equations (1) and (2) give the general water balance.

The HBV light model has four routines which include; the snow (not used in this research), soil moisture, response function and routing routines (Seibert and Vis, 2012).

$$\frac{\Delta S}{\Delta t} = Input - Output \tag{1}$$

Where; *Ds* = Change in Storge and *Dt* = Change over time

$$P - E - Q = \frac{d}{dt}(SP + SM + UZ + LZ + lakes) \tag{2}$$

Where; P is precipitation, E is evaporation, Q is runoff, SP is the snow pack, and SM is the soil moisture. The UZ and LZ are the upper and lower ground water zones.

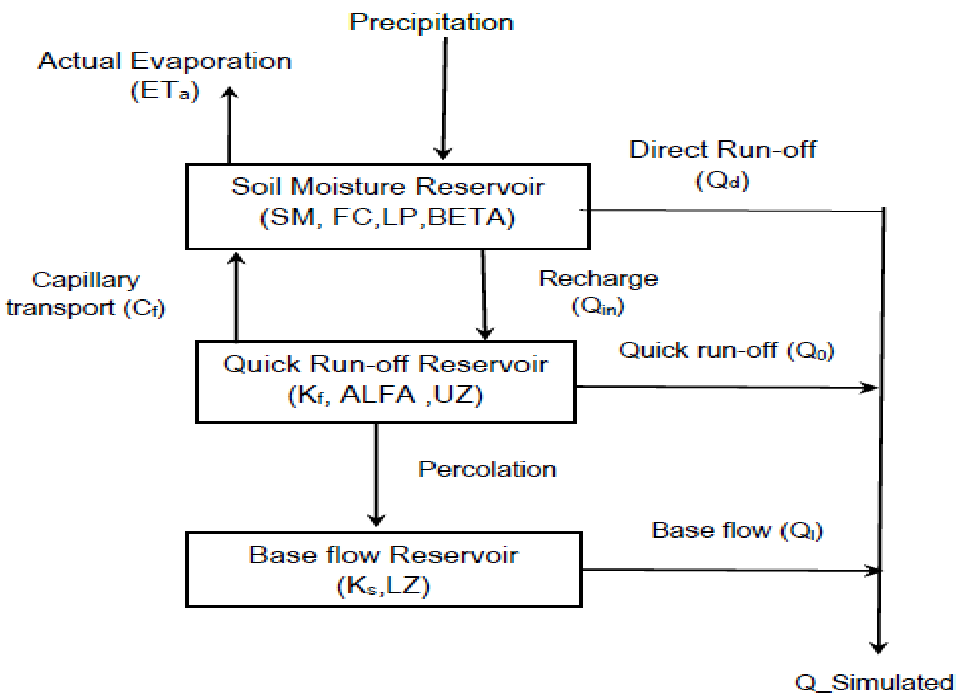


Figure 3: The General Structure and Equations of the HBV Model. Source: (Seibert, 2002)

The HBV light model uses sub-catchments as the primary hydrological units. The catchments classifications of land use, and area-elevations are used as input into the model. The model can be run with daily precipitation time series data but higher resolution can also be used in the model.

The channel routing is by a triangular weighing function through MAXBAS (length of weighing function). The soil moisture threshold for reduction of evapotranspiration defines LP. The maximal flow from the upper to lower groundwater box is defined by P_{ERC}; β is shape coefficient for the non-linear storage behaviour of the soil zone.

The model uses a warming up period of one year (Vis *et al.,* 2015). The warm-up period refers to the time that the simulation will run before the final results are collected and it allows the acclimatization of input data-set to the running conditions normal to the system being simulated.

Results and Discussions

The model was run in dynamic mode on a daily basis in order to simulate a combined period of eleven (11) years translating to a total of 4,017 time steps. The model calibration and validation was done by through trial and error method. The Monte Carlo runs were generated to investigate the catchment response characteristics, and to explore physically realistic model's parameters ranges. Initial Monte Carlo simulations were generated using parameter values from the literature (tuned with preliminary model runs) to define possible parameter ranges as shown in Table 1. However, the time dependent units change for simulations with more aggregated time steps (15 and 30days) were applied.

Table 1: Parameters and their ranges applied during the Monte Carlo Simulations

Parameter	Explanation	Unit	Minimum	Maximum
Soil and evaporation routine:				
FC	Maximum soil moisture storage	mm	100	550
LP	Soil moisture threshold for reduction of evaporation	—	0.3	1
β	Shape coefficient	—	1	5
Groundwater and response routine:				
K_0	Recession coefficient	d^{-1}	0.1	0.5
K_1	Recession coefficient	d^{-1}	0.01	0.2
K_2	Recession coefficient	d^{-1}	5E-05	0.1
UZL	Threshold for K_0-outflow	mm	0	70
PERC	Maximal flow from upper to lower GW-box	mm/d	0	4
Routing routine:				
MAXBAS	Routing,length of weighting function	d	1	2.5

Different parameter sets were produced by running more than 300, 000 Monte Carlo Simulations (MCS) for each catchment representation of the Nyangores and Amala sub-catchments on daily time steps. The efficiency R_{eff} value was used for assessment of simulations by the HBV model. The R_{eff} value compares the prediction by the model with the simplest possible prediction, a constant value of the observed mean value over the entire period. Several model parameter sets with R_{eff} comparable to the highest values were obtained. In the Nyangores sub-catchment, a R_{eff}>0.65 was obtained after running, 250,000 MCS. The performance of the model was termed satisfactory. In the case of Amala sub-catchment, a R_{eff}>0.59 was obtained after running 100,000 simulations of the Monte Carlos. The performance of the model was within acceptable range as per the selected performance criteria.

In addition, to visual observation of the hydrographs and evaluation of low flows (log R_{eff}), the values of R_{eff} > 0.65 and R_{eff}> 0.59 were considered satisfactory. The calibration results are shown in Figure 4 below and Table 2 together with their corresponding statistical measures for model performance assessment.

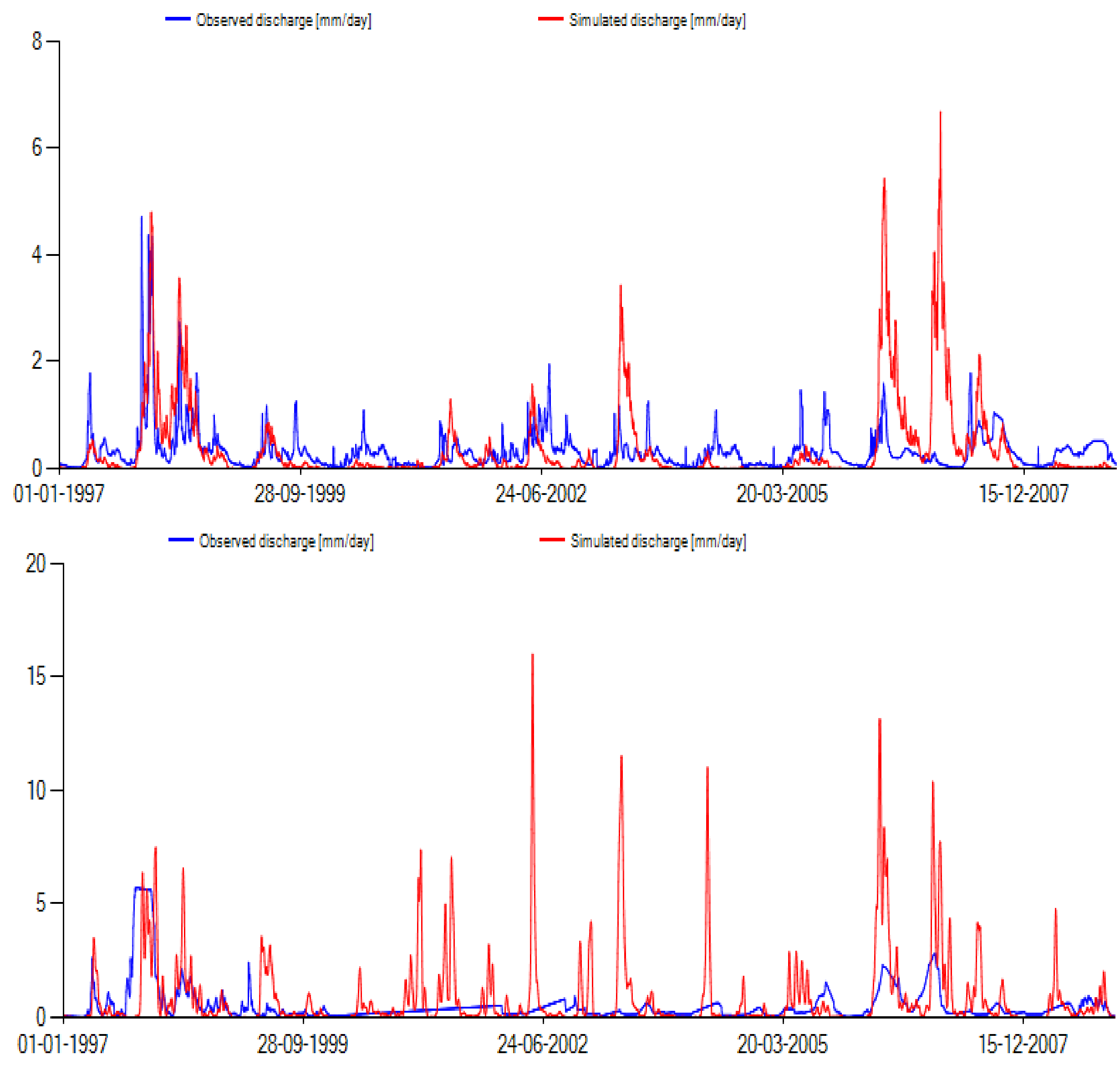


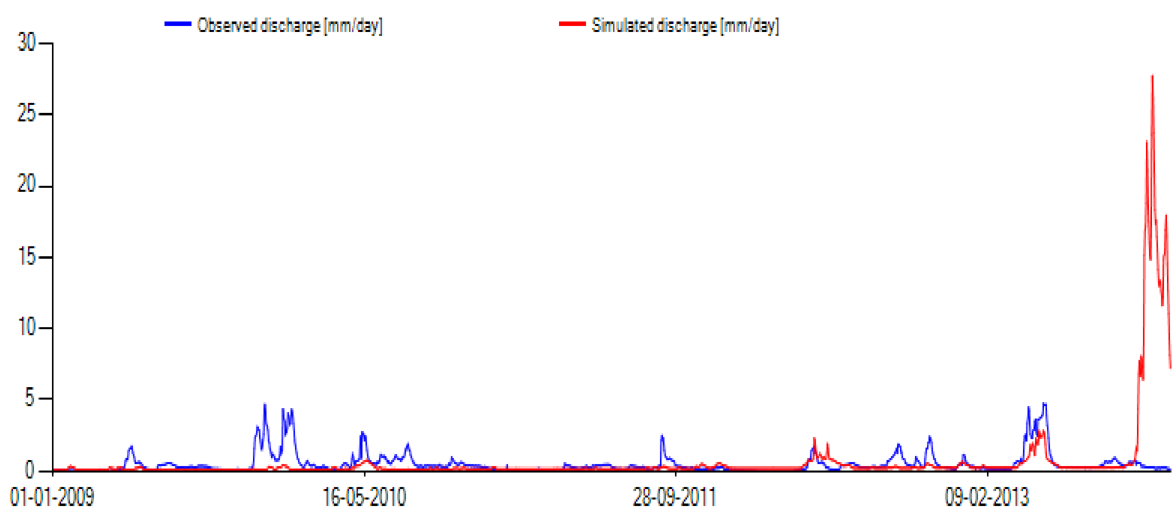
Figure 4:Simulated and Observed discharge in mm/day for Nyangores and Amala Sub-catchments above and below respectively for the calibration using daily time steps between January 1996 to December 2008

From the visual observation of the hydrographs in Figure 4, it indicates generally good flow simulations in particular during the recession flows, in the Nyangores sub-catchment with a bit of high peaks towards the end of the simulation period. In comparison to the Amala sub-catchment, the short-term fluctuations during the high-flow season were not modelled well. In fact, the model overestimated the discharge as clearly shown in the hydrograph. The mean annual (ΔQ) differences between observed and simulated runoff was negligible. The results show a good relationship between the simulated and observed low flows in the Nyangores catchment with a log $R_{eff} > 0.63$ compared the log $R_{eff} > 0.57$ for the Amala sub-catchment.

The coefficient of determination R^2 was >0.73 and >0.65 for the Nyangores and Amala catchments respectively. The parameter values for which the model was highly sensitive (yielding good simulations) only for comparable small intervals, were related to the soil moisture storage and runoff generation routine as shown in the standardized parameter values given in Table 2. The Table shows the smallest and largest parameter values that produced R_{eff}> 0.65 for the Nyangores and >0.59 for Amala respectively. A satisfactory model performance (R_{eff}>0.65) was attained in Nyangores with a soil moisture storage, FC, in the range of 408mm < FC < 514mm near the maximum parameter range whereas in Amala, the FC was lower, ranging between 265mm < FC < 350mm.

The run-off routine parameters P_{ERC} (maximum flow from upper to lower reservoirs) and UZL (threshold for K_0 flow) and the soil routine parameter, β (shape coefficient) were found to be the most sensitive parameters in that order in Nyangores sub-catchment. In Amala, the only sensitive parameters were K_2, P_{ERC} and K_1 respectively in that order. The K_0 values for Nyangores and Amala were found to be 0.11 and 0.05 respectively.

This means a major portion of the rainfall received in Amala leaves the catchment quickly as direct runoff, while the rainfall falling in Nyangores is stored and later on released as base flow. The difference in sensitivity of the parameters reflects on the different hydrological processes between the two sub-catchments suggesting different dominant run-off generation processes.



The validation period for the two sub-catchments was done for the period between 1st January, 2009 to 30th November, 2013 and the results indicated better efficiencies as compared to the calibration as shown by the hydrographs in Figure 5 and Table 2.

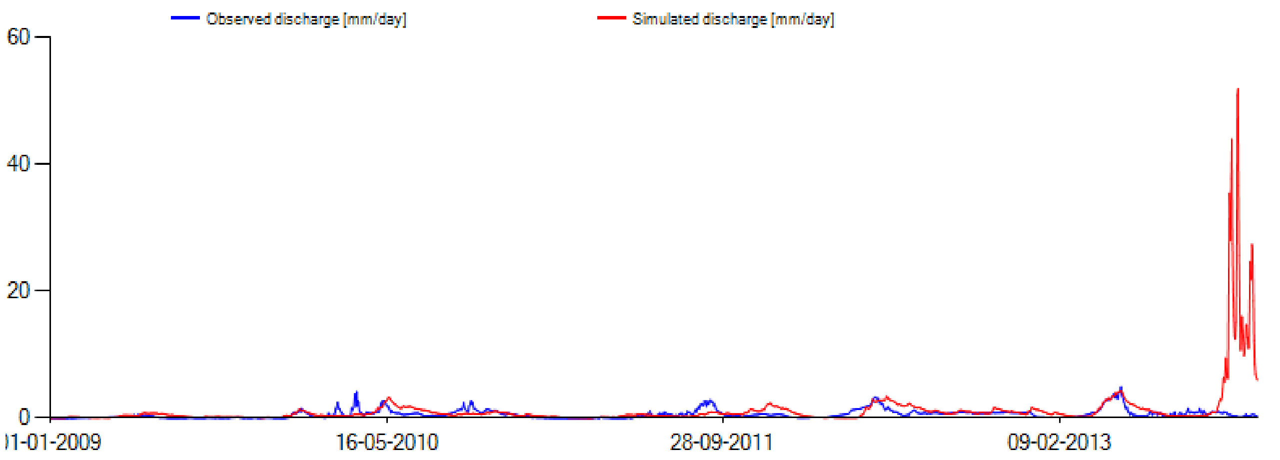


Figure 5: Simulated and Observed discharge in mm/day for Nyangores and Amala Sub-catchments above and below respectively for the validation using daily time steps between January 2009 to November 2013

The R_{eff} values for Nyangores and Amala sub-catchments were $R_{eff}>0.68$ and $R_{eff}>0.62$ respectively. These efficiencies were generally good, even though the model overestimated the observed discharge by about 131 mm/a (70%) in the Amala sub-catchment. Low flow simulations were acceptable with Nyangores and Amala having log $R_{eff}> 0.64$ and log $R_{eff}> 0.59$ respectively. The model showed better performance during the validation period as compared to the calibration period posting higher coefficient of determination $R^2> 0.75$ and $R^2> 0.69$ for Nyangores and Amala respectively. The reason as to why the model simulations during this period were better than the calibration period could be attributed to better data quality (fewer missing data) for the later years.

In addition, results indicate that the HBV Light model has the ability to reproduce good rainfall-run-off relation during mean and low flow periods.

Table 2: Calibration and Validation parameters and model efficiency results for Nyangores and Amala Sub-catchments for the period of 1996-2008 and 2009-2013 respectively

Calibration/Validation Parameters	Parameters	Units	Nyangores Catchment	Amala Catchment
	FC	(mm)	408.61	350.00
	LP	(—)	0.32	0.90
	β	(—)	5.20	12.00
	K_0	(d^{-1})	0.11	0.05
	K_1	(d^{-1})	0.11	0.99
	K_2	(d^{-1})	0.92	0.99
	UZL	(mm)	46.75	56.36
	PERC	(mm/d)	0.10	0.45
	MAXBAS	(d)	1.50	15.00
	R_{eff}	(—)	0.62	0.48
	$logR_{eff}$	(—)	0.60	0.46
Calibration	R^2	(—)	0.73	0.65
	ΔQ	(mm/a)	0.00	0.00
	R_{eff}	(—)	0.65	0.59
	$logR_{eff}$	(—)	0.63	0.57
Validation	R^2	(—)	0.75	0.69
	ΔQ	(mm/a)	-8.00	-131.00

Assessment of model performance

In order to obtain a process-based representation of the hydrological characteristics in the two sub-catchments, manual adjustments of the model parameters were done following Monte Carlo simulations (MCS). An automatic calibration of the model was avoided because of the limitations of data quality and quantity. The MCS was carried out to identify the sensitivity of the catchments' runoff generation characteristics, and to explore ranges of model parameters. Sensitivity analyses of model parameters was conducted through: (i) Assessing model results for different model structures (two catchment representations), and; (ii) Analysing the results of the MCS runs (over a 100,000 model runs for each catchment representations). The ranges for model parameters for the MCS analysis were kept wide as shown in Table 2 above; however, a search for suitable parameter sets with no plausible parameter values was avoided. In this regard, the experiences of related studies with the same model were used to define the ranges for each parameter (e.g. Seibert, 1997; Uhlenbrook *et al.,* 1999).

Daily models were used for all the sensitivity analyses. Assessment of the model performance was done both visually and statistically using the objective functions according to Nash and Sutcliffe (1970) and also Schaefli (2007), for both normal and logarithmic values (R_{eff}, and $logR_{eff}$).

Water Balance Analysés

A summary of the simulated and observed discharges at the outlet of the sub-catchment shows that the water balance closure was achieved at 127 mm and 119mm per year for the $Q_{simulated}$ and $Q_{observed}$ for the Nyangores Sub-catchment respectively. A simple water balance closure using the water balance equation shows 457mm of precipitation could not be accounted for. The $Q_{simulated}$ and $Q_{observed}$ for the Amala Sub-catchment were found to be 318mm and 188mm per year respectively. However the 279 mm of precipitation could not be accounted for but the results can be attributed to the interpolation method used either for the rainfall quantification or abstraction of the rivers' water.

Sensitivity Analysais

The sensitivity analysis was done to calibration parameters of HBV Light model to determine the parameters that influence the model performance more than the others. The sensitivity analyses were carried out for the soil moisture routine, response and routing routines. The results are shown in Figure 6. The analysis was done by reducing and increasing the final calibration values by 10% and the results plotted in a graph.

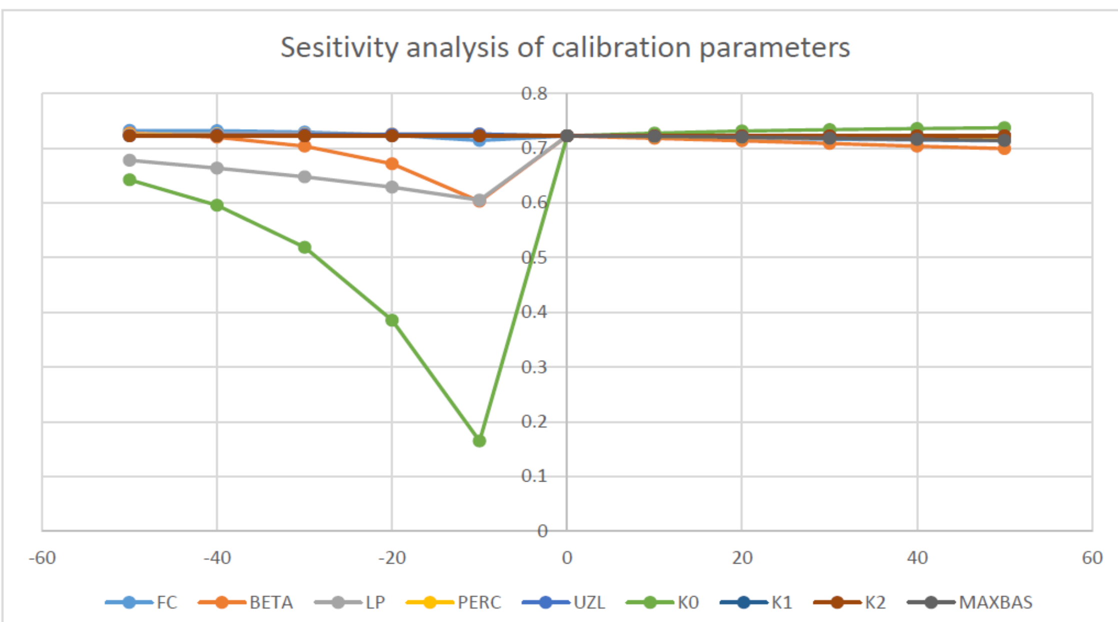


Figure 6: HBV Model Sensitive Parameters Analysis

From the sensitivity analysis, the results show that the coefficient of storage K_0 was the most sensitive of all the calibration parameters. The results show that a slight change of this value gives a great variation in the model performance. The LP, BETA and FC are also sensitive in that order. Other parameters such as UZL, K_1 and K_2 show very low sensitivity to the model performance.

Effect of varying time steps

When the computational time step was increased from daily to 15 days and 30 days' time step by using aggregated 15 and 30 days data sets respectively, the new calibration results gave better model performance for the two sub-catchments as compared to daily simulations. This was expected as large daily fluctuations during the wet season were smoothened out. The results show that the simulated average peak discharge was higher than the observed values, except during the periods 1999/2001and 2004/2005 for Nyangores and 2003/2004 and 2006/2007 for Amala. The model efficiencies for the 15 days were, R_{eff}>0.79 and R_{eff}>0.68 for Nyangores and Amala respectively. Also the mean annual *(*ΔQ) differences were negligible in both sub-catchments. Interestingly, low flows were better simulated by the model in the Amala sub-catchment as compared to Nyangores. The log R_{eff} was >0.71and >0.62 during the calibration and validation period respectively.

Partitioning of the flow hydrograph

The model was able to partition the total hydrograph into three components; the mean annual direct run-off (Q_{DR}), the interflow (Q_{IF}) and the base flow (Q_{BF}) as summarised in Table 3.

Table 3: Statistics of direct runoff Q_{DR}, and base flow Q_{BF} components from 1997 to 2008

		Run-off Component	
Catchment representation		Q_{DR}	Q_{BF}
Nyangores (mm/a)	Mean Q	18	101
	% to total	15%	85%
Amala	Mean Q(mm/a)	151	37
	% to total	80%	20%

Generally, the base flow is noticeably dominant in the Nyangores sub-catchment at 85% as compared to that of Amala sub-catchment of 20%. The direct run-off is however dominant in Amala at 80% as compared to Nyangores at 15%. The large difference in the run-off components between the two sub-catchments, demonstrates a distinct difference in the fast response characteristics between the two. These findings are supported by previous studies done by Dessu and Mango (2011) and also by Melesse (2012). These researchers found out that Nyangores had higher infiltration than Amala In this research, the ground water run-off was assumed to be the base flow. The results clearly demonstrate that the dry season run-off of the Mara River is largely sustained by ground water storage from the two sub-catchments.

Model performance efficiency

The model performance efficiency was carried out using the established statistical criteria such as NSE and R^2 (Abwoga, 2012). In addition to these indices, visual evaluation of the hydrographs was carried out in evaluating the simulation of peaks, low flows, recessions and timings. However for model comparison of these efficiencies it is challenging to do so if the modelling time periods are different. However, for purposes of how efficient the model was in simulating the observed flow, the indices were found to be sufficient in determining the HBV model performance as given in Figure 7.

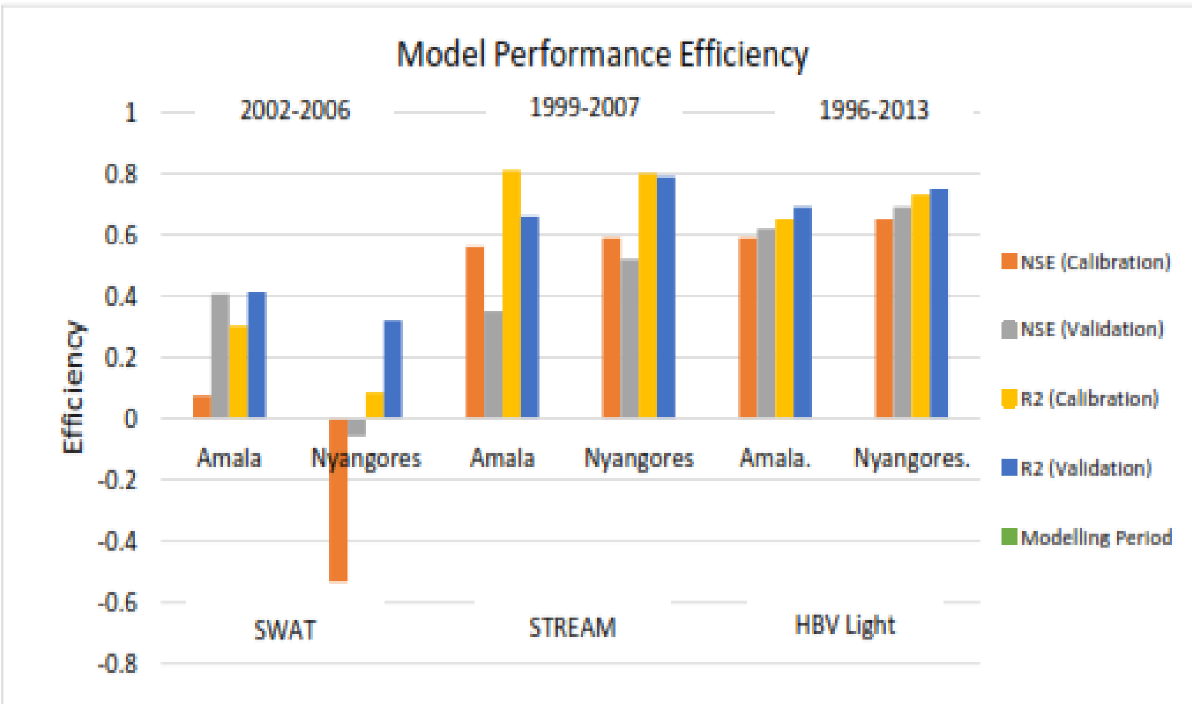


Figure 7: Comparison of Model Efficiencies

Figure 7 shows that the HBV Light model performed better in comparison to either SWAT or STREAM Model in simulating the hydrograph of the Nyangores and Amala Rivers. However, the STREAM model had a higher R^2 efficiency both at the calibration and validation as compared to HBV.

Conclusions

The Mara River Basin is facing unprecedented threat as a result of deforestation, expansion of agriculture, human settlement, sedimentation and erosion, flooding and low flows. Therefore, understanding the relation between the natural processes and anthropogenic activities that occur in the basin requires a reliable representation of the relevant hydrologic activities. The research assessed the ability of the HBV Light Model in simulating the long-term rainfall-runoff of the basin. The overall objective of the study was to apply a conceptual model simulating Mara river run-off as a function of the satellite observed and in-situ rainfall data. Based on the research questions the study was answering in its bid to achieve this objective, the following conclusions can be made:

a) There is a linear relationship between the in-situ rainfall and measured run-off, and the run-off simulation model was developed on the basis of this relationship.

b) The model was found to be sensitive mostly on the response routine parameter, K_0 which was responsible to the direct run-off (coefficient of storage in the upper zone), followed by soil moisture routine parameter BETA (β) and LP. It can be concluded that the K_0 parameter is affected by catchment parameters such land cover/land use (forests), infiltration or ground water storage capacity which in turn affects the evapotranspiration. Nyangores has the highest evapotranspiration and has the lowest K_0 while Amala is assumed to have the least evapotranspiration has the highest $K_{0.}$

c) Although the model tried to simulate the recession flow hydrographs giving the representation of catchment characteristics, it was not able to simulate well the peak flows in the catchment. The model over estimated the flow peaks which could be attributed to use of interpolated rainfall and discharge data where the data were missing.

d) The model's performance in terms of NSE and R^2 were better as compared to previous rainfall- run-off modelling done using SWAT and STREAM model. The values for NSE were 0.65and 0.59 for the calibration period and 0.69 and 0.62 for the validation of Nyangores and Amala respectively.

Acknowledgement

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THEME TWO

RENEWABLE ENERGY

SOLAR PHOTOVOLTAIC WATER PUMPING SYSTEM FOR ARID AREAS AND PASTORAL COMMUNITIES: CASE STUDY OF AYNALEM, SOUTHERN TIGRAY ETHIOPIA

Shewit Tsegaye (M.Sc.), Sebhatleab H (M sc.)

Abstract

This paper deals with the design and simulation of an efficient solar photovoltaic water pumping system for arid areas and pastoral communities. It provides theoretical studies of photovoltaic and modeling techniques using equivalent electric circuits. This allows a lower cost system. Each subsystem is modeled in order to simulate the whole system in MATLAB. Simulations make comparisons with the system without MPPT in terms of total energy produced and total volume of water pumped per day. The results validate that a system without MPPT and battery are cost effective and efficient enough. The low maintenance and simple operation, no fuel (transportation or storage) costs, environmentally benign, as well as competitive life-cycle economics place solar PV water pumping system the forefront of choices in supplying water to livestock or agriculture of pastoral community.

Keywords— Solar energy, Photovoltaic, water pumping system, MATLAB/ Simulink.

INTRODUCTION

Water resources are essential for satisfying human needs, protecting health, and ensuring food production, energy and the restoration of ecosystems, as well as for social and economic development and for sustainable development.

Solar-powered pumping systems have been in use long enough that a preliminary assessment can be conducted related to their efficiency and cost compared to other alternative powered pumping systems. This preliminary assessment should be completed before deciding if solar power is the best source of alternative power for a village water supply system. Generally, alternative power is only considered when the cost of tapping into the closest public power grid far outweighs the costs of using alternative power[1].

Remote water pumping systems are a key component in meeting this need. Before estimating the total electrical demand it is necessary to choose a specific place and proceed design by selecting type and quality of PV modules[2].

In this paper, a simple, direct coupled solar water pumping system with solar PV panel, pump controller and pump is presented. It provides theoretical studies of photovoltaic (PV) and its modeling techniques.

Description of the proposed system

Study area description

AYNALEM is located on north eastern part of the central plateau, west of the Great Rift Valley. It is particularly located 5 km south of Mekelle, northern Ethiopia.   The ground water potential of Aynalem was studied and concluded that it is sufficient and abundant [3].

SSE Homepage | Find A Different Location | Accuracy | Methodology | Parameters (Units & Definition)

ATMOSPHERIC SCIENCE DATA CENTER

NASA Surface meteorology and Solar Energy: RETScreen Data

Latitude 13.496 / Longitude 39.474 were chosen.

	Unit	Climate data location
Latitude	°N	13.496
Longitude	°E	39.474
Elevation	m	1286
Heating design temperature	°C	14.26
Cooling design temperature	°C	31.52
Earth temperature amplitude	°C	14.98
Frost days at site	day	0

Figure 1. SSE data for study area

Resource characterization

Resources is characterized by **solar radiation, air temperature and elevation. And these data can be found from national metrology agency, NASA surface metrology and SWERA.**

Table 1. Solar Radiation Data

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	19.7	57.5%	5.85	87.4	4.5	23.4	3	302
February	21.0	52.6%	6.27	87.3	4.6	25.5	1	310
March	22.8	51.9%	6.50	87.2	4.6	27.3	0	397
April	24.3	50.1%	6.82	87.2	4.2	28.4	0	426
May	26.3	42.3%	6.62	87.2	3.7	30.6	0	498
June	25.6	51.1%	6.05	87.1	5.0	28.6	0	468
July	24.1	58.8%	5.57	87.0	5.2	25.9	0	446
August	23.9	60.1%	5.46	87.1	4.8	25.5	0	442
September	24.8	48.7%	6.05	87.1	4.1	27.5	0	445
October	24.3	38.2%	6.22	87.3	3.1	28.0	0	433
November	21.7	45.8%	6.00	87.4	3.6	25.2	0	350
December	20.1	54.3%	5.66	87.4	4.0	23.5	1	314
Annual	23.2	51.0%	6.09	87.2	4.3	26.6	5	4831
Measured at (m)					10.0	0.0		

LOAD BASED ANALYSIS OF SPV WATER PUMPING SYSTEM

***1. Water-Demand*:** The first step is to determine the total water needed per day. Many producers are used to thinking of pumping lots of water in a short time frame with large capacity pumps. To determine '*Daily Water Requirement'* using the spreadsheet tool, the user enters the quantity and type.

*Gallons of water /day = quantity *required values of water per day per item*

= (10*17.5) + (10*19.0) + (4*20.0) + (40*2.0)

= 525 gallons per day

Barrels of water /day =12.5barrels

But additional gallons per day are needed to consider losses such as extra water cushion, offset evaporation and human caused losses.

Consider 25% of gallons of water calculated above are expected loss per day:

= 525*0.25 = 131.25 gallons per day

=3.125 barrels

Therefore the total water demand is (525+131.25=656.25) gallons per day.in barrels it is 15.625 barrels per day (2500littre per day).

The minimum number of days that should be considered is 5 days of storage for even the Sunniest locations on earth. In these high radiation locations there will be days when the sun is obscured, called days of autonomy[4].

Days of autonomy=-0.48*PSH_{ave}+4.58

Where $PSH_{ave}=\frac{\sum irradiance}{Number\ of\ months}=\frac{5.85+6.27+6.5+6.82+6.62+6.22+6.0+5.66}{8}=6.2425$

To determine storage tank capacity, Days of autonomy and non-shiny days should be considered .Then

Days of autonomy=-0.48*6.2425+4.58=1.58 $\approx$ 2.0

Storage capacity =days of autonomy*total water demand per day

=2*656.25 gallons

=1312.5gallons

≈ 31.25 Barrels

=5000 litter

***2. Pumping Requirements*:** 'Total Dynamic Head (TDH)*'* is the total "equivalent" vertical distance that the pump must move the water; or the pressure the pump must overcome to move the water to a discharge height.

Pump and Flow Rate: The flow rate, or volume of water that is pumped in some time period – gallons/ minute (gpm) is determined via the equation below:

Flow rate (Q) = $\frac{total\ water\ demand\ per\ day}{irradiance*60\frac{min}{hr}}$

Flow rate (Q) = $\frac{656.25\ \text{gallons per day}}{6.82\,{}^{kwh}/_{m\ day}*60\frac{min}{hr}}$ =1.6037 gpm Flow rate (phr.) = 1.6037*60*3.78541=364.24 litter per hr. Flow rate (per day.)= 1.6037*60*3.78541=364.24*12=4370.87litter per day.

Entering these values, static head is calculated as flows.

Static Head (ft.) =total vertical lift= water level+drawdown+elevation

Taking the corresponding values from the worksheet below we have:

Static head = total vertical lift=25ft +4ft=29ft

≈8.86m

To determine friction losses in pipe, the user is asked to enter the type of pipe (PVC, steel, plastic etc.), total length of the pipe being used, and the nominal inside diameter of the pipe. The approximate head loss caused by friction within the pipe is calculated using the Hazen-Williams Empirical formula. The value generated is in units of “feet of head”.Below illustrates the Hazen-Williams formula[5].

$H_{L=} \frac{10.472*}{c^{1.852}} \frac{Q^{1.852}}{D^{4.871}} *L = 35.5878$ ft.

H_L =10.847m

H_L is pressure head

Where L=44 ft.

D=1.25 ft. and Q = 1.60378 gpm

The equivalent friction loss for each fitting is calculated using the equation below shows.

Equivalent Length (ft.) =pipe diameter*quantity* $\frac{L}{d}$

=1.5 in *1*340 =42.6 ft.

Equivalent Length (m) =12.98m.

TDH can now be calculated by using equation:

Total Dynamic Head (Ft) =Total Vertical Lift (Static Head) +H_L+ Friction loss due to fittings = 29ft. +35.5878ft. +42.6ft. =107.187ft.

Total Dynamic Head (m) = 107.1878ft. =32.67m

3. Pump Selection and array sizing

If the Hydraulic Workload is acceptable for a solar solution, go to the Pump Selection sheet to determine an acceptable pump, the voltage at which you will run the pump, and the solar panel wattage needed to power the pump. This is all determined by the two important parameters: the previously calculated flow rate (Q) and TDH.

The hydraulic energy required (kWh/day) = volume required (m^3/day) * head (m) * water density x*gravity / (3.6 x 106) = 0.002725 x volume (m^3/day) *head (m) =0.002725*4.3708*8.86 =0.10556kwh/day

≈106watthour/day

The solar array power required (KWp) = $\frac{\text{Hydraulic energy required (kWh/day)}}{\text{Av.daily solar irradiation (kWh/m}^2\text{/day x F x E)}}$

= $\frac{0.10556\ kwh/day}{6.82*0.8*0.20}$ =0.09673 KW_P=96.7 W_P

Where F = array mismatch factor = 0.85 on average and E = daily subsystem efficiency = 0.20 - 0.40 typically.

Estimating PV panel systems

A procedure for estimating the electricity produced by a PV panel (collector) system in kWh/year is using the formula:

= 0.8 x kWp x S x ZPV

Where: kWp is the peak power of a PV unit

S is the annual solar radiation in kWh/m2

ZPV is the Over shading Factor which is 0.340

Therefore,

PV wattage=0.8*0.34*96.7wp*6.82kwh/m^2

=179.382wh/year ≈180 Whr/year

By choosing smaller values, you minimize the number of PV panels required.

Modules in series (rounded to higher integer) $= \frac{pumps\ \ Motor\ voltage}{17.4v}$

$= \frac{15v}{17.4v} = 0.862 \approx 1$

Number of PV in parallel (integer) $= \frac{pumps\ peak\ panel\ wattage}{Modules\ in\ series*17.4V*3.11A*.80}$

$= \frac{96w}{0.862x17.4vx3.11Ax0.8} = 2.5725 \approx 3$

Results

a. Solar Cell simulation results

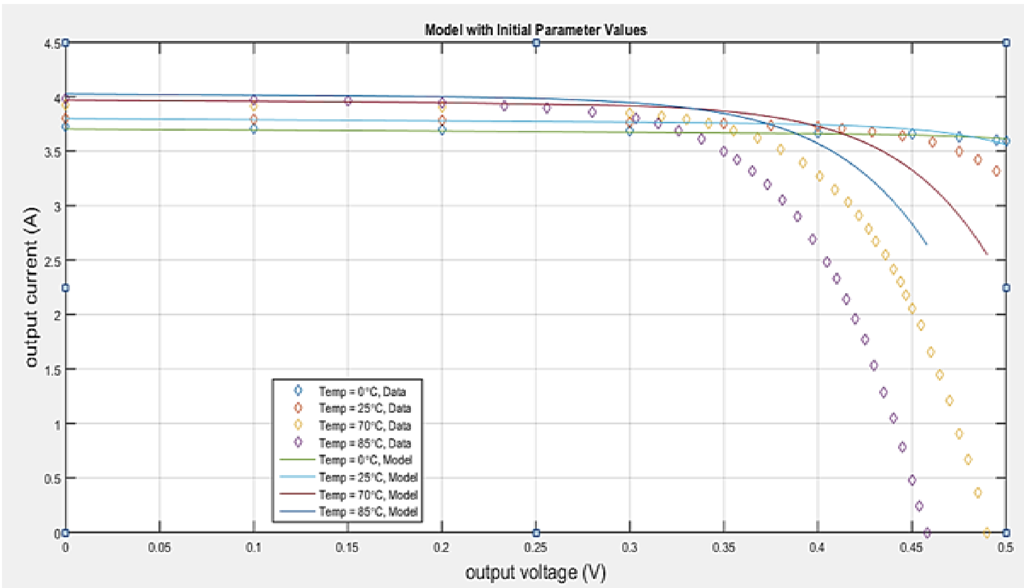

Figure 2. Solar cell model with initial values

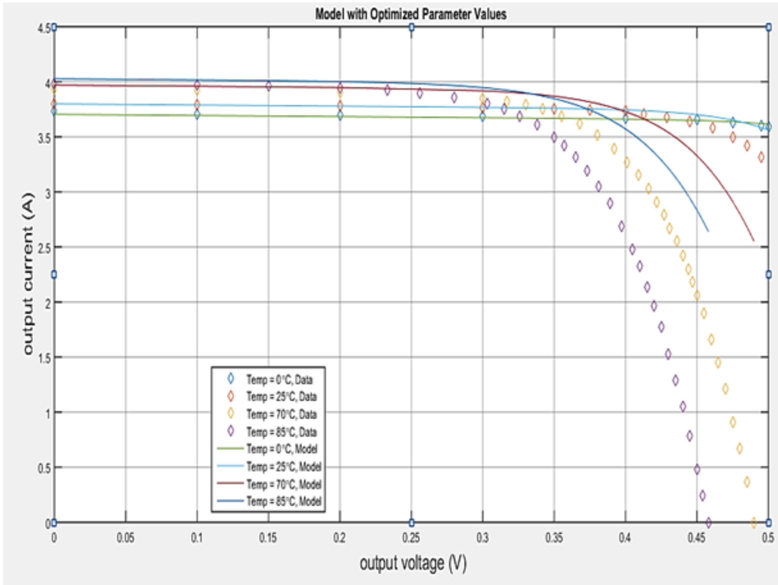

Figure 3. Solar cell model with optimized values

2. Pumping simulation Results

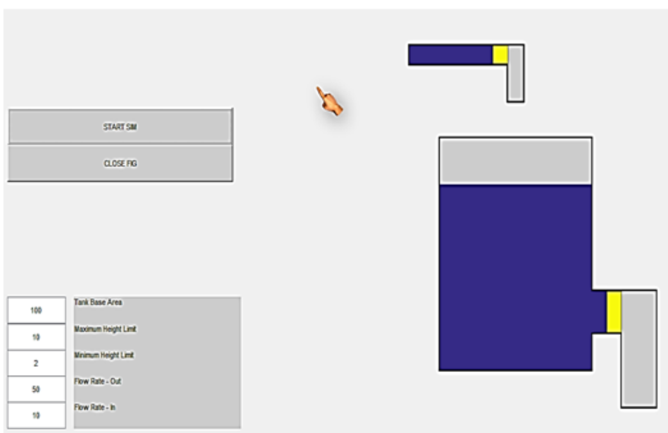

Figure 4. Simulink model for Pumping System

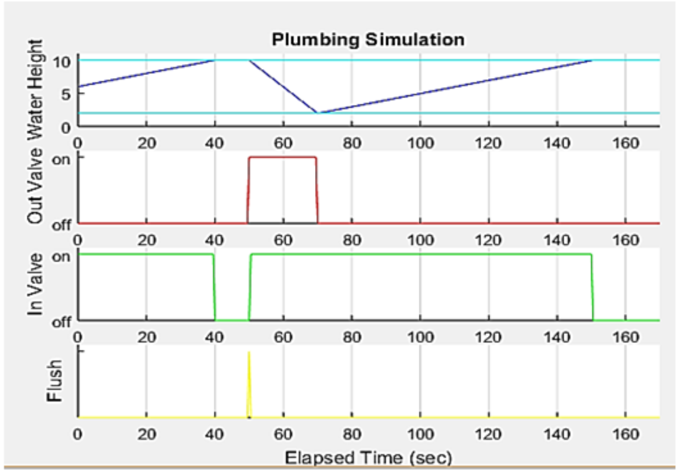

Figure 5. Pumping simulation results

Discussions

As it can be seen from the simulation results the water pumping system is carried out under the following considerations.
1. Selected water pumping system is direct coupled water pumping system.
2. Centrifugal pumps which are overall considered to be efficient and capable of pumping a high volume of water are selected.
3. Instead of storing energy in batteries, water is pumped in reservoirs for use when the sun is not shining.
4. The system doesn't include Maximum Power Point Tracker (MPPT), because the areas selected are Sub-Saharan arid areas with high solar radiation.
5. For financial and technical evaluation latest and updated computer architecture is utilized.

CONCULUSIONS

Photovoltaic powered water pumping systems are attractive for livestock and agriculture producers with remote water sources and limited access to AC power. Even though windmills have been in use for decades and will continue to provide effective solutions for water pumping, solar power has made significant steps towards becoming the system of choice for these situations.

The low maintenance and simple operation, no fuel (transportation or storage) costs, environmentally benign, as well as competitive life-cycle economics of solar systems place them at the forefront of choices in supplying water to livestock or agriculture.

As long as water pimping system is needed, direct coupled water pumping system without battery and MPPT are cost effective. This type of WP systems do have simple principle of operation and low maintenance cost.

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Rural Energy Technology Adoption: Costs and Benefits of Biogas Plants Development at household level in three selected areas of Tigray

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Abstract

The principal task in biogas plant development at household level is assessing costs and benefits. Biogas plant development has micro and macro benefits but should with sound investigation. Hence, this study is to assess costs and benefits of biogas plant development at household level. The study used both primary data type from respondents and secondary data type from literatures and previous studies. The area of the project was in three districts of Tigray in which the project is widely adopted by their household. The sources of primary data of this study are purposively selected 150 households via purposive sampling method. The response rate is 93%.To obtain the data questionnaire was designed and distributed to the selected households. The collected data were processed by editing, coding and summarizing in table, bar graph and pie charts and finally were analyzed using frequency, percent and cross tab with phi and Cramer's value descriptive statistics and spear man rho's correlation using excel and SPSS soft wares. Female household heads are using Biogas Plants as source of energy for cooking and other related household activities. Most of them live in rural areas with no access to electricity and other modern alternative sources of energy. The size of digester of the biogas plants ranges from 6 meter cubic to 8 meter cubic and 6 meter cubic being common at household level. The total costs that are required for construction of biogas plants ranges from 12,300 ETB to 14,000 ETB out of this total cost only minimum 2,300 ETB and maximum 3,500 ETB is covered by the users while the remaining is covered by Government Organizations and NGOs including loan from Microfinance institutions. Biogas as source of energy is used for lighting lump; baking Injera; Boiling water; cooking; and coffee making activities at household level. Location; owing cattle; feeding way of one's own cattle; source of income; and who cover costs of biogas construction and then installation are main decision elements for biogas plant projects whether to invest or not. And Sustainable waste management; saving cooking and cleaning time; fertilizer production; kerosene savings; and labor savings are benefits of biogas plants which differ as per the size of digester of the biogas plants. That is, their benefiting capacity increases as the size of digester of the biogas plants increase. The Biogas users have been obtaining benefits from the biogas and its slurry (as fertilizer) and they have been also facing problems of the biogas and its slurry. Problems of Biogas plants increases as it goes from urban to rural whereas Problems of the slurry increases as it goes from female to male. All concerned bodies need to give attention to female household heads in rural areas with regard to Biogas plants Development at household level because Biogas as source of energy has a strong linkage with such part of the community. It will be nice if Government organizations and NGOs adjust their incentives (Government) and interest rate of their loan (NGOs including the Microfinance institutions) to cover portion of Biogas initial cost (investment) as per the capacity and demand of the users. All stakeholders of Biogas Plants Development at household level need to focus on the decision element whether to invest or not on Biogas plant projects. Moreover, the stakeholders need to recognize the Benefits of Biogas that differ as per the size of digester of the biogas plants so that to act accordingly. All concerned bodies need to identify that problems of Biogas and its slurry have different severity for different locations (rural or urban) and different gender (male or female). Thus, it needs special treatment accordingly.

Key words: Benefits, Costs, Biogas Plants, Slurry, Household heads, Purposes of biogas, Decision elements for using biogas, Government organizations, NGOs, Problems of biogas, problems of slurry, Discontinuing Reasons of biogas, Deforestation

Introduction

Background of the study

Ethiopia with landmass of 1.1million square kilometers is third giant and second populous nation in the Sub-Saharan Africa with estimated population of about 85.5million. United Nation Development program [UNDP, 2010] ranked Ethiopia 157th in the human development index, with per capita average annual income of 120$ and about 40% of the population below poverty line. The energy poverty of the country is manifested in its indigenous biogas resource resilience. National energy balance of Ethiopia has been so far predominated by two sort energy resources (Hydro and biogas). The latter sourcing over 80% of its energy needs. As a result, the country has been suffering from massive depletion of indigenous biogas resources. Moreover, domestic petroleum consumption is completely imported resilient posing its evolving economy to recent fossil fuel prices soaring.

At global scale more than 3billion (nearly half of world human) deprived of access to modern energy alternatives. All of these people live in poor countries and depend on traditional biogas resources to meet their basic energy need. This has caused worsening health and environmental consequences. Central premise of world energy strategy, thus, has aimed at shifting from use of high-cost and environmental damaging fossil fuels to cost-effective renewable energies that can be sourced from renewable resources (biogas, wind, hydro and solar). Major challenge in Ethiopia's energy sector is aligning national energy supply with socio-cultural and economic developmental needs. However, energy crisis in the country is reflected in its overreliance on indigenously sourced biogas fuel.

This research project entitled " Rural Energy Technology Adoption : Costs and Benefits of Biogas Development at Household level" intends to analyze the reason behind why some of the adopted bio gas plants are not functioning because this source of energy is one component of natural resource management for sustainable development. The adoption, penetration and well functioning of the adopted biogas plants are important points of Natural Resource Management to contribute for sustainable development.

Problem Statement of the study

Most countries became aware of biogas technology by the middle of the twentieth century. However, real interest in biogas was aroused from 1973 onwards, with the onset of the energy crisis, which drew general attention to the depletion of fossil fuel, energy resources and the need to develop renewable sources of energy, such as biogas. The importance of biogas as an efficient, non-polluting energy source is now well recognized (Demuynck, M 1984).

International organizations like the Economic and Social Commission for Asia and the Pacific (ESCAP), the Food Program (UNEP) have done considerable work in disseminating and developing biogas and Agriculture Organization of the United Nations (FAO), the United Nations Industrial Development Organization (UNIDO), the World Health Organization (WHO) and the United Nations Environment technology. The gas is commonly used for cooking and lighting. There are a number of enterprises in each nation that produce stoves and lamps. Inorder to arrest the health disturbance, environmental and agricultural deterioration in developing countries caused by the traditional sources of energy, it is imperative to introduce other sources of renewable energy, such as solar energy, wind and biogas. This is for the reason that renewable energies don't face the safety (environmental and health problems) and food security problems (poverty).

Biogas was first introduced to Ethiopia in the 1970s (Gebreziabher,2007). Most of the biogas plants were installed at demonstration centers (Kebede, 1995; Gebreziabher,2007).Various institutions/agencies were involved in biogas dissemination of which the Ministry of Agriculture (MoA) through its Rural Technology Promotion Centers (RTPC) over the country was one. The different types (brands) of biogas technologies introduced in the country included the Indian, Chinese and other less known models (Gebreziabher,2007). Amongst which, for the same amount of biogas generated per day, the fixed dome Chinese model was regarded to be less costly than the floating dome Indian model (EESRC,1995; AFREPREN, 2001; Gebreziabher,2007). The high initial investment cost was seen as serious impediment to the dissemination or adoption of bioga s technology during that time. In Tigrai too the history of biogas introduction goes to 1970s. During this time four family sized biogas plants were introduced for demonstration purposes. Later on ten others were disseminated of which three of them were successful (Gebreziabher, 2007).

Although the growth rate in the use of sustainable energy technologies is increasing, the forecasted penetration rate is still relatively small in the global view by 2025 (Moore and Wustenhagen, 2003; Tesfahuney, 2009).Thus, Assessment of costs and benefit of biogas at household level contributes understanding about why the successful number of biogas plants is less and why the forecasted penetration rate is small. Such researches that have been conducted in Tigray region are few.

Hence, in this research, assessment of costs and benefits of biogas adoption has been conducted because it is already adopted and implemented in Tigray but the successful number of biogas plants is relatively very low. As the adopters' view, the biogas adoption has both advantages and disadvantages. The advantage is that they able to make use of biogas as source of energy for different purposes. The purposes include baking 'ingera' and bread, cooking 'wot', lighting etc. On the other hand, it has the following problems of large initial investment, damage costs, how to operate costs etc. The problems are caused from lack of knowhow and follow up about how to use it and how to repair when it is damaged; lack of manure and water during drought seasons.The researchers found assessment of costs and benefits of biogas contributes knowledge being as an important indicator of why biogas adoption and penetration rate are not as expected to be that leads to the unconsolidated supply- demand force of source of energy such as biogas.

Research Objective

General Objective: To assess Costs and Benefits of Biogas Plants Development at household Level

Specific Objectives:

1. To identify costs of biogas plants installation at household level
2. To recognize purposes of Biogas Plants installation at household level
3. To explore decision elements for having biogas plants
4. To assess Benefits of biogas plant installation at household level
5. To pin point problems faced by the households due to biogas plants installation

Significance of the study

The study contributes knowledge and understandings on costs and benefits of biogas plants at household level. It is an input for further study especially with regard to notifying economic feasibility of the project and expansion of Biogas plants development at household level. That is, it forwarded recommendation to Government organizations, NGOs including Microfinance Institutions and other financial institutions; and other concerned bodies and stake holders of Biogas Plants Development at household level.

Description of study areas

Ethiopia is typically an agrarian country; with agriculture continuing to be the largest sector in its economy Environmental degradation resulting from unsustainable use of forests and failure to replenish (recycle) the soil nutrients removed in the production cycle are widespread in Africa (Sanches et al., 1997; Gebreziabher, 2007). Likewise in Ethiopia land degradation is the major cause of agricultural stagnation and rural poverty (Hagos et al., 1999; Hengsdijk et al., 2005; Gebreziabher, 2007).

Land degradation has different facets. One of these - nutrient loss (depletion) through the removal or burning of dung, which was a source of soil humus and fertility, for fuel purposes brought about a progressive decline in land quality and agricultural productivity.

Tigrai is the most northern region of Ethiopia. The region's environmental resources particularly forests have been exploited at a more intensive scale for human use. As a result fuelwood has increasingly been substituted by dung and crop residues. Household fuel consumption in Tigrai over the past several decades indicates a rapid growth in the share of animal dung. For instance, the share of dung increased from about 10 percent of total household fuel in the 1980s to about 50 percent by 1999(Gebreziabher, 2007).Energy consumption for domestic uses in Tigrai could be divided into two as modern fuels and traditional biofuels. However, the traditional biofuels dominate despite their presence and that modern fuels such as petroleum and electricity are also used(Gebreziabher, 2007).

Review of literature

Biogas

Sustainable energy technologies are part of sustainable technologies. Examples of sources of sustainable energy technologies include solar power, wind, biogas etc.Such technologies offer the means of radically improving resource productivity and reducing the environmental harm of economic activity, but the development and use of sustainable technologies will depend on the attitudes, incentives and capabilities of people and organizations. It is well known that many socially and environmentally beneficial technologies are not widely taken up by consumers. HTTP://WWW.sustainable technologies.ac.uk/overview.htm

Generally, technological options for the use of biogas as energy source in rural areas are two: one at household or family level and another at village or community level (Parikh, 1983; Gebreziabher, 2007). Meaning, there are village size or community biogas plants and family size or household plants. Nevertheless, it should also be noted that there are large-scale and intermediate scale digesters used for agro-industrial applications such as in food factories, wineries, etc and for urban applications such as electric power generation (Daxiong et al., 1990; Heavner and Churchill, 2002; Gebreziabher, 2007).

Some of the biogas plants introduced to Ethiopia were used both for lighting and other cooking with small stoves fitted to them. Injera baking is an essential end use in the context of Ethiopia as far as household fuel consumption is considered and accounts for over half of the household’s fuel consumption, both in urban and rural areas (Tesfahuney, 2009). However, little attention was given to include injera baking in the biogas plants so far demonstrated (Gebreziabher, 2007).In fact, research work in this respect has shown that there exists the potential for use of biogas for injera baking, which in turn reinforces the possibility for integrating the various fuel end uses of household lighting, other cooking and injera baking into one biogas plant.

The byproduct of the biogas plant which is effluent usually dried in the sun, either separately or in combination with agricultural wastes. Cost of installation of the biogas plant varies according to type and size of the plant. A comparison of cost may be made on the basis of cost per m^3 of digester volume. Annual costs through depreciation, interest on loans, maintenance, repairs, overheads and labor costs.

On the other hand, annual savings through replacement of kerosene by biogas, and fertilizer by composted effluent, yield a marginal annual gain in the first 5 years. Thereafter income and profit are dubious: first, calculations are made on the assumption that kerosene is used as fuel, when wood is more common, and secondly, there is a tendency to buy digesters larger than necessary. Furthermore, figures on income and profit are based on the subsidy given to the farmers.

Assessing Costs and Benefit of Biogas

Production and utilization of biogas are beneficial in many ways. They have both direct and indirect economic benefits and social benefits. The direct economic benefit of biogas as a fuel, in place of firewood and coal, is a reduction in fuel expenses. Compared with kerosene lamps, biogas lamps not only reduce the cost of fuel, but also increase light level and improve living quality. Compared with direct burning of stalks, biogas produced from biogas fermentation increases the quantity of organic manure which can be sold to production teams, increasing the direct benefit to farmers (Deboosere, S et al 1986). Farmers can use the time saved from firewood collection for additional production, and thereby increase their income; fermentation effluent can be used as protein fodder for poultry.

Most biogas pits used for families in rural areas are 6 - 8 m^3, mainly ambient temperature fermentation models. In addition, they have a short service time: for those that have good maintenance conditions, the service time is above 10 years, but usually they can only be used for about five years. For those are handled improperly, the service time is even shorter

The Benefits for Biogas Users

Individual households judge the profitability of biogas plants primarily from the monetary surplus gained from utilizing biogas and bio-fertilizer in relation to the cost of the plants. The following effects, to be documented and provided with a monetary value, should be listed as benefits:

- Expenditure saved by the substitution of other energy sources with biogas.
- Expenditure saved by the substitution of mineral fertilizers with bio-fertilizer. Increased yield by using bio-fertilizer.
- Time saved for collecting and preparing previously used fuel materials .

The economic evaluation of the individual benefits of biogas plants is relatively simple if the users cover their energy and fertilizer demands commercially. In general, the monetary benefits from biogas plants for enterprises and institutions as well as from plants for well-to-do households should be quite reliably calculable. These groups normally purchase commercial fuels e.g. petroleum, gas and coal as well as mineral fertilizers. However, small farmers in the study area collect and use mostly traditional fuels and fertilizers like wood, harvest residues and cow dung. No direct monetary savings can be attributed to the use of biogas and bio-fertilizer. For that end, the monetary value of biogas has to be calculated through the time saved for collecting fuel, the monetary value for bio-fertilizer through the expected increase in crop yields.

However, in practice, a farmer would not value time for fuel collection very highly as it is often done by children or by somebody with low or no opportunity costs for his/her labor.

Energy

The main problem in the economic evaluation of the plant is to allocate a suitable monetary value to the non-commercial fuels which have so far no market prices. For the majority of rural household's biogas is primarily a means of supplying energy for daily cooking and for lighting. They use mainly firewood, dried cow dung and harvest residues as fuel. But even if the particular household does not purchase the required traditional fuel, its value can be calculated with the help of fuel prices on the local market. Which sources of energy have been used so far and to what extent they can be replaced must be determined for the economic evaluation of biogas by means of calorific value relations, Demirbas, B. Mustafa and H. Balat, 2009)

In the theoretical and empirical literature there are contrasting views on biogas resource use for basic human energy needs. The early proponents poised pessimistic view towards biogas fuel consumption. This band of theorists viewed that reliance on biogas resources for basic energy need deprives health and other wellbeing of users and also degrade the environment. Optimistic insisted that sustainable harnessing of biogas with the aid of modern technologies; offer renewable energy. Existing knowledge on biogas energy utilization was reviewed below.

Biogas resources comprise of residues from agriculture, harvests from forest (in the form of firewood, charcoal, residues), crop residue, energy crops, animal manure, residues from agro-industrial and food processes, municipal solid wastes, and other biological resources , A. Caputo, M. Palumbo, P. Pelagagge, F. Scacchia, 2005). These resources could be directly utilized for basic energy needs (e.g. firewood, charcoal, dung cake etc.) or transformed into invaluable renewable energies (e.g. biogas, bio fuel, bioelectricity, hydrogen energy etc.) for household as well as industrial and transportation sectors.

Biogas was the oldest form of fuel used in history of humankind and is also the fuel which was the mainstay of the global fuel economy till the middle of the 18th century M. Balat and G. Ayar, 2003). It accounts for 35% of primary energy consumption in developing countries, constituting about 14% of the world's total primary energy consumption and is only organic petroleum substitute that is renewable, M. Demirbas, B. Mustafa and H. Balat, 2009). It is used to meet a variety of energy needs, including generating electricity, heating homes, fueling vehicles and providing process heat for industrial facilities [23]. It is the first-ever fuel used by humankind and is also a fuel which was the mainstay of the global fuel economy till the middle of the 18th century T. Abbasi, 2010)

Biogas-based energies are basically derived from three sources: agricultural residues, forestry residues and energy crop. High fossil fuel prices and national security concerns have sparked interest on bio-based fuel development in continental Africa.

Hence, studies identify that biogas based energy can help reduce emission [16; 18]. However, biogas energy production may cause worsening food security due to competition for scarce resources. Energy security concern, however, sparked interest on renewable energy technologies. Resurgence of interest on production of renewable energy from biogas resources is thus geared varieties of social, economic, political, environmental and technical factors. Biogas is the general term which includes phyto-mass or plant biogas and zoomass or animal biogas/ cattle excreta T. Abbasi, 2010).

Studies indicate that biogas resources offer renewable energies that can play a pivotal role in the current global strategies for reducing greenhouse gas emissions by partially replacing fossil fuels E. Iakovou, A. Karagiannidis, D. Vlachos,2010) For instance, in Thailand with modernization, instead of reducing biogas energy consumption; there has been continuously increased tendency of its utilization for both households and production of modern energy .

Studies identified six categories of biogas resource for energy production: energy crops on surplus cropland, energy crops on degraded land, agricultural residues, forest residues, animal manure and organic wastes M. Hoogwijk, et al., 2003). Growing biogas energy yielding plants has been viewed to offer multiple benefits for energy security and livelihood of rural households. A recent study identified biogas energy as a major contributor to not only energy consumption in Sub-Saharan Africa but also to employment and poverty alleviation K. Openshaw 2010).

The author concluded that promoting the production and use of all types of biogas energy should be a priority, rather than discouraging as the so called "traditional fuel". A case study was conducted on agro-village of Shandong in China indicated that biogas from agricultural residues offer livelihood energy and increases the villagers' incomes as well as reduce green gas emission M. Demirbas, B. Mustafa and H. Balat 2009).

In case of India, decentralized power generation using biogas gasification was investigated and found that biogas based energy has several distinct advantages such as wide availability and uniform distribution that puts it ahead among the renewable energy. From industrialized countries viewpoint, an empirical study using French data analyzed household energy choice and fuel wood consumption, and concluded that in this era of soaring price of oil and growing need to combat global warming, wood appears to become increasingly competitive and desirable for the environment. The authors identify wood as a perfect substitute for polluting fossil fuels provided local production potential and sustainable availability for European Union. Hence, biogas is considered as the renewable energy source with the highest potential to contribute to the energy needs of modern society for both the industrialized and developing countries worldwide, M. Demirbas, B. Mustafa and H. Balat ,2009).
Furthermore, utilization of forest biogas has emerged as a key strategy for addressing a variety of environmental and energy related needs in the United States [5].

Despite remarkable contribution of biogas to world energy balance its use is in a primitive and inefficient manner in developing countries lead to a host of adverse effect on human health, environment, and social wellbeing. Biogas based electricity schemes already provide over 9 GigaWatt of worldwide generation capacity M. Demirbas, B. Mustafa and H. Balat).

Organic matter, particularly cellulosic or lingo-cellulosic matter is available on a renewable or recurring basis, including dedicated energy crops and trees, wood and wood residues, plants and associated residues, agricultural food and feed crop residues, plant fiber, aquatic plants, animal wastes, specific industrial waste, the paper component of municipal solid waste, other waste materials, all of them being well-known as biogas. In the same context, the term biobased product is used to designate any commercial or industrial product (either from food or feed) that utilizes biological products or renewable domestic agricultural (plant, animal, or marine) or forestry materials (ABB, 2003; Industry Report, 2008;OCAPP, 2007). Both in the application in chemistry and in transport and the generation of energy, biogas offers great opportunities for the conservation of energy management (IPM, 2007). At some stage in human history, biogas in all its forms has been the most important source ofvarious basic needs: food, feed, fuel, feedstock, fibers, fertilizers (Rosillo-Calle, 2007). Nowadays, biogas continues to be a subject of growing significance worldwide, in particular due to its suitability as source of bioenergy, as a result of global increase in the demand for energy, the constant rise in the price of fossil fuels and the need to reduce greenhouse gas emissions (Perlack et al., 2005; Thornley and Cooper, 2008; Thornley et al., 2008; Yuan et al., 2008).

Throughout the past decades, bioenergy and other renewable energies have been the subject of several international declarations and commitments on sustainable development (FAO, 2005; United Nations Conference on New and Renewable Sources of Energy (NRSE)**,** in 1981 - United Nations Conference on Environment and Development: in Agenda 21, emphasis was given to the role of bioenergy

- UN Millennium Declaration World Summit on Sustainable Development (WSSD), where energy was high on the agenda
- International Conference for Renewable Energies held in Bonn in June 2004
- Other important initiatives promoting bioenergy include the Global Environmental Facility

(GEF), the G-8 Task Force on Renewable Energy; the UNDP Initiative on Energy for Sustainable Development

Since the Kyoto Conference (1997), there has been an increasing interest about renewable energy sources and possible alternatives to fossil fuels that could contribute to a significantly reduction in greenhouse gas emission and enhance the overall sustainability of modern society (http://www.avanzi.unipi.it/ricerca/quadro_gen_ric/bi
omass_bioenergy/Biogas&bioenergy_ENG.htm). Energy crops may contribute to the goals of the Kyoto Protocol by increasing sequestration, thus playing a strategic role for development of sustainable energy production systems

From an ethical point of view, only biomass that is not competing with the food chain should be used for the production of fuels, chemicals, power or heat. Industrialized countries have over 1,500 million hectares of crop, forest and woodland, of which some 460 million hectares are crop land.

Achieving the 15 % target could require an average of 1.25 million hectares of crop land per year to be converted to energy plantations. This represents just over 2 % of the total land area in industrialized countries (Bauen et al., 2004).

In USA, the forestry category at 49% is by far the largest contributor to the state biomass, followed by municipal waste with 24%, field with 14%, and animal waste at 11% as the next most important, respectively .

Under this concern, biomass is a sustainable, potentially environmentally sound and a replenish able resource, since it can be replaced fairly quickly without permanently depleting the Earth's natural resources. By comparison, fossil fuels such as natural gas and coal require millions of years of natural processes to be produced. Alternatively, biomass can easily be grown or collected, utilized and replaced. However, extracting energy from biomass is an ancient practice, dating back to when people first burnt wood to provide heat and light. Growing biomass is a rural, labor-intensive activity, and can, therefore, create jobs in rural areas and help stem rural-to-urban migration (IBEP, 2006).

Costs and benefits of the project should perused before the plant is built or the program is implemented, however, due to downsize of its utilization by rural society from time to time in rural Tigray, it might be very important to assess the economic and financial implication of the project at household level and make necessary adjustment .For that matter, the economic viability of the programs and -units the objectives of each households decision-maker are of importance assessment in the survey areas. After selecting objectives and counterchecking if biogas technology can fulfill the objectives at an acceptable cost-benefit ratio, it is still not certain, that expenses are invested in the best possible way. For this, a comparison with other alternatives to biogas programs and biogas plants is necessary. The expected cost and benefits will be shown in the form of suitable investment criteria to allow statements regarding the economic advantage of the project.

The monetary benefits of biogas depend mainly on how far commercial fuels can be replaced and their respective price on the market 1 m^3 Biogas (approx. 6 kWh/m3) is equivalent to the following according to **Bateman et al ,1996.**

Table1. Monetary benefits of Biogas

Type of fuel	Approx KWh/kg	Weight(Kg)
Diesel, Kerson	12	0.5
Wood	4.5	1.3
Cow dung	5	1.2
Plant residues	4.5	1.3
Hard coal	8.5	0.7
City gas	5.3 m3	1.1m3
Propane	25 m3	0.24m3

Time consumption

A critical shortage of energy, primarily of firewood, is reflected less in the market prices than in the time the households - especially women and children - need to collect fuel wood. The time commonly spent for collection varies from several hours per week to several hours per day. Compared to this, the time needed to operate a biogas plant is normally low so that in most cases a considerable net saving can be realized. A financial evaluation of this time-saving is not easy. If the additional time can be used for productive purposes, the wages or the value of the contribution to production can be calculated. The utilization of biogas aervice saves time but also makes cooking more comfortable in comparison to the traditional methods; smoke and soot no longer pollute the kitchen.

Cost of Biogas plant User

Costs of biogas include the following main ones:

Capital costs

Capital costs consist of redemption and interest for the capital taken up to finance the construction costs. For dynamic cost comparison the capital fixed in the plant is converted into equal annual amounts.

Interest rate

Apart from the depreciation rates or length of amortization, it is dependent on the interest rate at which the capital is provided. In each case current interest rates are to be laid down for the cost calculation, which reflect the opportunity costs of the invested capital. To avoid distortions of the financing costs the comparisons should always be calculated with the same interest rate in real terms

Lifetime of plants

In calculating the depreciation, the economic life-span of plants can be taken as 15 years, provided maintenance and repair are carried out regularly. Certain parts of the plant have to be replaced after 8 - l0 years, As a rule, real prices and interest rates should be used in the calculations. For cost calculation inflation rates are irrelevant as long as construction costs refer to one point of time. However, in calculating the cash reserves put aside for servicing and repair the inflation rate must be considered.

Right after description of the benefit and cost variable, what will fellow is measuring the worth of the bio gas development plant at micro level and put some decision criteria whether the programe is feasible or not. According to **Sasse(1990),** we will have three different approaches used to measure the profitability of the plant and the dynamic approach deals with a consideration of benefits and costs over several years and therefore shall be pointed.

Theoretical frame work

Traditionally, conventional biomass is considered to come from three distinct sources: wood, waste, and alcohol fuels as summarized below,

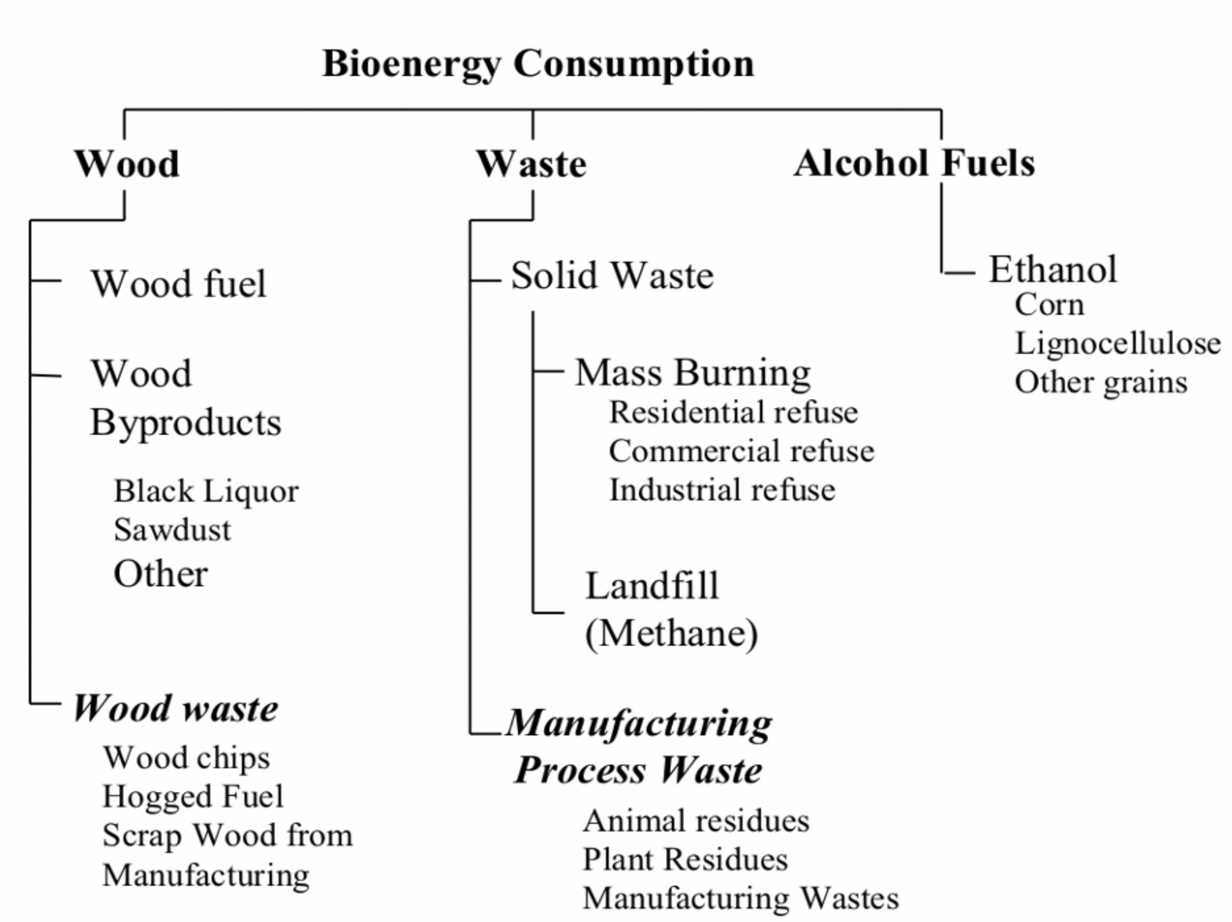


Figure1. Components of Bio-energy consumption Biomass sources for bioenergy (adapted upon Rosillo-Calle et al., 2007)

Research Methodology

Data type and source

This study used both primary and secondary data types.The Primary data for this study was derived from households' survey in three selected weredas of Tigray who adopt the biogas plant development scheme. The three Weredas of Tigray namely: Kiltoawulalo(Abrha WoAtsbeha), Korem(Ofula) and Hintalo wajirat(Adigudom) were surveyed. Moreover, the study used the secondary data type from literatures and previous studies.

Sampling Design

Likewise from each of the three selected weredas of Tigray households who has already adopted Biogas as source of energy were selected via purposive sampling technique. The sampling units was taken proportionally from the selected weredas to sum up about 150 households of sample size was supposed to be involved in the survey. The response rate is 93 % (139 completed and returned questionnaires out of 150 questionnaires designed and distributed).

Data collection Instruments

Questionnaire was used as data collection instrument of this study. The questionnaire was designed to incorporate the socio economics characteristics of the biogas users; costs of biogas plants; benefits of biogas plants and its slurry; purposes of biogas plants; Decision elements for using biogas; problems of biogas plants and its slurry; and Discontinuing reasons of biogas. The questionnaire has addressed all the objectives of this study.

Data Processing and Method of Analysis

The collected data were processed via editing, coding and summarizing using tables, pie charts, bar graphs and then analyzed using frequency distribution, percent, cross tab with phi and Cramer's value descriptive analysis and spear man rho's correlation with the help of excel and SPSS soft wares.

Data analysis and Discussion

Socioeconomics of Respondents

Table2. Qualitative Characteristics of Respondents

Characteristics		**Frequency**	**Percent**
Gender of household head	Male	50	36%
	Female	89	64%
	Total	**139**	**100%**
Age	Young(30-40 years old)	3	2%
	Adult(41-50 years old)	45	33%
	Old(51-60 years old)	74	53%
	Retired(>60 years old)	17	12%
	Total	**139**	**100%**
Level of education	Never had before	101	73%
	Primary school	35	25%
	Secondary school	1	0.7%
	Diploma	1	0.7%
	University Degree	1	0.7%
	Total	**139**	**100%**
Location	Rural	114	82%
	Urban	25	18%
	Total	**139**	**100%**
Having cattle	Yes	139	100%
	No	0	0%
	Total	**139**	**100%**
Feeding way of cattle	Free gathering	89	73%
	Indoor control	50	27%
	Total	**139**	**100%**
Having own Biogas plant	Yes	139	100%
	No	0	0%
	Total	**139**	**100%**
Size of Biogas Digester	6 meter cubic	119	86%
	8 meter cubic	20	14%
	Total	**139**	**100%**
Source of income	Civil Service	11	8%
	Farming	110	79%
	Business	18	13%
	Total	**139**	**100%**

Table3. Quantitative characteristics of Respondents

Characteristics	Minimum	Maximum
Family size	3	6
Experience of using Biogas in years	1	4
Number of own cattle	1	7

Most of the respondents (64%) are female household heads. That is, the Biogas plants are used by females as source of energy for cooking and other related household activities. This match with the previous literatures dealing with Ethiopian culture that indicates cooking and other related household activities are performed by females. Most of them are old whose ages range from 51 to 60 years old. Most of the respondents (73%) are with no education and 82% of all selected households live in rural areas. That is, Biogas is more important for rural society with no access to electricity and other modern source of energy than to that of urban society having alternative modern source of energy.

All the respondents have cattle and 73% of them use free gathering as a way of feeding their cattle. This contradicts with previous literatures which relate indoor feeding way of cattle and Biogas production. Moreover, free gathering way of feeding cattle is not good for biogas production as source of energy as the cattle release their manure outside. All the selected households do have own biogas plants whose size of their digester ranges from 6 meter cubic (86% of them) to 8 meter cubic (14% of them). The difference in size of Biogas digester indicates the difference amount of costs required for construction of the biogas plants and amounts of benefits obtained from the biogas plants.

Table4. Costs incurred for Development of Biogas plants

Costs		**Frequency**	**Percent**
Interest rate of any loan for Biogas	15%	139	100%
Costs covered by	NGOs and Government Organizations	139	100%
Costs	**Mean**	**Minimum**	**Maximum**
Costs covered by one’s own	3,041.67	2,300	3,500
Total costs of construction of Biogas plants	12,794.53	12,300	14,000

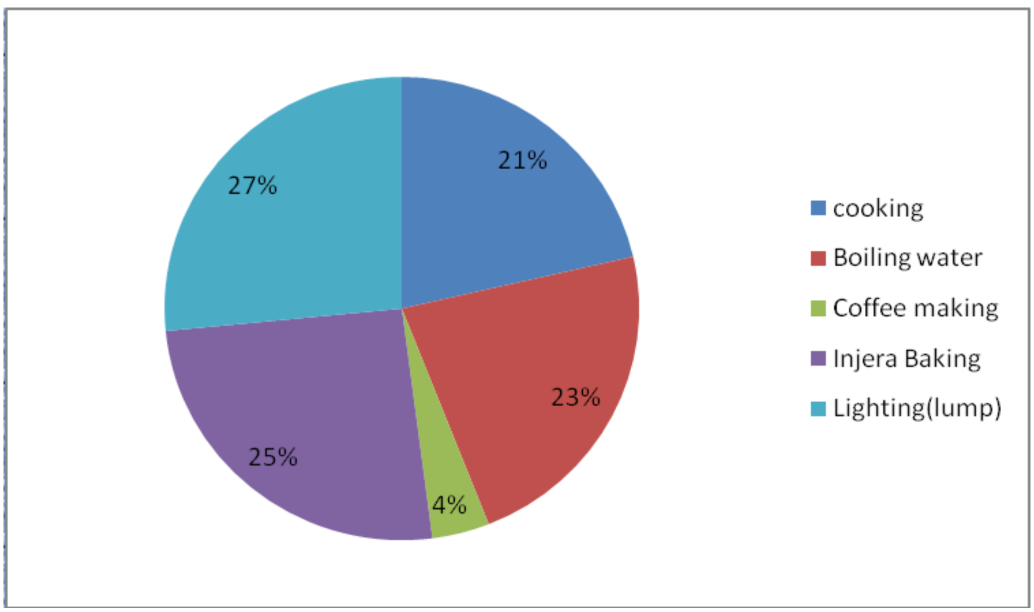
Costs of Biogas plants installation

Like previous researches and literatures that link farming activity with biogas production for most of the selected household (79%) farming activity is their source of income. The respondents' family size ranges from 3 to 6 ; their experience of using biogas as source of energy ranges from 1 to 4 years; owning minimum 1 cattle and maximum 7 cattle.

Similar to the literatures and past studies, the total costs that are required for construction of biogas plants ranges from 12,300 ETB to 14,000 ETB out of this total cost only minimum 2,300 ETB and maximum 3,500 ETB is covered by the users while the remaining is covered by Government Organizations and NGOs. The NGOs include Microfinance institutions which allow loan for the users of biogas plants with interest rate of 15%.This indicates that Government and NGOs are helpful organizations for the biogas plants development at household level as this project requires high initial costs or initial investments.

Purposes of Biogas plants Development

Figure2. Activities using Biogas as source of energy



The biogas plants installed are being used for lighting lump(27%);Baking Injera(25%);Boiling water(23%);cooking(21%); and coffee making(4%) activities of households.That is,the biogas plants as source of energy are used in the households taking the place of rural electrification and fuel wood. Especially, replacing fuel wood is advantageous for the environment as it reduces deforestation. This is like what is said in letratures and what is studied in previous researches.

Decision Elements for Biogas Plants Installation

Table5. Decision elements for need of Biogas plants

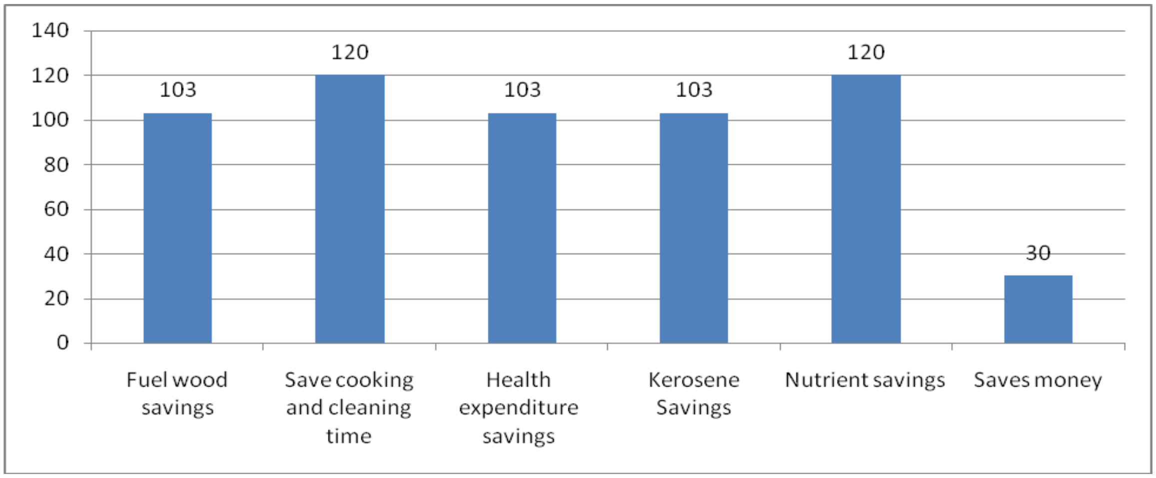
Decision elements		Frequency
Location	Rural	114
	Urban	25
	Total	**139**
Owning cattle	Yes	139
	No	0
	Total	**139**
Feeding way of their cattle	Free gathering	89
	Indoor controlled	50
	Total	**139**
Source of income	Civil service	11
	Farming	110
	Business	18
	Total	**139**
Who cover costs	NGOs and Government Organizations	139
	Own	0
	Total	**139**

Similarly with the literature and previous studies, Location; owning cattle; feeding way of one's own cattle; source of income; and who cover costs do matter with regard to making decisions whether to invest in biogas plants or not. That is, especially rural society they do need biogas as source of energy seriously unlike to the urban society with a lot of alternatives to be used as source of energy. Owing cattle is a mandatory to make biogas plants investment as manure is one of the main and primary inputs of biogas production. Feeding way of one's own cattle is also important one for biogas plants as it is related with amount and extent of getting manure easily. Furthermore, Farming activity is crucial as it includes owing cattle. In additions, who covers costs is also one of the main decision elements for need of biogas plants as this project requires huge amount of money as initial cost (investment).

Benefits of Biogas Plant and its slurry

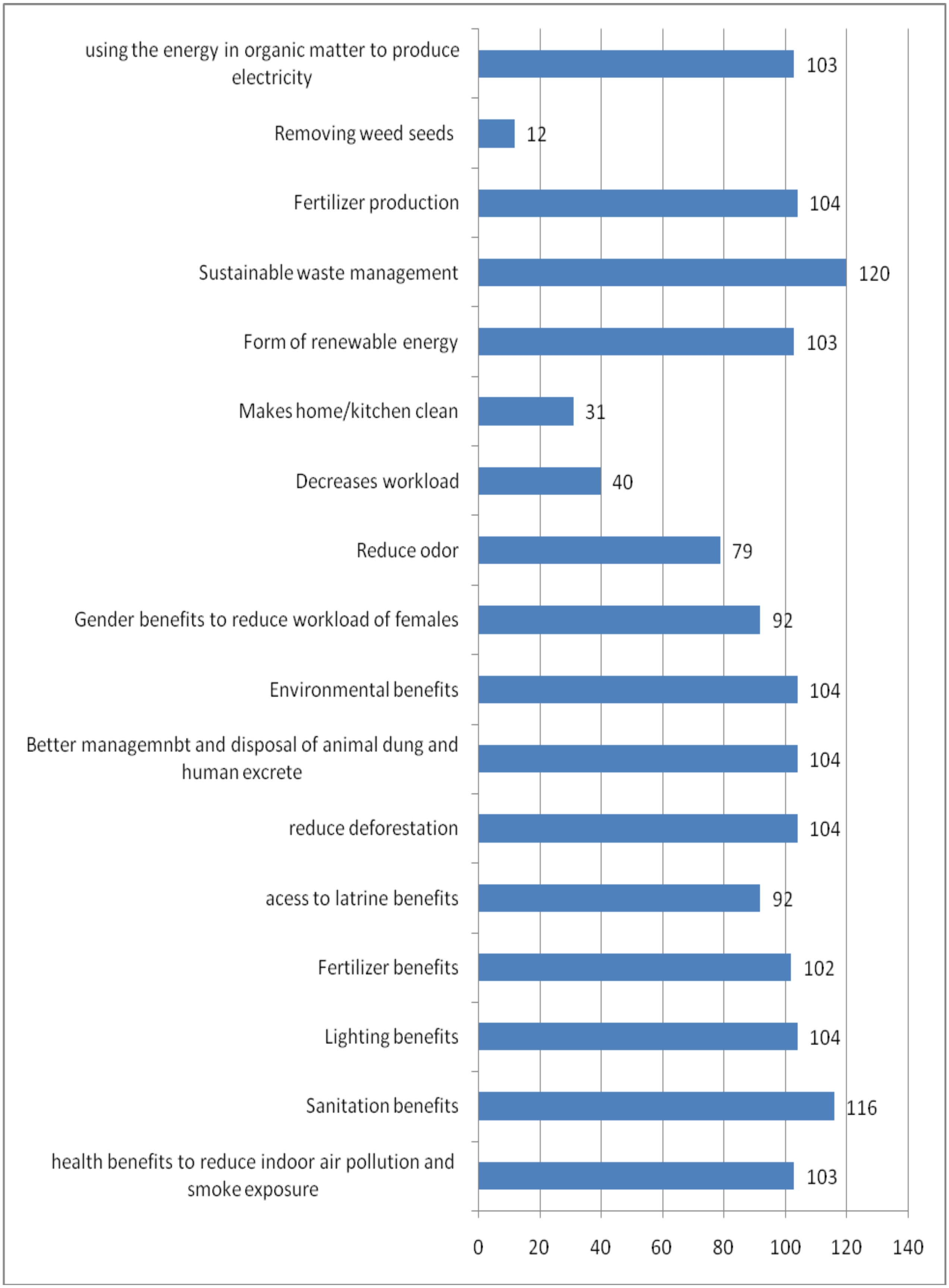
Benefits of Biogas Plants

Figure6. Savings as a result of using of Biogas plants as source of energy



Using Biogas as source of energy does save cooking and cleaning time; nutrient of cooked food items; fuel wood; health expenditures; kerosene and finally it saves money. This is similar with both the available theoretical and empirical literatures. That means, the cooking time gets shorter and shorter as the source of energy is strengthened at uniform rate unlike that of other traditional source of energy. It also reduces the frequency and lengths of cleaning time as all manure and human excrete are used for biogas source of energy production. The nutrient content of all food items cooked by biogas source of energy will not be damaged as cases with other traditional source of energy. Health expenditures also get reduced as the duration and extent of the household exposure to smoke is reduced when the household is using biogas instead of all the other traditional sources of energy. Biogas also replaces fuel wood and kerosene that resulted in saving of the environment from deforestation and saving of money that was to be paid for kerosene.

Figure7. Benefits obtained from using biogas as source of energy



In similar way to what is available in the literatures, as shown in the above figure Biogas has a lot of benefits for the society who are using it as source of energy.

Benefits of Biogas plants' slurry

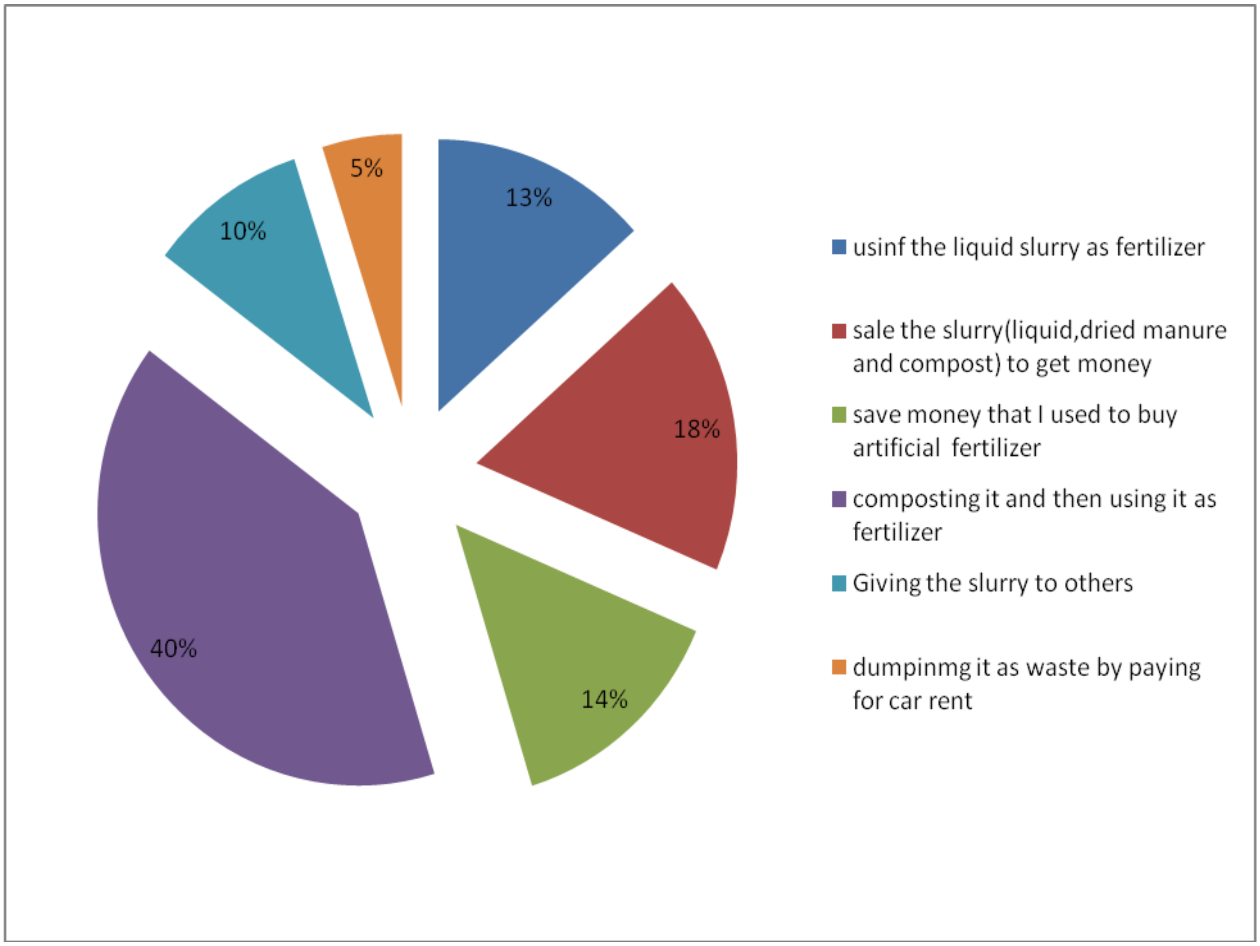


Figure8.Benefits of slurry

The slurry which is coming out of the biogas plant as its byproduct is also useful as mentioned in the above figure similar to what is acquired from the literatures and previous studies.

Relationship between size of biogas digester and its benefits

Table3. Benefits Difference by size of digester of Biogas Plants

Relationship between Benefits of biogas and size of Biogas Digester	**p-vale**	**Spearman's rho (r)**
Sustainable waste management	0.00	0.98
Saving cooking and cleaning time	0.00	0.97
Fertilizer benefits	0.04	0.18
Kerosene savings	0.05	0.17
Labor savings	0.00	0.09

Sustainable waste management; saving cooking and cleaning time; fertilizer production; kerosene savings; and labor savings are benefits of biogas plants which differ as per the size of digester of the biogas plants. That is, their benefiting capacity increases as the size of digester of the biogas plants increase. This is similar logic as what is mentioned in the literatures.

Problems of Biogas plant and its slurry

Problems faced due to biogas plants and its slurry

The respondents (62%) of them faced problems of the biogas plant and moreover 79% of them faced problems with the biogas plants' slurry.

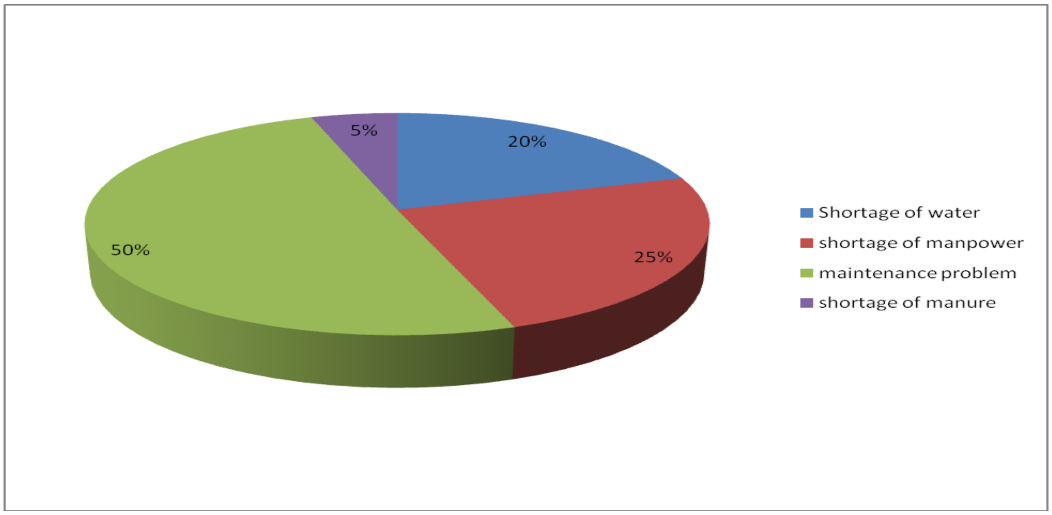


Figure9. Problems of Biogas Plants

Maintenance problem; followed by shortage of manpower; shortage of water; and shortage of manure respectively are problems faced by biogas users as source of energy. That is, there is lack of spare parts and low skill for maintenance of the biogas plants and/or its parts. Biogas plants project as source of energy requires huge labor, manure and water resources. So it is difficult to install biogas plants as source of energy in dry season and dry area without having cattle and helpful family members.

Table4. Problems by Location and Gender of household head

Problem by location and Gender	**P-value**	**Cramer's value**
Problems of Biogas plants increases as it goes from urban to rural	0.00	0.51
Problems of the slurry increases as it goes from female to male	0.05	0.18

The problems of biogas plants and its slurry are different for different location and gender as shown in the above table. That means, male household heads do face more problems of slurry than that of female household heads as the activity of slurry is mostly related with males in Ethiopian culture where as the problems of biogas are faced by rural households as biogas is mostly used in rural areas.

Reasons for Biogas Plant not being fully functional

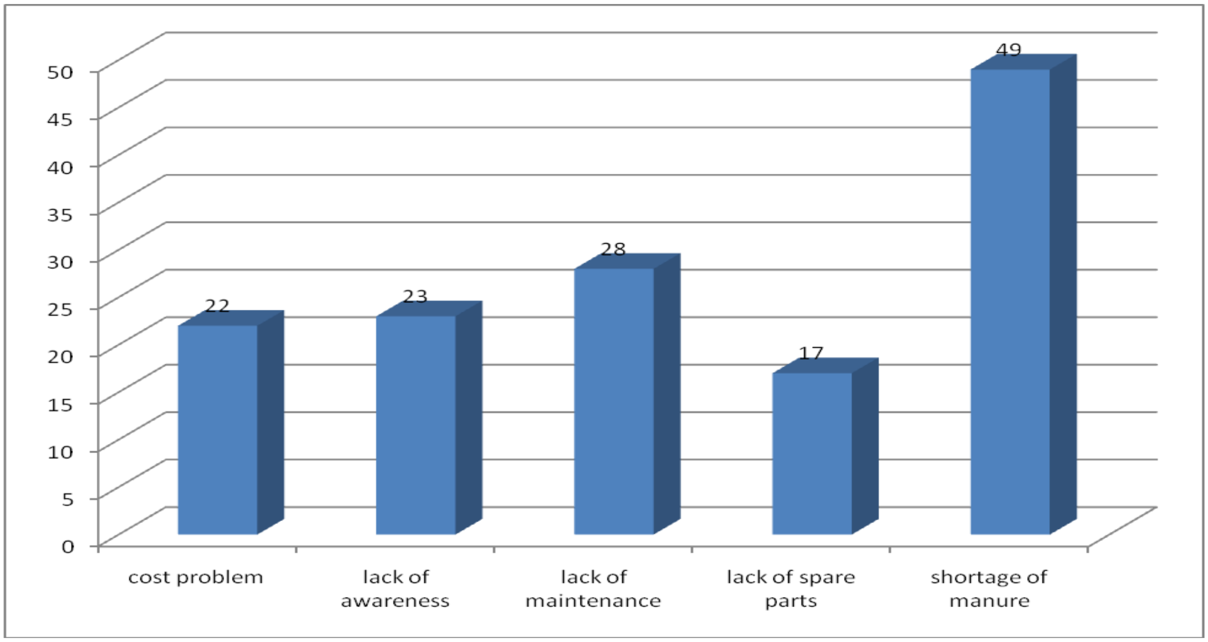


Figure10. Discontinuing reasons of Biogas as source of energy

Shortage of manure followed by lack of maintenance; lack of awareness; cost problem and lack of spare parts respectively are the reasons for not be functioning the biogas plants. All the biogas plants are not functioning in full and to what is supposed to be due to these problems.

Conclusion and Recommendations

Conclusion

Female household heads are using Biogas Plants as source of energy for cooking and other related household activities. Most of them live in rural areas with no access to electricity and other modern alternative sources of energy. Free gathering way of feeding cattle is common in the rural areas. This is contradicting with using Biogas plants as source of energy as it affects the manure input of the biogas plants. The size of digester of the biogas plants ranges from 6 meter cubic to 8 meter cubic and 6 meter cubic being common at household level.

The total costs that are required for construction of biogas plants ranges from 12,300 ETB to 14,000 ETB out of this total cost only minimum 2,300 ETB and maximum 3,500 ETB is covered by the users while the remaining is covered by Government Organizations and NGOs. Thus, Government and NGOs including Microfinance Institutions cover the large portion of the initial cost (investment) of the Biogas plants as source of energy.

Biogas as source of energy is used for lighting lump; baking Injera; Boiling water; cooking; and coffee making activities at household level. Location; owing cattle; feeding way of one’s own cattle; source of income; and who cover costs of biogas construction and then installation are main decision elements for biogas plant projects whether to invest or not.

Using Biogas as source of energy saves cooking and cleaning time; nutrients of cooked food items; fuel wood; health facility expenditures; kerosene; and finally it saves money. Moreover, the following listed in detail are main benefits of using biogas as source of energy:

* Sustainable waste management
* Sanitation benefits
* Health benefits to reduce indoor air pollution and exposure to smoke
* Lighting benefits(electrification)
* Fertilizer production
* Reducing deforestation
* Better management and disposal of animal dung and human excrete
* Environmental benefits
* Gender benefits to reduce females' workload
* Being one form of renewable energy

Moreover, the slurry byproduct of biogas production as source of energy has the following benefits:

* Composting it and then using it as fertilizer
* Using liquid slurry as fertilizer
* Selling the slurry to get money
* Saving money that was to be paid for artificial fertilizer
* Giving the slurry as a gift to others

And Sustainable waste management; saving cooking and cleaning time; fertilizer production; kerosene savings; and labor savings are benefits of biogas plants which differ as per the size of digester of the biogas plants. That is, their benefiting capacity increases as the size of digester of the biogas plants increase.

Maintenance problem; followed by shortage of manpower; shortage of water; and shortage of manure respectively are problems faced by biogas users as source of energy. That is, there is lack of spare parts and low skill for maintenance of the biogas plants and/or its parts. Biogas plants project as source of energy requires huge labor, manure and water resources. So it is difficult to install biogas plants as source of energy in dry season and dry area without having cattle and helpful family members.

Problems of both the biogas plant and its slurry have been faced by its users as source of energy. The problems of biogas plants and its slurry are different for different location and gender. That is, Problems of Biogas plants increases as it goes from urban to rural where as Problems of the slurry increases as it goes from female to male. That means, male household heads do face more the problems than that of female household heads. Furthermore, Shortage of manure followed by lack of maintenance; lack of awareness; cost problem and lack of spare parts respectively are the reasons for not be functioning the biogas plants. All the biogas plants are not functioning in full and to what is supposed to be due to these problems.

Recommendation

All concerned bodies need to give attention to female household heads in rural areas with regard to Biogas plants Development at household level because Biogas as source of energy has a strong linkage with such part of the community.

The Biogas users as source of energy need to pay attention to the advantage of indoor controlled feeding way of their cattle especially with respect of manure input of the biogas plant.

It will be nice if Government organizations and NGOs adjust their incentives (Government) and interest rate of their loan (NGOs including the Microfinance institutions) to cover portion of Biogas initial cost (investment) as per the capacity and demand of the users.

All stakeholders of Biogas Plants Development at household level need to focus on Location; owning cattle; feeding way of one's own cattle; source of income; and who cover costs of biogas construction and installation as these are the main decision elements for Biogas Plants projects whether to invest on or not. Moreover, the stakeholders need to recognize that sustainable waste management; saving cooking and cleaning time; fertilizer production; kerosene savings; and labor savings are benefits of biogas plants which differ as per the size of digester of biogas plants. And All concerned bodies need to identify that problems of Biogas and its slurry have different severity for different locations (rural or urban) and different gender (male or female). Thus, it needs special treatment accordingly. On the other hand, Biogas users need to adjust their feeding way of their cattle to solve shortage of manure; they need to dig out water from the ground of their surroundings to solve shortage of water; and they need to be guided by plan to solve their shortage of manpower problems of biogas. Moreover, Biogas users need trainings on simple maintenance of their Biogas plants; and awareness on how to operate Biogas plants.

Microfinance institutions and other financial institutions should pay attention to Biogas users in order to solve the users' cost problem. Furthermore, Construction materials shop need to use the opportunity of providing Biogas plants' spare parts to the Biogas users to solve lack of spare parts of the biogas plants.

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Appendix
Questionnaire

Questionnaire

I. Introduction

This questionnaire is prepared for academic research purpose of staff of the accounting and finance department. Your information is needed to do analysis and to prepare research report on the above mentioned research topic. We promise you to keep your information confidential and we will share with you specially the key findings and recommendations of the research.

II. Personal Information

2.1. Household No: ---------------------

2.2. Date______________________________ 2011

2.3. Sex of the household head male_________ female______________

2.4. Age of the household head _________________

2.5. Educational level of the household head?

1. Never had____
2. Primary____
3. Secondary ____
4. Diploma _____
5. University degree____

2.6. Family size of the household ________________

2.7. Location of household head? 1. rural_______ 2. urban_______

2.8. Do you have cattle? Yes __________ No__________

2.9. If yes, how many____________________

2.10. How do you feed the cattle?

1. Free gatherers____ 2. Indoor controlled _________ 3. Others (specify) ____________

2.11. Do you have biogas digester? ___________

2.12. What is the size of your digester? __________________

2.13. What is the model of the digester? ____________

2.14. For how long have you been using the digester? ______________

2.15. How much was the cost of constructing the digester? ________________

2.16. Have you covered the construction cost by yourself? ____________

2.17. If no how much did you cover yourself? ______________

2.18. Who covered the remaining cost? ____________________

2.19. If it is obtained by loan, how much is /was interest rate? ___________________

2.20. What benefits do you get from using biogas?

1. It saves money? ___________
2. It decreases my work load? ____________
3. It makes my home/kitchen clear? ________
4. Other (specify) __________________

2.21. How much money do you save? ________________

2.22. Is there an increase in interest of cooking because of biogas? Yes_____ No________

2.23. Do you face any problem associated with biogas? Yes_______ No__________

2.24. If yes, what is it?

2.27. What do you to the slurry?

1. I use the liquid slurry as a fertilizer_________
2. I compost it to use it as a fertilizer__________
3. Give the slurry to others _______________
4. I dump it as waste by paying for the car that takes it
5. Other (specify) ______________

2.28. What are the benefits that you get from the slurry?

1. Use the liquid slurry as a fertilizer _______________
2. Sale the liquid slurry, the dried manure and/or the compost from the slurry to get money ____________
3. Save the money I used to spend to buy artificial fertilizer _________________
4. Other (specify) ______________________

2.29. Is there any problem you face because of the slurry? Yes____________ No____________

2.30. Source of income to household?

1. Civil service___ 2. Farming _____ 3. Business _____ 4. Other (specify)_______

2.31. In which average monthly income bracket do you fall? _____________

2.32. Who initiated the idea of biogas production to you?

1. Own initiative _________
2. NGO _____________
3. Government __________
4. Other (specify) ____________

2.33. What are the reasons for the biogas plant not being operational?

____

____

____

2.34. What was your energy consumption?

Activities	Firewood	charcoal	Dung resides	Electricity	Biogas	Kerosene
Cooking						
Boiling water						
Coffee making						
Injera Baking						
Other(specify)						

III. Benefits resulting from Biogas plant installation at household level

3.1. Benefit factors of Biogas plants

Benefits	Disagree (1)	Neutral (2)	Agree (3)
Form of renewable energy production			
Sustainable waste management			
Fertilizer product			
Weed seeds and pathogens get removed			
Converts organic waste into a valuable product electricity,heat&fertilizer)			
Uses the energy in the organic matter to produce electricity and heat			
Reduces odor significantly			
Gender benefits(decrease in the workload of rural women)			
Environmental benefits(improvement of the local, national and global environment)			
Better management and disposal of animal dung and human excrement			
Reduce the pressure of deforestation			
Health benefits(indoor air pollution and smoke exposure in rural reduced)			

3.2. Benefit amounts of biogas

Benefits	Amounts in birr per month
Fuel wood savings	
Savings in cooking and clearing time	
Latrine access savings	
Fertilizer use benefits	
Health expenditure savings	
Lighting benefits	
Kerosene savings	
Nutrient savings	
Labor savings	
Sanitation benefits	
Other(specify)	

IV. Costs of Biogas

Costs	Amounts in birr
4.1. Civil construction costs	
-Bricks/stone hard core	
-sand	
-stone chips	
-cement	
-pipes	
-timber	
-nails	
4.2. Labor costs	
-digging the pit	
-for construction	
-nails	
-mason	

4.3. Supply line costs	
-galvanized pipes	
-gas valves	
-filter	
-biogas stove	
-biogas lamp	
-biogas mitad	
4.4. Capital costs(initial investment)	
4.5. Annual maintenance costs	
Other(specify)	

THEME THREE

IRRIGATION & DRAINAGE

Salinization pattern and its spatial distribution in the irrigated agriculture of Northern Ethiopia: An integrated approach of quantitative and spatial analysis

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Abstract

Salinity adversely affects the environment, agro-ecosystems and agricultural productivity of arid and semi-arid regions worldwide. This salinization is occurred due to natural, human or both actions on the earth dynamics. This study was conducted to quantify the magnitude and map the spatial distributions of salinity hazards of irrigated agriculture in the semi-arid Tigray areas of northern Ethiopia. A total of 717 soil and 13 water samples from nine irrigation schemes were used for analysis. The soil samples were collected on a grid basis from 0-15cm and 15-30cm soil depths in the plants root zone and surface water samples were collected from the irrigation water source, middle and lower cross- sections of the irrigation schemes. These soil and water samples were analyzed quantitatively for 14 salinity parameters and results have compared with worldwide standard values. In addition, the spatial analysis was made for three basic salinity parameters of hydrogen ion concentrations (pH), Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR). Even if, there is no significant variations between soil layers and among the irrigation cross-sections, a salinity hazard is occurred. Higher pH average values are spatially concentrated at downstream whilst SAR and EC showed inconsistent variations among irrigation schemes. The quantitative and spatial salinity analysis revealed that Gum Selassa, Gereb Kunchi and Tegahne irrigation schemes have potential salinity hazards. As a result, use of salinity management strategies such as leaching, addition of gypsum, use of salinity tolerant crops has paramount importance. Irrigation users and decision makers should consider these possible measures of minimizing salinity build-up thereby increasing agricultural productivity of the irrigation schemes in a sustainable way.

Keywords: Irrigation schemes; Salinity; spatial distribution; semi-arid region, Tigray region, Ethiopia

Introduction

Soil salinity has started to affect humanity since centuries (Shahid, 2013). This soil salinization is caused due to natural or anthropogenic acts on the earth system. Today, nearly 20% of the world irrigated agriculture is threatened by salinization (Li et al., 2014; Adejumobi et al., 2016). This is even worse in arid and semi-arid regions in which 30% of the irrigated agriculture are saline (Li et al., 2014). This is due to the limited rainfall amount (< 400 mm) and greater evapotranspiration conditions (Huang et al., 2010). Beyond its inherited salinity natures of the arid and semi-arid regions, 41% of the land surface is irrigated with saline water (UNDP, 1997). As a result, the sustainability of land and water resources for agricultural use remains under question.

Salinization adversely affects the environment, agro-ecosystems, agricultural productivity and sustainability (Shahid, 2013). This is caused due to its complex degradation dynamics of the soil and water resources which hinders societal biophysical and socio-economic base which has a direct impact on food security of livelihoods. Use of poor quality water, coupled with the intensive use of soils for irrigation, results the development of salinity affected irrigated agriculture (Crescimanno et al., 2007). When soils under irrigation are converted to salt affected soils, salinity contaminated irrigation agriculture persists (Im-Erb and Sukchan, 2007). Salt-affected soils varies due to physical and chemical characteristics of the soil, depth of water table, leaching capacity, crop cultivation system and salt distribution pattern (Qureshi and Akhtar, 2007). This occurs due to the natural phenomena (salt deposition from the beneath parent material) or human actions (poor drainage facility, poor quality irrigation water use or over-irrigation) (Thomas & Morini, 2005). Salt-affected soils results from chemical, physical and biological interactions of the soil and water resources (Kidane et al., 2006).

The severity of salinity hazard, i.e. salinization, is associated with low agricultural productivity, on site land degradation and is mainly an environmental problem that eventually leads to desertification (Im-Erb and Sukchan, 2007). In agriculture where human being depends on, salinity effect manifests in loss of crop stand, reduced plant growth, reduced yields, and may cause crop failure; by preventing water extraction from the soil due to reduced osmotic potential (Ayers and Westcot 1985; Dennis, et al., 2007).

The Tigray region in the northern Ethiopia, is known for its semi-arid environment, vulnerable to soil salinity as a result of the recent intensifications of irrigated agriculture. The regional government has been expanded irrigated agriculture for the sustenance of its indigenes in the last twenty years (Alemayehu et al., 2009). As a result, regional irrigated land has increased from 15,000 ha before 2004 to more than 243,000 ha in 2015 (BoARD, 2015). Furthermore, the government has an ambitious plan to irrigate 50% of the total 1.5 million hectares of available arable land in the near future (Gebresilassie, 2014; GTP, 2011). To achieve these goals, earthen dams and diversions has been constructed continually in the last two decades as a means of harvesting surface water for small and medium scale irrigation developments. However, despite of the good achievements on the intensification of irrigated agriculture in the semi-arid areas of the region, the attention given to field level agricultural water management was very poor. In addition, due to lack of knowledge and awareness on improved irrigated land and water management strategies, irrigation farmers are using traditional irrigation water application systems.

Consequently, irrigation application efficiency in the region remains below 40% (Kifle and Gebretsadkan, 2016). This poor on-farm irrigation water management practices; has led to waterlogging, poor water distribution and salinity development of the irrigated agricultural lands (Kidane et al., 2006). As a result, a considerable irrigated land of the irrigation schemes is being converted into unproductive areas as a result of the on-site salinity buildups (Kebede, 2009). This indicates, field level agricultural land and water management techniques was lacking in the irrigated farmlands (Kifle and Gebretsadkan, 2016; Tsegay et al., 2015; Kifle et al., 2008).

Despite the existence of some local studies conducted to investigate salinity hazard developments in this semi-arid region (e.g., Yazew, 2005, 2006; Bekele et al., 2012; Kebede, 2009), a comprehensive study to identify the main salinity sources, quantifying the magnitude and mapping its spatial distributions is lacking. Identifying the main driving forces of salinity (from the soil itself or the water applied) that forms a soluble salt accumulation in the soils of irrigated agriculture is essential in understanding and taking management measures for future agricultural productivity. Moreover, soil depth based salinity status determination at which most crops grow is vital. This is helpful to identify whether salts are going down the soil profile or emerging due to capillary rise from the groundwater tables near the surface. Therefore, this study was aimed at understanding the salinity patterns by quantifying the magnitude, mapping its spatial distributions in selected irrigation schemes of the region. This is used to deliver and put ways forward recommendations for decision makers and irrigation users to improve the agricultural productivity in a sustainable way and minimize the salinity build-up in the soil profiles of the region and other areas with similar socio-economic and agro-ecological conditions.

Materials and Methods

Area description

This study was conducted in the semi-arid region of Northern Ethiopia (Tigray) by selecting four districts including Hintalo-Wajirat, Enderta, Kilte-Awlaelo and Atsbi-Wenberta from which nine irrigation schemes were selected, for this study (Fig. 1). These irrigation schemes are Gereb Kunchi, Gum Selassa, Gereb Mehizi, May Gassa and Gereb Wedicheber from Hintalo-Wajirate, Gereb Kokhi and Arato from Enderta, Korir from Kilte-Awlaelo and Tegahne from Atsbi-Wenberta district (Table 1 and Fig. 1). The boundary of all studied irrigation schemes were delineated by taking GPS points from the irrigation schemes.

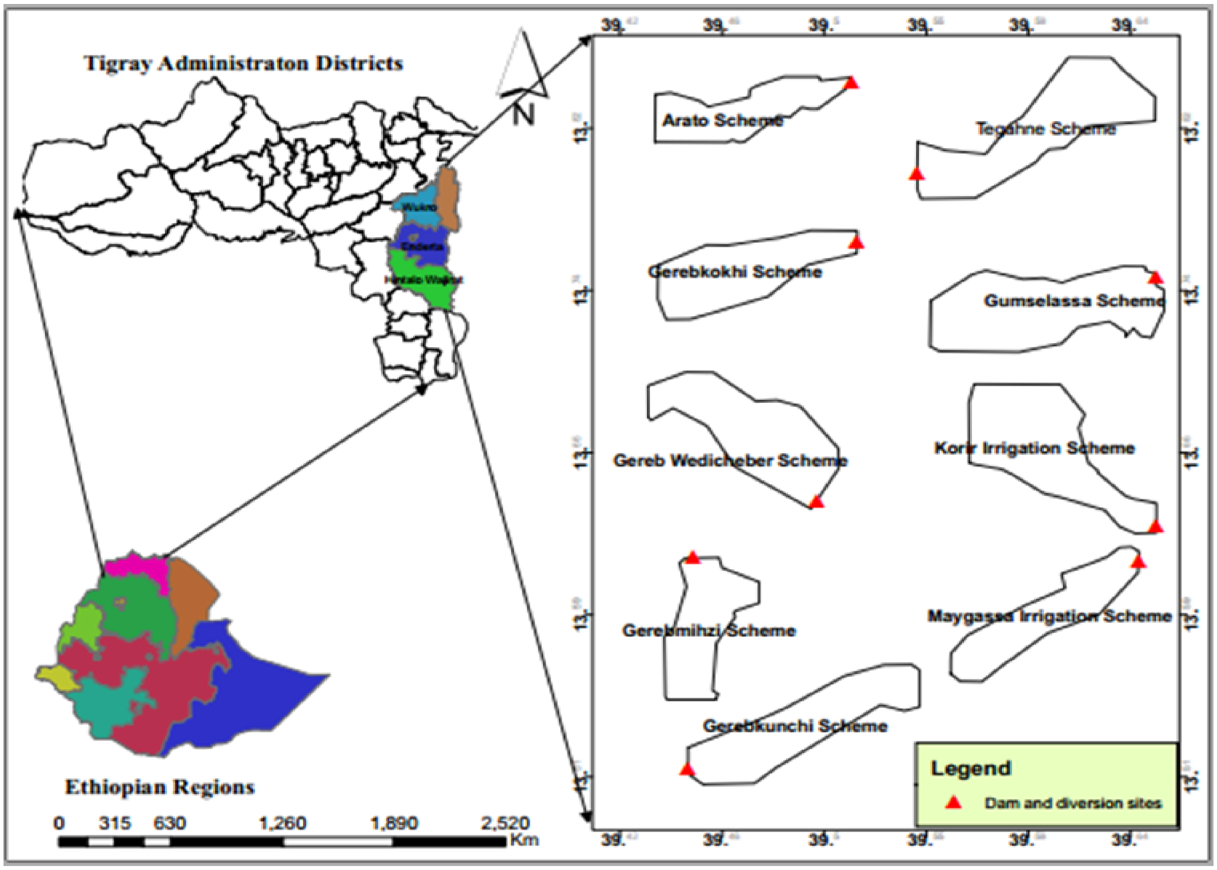

Figure 1: Location map of the irrigation schemes, dam and diversion sites

These districts are known for their semi-arid climate which are mainly characterized by mixed-agriculture with erratic rainfall and sparse vegetation coverage (Esser et al., 2002). Cropping practices are dominated by horticultural crops production during irrigation season and cereal production during rain fed. The districts' average annual temperature and mean annual rainfall ranges from 19-23^{o}c and 504-543 mm, respectively (Oicha et al., 2010; Yazew et al., 2005). The irrigation schemes have clay and clay loam soil textural classes (Table 1). Geology of the irrigation schemes is characterized by Flood basalt volcanic, Amba Aradam Formation, Antalo Super sequence and Metamorphic (basement) rocks (Gebreyohannes et al., 2010). Other characteristics such as water sources, irrigation potential and actual irrigation capacity of each irrigation scheme are summarized in Table 1.

Table 1: Characteristics of the irrigation schemes

[a]Awulachew et al. (2007)

Irrigation scheme	District	Water sources	[a]Designed command area (ha)	[a]Actual irrigated area (ha)	Soil textural class
Gereb Kunchi	Hintalo-Wajirat	Earthen dams	35	32.53	clay
Gum Selassa	Hintalo-Wajirat	Earthen dams	110	177.72	clay
Gereb Mihzi	Hintalo-Wajirat	Earthen dams	80	65.20	Clay loam
May Gassa	Hintalo-Wajirat	Earthen dams	80	39.58	Clay loam
Gereb Wedicheber	Hintalo-Wajirat	Earthen dams	80	66.97	clay
Gereb Kokhi	Enderta	Diversion	48	53.30	Clay loam
Arato	Enderta	Diversion	120	40.41	clay
Korir	Kilte-Awlaelo	Earthen dams	100	120.19	clay
Tegahne	Atsbi-Wenberta	Earthen dams	60	50.21	Clay loam

Data collection and sampling procedures

For this study, nine irrigation schemes which were reported to have salinity problems are purposely selected (Table 1). However, existence of salinity in these irrigation schemes was checked after frequent field visit. Accordingly, a total of 717 soil and 13 water samples were collected from these irrigation scheme for further analysis. The 717 soil samples were collected, from 0-15cm and 15-30cm soil depth, on a grid basis at the dry season (irrigation season) from April to May. Each sample was taken at an interval of 100 m at the same spot from both soil depths. On the other hand, water samples were collected from the source of irrigation water (upstream), in the middle and the bottom (downstream) of irrigation scheme. Water samples from some of the studied irrigation schemes were not included as water was not exist in the irrigation schemes at the time of data collection (Table 2). As a result, only 13 water samples were considered for water analysis. To delineate the salinity and to develop maps showing the spatial distribution of the salinity hazard, a GPS reading of all sampling points was collected from each irrigation scheme. The collected soil and water sample sizes from each irrigation schemes are summarized in Table 2.

Table 2: Sample size of the collected soil and water samples from each irrigation scheme

Irrigation scheme	Soil sample size			Water sample size		
	0-15cm	15-30cm		water source	middle	downstream
Gereb Kunchi	54	54				
Gum Selassa	234	234				
Gereb Mihzi	54	54		1	1	
May Gassa	59	59		1		
Gereb Wedicheber	86	86		1		
Gereb Kokhi	31	31		1		
Arato	61	61		1	1	
Korir	76	76		1	1	1
Tegahne	62	62		1	1	1
Sum	717			13		

Data analysis

Data analysis were carried out, first at laboratory and then statistical and geo-statistical analysis has followed. Before proceeding to the laboratory analysis, all soil samples were air-dried, crushed, and passed through a 2-mm sieve. The 1:5 soil to water ratio suspensions were prepared by weighing 10 g of soil into a pop-top tube, adding 50 ml of deionized water, and shaking for 5 min on an end-over-end shake (Yao & Yang, 2010).

Laboratory analysis of the soil and water samples were done at Mekelle Soil Research Center laboratory, Tigray Agricultural Research Institute. Salinity indicator parameters including, pH, EC, Ca^{2+}, Mg^{2+}, HCO^{-3}, Cl^{-}, and Na^{2+} were analyzed in the soil laboratory. The laboratory analysis procedures adopted by Pansu & Gautheyrou (2006) were applied to analyse these parameters (Table 3). Moreover, the quality of the soil and water samples, for agricultural use, were statistically evaluated through various indices such as the total dissolved solids (TDS), sodium adsorption ratio (SAR), magnesium adsorption ratio (MAR), residual sodium carbonate (RSC), residual sodium bicarbonate (RSBC), the permeability index (PI) and the Kelly ratio (KR). Equations for obtaining these indices are summarized in Table 4.

In addition, the standard threshold values of the salinity parameters used to compare with the measured values from the irrigation schemes are given in Table 5. The statistical and laboratory analysis results are

Water quality parameters	Symbol	Methods used
pH	pH	Potentiometric (1:2.5 H2O, v/v)
Electrical conductivity	EC	Conductometery (1:2.5 H2O, v/v)
Calcium	Ca^{2+}	EDTA (0.05 N) titrimetric
Magnesium	Mg^{2+}	EDTA (0.05 N) titrimetric
Sodium	Na^{+}	Flame photometric
Chloride	Cl^{-}	Titration using 0.05 N $AgNO_3$
Bicarbonate	HCO_3^{-}	Titration (with 0.01 N H2SO4)
Soil texture	-	hydrometer method (Bouyoucos)

Source; Pansu & Gautheyrou (2006)

also given in Tables 6, 7 and 8.

Table 3: Methods adopted for soil and water analysis for agriculture purposes

Moreover, the collected GPS readings for each sampling points were used to indicate the spatial distributions of salinity. Maps of salinity distributions across the irrigation schemes were produced using Arc GIS tools. GIS spatial interpolation techniques were employed to map the geo-spatial salinity distributions in the irrigation schemes. Geo-statistically, the salinity hazard was interpolated by using a universal kriging interpolation method of the spatial tools in the Arc GIS environment (Allbed et al., 2014). Hence, the major salinity indicator parameters, i.e., pH, EC and SAR for the 0-15 and 15-30cm soil layers of each irrigation scheme were interpolated into maps to show their spatial distribution.

Table 4: Irrigation soil and water qualities measuring parameters to salinity hazard with formulas, units and sources

Irrigation water quality parameter	Symbol	Formula	Units	Source	Remark
Total dissolved solutes	TDS	$TDS = EC \times 640$	TDS = mg/l & EC = dS/l	Richards (1954)	800 was used instead of 640, when EC >5 dS/m
Sodium adsorption ratio	SAR	$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$	meq/l	Richards (1954)	
Magnesium adsorption ratio	MAR	$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$	%	Raghunath (1987)	
Residual sodium carbonate	RSC	$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$	meq/l	Gupta & Gupta (1987)	
Residual sodium bicarbonate	RSBC	$RSBC = HCO_3^{-} + Ca^{2+}$	meq/l	Gupta & Gupta (1987)	
Permeability index	PI	$PI = \frac{Na^{2+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100$	%	Doneen (1964)	
Kelly ratio	KR	$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}}$	meq/l	Kelly (1963)	

All anions and cations are in meq/l; meq/l= mill equivalent per liter, dS/m= deci Simien per

Results and Discussion

Quantitative soil and water salinity assessment

The status of the salinity hazard of all irrigation schemes were quantified from both the soil and water samples. The analysis of the soil samples is given for each soil profile 0-15cm (Table 6) and 15-30cm (Table 7) root zone. In order to know if the water in the irrigation schemes have also effects to cause salinity hazards, water samples from upper, middle and bottom cross-sections of the irrigation schemes were analyzed and the result is presented in Table 8. Each soil and water sample were analyzed against 14 salinity parameters as shown in Table (6, 7 & 8). Summary of these results are presented in section 3.1.1 to 3.1.2.

Laboratory analysis

Salinity parameters such as pH, EC and the exchangeable cations and anions were analyzed in laboratory and were subjected to statistical analysis. As a result, these parameters are presented based on laboratory and statistical analysis in detail. The pH is a measure of the hydrogen ion concentration in a solution (Obiefuna and Sheriff, 2011). Except the Gereb Kunchi and Tegahne irrigation schemes, the average pH values of the soil and water samples are generally safe to use for irrigation water for both soil layers (Table 6, 7 & 8). The average pH value of Gereb Kunchi is 8.5 and 8.59 for the 0-15 and 15-30cm soil profiles, respectively, whilst it is 8.49 and 8.45 for the 0-15 and 15-30cm soil profiles, respectively in Taghane scheme (Table 5, Figures 2 &3). The result of the pH values for both schemes indicated that it is beyond the limit to use for irrigation purposes as compared to the FAO standards (Ayers and Westcot, 1985).

As indicated in figures 2 and 3, the Gereb Wedicheber and Gereb Kokhi irrigation schemes are in a position of approaching the limits of the threshold values (Table 5) for all the soil depths. In addition, this tendency is observed in the Gereb Mihzi irrigation scheme at the 15-30cm soil profile. On the contrary, analysis of pH of the collected water samples, showed that all the irrigation schemes are safe to use for irrigation purposes. Reasons could be the availability of complex chemical reaction among the cations and anions in the soil than what is happening the water. Generally, since the average pH values of each irrigation schemes were greater than 7, irrigation schemes tends to have alkaline properties and hence salinity.
The soil and water samples of the irrigation schemes were also analyzed for exchangeable cations (Na^+, Ca^{2+} and Mg^{2+}) and anions (HCO^-_3 and Cl^-) concentrations following the procedures given in Table 3. Accordingly, average values of these cations and anions of each irrigation scheme lays under safe conditions to use for irrigation purposes for both soil profiles (Table 6 & 7). Unlike the soil results the water samples analyzed result have variations as there are tendencies of being out of limit (Table 8). For example, at the upper cross-sections of the Gereb Kokhi irrigation scheme, the value of Mg^{2+} is 6.6 meq/l which is not safe to use for irrigation and Ca^{2+} has also a tendency to be out of limit in that scheme (Table 8). The exchangeable anions and cations are indicative in the water samples as compared to the soilsamplesoftheirrigationschemes.

The electrical conductivity (EC) and total dissolved soils (TDS) are important parameters to determine salinity effects in a given irrigated agriculture. As explained in the Tables 6 and 7, the average values of EC and TDS of the irrigation schemes are within the range of recommended standards for irrigation in both soil profiles. However, the Tegahne irrigation scheme for both soil profiles (Figures 2&3) and the Gereb Kunchi for the 15-30cm soil profile (Figure 3) reveals greater EC and TDS potentials which show, values above the limit to use for irrigation as compared to the recommended average values, 1000meq/l (Robinove et al., 1958). Similarly, water analysis of the irrigation schemes showed values within the standard, which implies the possibility for irrigation use, however, a tendency of salinization is observed at the upper scheme of Gerb Kokhi and bottom scheme of Korir irrigation schemes. The possible reasons for this occurrence could be the availability of salinity inducing parent materials in the soil profiles.

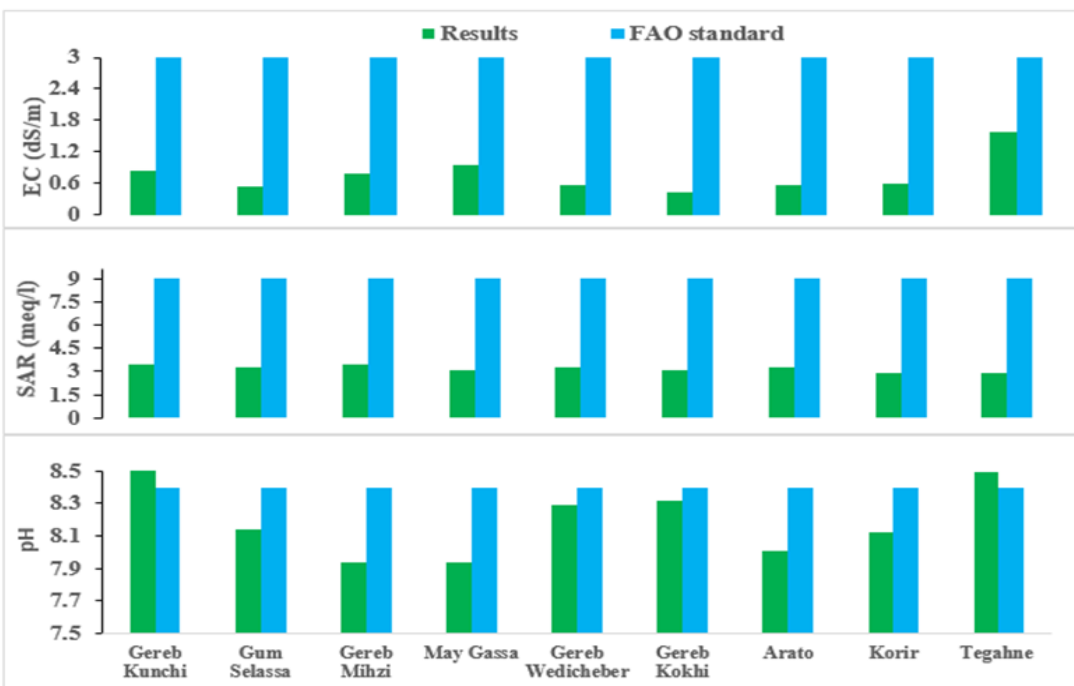

Figure 2: Comparison of measured values of the EC, SAR and pH with that of the FAO recommendations (0-15cm soil depth)

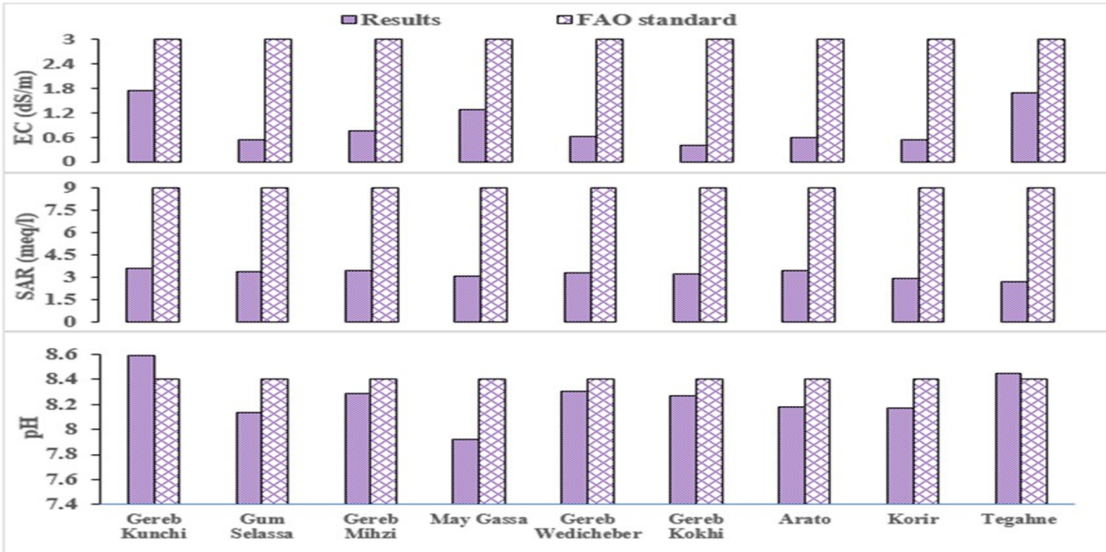

Figure 3: Comparison of measured values of the EC, SAR and pH with that of the FAO recommendations (15-30cm soil depth)

Salinity indices

The salinity of the irrigation schemes were also analyzed based on the salinity indices in given Table 4. The sodium adsorption ration (SAR) and a magnesium adsorption ratio (MAR) are important quantitative criteria in determining the quality of the soil and water for irrigation (Obiefuna and Sheriff, 2011). The average soil and water SAR values of each irrigation scheme are not out of range to use for irrigation purposes (Table 6, 7& 8 and Figure 2 & 3). In this regard, the SAR parameter does not show any significant differences among the irrigation schemes for both the soil and water samples. The MAR value is dependent on the concentration of calcium and magnesium on the soil and water samples. These elements often make a state of equilibrium (Salifu et al., 2015). According to Raghunath (1987) and Gupta and Gupta (1987) suggested that when MAR is greater than 50% it becomes hazardous for crop production (Table 5).. The MAR results of the irrigation schemes for the soil (for both soil profiles) and water samples shows average values below the maximum limit (Table 6, 7 & 8). Hence, there is no salinity effects associated with magnesium concentration in the irrigation schemes.

The average values of the residual sodium carbonate (RSC) and residual sodium bicarbonate (RSBC) from each irrigation schemes have significant implications with regard the salinity effects. RSC values greater than 2.5meq/l are unsuitable for irrigation (CFC, 1975, Table 5). Since, the average values obtained from all irrigation schemes are not greater than 2.5meq/l the irrigation schemes are under permissible conditions for irrigation purposes (Table 5). The recommended value for RSBC is also safe when it is less than 1.25meq/l. Hence, there is no any irrigation scheme which have RSBC values greater than the recommendation. Hence, there is no effect of bi/carbonate concentrations which hinders crop growth. Therefore, the estimated RSC and RSBC values didn't show any clear significant differences amid each irrigation scheme.

If the permeability index (PI) value exceeds 65, water is considered suitable for irrigation (Doneen 1964, Table 5,). The Kelly ratio (KR) value is also suitable for irrigation if the average values of a given irrigation scheme are less than one (Sundary et al., 2009, Table 5). Accordingly, the average values of the water and soil samples collected from each irrigation scheme are laid under non-suitable for irrigation schemes (Table 6, 7 & 8). In most of the irrigation schemes, the average KR values collected from the soil profiles are generally unsafe for irrigation uses. Exceptions were occurred for the May Gassa and Korir for both soil depths and Gereb Kokhi (0-15cm) and Tegahne (15-30cm) schemes which showed safe conditions to use for irrigation. In contrast, the water samples taken from all cross-sections of the irrigation schemes are under safe conditions for irrigation uses (Table 8).

Table 5: Recommendations of various salinity parameters in agricultural uses

Salinity parameter	Symbol	Unit	Acceptable limit	Sources
Electrical Conductivity	EC	dS/m	0 – 3	Ayers and Westcot 1985
Total Dissolved Solids	TDS	mg/l	0 – 2000	Ayers and Westcot 1985
Calcium	Ca^{2+}	meq/l	0 – 20	Ayers and Westcot 1985
Magnesium	Mg^{2+}	meq/l	0 – 5	Ayers and Westcot 1985
Sodium	Na^{+}	meq/l	0 – 40	Ayers and Westcot 1985
Sodium adsorption ratio	SAR	-	0 – 9	Ayers and Westcot 1985
Bicarbonate	HCO_3^-	meq/l	0 – 10	Ayers and Westcot 1985
Chloride	Cl^-	meq/l	0 – 30	Ayers and Westcot 1985
Alkalinity/ basicity	pH	0-14	6.5 - 8.4	Ayers and Westcot 1985
Magnesium adsorption ratio	MAR	%	<50	Raghunath (1987)
Residual sodium carbonate	RSC	meq/l	<2.5	CFC, 1975
Residual sodium bicarbonate	RSBC	meq/l	<1.25	Eaton (1950)
Permeability index	PI	%	>65	Doneen (1962)
Kelly ratio	KR	meq/l	<1	Sundary et al. (2009)

Table 6: Average values of salinity parameters for each irrigation scheme at 0-15cm root depth

Irrigation schemes	pH	EC	Ca^{2+}	Mg^{2+}	HCO^-_3	Cl^-	Na^+	TDS	SAR	MAR	RSC	RSBC	PI	KR
Gereb Kun-chi	8.50	0.83	3.20	1.12	3.45	6.16	4.77	531.44	3.43	24.70	-0.87	0.25	22.23	1.26
Gum Selassa	8.14	0.54	3.32	1.11	3.27	5.61	4.76	345.71	3.27	23.75	-1.16	-0.05	20.73	1.14
Gereb Me-hizi	7.94	0.80	3.33	1.69	3.24	6.14	5.40	510.10	3.43	33.64	-1.79	-0.09	17.65	1.09
May Gassa	7.94	0.95	3.58	2.06	3.49	7.65	5.16	605.63	3.11	36.16	-2.15	-0.09	18.19	0.95
Gereb Wedicheber	8.29	0.58	3.26	1.84	3.79	6.44	5.22	370.16	3.31	34.65	-1.31	0.53	19.87	1.06
Gereb Kokhi	8.32	0.42	3.18	2.35	3.63	5.73	5.06	271.20	3.09	40.74	-1.90	0.45	19.04	0.96
Arato	8.01	0.58	3.45	1.77	3.76	5.70	5.22	369.34	3.29	33.16	-1.46	0.32	19.50	1.05
Korir	8.12	0.59	3.84	2.38	3.63	5.63	4.86	378.78	2.86	38.71	-2.59	-0.21	18.19	0.86
Tegahne	8.49	1.58	5.39	2.21	3.78	5.87	4.72	1011.41	2.89	-93.58	-3.82	-1.61	17.92	1.40
Mean	8.12	0.76	3.62	1.84	3.56	6.10	5.02	488.20	3.19	19.10	-1.89	-0.06	19.26	1.09
Std. dev	0.22	0.35	0.70	0.48	0.21	0.65	0.25	222.85	0.21	42.64	0.89	0.64	1.51	0.17

Note: pH (dimensionless), MAR and PI in % and the remaining in meq/l

Table 7: Average values of salinity parameters for each irrigation scheme at 15-30cm root depth

Irriga-tion schemes	pH	EC	Ca^{2+}	Mg^{2+}	HCO^{-}_{3}	Cl^{-}	Na^{2+}	TDS	SAR	MAR	RSC	RSBC	PI	KR
Gereb Kunchi	8.59	1.76	2.89	0.81	3.51	5.36	4.77	1123.56	3.63	13.43	-0.19	0.62	23.14	1.47
Gum Selassa	8.14	0.54	3.51	0.99	3.42	5.81	4.87	346.75	3.34	21.76	-1.08	-0.09	21.00	1.16
Gereb Mehzi	8.29	0.77	3.47	1.58	3.37	6.03	5.38	495.64	3.42	30.87	-1.68	-0.10	18.29	1.09
May Gassa	7.92	1.27	3.57	2.03	3.49	5.49	5.00	811.48	3.04	36.54	-2.10	-0.08	18.53	0.94
Gereb Wedicheber	8.31	0.63	3.25	1.80	3.77	6.45	5.18	400.97	3.30	34.04	-1.28	0.53	19.77	1.06
Gereb Kokhi	8.27	0.40	2.84	1.64	3.36	5.23	4.80	254.30	3.25	35.28	-1.12	0.52	20.47	1.11
Arato	8.18	0.60	3.55	1.67	3.79	5.56	5.42	382.51	3.41	32.65	-1.43	0.25	19.09	1.09
Korir	8.17	0.54	4.17	2.29	3.58	5.39	4.85	344.42	2.88	36.89	-2.88	-0.59	17.98	0.91
Tegahne	8.45	1.69	5.49	2.30	3.83	6.03	4.74	1080.77	2.67	29.89	-3.96	-1.66	16.88	0.83
Mean	8.47	0.91	3.64	1.68	3.57	5.71	5.00	582.27	3.22	30.15	-1.75	-0.07	19.46	1.07
Std. dev.	0.19	0.52	0.80	0.52	0.18	0.40	0.26	334.28	0.30	7.78	1.11	0.71	1.88	0.18

Note: pH (dimensionless), MAR and PI in % and the remaining in meq/l

Table 8: Values of salinity parameters for water from upper, middle and lower cross-sections of the irrigation schemes

Schemes	Cross-sections	pH	EC	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	Na^{2+}	TDS	SAR	MAR	RSC	RSBC	PI	KR
May Gassa	Upper	7.53	0.55	6.60	5.40	2.40	0.80	2.87	352.0	1.2	45.0	-9.6	-4.2	10.6	0.2
Gereb Mihzi	Upper	7.65	0.28	9.40	5.00	2.00	2.80	0.84	179.2	0.3	34.7	-12.4	-7.4	9.3	0.1
Korir	Upper	7.20	0.41	7.60	5.00	3.20	3.60	0.46	262.4	0.2	39.7	-9.4	-4.4	13.7	0.0
Arato	Upper	7.61	0.96	4.80	3.40	2.40	3.60	3.43	614.4	1.7	41.5	-5.8	-2.4	13.6	0.4
Tegahne	Upper	7.00	0.50	3.80	2.40	2.40	4.40	1.10	320.0	0.6	38.7	-3.8	-1.4	21.4	0.2
Gereb Kokhi	Upper	7.71	1.77	13.00	6.60	2.00	3.60	3.94	1132.8	1.3	33.7	-17.6	-11.0	6.2	0.2
Gereb Wedicheber	Upper	7.51	0.41	4.80	4.60	2.20	2.80	1.92	262.4	0.9	48.9	-7.2	-2.6	13.3	0.2
Gereb Mihzi	Middle	7.81	0.59	3.00	2.60	3.40	3.60	4.22	377.6	2.5	46.4	-2.2	0.4	19.2	0.8
Korir	Middle	7.41	1.35	8.80	5.60	1.80	4.40	3.29	864.0	1.2	38.9	-12.6	-7.0	7.8	0.2
Arato	Middle	7.72	1.04	5.40	4.60	2.60	4.00	3.98	665.6	1.8	46.0	-7.4	-2.8	11.8	0.4
Tegahne	Middle	7.92	0.50	3.60	2.40	4.40	4.00	3.37	320.0	1.9	40.0	-1.6	0.8	22.8	0.6
Korir	Lower	7.74	1.57	10.40	5.80	3.20	4.00	3.88	1004.8	1.4	35.8	-13.0	-7.2	9.1	0.2
Tegahne	Lower	8.01	0.54	2.40	2.00	3.80	3.60	2.78	345.6	1.9	45.5	-0.6	1.4	27.5	0.6

Note: pH (dimensionless), MAR and PI in % and the remaining in meq/l

Spatial distributions of soil salinity

Identifying spatial salinity hazard distribution within the schemes is helpful for irrigation users and decision makers to put solutions for all or parts of the irrigation schemes. The results of the spatial soil salinity distribution, presented in this section, is due to soil sample analysis alone. Hence, a gridded spatial salinity map of the nine irrigation schemes are given for the SAR, pH and EC parameters. Spatial salinity maps for Arato, May Gassa and Gereb Kunchi irrigation schemes are given in Figures 4, 5 & 6, respectively. We used the location of the water sources (dam/diversion point) given in each figure, as a reference point so as to identify the irrigation schemes' spatial salinity distribution.

SAR spatial distribution

As indicated in Figures (4, 5 & 6) a sample of the SAR spatial distributions of schemes are given in soil depth basis (0-15cm &15-30cm soil profile). Accordingly, Gereb Wedicheber, Tegahne, Korir and Gereb Kokhi irrigation schemes have shown relatively higher SAR values at the downstream scheme for both soil profiles. While, Gum Selassa and Gereb Mihzi showed higher values at the upstream schemes for both soil profiles.

The Gereb Kunchi, however, has maximum values at the downstream for the 0-15cm soil profile while the maximum values for the 15-30cm soil was found at upstream schemes. Exceptionally, the Arato irrigation scheme has a maximum value at the middle of the irrigation scheme. In general, there are no consistent SAR variations among the irrigation schemes and between the soil depths. However, compared to the recommended standards of FAO (Ayers and Westcot, 1985), the spatial distribution maps of SAR for all of the irrigation schemes were felt under safe to use for irrigation in both soil depths.

pH spatial distribution

Unlike the SAR, the pH spatial map has become an indicator parameter in showing a consistent variation among the irrigation schemes. Except Arato (higher in the upstream), the remaining irrigation schemes have maximum pH values at the downstream. The location of the maximum pH value of the Arato (9.1), Gereb Kunchi (9.2), Gereb Wedicheber (8.8), Korir (8.5), Gum Selassa (8.52) and Tegahne (8.8) irrigation schemes have identified in their respective maps. These irrigation schemes have values above the limit for irrigation purposes that could take an attention towards putting adaptation strategies. Generally, the studied irrigation schemes have shown an increasing trend towards the salinity hazard for both soil depths, especially at their downstream cross-sections. This is due to the low laying positions such that soil and water properties from the upper schemes flow and concentrates towards it.

EC spatial distribution

The EC maps of sample irrigation scheme are also presented in Figures (4, 5 &5). Yet, there is no clear consistency of the EC values for the upper, middle and downstream cross-sections of the irrigation schemes. Higher EC values were obtained in the upper cross-sections of Gum Selassa, May Gassa, Tegahne and Gereb Wedicheber whereas Arato and Korir irrigation schemes revealed their maximum values at the downstream. Exceptional is the Gereb Kunchi irrigation scheme, which showed a very high EC values with clear variations between the soil depths. This irrigation scheme has a maximum value of 5.94 dS/m in the 0-15cm and 10.12 dS/m in the 15-30cm, which is categorized as very toxic for plants to grow (Ayers and Westcot, 1985).

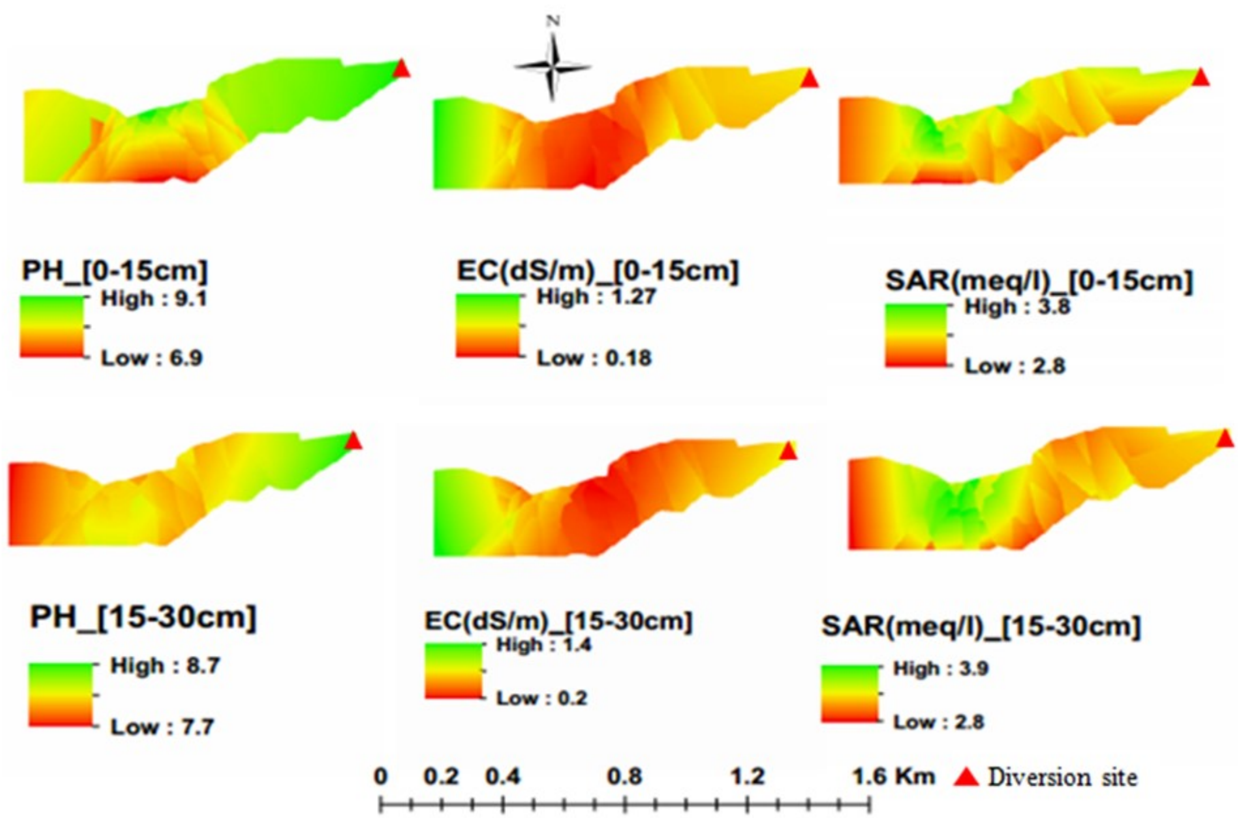

Figure 4: Spatial salinity distributions (pH, CE and SAR) of Arato irrigation scheme

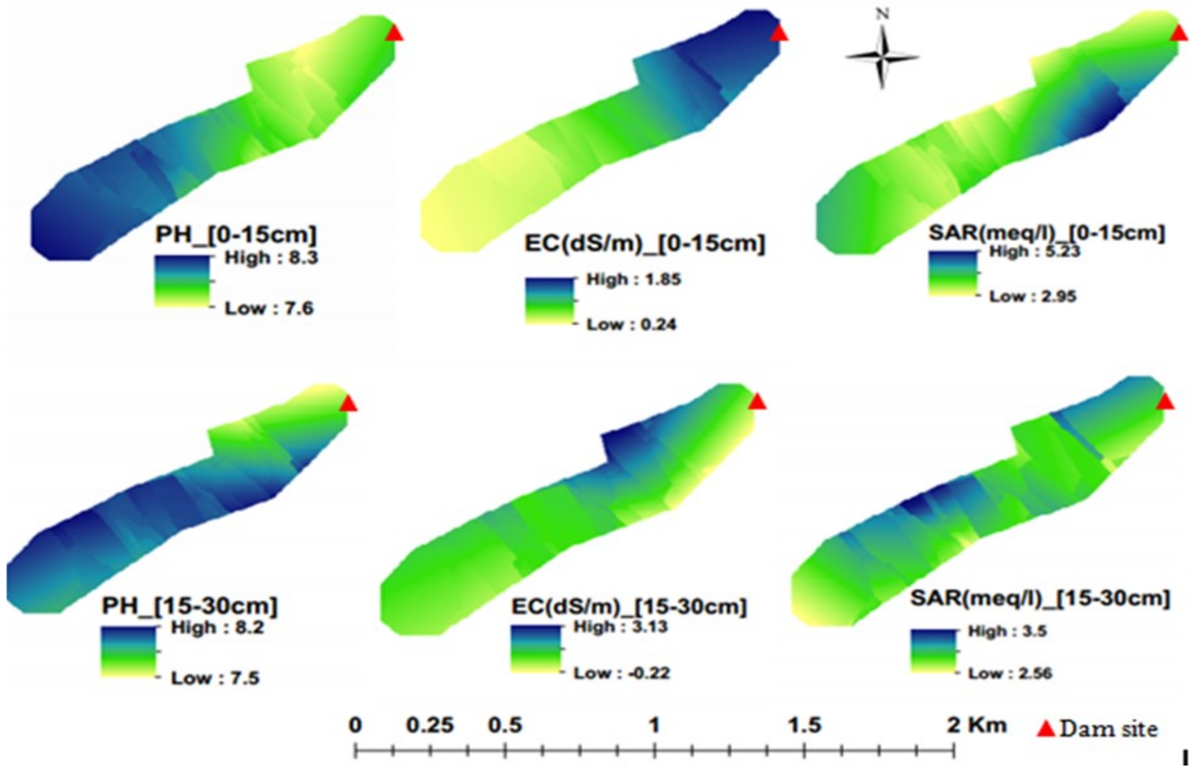

Figure 5: Spatial salinity distributions (pH, CE and SAR) of May Gassa irrigation scheme

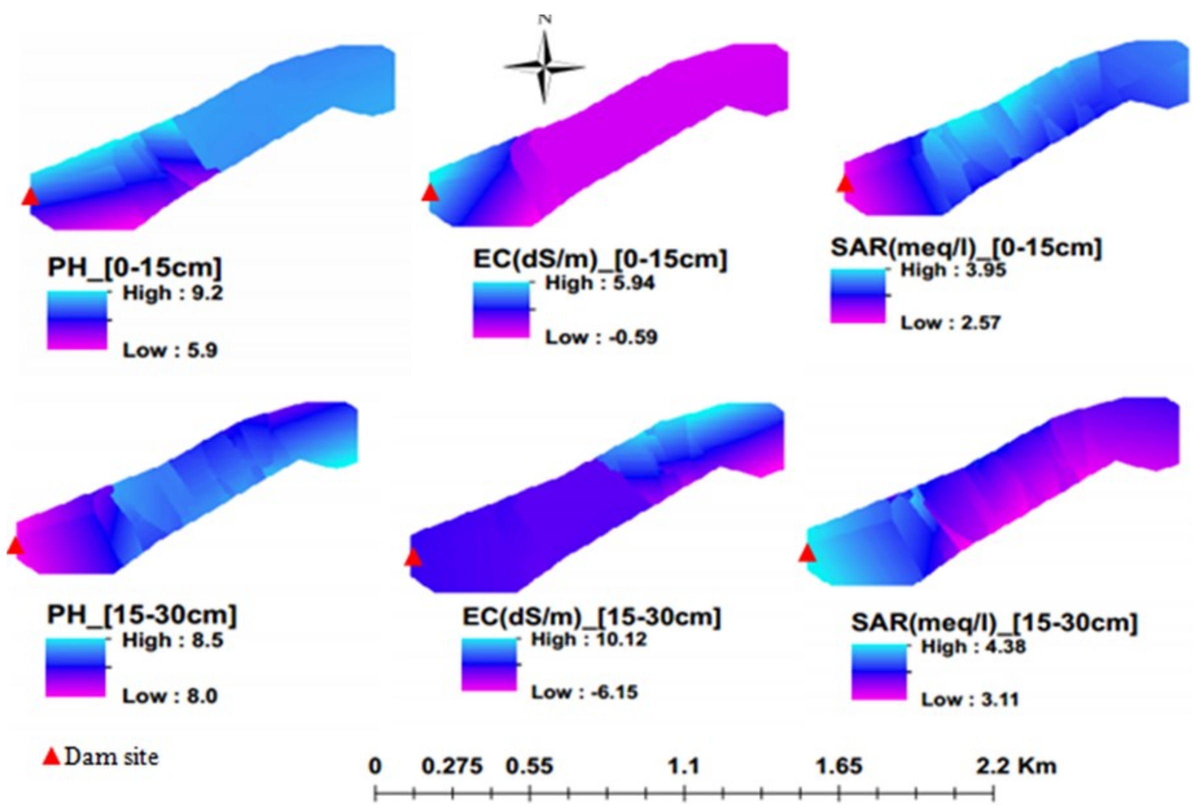

Figure 6: Spatial salinity distributions (pH, CE & SAR) of Gereb Kunchi irrigation scheme

The spatial map of each irrigation scheme has helped to show spatial salinity variations for the pH, EC and SAR parameters. Even if, the majority of the schemes is safe to use for irrigation purposes, the Gum Selassa, Gereb Kunchi and Tegahne irrigation schemes have shown higher quantity of soil salinity. Yazew et al., (2005) has revealed higher presence of soil salinity in Gum Selassa than Korir irrigation scheme. Similarly, Haile et al. (2002) indicated that 0.15, 0.29 and 0.15 dS/m EC values were obtained in the top, middle and bottom of the Gum Selassa irrigation scheme, respectively. Hence, there should be a quick introduction of salinity prevention and reduction strategies in these schemes. These could be in terms of soil amendment additions such as gypsum and organic manures, effective use of water applications based on the crop water requirements, and it is also better to introduce drainage facilities for leaching the soluble salts in the irrigation schemes. By far the development and introduction of salt tolerant crops are vital in these schemes.

Conclusions

Soil salinity, waterlogging, in-situ erosion and low soil fertility are among the serious problems existing to varying extent and severity at the irrigation schemes in the Tigray region. Expansion of salt affected soils in the irrigation schemes are increasing in time and space as a result of expansions in irrigated agriculture. However, the rate and spatial distribution of salinity developments occurred in the irrigation schemes are yet unknown. Hence, formation of salt affected soils as a result of expansions in irrigated agriculture were quantified and mapped by taking soil and water samples from nine irrigation schemes in the region. The soil samples were collected on grid basis at fixed intervals based on soil profiles at which crops are grown. The water samples were also collected from the upper, middle and lower cross-sections of the irrigation schemes. The soil and water samples were analyzed for various salinity parameters (cations, anions, pH and their derived indices). The soil data were interpreted in quantity and mapping so as to clearly identify the salinity hazards in the irrigation schemes. The water samples, however, were analyzed for its quantity for each scheme. The spatial analysis reveals that, pH is higher at downstream scheme while SAR and EC doesn't have consistent variations among the irrigation schemes. The soil and water quantitative analysis and the spatial distributions of the salinity revealed that the Gum Selassa, Gereb Kunchi and Tegahne irrigation schemes have a potential salinity hazard. However, the soil profile based soil analysis and scheme cross-sections (upper, middle and lower) based water analysis doesn't show any clear significant evidence to be become salt affected soils in the irrigation schemes. Application of appropriate salinity management strategies such as effective irrigation water management, use of ameliorative methods (such as gypsum and organic manure) and drainage facilities (leaching) should be practiced for controlling the salinity hazards in the irrigation schemes. It is also useful to introduce promising salinity tolerant crops in the salinity affected soils of the irrigation schemes. Beyond the soil and water sample analysis in the laboratory, applications of infield instruments such as salinity sensors (kits), electromagnetic sensors (EM38) have paramount importance for quick on site salinity assessments in the irrigation schemes. Geographic Information Systems (GIS) and advanced techniques of remote sensing and modelling should also be employed in the assessments and monitoring of the salt affected soils in the irrigation schemes.

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Improving crop and water productivity of onion and potato through the use of wetting front detectors by water user associations in Koga irrigation Scheme, Ethiopia

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Abstract

Whilst irrigation schemes and technologies are extensively promoted in Africa, proper water management guidance for farmers is often lacking. Improper on-farm irrigation management practices lead to poor water distribution, non-uniform crop growth, and disputes in irrigation schemes due to unequal water allocation. Hence, the objective of the study was to introduce wetting front detectors (WFDs), a simple mechanical tool, to water user associations to guide them on water allocation within the scheme. Two water user associations (WUA's) were selected in Tagel, Adibera and Chihona irrigation blocks. The water allocation was compared against a control group where nor WUA's nor farmers had access to a WFD. Potato fields which were irrigated based on WFD response received on average 40% less water compared to control field ($p<0.05$) resulting in a significant yield increase of 6 % in the WFD plots.Similarly, for onion a reduction in irrigation depth of 24% was obtained when farmers were guided by WFD, leading to a non-significant yield increase by 1.3%. Furthermore, the results showed that not all farmers necessarily need to have a tool installed in their field as long as communication and information between farmers within the same WUA is facilitated. The water saved by the WUA couldincrease the areal coverage of 2016 cultivated onion and potato by 33 % and 75 %, equivalent to 2 % - 5 % of the entire irrigated land and 1% to 5 % of the potential command area. Improving on-farm water management not only at farm level but also scheme level could result in meeting the potential command area in the scheme if similar savings would be obtained for other crops and water seepage/losses along the canals could be reduced. The higher crop productivity, areal expansion and increased nutrient use efficiency of agricultural inputs could positively influence the economic aspect of smallholder cultivation in these schemes.

Key words:irrigation, on-farm water management, water productivity, water users association, wetting front detectors

Introduction

In Sub-Saharan Africa (SSA), irrigation is being extensively promoted as a coping mechanism against climate variability. From the irrigated land, the estimated irrigation consists out of 38 % traditional, 20 % modern communal, 4 % modern private and 38 % public schemes (Awulachew *et al.*, 2007).

With on-farm water management being efficiently carried out, the distribution of water within the schemes can be optimized leading to a reduction in inequitable water allocation and an increase in economic viability of the entire scheme (Bjornlund *et al.*, 2017). Many irrigation scheduling technique remain of high complexity to farmers or water user associations. Simple, mechanical tools such as the wetting front detector (WFD) (Stirzaker, 2003; Fessehazion *et al.*, 2011; Stirzaker *et al.*, 2017) have proven very successful in enhancing on-farm water knowledge for irrigators in SSA. These show great potential in training water user associations in better water allocation among farms at the same scheme outlet as improving water use efficiency at farm level does not necessarily result in increased water use efficiency at scheme level (Giordano *et al.*, 2017). Therefore, this study introduced wetting front detectors to WUA's in three blocks of an irrigation scheme and assessed the potential effect on irrigable land expansion in the scheme. Furthermore, the study compared the results obtained in WUA's groups using a WFD against control groups using tradition irrigation knowledge. The effect of water usage on crop and water productivity were assessed for onion and potato.

Material and method

Site description

Koga watershed is located in the headwaters of the Blue Nile, Ethiopia. The elevation stretches from 1800 m at the gauge station ($11^0 22'12''$N latitude and $37^0 02'15''$E longitude) to 3000 m above sea level (Gebrehiwot et al., 2010).

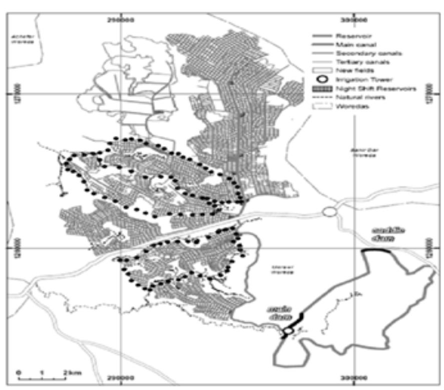

Figure 1: Map of Koga irrigation Scheme, Dotted line indicate the experimental blocks of Tagel(T) (616 ha), Chihona (C) (617 ha) and Adibera(A) (803 ha) Source (Eguavoen and Tesfai, 2011).

The reservoir stores 83 10^6 m^3 able to irrigate twelve irrigation blocks 7,000 ha (Haileslassie *et al.*, 2016). Through a main canal of 19.7 km, water from the reservoir is diverted to eleven night storage reservoirs (NSRs), one located per block with the exception of Amarit block, get water directly from the main dam.

In 2016, the cultivated area of wheat, potato and onion in the scheme were 2576, 495 and 186 ha respectively.

Experimental design

The irrigated area in 2016 for the selected blocks were 338 ha, 352 ha and 463 ha in Tagel, Chihona and Adibera, respectively. Two WUAs located along the same quaternary canal in each block were selected (Figure 1). The three WUA irrigating onion covered a total area of 2.04 ha managed by 9 WFD (24 farmers) and 0.82 ha managed by farmer's practice (7 farmers). For potato a total of 1.68 ha of land was managed by 10 WFD (19 farmers) and 0.42 ha of land was irrigated using farmers practice (6 farmers).

Table 1: Overview of the total ha per block irrigated through WFD or farmer's practice with the number of farmers following the WFD in parenthesis.

Block	*Onion*		*Potato*	
	WFD	Control	WFD	Control
Adibera	0.36 (7)	0.04 (2)	0.71 (8)	0.26 (2)
Chihona	0.81 (6)	0.35 (3)	0.81 (8)	0.14 (3)
Tagel	0.86 (11)	0.43 (2)	0.16 (3)	0.02 (1)
Total	**2.04 (24)**	**0.82 (7)**	**1.68 (19)**	**0.42 (6)**

Each farmer ploughed their land and prepared 5 m (onion) length or 20 m (potato) length furrows. The WFD were installed at 75 % of the furrow inlet where the shallow detector was placed at 20 cm depth and the deep detectorat 40 cm depth (details in Stirzaker et al. (2004)) (Figure 2).

Figure 2: **Schematic diagram for the installation of the wetting front detector according to Stirzaker et al. (2004) (left) with an example for onion (right).**

Table 2: Overview of median and standard deviation (SD) of soil physico-chemical properties of the topsoil (0 – 20 cm) in the scheme.

	pH (H_2O)	Bulk density (g cm^{-3})	FC (%)	WP (%)	CEC (cmol kg^{-1})	Sand (%)	Silt (%)	Clay (%)	N (%)	P (ppm)	Fe (ppm)
Median	5.0	0.90	31.06	19.02	21.00	22.00	54.00	24.00	0.21	14.72	15.38
SD	0.3	0.03	2.11	1.10	2.33	6.36	8.59	4.27	0.03	7.91	2.19

Quantification of water usage, crop and water productivity at field and WUA level

To know the amount of water irrigated, a 2-inch Parshall flume was used at the inlet of the fieldand quaternary outlet and water depth was measured. The depth of the water that passed through the Parshall flume was recorded on a daily basis according to:

$$Q=0.1207*h^{1.55} \qquad \text{Eq. 1}$$

Where Q is the discharge (m^3s^{-1}) and h is the water depth (m) through the Parshall flume.

In each field where WFD were installed the response time for both the shallow as well as deep detector was recorded and shared information for the farmers. Total irrigation amount applied was calculated according to:

$$I = Q * t \qquad \text{Eq. 2}$$

All collected data were tested for normality using SPSS (version 20) software and (ANOVA) at a 5% significance level was performed.

WithI the total volume irrigated (m^3), Q the discharge to the field ($m^3\ s^{-1}$) and t the total irrigation time for the field (s).

Additionally the irrigation productivity (IP) was calculated by dividing the obtained marketable yield for each plot by the total irrigation volume applied (m^3).

All collected data were tested for normality using SPSS (version 20) software and (ANOVA) at a 5% significance level was performed.

Result and discussion

Response time of the shallow detector

Median pop up time of shallow detector was 10.8, 5.7, 5.1 and 5 minutes for potato and 3.2, 2.5, 2.9 and 2.5 minutes for onion at initial, development, mid and late stage respectively. The shallow detector response time mainly depended on the soil residual moisture content and crop stage. Due to the increase in soil moisture during the season the detector showed a non-significant faster response in the late stage compared to the mid-crop stage.

Irrigation water applied at various stages

The pattern of irrigation depth applied for the various stages followed the response of the shallow detector in the field. In each stage higher irrigation depth was observed in the control compared to the WFD treatment for both crops ($p<0.05$).

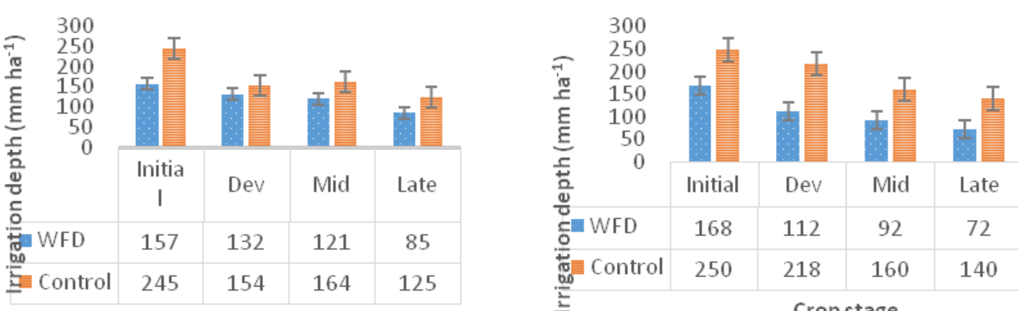

Figure 3: Average and standard error for irrigation depth (mm) applied to onion (left) and potato (right) in the WFD (blue) and control (orange) treatment.

Irrigation water used at farm and WUA level

Potato under farmers practice received 738 mm ha^{-1} whilst those under WFD treatment received only 442mm ha^{-1}(Table 4) resulting in a significant reduction of 40 %. The obtained average irrigation depth reduction falls within the range of 12 % to 60% reported by Schmitter et al. (2017) who measured the impact of WFD on irrigation depth in potato fields having hetereogenous furrow lengths. Fields under onion cultivation received 512 mm $ha^{-1}$when farmers managed by WFD irrigation scheduling tool, a 24 % reduction compared to those not receiving any information who used 672mm ha^{-1} (Table 4). Melaku et al., (2016), who used overhead irrigation instead of furrows, showed a 20 % decrease in water application when farmers were guided by the WFD.

Table 4: Minimum (min.), maximum (max.), median, standard deviation (SD) and coefficient of variation (CV, %) for the applied irrigation depth.

	Onion		Potato	
	WFD	Control	WFD	Control
Min.	389	368	210	713
Max.	632	976	527	830
Median	512[a]	672[b]	442[a]	738[b]
SD	56	213	70	41
CV (%)	32	11	16	6

At WUA level, irrigation volumes released for potato fields were on average 4634 m^3, 4504 m^3 and 4150 m^3per ha for the WFD treatment and 7252 m^3, 8299 m^3 and 7390 m^3 per ha for farmers' practice treatment in Chihona, Tagel and Adibera respectively. This resulted in a significant water saving of 36%, 46% and 44% at Chihona, Tagel and Adibera. Water released for the onion fields following the WFD signaling was 5265 m^3, 4620 m^3 and 5261 m^3 whereas for the control 8785 m^3, 4621 m^3 and 5956 $m^3$for Chihona, Tagel and Adibera, respectively. Control farmers used 40 % more water compared those having access to irrigation information ($p< 0.05$) in Chihona block. However,in Adibera reductions in water release where only 13 % and no difference was observed at Tagel block.

This could indicate that WUA’s in Tagel and Adibera are more experienced in onion irrigation compared to Chihona block.

Crop yield **at field and WUA level**

Farmers following the information provided by the WFD obtained onion yields between 17.8 ton $ha^{-1}$and 32.2 ton ha^{-1} which was on average 2 % higher ($p > 0.05$) compared to those using traditional irrigation knowledge (18.1 to 19.2 ton ha^{-1}). Similar results were obtained for potato, where yields in the WFD treatment ranged between 25.4 ton ha^{-1} and 31.1 ton ha^{-1},a 6 % increase ($p<0.05$) compared to the control treatment (25.0 ton ha^{-1} and 26.5 ton ha^{-1}). The obtained values for potato lie within the range of those reported by Schmitter et al. (2017), who obtained an average value of 25.3 ton ha^{-1} and 21.9 ton ha^{-1} for WFD and control managed plots, respectively.

The variation in the WFD treatment between farmers was higher compared to the control plot and most likely related to difference in fertilizer application and its interaction with water management. The potential of reducing the high fertilizer rates applied in the scheme was shown by Endri et al. (2017) who identified that 20 % and 50 % less N and P could be applied for onion when improving on-farm water management in farmers’ fields when using WFD to schedule irrigation.

At WUA level, median potato yields following WFD advice were 27.6 ton ha^{-1}, 27.0 ton ha^{-1} and 27.4 ton ha^{-1} and following farmers’ practice were 26.0 ton ha^{-1}, 26.4 ton ha^{-1} and 25.3 ton ha^{-1} at Chihona, Tagel and Adibera, respectively. This corresponded to a 6% ($p>0.05$), 2% ($p>0.05$) and 1 % ($p<0.05$) yield increase, respectively. Median onion yields of 18.5 ton ha^{-1}, 18.9 ton ha^{-1} and 19.4 ton ha^{-1} were obtained when farmers followed irrigation advice (i.e. WFD) compared to 18.7 ton ha^{-1}, 18.7 ton ha^{-1}, 18.3 ton ha^{-1}control in Chihona, Tagel and Adibera, respectively. The analysis showed a non-significant increase of 1 % and 6 % yield in Tagel and Adiberarespectively and a slight decrease (- 1 %) in Chihona.

Irrigation productivity at farm and WUA level

Median irrigation productivity for irrigated onion fields (3.7 kg m^{-3}) in the WFD treatment was found to be 24 % higher than those obtained in the control fields (2.8 kg m^{-3}) ($p<0.05$) . Similarly for potato a 45 % higher irrigation productivity was found when farmers had access to irrigation scheduling information (6.3 kg m^{-3}) compared to the control (3.4 kg m^{-3}) ($p<0.05$) (Table 6).

At WUA level similar results were obtained with the WFD treatment (i.e. 5.8 kg m^{-3}, 5.8 kg m^{-3} and 6.7 kg m^{-3})resulting in a 38%, 45% and 49% higher irrigation productivity compared to the control (i.e. 3.6 kg m^{-3}, 3.2 kg m^{-3} and 3.4 kg m^{-3}) ($p<0.05$) for Chihona, Tagel and Adibera block, respectively. The results for onion was a combination of the differences observed in the irrigation water released and its effect on yield.While a difference of 41 % and 12 % was obtained for Chihona and Adibera no difference was observed in Tagel between both treatments. Mean dry matter based irrigation productivity for onion following the WFD based information resulted in 3.6 kg m^{-3}, 4.1 kg m^{-3} and 3.6 kg m^{-3} compared to 2.2 kg m^{-3} and 4.2 kg and 3.1 kg m^{-3} in the control for Chihona, Tagel and Adibera block, respectively.

Estimated areal increase in irrigation at WUA, block and scheme level

Subtracting the portion used for the WFD treatment from the irrigation volume released at the quaternary outlet resulted in a water saving of24,877m^3;22,431m^3 and 24,769 m^3 for onion and 37,293 m^3;31,561 m^3 and 27,350 m^3 for potato at Adibera, Chihona and Tagel, respectively. Considering the total land area available at the quaternary outlet the estimated savingin 2016 would be sufficient to irrigate 85 %, 74 % and 72 % of the available irrigable land for onion and 123 %, 90 % and 88 % for potato in Adibera, Chihona and Tagel, respectively.

At block level the estimated water saved in onion irrigation would be sufficient for an additional 6 to 10 ha which would be between 2 % to 3 % of the total irrigated land in 2016 and between 1 % and 2 % of the potential land in each block. Given the larger water saving effect in potato,it could irrigate between 40 ha and 70 ha (i.e. 12 – 15 %) additionally for 2016 and around 7 % to 9 % of the total potential land.

Following a similar approach at scheme level the water saved could irrigate 61 ha or 372 ha of onion or potato, respectively which is an areal increase at scheme level of 33 % and 75 % of onion and potato in 2016. Taking into account the total irrigated land in 2016 it would represent an expansion of 2 % for onion and 10 % for potato, roughly 1 % and 5% respectively of the potential irrigable scheme (which is 7,000 ha).

Conclusion

The field based evidence following the WFD information was used to decide on water cut-off times by the WUA resulting in a feasible and equitable way of managing water. The largest water and crop productivity gains were found for potato, the results in the onion group did show similar trends. However, the margin of water productivity improvement seemed to be higher for potato compared to onion. The reduction in irrigation volume could positively influence water allocation at the tail of the scheme and potentially decrease water conflicts in the future. Simultaneously, the estimated areal increase for both onion and potato at WUA and scheme level would indicate that the designed command area of 7,000 ha could be successfully irrigated in the future as farmers and WUA gain confidence in irrigation. The results show that not all farmers necessarily need to have a tool installed in their field as long as communication and information between farmers within the same WUA is facilitated.

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Improving Crop Water Productivity with Alternate Furrow Irrigation in Semi-Arid Conditions of Northern Ethiopia.

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Abstract
The major production constraint in irrigated agriculture, especially in arid and semi-arid areas, is scarcity of irrigation water. Thus, improving the management of irrigation water by adopting best water-saving irrigation techniques is very crucial to reduce water losses and thereby enhance water use efficiency (WUE) of crops. Hence, this research was conducted for two years to identify the effect of Alternate Furrow Irrigation (AFI) on yield, WUE and economic return of onion (Allium cepa L.) at Hamedo irrigation scheme as compared to Conventional Furrow Irrigation (CFI), at different water levels (100, 80 and 60% of crop evapotranspiration, ETc). Results indicated that AFI maintained almost similar bulb yield but with up to 50% reduction in irrigation amount when compared to CFI. The maximum marketable bulb yield obtained at 100% ETc with CFI was 22.9 ton/ha which is not statistically significant with that of obtained underAFI(20.8 ton/ha). However, the WUE of onion under AFI at 100% ETc was higher (7.12kg/m^3) than that of CFI at 100% ETc (3.9kg/m^3).Moreover, the amount of water saved by AFI, at all levels of water, was also much higher (293.8-413.1mm) than even that of 60%ETc under CFI (238.4mm).Overall, under limited water resources, application AFI increased the benefit-cost ratio (BCR) associated with labor and water delivery (pumping) to the field. Therefore, it can be recommended that AFI at 100% ETc is a practical technique to improve yield and water use efficiency for irrigated crops in the conditions of the study area and other similar agro ecologies elsewhere in the world.

Keywords: Alternate furrow irrigation, Onion yield, water productivity, benefit cost ratio.

Introduction

The central zone of Tigray region, Northern Ethiopia is one of the potential areas for vegetable production in Ethiopia (AxARC. 2009; EHDA, 2011).However, shortage of irrigation water is the major limiting factor for crop production as the climate of the region is mainly semi-arid and most of the region experiences scanty, erratic and inadequate rain fall with high temporal and spatial variability that remains insufficient for crop production (Araya et al. 2005; Zenebe., et al. 2012).Due tot his erratic and inadequate rain fall which leads to scarcity of surface water resources especially during dry season, farmers and other stakeholders are forced to see another option for source of irrigation water, and they tend to develop and utilize ground water sources like shallow wells and deep wells (BoARD, 2015).But here farmers face two kind of problems, the amount of water is not sufficient to irrigate their land (approximately 0.5 a hectare) on one hand, and the high costs of pumping the water to the field on the other hand.

Surface irrigation in Ethiopia in general and Tigray in particular, is the oldest and still the most widely used method of water application to agricultural lands. This type of irrigation method, especially furrow and basin, are commonly used in our country in almost all-large and small irrigation schemes FAO (2001). The main challenge here is that how to utilize the available water more efficiently. Farmers often use more water to irrigate their plots without giving attention to the water losses and as a result the irrigated area by a farmer having a shallow well is not more than half a ‘’tsmad’’ (1250m^2) while there is more than half a hectare of potential irrigable land. Furthermore, due to technical and economic difficulty of developing water sources for irrigation in the region, there is substantial consensus of utilizing the available water resources economically to save water and expand the irrigable area and increase frequency of production so that a farmer can produce enough food throughout the year.

Recently elsewhere in the world, there is a growing interest in AFI, an irrigation practice whereby water is applied to alternate furrows instead of every furrow, while the in-between furrows remain dry and yield stress is allowed with minimal effects on yield(Kang et al., 2000a;Ibrahim and Emara, 2010;Slatni et al., 2011; Mashori, 2013 and A.A. Siyal et al., 2016). Alternate furrow irrigation system may supply water in a manner that greatly reduces the amount of surface wetted leading to less evapotranspiration and less deep percolation.Comparing to CFI, the reduced evapotranspiration is due to a reduction in wet soil surface and the reduced deep percolation is due to the lower wetted surface which result in lower infiltration. Generally, the efficiency of conventional furrow irrigation can be improved by converting it to alternate furrow irrigation (Mintesinot et al., 2004, Awad Abd El-Halim. 2013 and Mohammed M., and Narayanan K., 2015). It minimize irrigation costs and irrigation applications with up to 50% reduction in irrigation amount without a loss in yield or only slight reduction.

Theconventional furrow irrigation practiced by farmers in the region, where every furrow is irrigated during consecutive watering, is known to be less efficient particularly where there isshortage of irrigation water. Subsequently, this improper on farm irrigation management practices in the region may lead to non-productive water loss, poor water distribution, non-uniform crop growth, water logging, salinity and leaching of valuable nutrients below the root zone (Eyasu, 2005; Kifle and Gebretsadikan. 2016). Applying too much water with CFI could result in extra pumping costs, particularly where there is shortage of irrigation water. Whereas, AFI can minimize water application and irrigation costs, save water, control soil salinity build up.

Farmers in developing countries like Ethiopia, especially Tigray region,have nochance to adopt pressurized irrigation technologies due to their high initial cost and technical difficulties such as installation, operation and maintenance (Haregeweyn et al. 2011; Gebremedhin et al. 2017).Accordingly, farmers want to staywith the traditional surface irrigation methods mainly furrow and basin. This may be due to their simplicity to operate and maintain based on farmer's knowledge and skill.So, it is fortunate to improve the CFI to AFI that could be easily accepted by farmers.However, before introducing and promoting AFI for adoption, it is important to evaluate it under the soil and climatic conditions of the targeted districts.

The objective of this study is to evaluate the improvements in water productivity, water savings and economic returns that could be achieved with AFI compared with CFI at different levels of water application with no or insignificant reduction of onion bulb yield. This paper also provides lessons for farmers, extension workers, water managers and decision makers how to use the limited available water more efficiently withAFI and increase their agricultural production by expanding their irrigable land using the saved water.

Materials and methods

Description of the study area

The experiment was conducted in Tigray region, northern Ethiopia for two consecutive years 2011/12 and 2012/13 on a sandy clay loam soil at the Research Station of Axum Agricultural Research Center (**Fig.1**). It is located in $14^0$409'38"N and$38^0$735'45"E and altitude 1390 m above sea level. The average annual rainfall of the area was 650 mm. Seasonal rainfall patterns at the experimental area shows uni-modal distribution, which extends from June to early September. The mean minimum and maximum monthly temperature ranges from 12.2^0c to 27.9^0c, respectively. The soil type of the experimental site was sandy clay loam.

Experimental design and treatments

The experiment was laid out in a factorial randomized complete block design (RCBD) with three replications. The design consisted of two irrigation methods (Alternate furrow irrigation and Conventional furrow irrigation) and three levels of irrigation amount (100, 80 and 60% ETc), see Table 1. The plot size was 4 m × 4 m and the spacing between blocks and plots were 2 m and 1 m respectively. The plots in each replication were represented randomly for each treatment.Cultural management practices other than application of irrigation water were done according to the national recommendations.

Table 1. Treatment settings of the experiment

Treatments	Treatment Description
T1(CFI@100%Etc)	Conventional furrowwith 100% crop water requirement
T2(CFI@80%Etc)	Conventional furrowwith 80% crop water requirement
T3(CFI@60%Etc)	Conventional furrowwith 60% crop water requirement
T4(AFI@100%Etc)	Alternate furrowwith 100% crop water requirement
T5(AFI@80%Etc)	Alternate furrowwith 80% crop water requirement
T6(AFI@60%Etc)	Alternate furrowwith 60% crop water requirement

Crop water requirement and crop water productivity

The reference evapotranspiration (ETo) was estimated using the CROPWAT computer program or FAO Penman-Monteith equation(Allen et al., 1998) using the meteorological data collected from a nearby weather station. The crop water requirements (ETc) over the growing season stages were determined by multiplying the ETo values with the onion crop coefficients (Kc) given by Allen et al. (1998) as 0.7 for the 1st, 0.90 for the 2nd, 1.05 for the 3rd and 0.75 for the 4th growth stages according to the following equation.

$$ETc = Kc*ETo \quad (1)$$

where ETc is the crop water requirement, Kc is the crop coefficient and ETo is the reference evapotranspiration. Since there was no rainfall during the experimental period, net irrigation requirement was taken to be equal to ETc.

Table 2. Crop water Requirement and Irrigation water applied (mm) to each treatments.
CWR=Crop water requirement, NIR= Net irrigation water requirement, GIR= Gross irrigation water re-

Treatments	CWR	E. Rainfall	NIR	GIR
T1(CFI@100%Etc)	352.6	0.0	352.6	587.7
T2(CFI@80%Etc)	281.1	0.0	281.1	468.5
T3(CFI@60%Etc)	209.6	0.0	209.6	349.3
T4(AFI@100%Etc)	176.3	0.0	176.3	293.9
T5(AFI@80%Etc)	140.6	0.0	140.6	234.3
T6(AFI@60%Etc)	104.8	0.0	104.8	174.7

quirement

Crop water productivity or water use efficiency was calculated (Zhang et al., 1998) as:

$$WUE = Y/ ETa \quad (2)$$

where Y is the crop yield (kg/ha) and ETa is the actual evapotranspiration (mm).

Net return (NR) and Benefi-cost ratio (BCR) due to irrigation were calculated as follows:

NR = Gross revenue – Total costs (3)

BCR = NR/Total costs (4)

Data was subjected to statistical analysis using SAS 9.1 software and analysis of variance (ANOVA) was performed to evaluate the statistical effect of treatments. Least Significant Difference (LSD) test at probability level (P) ≤ 0.05 was also used to test any significant difference between treatment means.

Yield and water use efficiency of onion

The responses of onion bulb to irrigation methods and different levels of water stress. The analysis of variance (Table 3.) indicated that the yields were statistically significantly ($p < 0.05$) affected by the amount of irrigation water applied. The maximum bulb yield was found in T1 (22.9 ton/ha) when full irrigation i.e. 100 % of ETc was applied under CFI. Whereas minimum yield of onion was obtained under the fully stressed treatment T6 (10.7 ton/ha). There was no significant different between the yield of T1 (22.9 ton/ha) and T2 (22.2 ton/ha) in spite of of the fact that it was stressed by 20% throughout the growing season. Similarly, T4 (100% ETc under AFI method) maintained similar yield (20.8 ton/ha) while there is a 50% reduction in irrigation water. This finding is also supported by the outcomes obtained by different researchers (Kang et al., 2000a; Mashori, 2013 Mohammed M and Narayanan K 2015 and A.A. Siyal et al., 2016).

Table3. Mean effect of water application techniques on Yield, yield reduction and amount of water saved

MY=marketable yield, YR= yield reduction, VAW= volume of applied water. PEIL = Possible expansion

Treat-ments	MY (t/ha)	WUE (kg/ m^3)	YR (%)	VAW (m3/ha)	Water saved (m3/ha)	PEIL (%)	YI of PEIL (q/ha)
T_1	22.9^a	3.90^c	0.0	5877.0	0.0	0.0	0.0
T_2	22.2^a	4.73^{cb}	3.1	4685.0	1192	25.0	55.0
T_3	14.6^b	4.19^c	36.2	3493.0	2384	68.0	99.0
T_4	20.9^a	7.12^a	8.7	2938.5	2938.5	100.0	209.0
T_5	17.4^b	7.43^a	24.0	2342.5	3534.5	151.0	261.0
T_6	10.6^c	6.09^{ba}	53.7	1746.5	4130.5	236.0	250.0
Mean	18.1	5.58	-	-	-	-	-
Cv %	8.90	12.18	-	-	-	-	-
LSD 0.05	3.5	1.46	-	-	-	-	-

of irrigable land, YI= yield increment due to the expanded area

Similarly, water use efficiency significantly influenced ($P < 0.05$) by the irrigation practices in combination with deficit irrigation applied in onion production. The highest WUE (7.43 kg/m3) was obtained by AFI at 80% ETc followed by AFI at 100% ETc (7.12kg/m3) and the minimum (3.9kg/m3) was obtained by CFI at 100% ETc. AFI at different water levels has indicated better performances in terms of WUE. Moreover, the amount of water saved by AFI, at all levels of water, was also much higher (293.8 - 413.1mm) than that of CFI (0 -238.4mm).But the amount of water saved without significant yield reduction was (119.2- 293.9 mm) which is enough to expandthe irrigable area from 20-50% of the available irrigation area. Similar results have been also reported by Ibrahim and Emara (2010) and Slatni et al. (2011). Mohammed M., and Narayanan K., (2015) also reported thatalternate furrow irrigation showed 5.5% yield reduction with 50% irrigation water.

Economic analysis of treatments

The production costs are not the same for both the CFI and AFI treatments because we assume water charges are based on volumetric amount of water applied, not based on the land area and crop grown. The economic analysis of AFI and CFI shows that the fixed costs (ploughing, seedling, fertilizer, weeding and cultivation) per hectare for growing onion using CFI and AFI is the same (18610 birr/ha), whereas the variable costs (cost of water, labor and pumping) are different based on the volume of water accessed for irrigation and it is amounted tobe 12117.

and 515.9 birr/ha for CFI and AFI respectively. The per hectare crop production for AFI and CFI is however different because of the different amounts of water available to the crop, with the net return being 94678.3 birr/ha for CFIand 84874.2 birr/ha for AFI. This shows that the farmer who used 50% less water using AFI than the farmer who used CFI, will have about 2.1ton/ha (or 9.2%) less bulbyield if they keep it to use, or will have about10098 birr (or 10.6%) less economic gain if they sell their total crop. These results could be due to the high evapotranspiration, which leads to high yield.Similar results were also reported byA.A. Siyal et al., (2016)who reported that AFI produced 1040 kg/ha (7%) less than that of CFI, and 416 dollars (9%) les income than CFI.

Table 4. Economic analysis showing the difference in benefits obtained between the CFI and AFI.

	AW	CWA	TFC	GI	NR	BCR
Treatment	m3/ha	birr/ha	birr/ha	birr/ha	birr/ha	birr/ha
CFI@100% ETc	5877.0	587.7	19821.70	114500.0	94678.3	4.8
CFI@80%ETc	4685.0	468.5	19577.70	111000.0	91422.3	4.7
AFI@100% ETc	2938.5	293.9	19125.85	104000.0	84874.2	4.4

AW= Applied water, CAW= Cost of applied water use, TFC= Total fixed cost, GI= Gross income, NR= Net return and BCR= Benefit cost ratio

Furthermore, 9.2% less yield or 10.6% less income may seem like much worse to some people and they will certainly question why they should change if they see a decrease in yield or income for adopting AFI practices compared with those who retain CFI. However when we compare them in terms of water saving and the potential ofexpanding the irrigable land, AFI can increase the yield and income of a farmer roughly by 45.4 and 50% respectively. However, when we consider the additional production from the expanded area, the net income of AFI will be 39.4%.

Conclusions and recommendations

Alternate-furrow irrigation can be used as an efficient method in the semi-arid areas Tigray, northern Ethiopia as it is easy to apply (farmers friendly) The experimental results on alternate furrow irrigation for onion production revealed that this method can maintained similar yield (20.8ton/ha) with up to 50% water reduction (saving) compared with CFI (22.9 ton/ha). Similarly, it candrastically improve onion water productivity (7.12 kg/m3) as compared to CFI (3.9 kg/m3) and can be used as a practical water management practices to save water and thereby to expand irrigable areas. In addition to water saving and water productivity, AFI can also minimize costs associated with labor and pumping (fuel) by 42.6% as compared to CFI. Moreover, AFI increases the irrigable area, production and net income by 50, 45.4 and 34% respectively. Whereas, CFI increases the benefit cost ratio (4.8) and net return (94678 birr/ha) of farmers as compared to AFI but with no water saving. Therefore, the preference between AFI and CFI depends on the availability and value of water in relation to crop returns. Hence, it is recommended that if the cost and amount of available water is high and scarce, then the alternate furrow irrigation with 100% ETc will essentially be the best choice under the conditions of the study area and other similar agroecology elsewhere in the world.

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Effect of irrigation application methods under deficit irrigation on yield and water use efficiency of onion in dry land area of north Ethiopia

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Abstract

North Ethiopia is known as semi arid and water scarce region. Irrigation is vital to improve agricultural productivity in dry land areas. In Tigray region, farmers commonly produce onion using surface and drip irrigation methods. The experiment was conducted at Wukiro-Korir irrigation scheme with the objective of evaluating the effect of different irrigation application methods under deficit irrigation on water use efficiency and yield of onion. The design of the experiment was split plot. Irrigation application methods (every furrow, alternate furrow and drip irrigation) were taken as main plot and deficit irrigation (100%, 75% 50% and 25%) crop water requirement (CWR) were taken as sub plot. The results of the experiment showed there was no significant different on yield and irrigation water use efficiency (IWUE) of onion with the interaction effect. On the other hand, irrigation application methods have significant effect on irrigation water use efficiency (IWUE) and marketable yield. The highest (5.39 kg/m^3) and the least (3.27 kg/m^3) IWUE was obtained from alternate and every furrow irrigation, respectively. However, there was no significant different on IWUE between drip and alternate. Similarly, the highest marketable yield (12588 kg/ha) was obtained from drip and the least from alternate furrow (9662 kg/ha) but there was no significant different in yield between alternate and every furrow irrigation treatments (11490 kg/ha). This implies application of alternate irrigation is better in terms of water saving without yield reduction significantly. Water depth has also significant effect on marketable yield and irrigation water use efficiency. The highest yield was obtained from 100% CWR (15436 kg/ha) and the least from 25% CWR (5128 kg/ha) but there was no significant difference on yield between the treatments 100% CWR and 75% CWR (14657 kg/ha). Similar to marketable yield, irrigation water use efficiency of onion was also significantly different with water amount. The highest IWUE was obtained from 25% CWR (4.81 kg/m^3) and the least from 100% CWR (3.68 kg/m^3) but there was no significant different on IWUE among the treatments 75% CWR, 50% CWR and 25% CWR. Therefore, from this study it can be concluded that farmers in the region should have to use water and energy saving irrigation application method which is the alternate irrigation. On the other hand, deficit irrigation has significant effect on yield and water use efficiency of onion. There was no significant difference on yield of onion between the treatments with 100% CWR and 75% CWR, so, farmers should have to practice treatment which apply less amount of water and have better irrigation water use efficiency.

Key words: drip irrigation, alternate irrigation, every furrow, deficit irrigation, North Ethiopia

INTRODUCTION

Irrigation development can meet its objectives if it is managed properly. Poor management may result in adverse effects. In many irrigation schemes in arid and semi-arid areas, crop yields are reduced and even land is abandoned due to environmental hazards such as water logging, salinity, erosion and sedimentation of reservoirs (Yazew, 2005; Umali, 1993; Ritzema et al., 1996). There are different water use efficiency technologies for dry land areas. The first technology is alternate furrow irrigation system (AlF), which offers opportunity for reducing amount of irrigation water and permits irrigating a field in a shorter time with a given water supply. The reduced size of irrigation may not reduce yields appreciably and thus increase irrigation water use efficiency (Musick and Dusek, 1974). Besides, Zhang et al., (2000); Kang et al., (2000) and Kifle et al., (2017) also noted that alternate irrigation is a recent development towards optimum utilization of irrigation is to irrigate alternate furrows during each irrigation time. The second alternative technology of developing new irrigation techniques for improving traditional irrigation (maximizing water use efficiency) is Deficit Irrigation (DI). According to Chaves and Oliveira (2004); Kifle and Gebretsadikan (2016); and Bekele and Tilahun (2007), deficit irrigation increased instantaneous Water Use Efficiency (WUE) of common bean, potato and onion, respectively. Pressurized Drip Irrigation (PDI) is the third technique of improving irrigation efficiency and water productivity of crops. Drip irrigation offers the following advantages over traditional surface watering methods and sprinkler: High levels of water use and irrigation efficiency, maintains soil moisture at an optimum level, Fertilizers can be applied efficiently through the drip system and increases yield and quality of crops (Haman and Izuna, 1989; Isaya, 2001; Quassim, 2003 and Lamont et al., 2004). It is known that such types of studies are importance for dry land areas with limited water resources, however have not been not practiced in the region. As water resources is very much scares in the region, practicing improved irrigation application systems and optimum water regime without significantly affecting the yield and thereby expanding irrigable land with the given limited amount of water. Therefore, this experiment was executed to evaluate the effect of different irrigation application methods under deficit irrigation on water use efficiency and yield of onion.

MATERIALS AND METHODS

Study area description

The study site is located near Wukiro town, in Kilite Awlaelo district. It is far about 43 km apart in the north side of Mekelle town which is the capital of Tigray regional state, north Ethiopia. Geographically, it is located at latitude of $13^{0}59'$ North and longitude of 39^{0} 13′ East with an altitude of 2020 masl in the Eastern zone of Tigray regional State. The source of irrigation water for the experiment is surface water which is Korir micro dam. The area has Woyina dega agro climate with sandy clay soil textural class. Common crops grown in the area are vegetables (onion, tomato, potato and cabbage) and cereals such as wheat and barley. The area has annual average rainfall 560 mm.

Experimental design and treatments setting

The experiment was conducted on the plot size of three meter width and four meter length with double row 20 cm between the plants and with the row 40 cm spacing of the furrow with 10 cm plant spacing. The treatments were laid with 1 m spacing between plots and 1.5 m free row spacing between the blocks and on border side. The experiment was arranged in split plot design with three replications. Three irrigation application methods (every furrow (EFW), alternate furrow (AlF) and drip irrigation (DP)) were laid as the main plot and four deficit irrigation levels (100% CWR, 75% CWR 50% CWR and 25% CWR) were laid as the sub plot. The experiment had 36 plots in total.

Table 1. Treatments and their combinations

Where, EFW- every furrow, AlF- alternate furrow, DP- Drip, CWR-crop water requirement

Irrigation application methods	Deficit irrigation level	Treatment combinations	Treatments
EFW	75% CWR	CFW 75%	T_1
	50% CWR	CFW 50%	T_2
	25% CWR	CFW 25%	T_3
	100% CWR	CFW 100%	T_4
AlF	75% CWR	AlF 75%	T_5
	50% CWR	AlF 50%	T_6
	25% CWR	AlF 25%	T_7
	100% CWR	AlF 100%	T_8
DP	75% CWR	DP 75%	T_9
	50% CWR	DP 50%	T_{10}
	25% CWR	DP 25%	T_{11}
	100% CWR	DP 100%	T_{12}

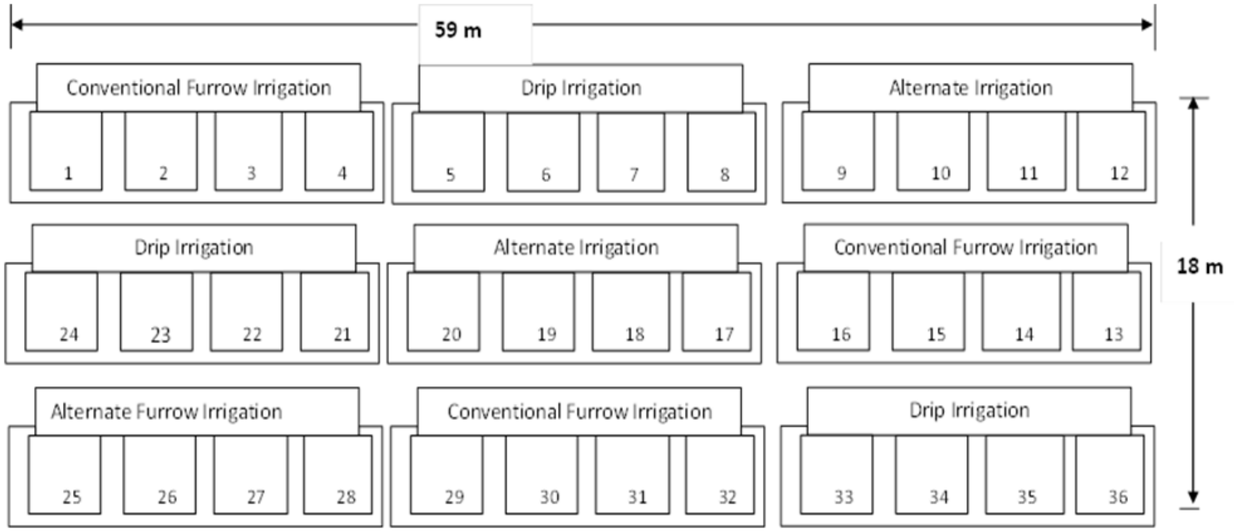

Fig.1. Lay out of the experimental plots

Crop water requirement and irrigation scheduling

Meteorological data (minimum and maximum temperature, relative humidity, wind speed and daily sunshine hours) were collected to estimate crop and irrigation water requirement. Reference evapo-transpiration was estimated using Modified FAO Penman Monteith method (Allen et al., 1998). Crop water requirement was estimated from the inputs reference evapo-transpiration and respective crop coefficients of the crop stages (Allen et al., 1998). Irrigation requirement was computed by subtracting effective rain fall from the estimated crop water requirement. Fixed interval (five days) and variable depth (refill to field capacity) irrigation scheduling criteria was adopted for irrigation scheduling. Seventy percent and eighty percent application efficiency was considered for furrow and drip irrigation treatments, respectively.

Table 2. Crop water requirement and irrigation scheduling of onion at korrir irrigation site

Date	ETo (mm)	Kc	CWR (mm)	Net Irri. (mm)	Gross irri. (mm)
25/1/2011	31.88	0.70	22.31	22.31	31.87
1/2/2011	31.98	0.70	22.39	22.39	31.99
8/2/2011	32.11	0.70	22.53	22.53	32.19
15/2/2011	32.53	0.76	24.67	24.67	35.24
22/2/2011	33.30	0.84	27.98	27.98	39.97
1/3/2011	34.35	0.92	31.66	31.66	45.23
8/3/2011	35.51	1.00	35.63	35.63	50.90
15/3/2011	36.61	1.05	38.44	38.44	54.91
22/3/2011	37.50	1.05	39.38	39.38	56.26
29/3/2011	38.09	1.05	40.00	40.00	57.14
4/4/2011	38.37	1.05	40.28	40.28	57.54
4/4/2011	38.37	1.04	39.92	39.92	57.03
19/4/2011	38.23	1.00	38.10	38.10	54.43
26/4/2011	21.77	0.96	20.90	20.90	29.86
Total	480.59		444.2	444.2	634.56

Data collection and statistical analysis

Disturbed and undisturbed soil samples were collected from 60 cm depth to characterize the soil in terms of physical and chemical characteristics. Physical characteristics such as initial soil moisture content, average bulk density, soil texture and chemical characteristics, EC, pH and organic matter were analysed in Mekelle soil research centre laboratory. Amount of irrigation water applied was measured and recorded. Yield, water use efficiency and yield component data were collected and analysed. Statistical analysis was done using Genstat statistical software.

RESULT AND DISCUSSION

Soil characteristics and analysis

As presented in the Table 3, the soil physical and chemical property analysis of the experimental plots revealed that it has a sandy clay texture with percentage of sand, silt and clay as 48.3%, 21% and 30.7%, respectively. Bulk density of the soil is 1.11 g/cm^3 at a depth of 0-20 cm, 1.17 at a depth of 21-40 cm and 1.19 g/cm^3 at a depth of 41-60 cm.

Accordingly, the soil in the experimental site has an average moisture content of 27.54% at field capacity (FC) and 11.98% at permanent wilting point (PWP) with average total available water holding capacity of (TAW) 15.56% in volume percentage.

Table 3. Soil physical and chemical characteristics of korrir experimental site

Depth (cm)	Soil physical and chemical characteristics										
	% sand	% silt	% clay	Texture	EC (ds/m)	pH	OM %	Bulk density (g/cm^3)	FC Vol (%)	PWP Vol (%)	TAW Vol (%)
0-20	51	27	22	loam	0.77	7.24	0.9	1.11	25.06	11.16	13.91
21-40	49	17	34	sand clay loam	0.66	7.45	0.82	1.17	27.96	12.37	15.59
41-60	45	19	36	sandy clay	0.66	7.62	0.9	1.19	29.58	12.41	17.18
Average	**48.3**	**21**	**30.7**	**sandy clay**	**0.70**	**7.44**	**0.87**	**1.16**	**27.54**	**11.98**	**15.56**

Effect of irrigation methods on yield and water use efficiency of onion

As observed from Table 4 underneath, crop water use efficiency was significantly affected by the interaction effect however; there was no significant effect on yield of onion and irrigation Water Use Efficiency. Irrigation Water Use Efficiency (IWUE) and marketable yield of onion were significantly affected by the main effect irrigation application method (Table 5). The highest yield was recorded from drip irrigation for marketable (12588 kg/ha) and lowest yield was obtained from alternate irrigation (9662 kg/ha) treatments. However, there was no significant different between alternate and every furrow treatments. Kifle et al. (2017) and Kang et al. (2000) also reported similar results. In contrary to the above, there was no significant different with irrigation application methods on total yield of onion. It seems alternate furrow irrigation have good potential compared to every furrow and drip irrigation treatments in terms of water saving and environmental protection. The amount of water applied with alternate furrow is approximately half of every furrow and drip irrigation. This tells us farmers can produce similar amount of onion with less water. The saved water can be used for the extension of irrigable area in the scheme. On the other hand, the highest irrigation water use efficiency was observed from alternate furrow irrigation treatment (5.39 kg/m^3); the least from conventional furrow treatment (3.27 kg/m^3) and intermediate irrigation water use efficiency from drip irrigation.

Table 4. Interaction effect of irrigation application methods and deficit levels on yield and water use efficiency

Treatment combinations	Marketable yield (kg/ha)	IWUE (kg/m3)
T1 (CFWL1)	15022.6	3.786
T2 (CFWL2)	10304.1	4.158
T3 (CFWL3)	5124.5	4.754
T4 (CFWL4)	15509.7	2.897
T5 (AIFL1)	12507.2	5.349
T6 (AIFL2)	8604.7	5.855
T7 (AIFL3)	3975.4	6.259
T8 (AIFL4)	13559.8	4.308
T9 (DPL1)	16440.7	5.255
T10 (DPL2)	10390.5	5.18
T11(DPL3)	6283.5	6.388
T12 (DPFL1)	16905.6	4.101
LSD (0.05)	ns	ns
CV%	10	6.1

Table 5. The effect of irrigation application methods on yield and water use efficiency

Treatment	Marketable yield (kg/ha)	Total yield (kg/ha)	IWUE (kg/m3)
CFW	11490[a]	13208	3.27[b]
AF	9662[b]	11277	5.39[a]
DP	12588[a]	13953	4.66[a]
LSD (0.05)	1977.9	ns	1.098
CV%	7.8	8	10

Effect of deficit irrigation on yield and water use efficiency of onion

Similarly, deficit irrigation levels were significantly affected the yield of onion and irrigation water use efficiency (Table 6). The highest marketable yield was obtained from 100% crop water requirement and the lowest yield was obtained from 25% crop water requirement. However Yield of onion has no significant different between water application of 75% CWR and 100% CWR. The treatment with 25% water application had the highest value in terms of irrigation water use efficiency. But this value did not mean that the treatment has better performance. If we observe the corresponding yield, it was very small in comparable to other respective treatments. Application 75% of crop water requirement and 50% crop water requirement did not have significant different on water use efficiency with 25%. However, in terms of yield comparison, 75% of crop water requirement similar to 100% crop water requirement. This mean that farmers should have to practice 75% CWR water amount to get mutual benefits in terms of yield and water saving.

Table 6. The effect of irrigation deficit levels on yield and water use efficiency

Treatment	Marketable yield (kg/ha)	IWUE (kg/m3)
75% CWR	14657	4.63
50% CWR	9766	4.64
100% CWR	15436	3.68
25% CWR	5127.8	4.81
LSD (0.05)	1092.1	0.345
CV%	7.8	10

CONCLUSION

The experiment was conducted to evaluate the effect of different irrigation application methods under deficit irrigation on water use efficiency and yield of onion. The experimental treatments were arranged in split plot design. The results revealed that there was no significant different on yield and irrigation water use efficiency (IWUE) of onion with the interaction effect. Irrigation application methods have significant effect on irrigation water use efficiency (IWUE) and marketable yield. The highest (5.39 kg/m^3) and the least (3.27 kg/m^3) IWUE was obtained from alternate and every furrow irrigation, respectively. Similarly, the highest marketable yield (12588 kg/ha) was obtained from drip and the least from alternate furrow (9662 kg/ha) but there was no significant different in yield between alternate and every furrow irrigation treatments (11490 kg/ha). Deficit irrigation has also significant effect on marketable yield and irrigation water use efficiency. The highest yield was obtained from 100% CWR (15436 kg/ha) and the least from 25% CWR (5128 kg/ha) but there was no significant difference on yield between the treatments 100% CWR and 75% CWR (14657 kg/ha). Therefore, from this study it can be concluded that farmers in the region should have to use water and energy saving irrigation application method which is the alternate irrigation. On the other hand, deficit irrigation has significant effect on yield and water use efficiency of onion. There was no significant different on yield of onion between the treatments with 100% CWR and 75% CWR, so, farmers should have to practice treatment which apply less amount of water and have better irrigation water use efficiency.

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THEME FOUR

WATER SUPPLY & SANITATION

Microbial Quality of Drinking Water Stored at the Household Level, Hawassa City, Ethiopia

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Abstract

Microbial contamination of drinking water is a common cause of waterborne diseases in developing countries. The main objective of this study is to assess microbial quality of drinking water stored at household level, Hawassa City, Ethiopia. Cross sectional study was conducted and a total of 120 water samples (60 tap, 60 household) were collected from 60 households to test microbial quality. Physicochemical parameters – temperature, turbidity, pH and residual free chlorine were measured. Households were asked for the occurrence of diarrheal diseases. Presence total and faecal coliform bacteria in the collected water samples were tested using Wagtech membrane filtration method. Data were statistically analyzed and compared standards. Paired-t test was used to analyze variance between tap and household water samples. Pearson chi square test was used to determine any significant association between bacterial quality and occurrence diarrheal diseases. Eight (13.3%) tap and twenty eight (46.7%) household water samples were found positive for the total coliform test, five (8.3%) tap and nineteen (31.7%) household water samples were also positive for the faecalcoli form test. Eleven (18.3%) household water samples had faecal coliform 10-100CFU/100ml, which falls under high risk category. The paired-t test ($p<0.05$) showed significant variation between faecal contamination of tap and household water samples. The Pearson chi square test implied likelihood of diarrheal disease is 15.7 higher in households with positive faecal coliform results than those with negative results ($p<0.001$). It is concluded that significant level of faecal contamination of water occur at the household level.

Keywords: *Drinking water storage, Faecal coliform, Total coliform, Household, Hawassa*

Introduction

Diseases related to lack of access to safe drinking water still remains as a major burden on human health (1). In developing countries, a large percentage of the population lackaccess to safe drinking water, the problem is more severe especially in Asia and sub-Saharan Africa (2, 3). In Ethiopia, over 60% of communicable diseases are due to poor environmental health conditions arising from lack of safe and adequate water supply (4). Domestic water supply from any improved water sources reached to 64.8% (5). However; diarrhea prevalence is highest among children residing in households that drink from unprotected wells (18%), rural areas (14%) and urban areas (4%) (6).

In most developing countries; besides the water source, households' poor drinking water handling and storage practices can cause microbial contamination of water (1, 7-9).

It is recommend to inspect drinking water delivery systems from source to mouth, and "handling of water at home" is one element (10). Regarding microbial quality, it can be assessed using indicator organism. Coliform bacteria is the most common indicator that have been usedto express microbial quality and faecal coliform are commonly used to assess faecal contamination (4, 11, 12). This study therefore aims to investigate microbial quality of drinking water stored at household using coliform bacteria.

Materials and Methods

Study Period and Area

This study was conducted in May, 2016 in Hawassa City, Ethiopia. Hawassa is the capital city of the Southern Nations Nationalities and Peoples Regional State (SNNPRS) located 275 km south of the country's capital city – Addis Ababa. Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia, the city has a total population of 157,879. The city administration has eight sub cities where some of the sub cities are known for the presence of overcrowded households and substandard housings.

Study Design

A cross sectional study was conducted to determine physicochemical and microbial quality of drinking water stored at household level. Experimental study design was implemented to investigate physicochemical and microbial quality of water samples collected from households.

Sample Size

First, sample size was calculated using single population proportion (SPP)formula $N = \frac{Z^2 P(1-P)}{d^2}$ where, N=sample size, P=proportion, d=margin of error and Z value of 1.96 is used at 95% CI and margin of error is 5%. Similar studies reported that above 53% of water samples analyzed for microbial quality and compared with WHO drinking water quality guideline were categorized as unsafe for drinking. Considering 53% as a proportion (p), the determined size became 388. Then, 15% of the determined sample size were taken as representative sampling points for the experimental analysis. As basic assumption that water quality may not vary at a nearby distance (13). $Number\ of\ sampling\ points = Nx15\%$, where N=sample size determined using SPP. Number households=60. From each household, water samples were collected from tap and drinking water storing containers. A total of 120 water samples were collected.

Water Sample Collection and Processing

Water samples were collected according to the standard procedure stated in WHO drinking water guideline (14). Each water sample, 500ml, was collectedusing sterile bottles and immediately transported to the SNNPRs regional public health laboratory with an ice box.First, temperature, pH and turbidity was measured. Residual free chlorine was determined using Wagetechcomparator-disc with DPD number 1 chlorine tablet. Wagtech membrane filtration was used to conduct bacteriological tests according to the recommended standard procedures. A 100ml of the water sample was filtered using membrane filter (0.45µm pore size). The membrane filter was incubated at 37^{o}C using Membrane Lauryl Sulphate Broth (MLSB) media for 18 hours. After 18 hours, colonies of total coliform bacteria were counted. The membrane was incubated at 44.5^{o}C for 18 hours in order to detect presence of faecal coliform bacteria. Households were also asked for the occurrence of diarrheal diseases within the previous two weeks prior to sample collection.

Data Analysis

Data was analyzed using SPSS statistical software (version 23). Results obtained forthe measured physico-chemical parameters and bacteria counts were compared with national and international (WHO) drinking water quality standards. Paired-t test was used to analyze whether variables measured for the tap and the household water samples have any statistically significant variance at $p<0.05$. Pearson chi square test was used to determine if any significant correlationwas there between contaminated household water samples and diarrheal diseases.

Results and Discussion

Physico-Chemical Parameters

As shown in ***Table 1***, temperature>20^0C were measured for 45 (75%) household and 43 (71.7%) tap water samples. Turbidity >5NTU were measured for 5 (8.3%) water samples taken from households, no tap water sample were found with turbidity >5NTU.pH >8 were measured for 9 (15%) household and 1 (1.7%) the tap water samples(***Table 1***).

Table 1. Comparison of physico-chemical parameters of drinking water for household and tap water samples with WHO recom-mended values, Hawassa, 2016.

Table 1. Comparison of physico-chemical parameters of drinking water for household and tap water samples with WHO recommended values, Hawassa, 2016.

Recommended Parameters	Results		Standard	
	Tap water	Household water	WHO	National
Temperature (^{0}C)				
> 20	43 (71.7%)	45 (75%)	Unaccepted	Unaccepted
15.01 – 20	17 (28.3%)	15 (25%)	Accepted	Accepted
Total	60 (100%)	60 (100%)		
Turbidity (NTU)				
> 5	-	5 (8.3%)	Unaccepted	Unaccepted
2 – 4.99	-	2 (3.3%)	Accepted	Accepted
0.1 – 1.99	2 (3.3%)	1 (1.7%)	Accepted	Accepted
0	58 (96.7%)	52 (86.7%)	Accepted	Accepted
Total	60 (100%)	60 (100%)		
pH				
> 8	1 (1.7%)	9 (15%)	Unaccepted	Unaccepted
6.5 – 8	56 (98.3%)	51 (85%)	Accepted	Accepted
Total	60 (100%)	60 (100%)		
Residual free chlorine (mg/L)				
> 0.5	3 (5%)		-	-
0.2 – 0.49	31 (51.7%)	6 (10%)	Accepted	Accepted
0.1 – 0.19	17 (28.3%)	29 (43.3%)	Unaccepted	Aaccepted
0	9 (15%)	25 (41.7%)	Unaccepted	Unaccepted
Total	60 (100%)	60 (100%)		

High water temperature enhances the growth of microorganisms and may also increase taste, odor, color and corrosion problems (15-17). Most pathogens require higher temperature to proliferate in the water(17, 18). Prevalence of *Vibrio cholerae* in water is higher at a temperature above 20^{0}C and it is recommended to keep water below 20^{0}C(18). Other similar studies also reported that majority of drinking water samples taken from taps or stora1ge containers have a temperature >20^{0}C, which is above WHO standard (4, 12, **15, 19).**

Water pH (acidic or alkaline)is a factor that determine solubility of both organic and inorganic compounds in the water. International and national guidelines recommend a pH range of 6.5 – 8.0 for drinking water. Out of the total samples collected from the households, 15% were not meet the recommended pH range. Turbidity deteriorate the physical quality andacceptance of drinking water as well contribute to the alteration of color, odor and taste the water (1, 20). All the sampled tap water meet both the WHO and national standard (<5NTU) while 5 (8.3%) of household water samples had turbidity above the standards. Residual free chlorine is important to control regrowth of microbes in the distribution system and at home (1, 21). In 9 (15%) tap and 25 (41.7%) household water samples, no residual free chlorine was detected. In 17 (28.3%) tap and29 (43.3%) household water samples the detected residual freechlorine was < 0.2mg/L (Table 1). The result implied that majority of the water (43.3% tap and 85% household)samples tested for residual free chlorine fall below the standard level of WHO (0.2-0.5mg/L). Water samples – 15% from the tap and 41.7% from the household water – were also fall below the national standard (0.1–0.2 mg/L).

Table 2. Paired-t test of physicochemical and bacteriological parameters measured for the tap and household water samples, Hawassa, 2016

Variables	Pairs	*t*
Temperature	Tap (^{0}C) - HH (^{0}C)	-1.840
Turbidity	Tap (NTU) - HH (NTU)	-2.586*
pH	Tap - HH	-4.652**
Residual Free Chlorine	Tap (mg/L) - HH (mg/L)	9.503**
Total coliform	Tap (CFU/100ml) – HH (CFU/100ml)	-3.139*
Faecal coliform	Tap (CFU/100ml) - HH (CFU/100ml)	-2.633*

**** Significant at p < 0.05, ** Significant at p < 0.01***

The paired-t test result showed that there was a significant mean variance (p <0.05) between the physicochemical parameters measured to the tap water samples and the household water samples, except for the temperature (Table 2). The t values indicated that the household water samples had higher turbidity and pH and lower residual free chlorine than the tap water samples (the quality decreased after storage).

Bacteriological Quality

Regarding the bacteriological quality; 8 (13.3%) tap and 28 (46.6%) household water samples found positive for the total coliform test, 5 (8.8%) tap and 19 (31.6%) household water samples found positive for the faecal coliform test (***Table 3***). Other similar studies conducted in different cities of Ethiopia also revealed comparable findings regarding microbial quality of drinking water (2, 4, 12, 22). Both the national and WHO standard recommended 0CFU/100ml of water for coliform. Based on the level of faecal coliform present; WHO drinking water sanitary inspection guideline also set risk-to-health category (***Table 3***). The paired-t test analyzed to bacteriological test results indicated that there were a significant mean variance ($p < 0.05$) between the tap and household water samples. The t values implied that more coliform bacteria detected in household water samples than the tap water samples (***Table 2***). Variables were also computed to identifythe specific points of faecal contamination(***Table 4***). From 19 (31.6%) faecally contaminated household water samples, 15 (25%) water samples were contaminated at the household level. From 11 (18.3%) abdominal discomfort cases, 7 (11.7%) of them were from households tap water was negative but household water was positive for faecal coliform. This result has an important implication regarding the need to deal with drinking water quality beyond the source and the tap, at the household level.The association between quality and household water handling also well noted in other studies (21, 23, 24).

Table 3. Comparison of bacteriological quality of water samples collected from taps and households with WHO recommended values, Hawassa, 2016.

Recommended Parameters	Results		Standard		Risk
	Tap water	Household water	WHO	National	
Total Coliform (CFU/100ml)					
> 100	3 (5%)	14 (23.3%)	-	Unaccepted	
10 – 100	5 (8.3%)	14 (23.3%)	-	Unaccepted	
1.01 – 9.99	-	-	-	Unaccepted	
0.01 – 1.00	-	-	-	Unaccepted	
0	52 (86.7%)	32 (53.3%)	-	Accepted	
Total	60 (100%)	60 (100%)			
Faecal Coliform (CFU/100ml)					
> 100	3 (5%)	8 (13.3%)	Unaccept-ed	Unaccepted	Very High
10 – 100	2 (3.3%)	11 (18.3%)	Unaccept-ed	Unaccepted	High
1.01 – 9.99	-	-	Unaccept-ed	Unaccepted	Low
0.01 – 1.00	-	-	Unaccept-ed	Unaccepted	Very low
0	55 (91.7%)	41 (68.3%)	Accepted	Accepted	
Total	60 (100%)	60 (100%)			

Table 4. Faecal coliform test results from the tap and household water samples computed to identify specific points of faecal contamination and abdominal discomfort, Hawassa, 2016.

Variable	Computed if conditions satisfy		Frequency (Percentage)	If abdominal discomfort	Frequency (Percentage)
	Tap	Household			
FaecalColiform	Positive	Positive	4 (6.6%)	Yes	2 (3.3%)
	Positive	Negative	-	Yes	-
	Negative	Positive	15 (25%)	Yes	7 (11.7%)
	Negative	Negative	41 (68.4%)	Yes	2 (3.3%)
				No	49 (81.7%)
Total			60 (100%)		60 (100%)

A cross tabulated descriptive analysis wasconducted to find out whether significant association was there between faecal contamination of household water samples and occurrence diarrheal diseases. As shown in ***Table 5***, from the total of 11 diarrheal cases reported, 9 of them occurred in the households where the stored drinking water samples were faecally contaminated.

Table 5. Result of the cross tabulation of diarrheal diseases versus faecal coliform positive water samples of the households, Hawassa, 2016.

The Pearson chi square test ($p < 0.001$) implied that the likelihood of diarrheal is 15.7 higher in households'

Variable		Faecal coliform		Total
		Positive	Negative	
Abdominal discomfort/diarrheal diseases	Yes	9	2	11
	No	10	39	49
Total		19	41	60

positive faecal coliformresults than households with negative results. Similar studies also support the significant association (9, 11, 12, 25, 26). From this study, it is concluded that microbial contamination of drinking water stored at the household level is significantly higher than the corresponding tap water. Faecal contamination occurred at the household level is also a possible cause of abdominal discomfort and diarrheal diseases.

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Efficiency of Slow Sand Filtration in Removing Bacteria and Turbidity from Drinking Water in Rural Communities of Central Ethiopia

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Abstract

This study was aimed at evaluating the efficiency of slow sand filtration (SSF) in clay pots in removing total and thermo tolerant/faecal coliforms (TC and TTC/FC) and turbidity (TR) from drinking water. Triplicate water samples in two-week interval were collected to determine the presence of TC and TTC/FC and turbidity in the water samples. Membrane filtration and epifluorescence microscope methods were used for TC and TTC/FC enumeration, and turbidity was measured using Turbidimeter. Mean analyses of water samples for TC, TTC/FC and turbidity from influent and effluent of SSF in clay pots for spring users showed that average TC from influent was 888.9 cfu/100ml where as from effluent it was 5.5 cfu/100ml. Moreover, average TTC/FC from influent was 289.4 cfu/100ml where as from effluent it was 2.5 cfu/100ml. Average turbidity from influent was 9.0 NTU and from effluent it was 0.9 NTU. The study showed that average removal efficiency of SSF in clay pots from spring users were 97.4 % and 96.9 % for TC and TTC/FC, while the removal efficiency for turbidity was 92.9 %. Water analyses from the effluent of slow sand filtration in clay pot showed that it is safe for drinking purpose from bacteriological point of view.

Key words: Coliform; drinking water; Ethiopia; rural water supply; slow sand filter

Introduction

Approximately over one billion people world-wide lacks access to adequate amounts of safe water and rely on unsafe drinking water sources from lakes, rivers and open well. Nearly all of these people live in developing countries, especially in rapidly expanding urban fringes, poor rural areas, and indigenous communities (Gundry *et al*., 2004; Bartram *et al*., 2005). Much of the global population now consumes untreated, non piped drinking water, usually consisting of small volumes <40 lpcd (liter per capita per day) collected and stored in the home by users.

The greatest risk associated with the ingestion of water is the microbial risk due to water contamination by human and/or animal feces. The effects of drinking contaminated water result in thousands of deaths every day, mostly in children under five years of age in developing countries (WHO, 2004a). Diseases caused by consumption of contaminated water, and poor hygiene practices are the leading causes of death among children worldwide, after respiratory diseases (WHO, 2004a).

In Ethiopia, over 60 % of the communicable diseases are due to poor environmental health conditions arising from unsafe and inadequate water supply and poor hygienic and sanitation practices (Abebe, 1986). About 80 % of the rural and 20 % of urban population have inadequate and unsafe water supply of 3-4 liter per capita per day that is fetched from a distance of 3-8 km with human power (WHO, 2004a). Three-fourth of the health problems of children in the country are communicable diseases arising from the environment, especially water and sanitation (IWSC, 1989).

Forty six percent of the mortality rate of less than five years of age is due to diarrhea in which water related diseases occupy a high proportion. The Ministry of Health of Ethiopia estimated that 6000 children died each day from diarrhea and dehydration (MOH, 1997). Indicator organisms of faecal pollution include the coliform group as a whole and particularly *Escherichia coli*, *Entrococcus faecalis* and some thermotolerant organisms such as *Clostridium perferingens* (WHO, 1984). The overall concepts adopted for microbiological quality is that no water intended for human consumption shall contain *E.coli* in 100ml sample (WHO, 2004b).

The mapping of water resources in the study area in the central Highlands of Ethiopia-Yubudo-Legebatu PAs in Dendi woreda-showed that the community had access to 28 water sources including rivers and springs distributed unevenly across three land types: upland, mid-slopes and bottomlands. Most of these sources were found unsuitable for human consumption as livestock has open access to all the sources at any point in time. Analyses of water for coliform count showed that, during the main rainy season most of the water sources were contaminated for human consumption. The situation was worse on bottomland and mid-slopes where no source of clean (potable) water was available during the main rains. The reason was that human feces, animal dung and urine were washed down the slopes and deposited directly into the water sources. In addition washing/watering served to initiate and replenish organic contamination (Eline and Abiy, 2005). Community or municipal water treatment systems are frequently impractical and often unaffordable in these settings. At the present time, inexpensive household water treatment such as slow sand filtration provides a reasonable alternative for many of these people.

In order for a household water treatment technology such as SSF to achieve widespread sustainable use among the poor, it must meet the "criteria of the poor" (Duke & Baker, 2005). Slow sand filters can be constructed from local materials, mainly from properly graded sand/gravel, concrete/clay, and standard piping, can operate without the use of specialized equipment, and is much less labor intensive than rapid filters. Also slow sand filters operate under gravity flow conditions, and energy, its on-going energy demand is minimal. Thus, SSF is an attractive treatment alternative for local communities. Therefore, the researcher evaluates the efficiency of SSF in clay pots in removing coliform bacteria and turbidity in drinking water for household use in the central highlands of Ethiopia.

Materials and Methods

Description of the Study Area

The study was conducted in West Shoa, Dendi district, Ginch town, Yubudo-Legebatu Peasant Association (YLPA) (Figure 1). YLPA is located at about 80km west of Addis Ababa in the Dendi district of Oromiya region. The PA is located at about 20km from the district town Ginchi. The study area has uneven topography with upland, mid-slopes and bottom lands. It receives mean annual rainfall ranging from 800-1172.2mm and has an average temperature of between 9.3 ^{0}C and 23.8 ^{0}C. The altitude of the area ranges between 1600 and 3268 meter above sea level. Total population in YLPA is 5614 and the number of households in upland and bottom land of YLPAs is 796 (Source: Ginchi Bureaus of Agriculture, 2007). The mapping of water resources in YLPAs in Dendi woreda- showed that the community had access to 28 water sources including rivers and springs distributed unevenly across different land types; upland, mid-slopes and bottom lands (Eline and Abiy, 2005).

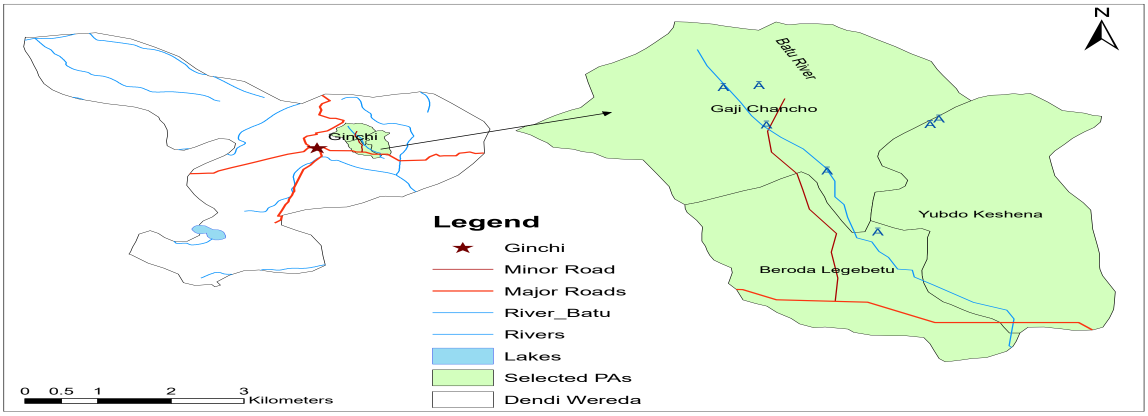


Figure1. Map showing the study area, Dendi Wereda, Ginchi town, Yubudo-Legebatu PA.

Design of the Study

The study was made up of field work. The fieldwork consisted of analyses of drinking water quality for indicator bacteria, such as TC and TTC/FC and for turbidity from the influent and effluent of slow sand filtration in clay pots (Figure 2) from intervention groups. Moreover, the field work comprised of interviewing 40 intervention households who used an SSF in clay pots to record the perceptions of the users with regard to water quality from the filter, ease of use, and level of satisfaction with the filter to assess sustainability using questionnaires and observations.

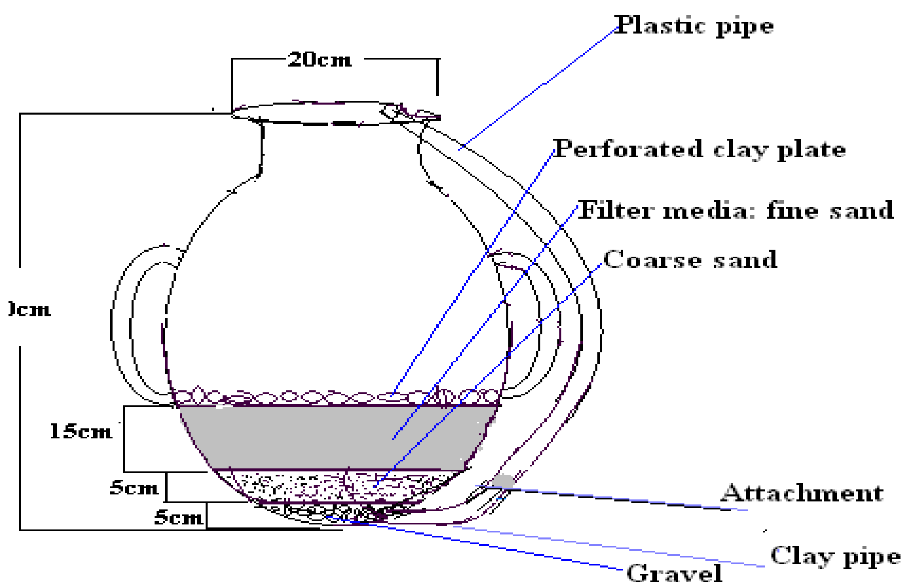


Figure 2. Schematic drawing of slow sand filtration in clay pot

The basic components of a slow sand filter shown above are: perforated clay plate, sand bed (clean fine sand and clean coarse sand), clean round gravel and outlet hose (plastic pipe). The perforated clay plate reduces splashing of sand when influent or flow water is added. Sand is the usual filter medium because of its low cost, durability and availability.

The sand has a relatively fine grain size (effective size 0.15 to 0.3mm). The gravel provides an unobstructed passage for a treated water from the filter bed, which prevents sand from clogging the underdrain piping and supports the filter sand bed. The plastic pipe is attached to the protrude clay pipe and the filtered water is passed through plastic pipe. After taking water, the plastic pipe is attached to the top of the clay pot. Bed depth of the filter media is 25cm (15cm fine sand, 5cm coarse sand and 5cm gravel). Water percolates slowly through the porous sand medium and organic and inorganic particulate matter and pathogenic microorganisms are removed by physical filtration and biological degradation in the sand bed.

Water Samples and Sampling Points

Forty households were selected for this study where 40 households were intervention groups who used slow sand filtration in clay pot, comprised of spring users (20) and river users (20). Raw water samples were collected from the influent and effluent of slow sand filtration in clay pots. Samples were taken at two-week interval using a sterile 200ml glass bottle, labeled and kept in cool ice box during transportation. The experiment was carried out in Applied Microbiology Laboratory of the Department of Biology, Addis Ababa University. The appropriate tests were undertaken within 8 hours of collection to avoid the growth or death of organisms in the sample.

Samples Analyses

All samples were analyzed for TC, TTC/FC and turbidity in Applied Microbiology Laboratory, Department of Biology, Addis Ababa University (Figure 3). To determine the presence of TC and TTC/FC in the water samples, standard membrane filtration methods were used as described in membrane filtration techniques (APHA, 1998). Turbidity was measured using Turbidimeter (HACH- *2100P model Turbidimeter, German*).

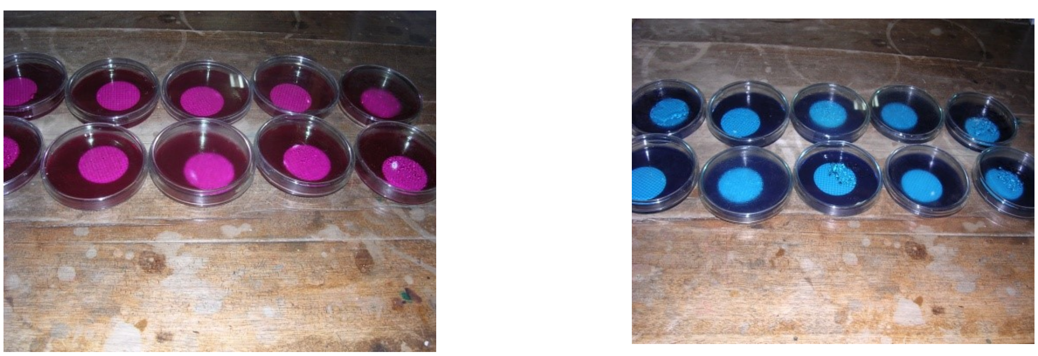
Figure 3. Sample water quality analyses in the laboratory.

Drinking water was analyzed by filtering 100ml, or by filtering replicate smaller sample volumes. Using sterile forceps, a sterile membrane filter paper (0.45µm pore sizes, 47mm in diameter, sterile and gridded were from WAGTECH) was placed on the membrane filter support assembly (from WAGTECH). The funnel unit was placed carefully over the filter support assembly and locked in place. The samples were mixed thoroughly by shaking for about 30 minutes and poured in to the funnel assembly. Then the entire volumes of samples were filtered through the membrane-filter by using a vacuum pump. Funnel and membrane-filter assembly were rinsed by sterile dilution water to avoid contamination between water samples.

Up on completion of the filtration process, the vacuum was disengaged, unlocked and using a sterile forceps, membrane paper were removed immediately and placed on rehydrated Difco M-Endo Agar (LES) (No.0736) with a rolling motion to avoid entrapment of air in glass Petri dish. Finally the prepared culture dish were inverted and incubated for 22 to 24h at 35 $\pm$0.5 ^{0}C. Up on completion of the incubation period, typical coliform colonies (pink to dark red color with sheen) were seen on the surface of the membrane filter paper. Colony counts on the filter paper were determined using a low-power (10 to 15 x magnifications) binocular wide-field-dissecting microscope, with a cool white fluorescent light source for optimal viewing of sheen. Then total coliforms per 100ml of sample were calculated. This meets the objectives on determination of total coliforms from influent and effluent of slow sand filtration and from home storage containers.

Membrane filter papers were placed on rehydrated M-FC agar with rosolic acid (to increase specificity of medium). Culture dishes were inverted and incubated for 24 $\pm$2h at 44.5 $\pm$0.2^0 C. Up on completion of the incubation period; blue colored colonies on the surface of the filter paper were counted. Then TTC/FC colonies per 100_ml of sample were calculated. Verification tests were done by transferring growth from each colony and placed in lauryl tryptose broth; incubating the lauryl tryptose broth at 35±0.5^{o}C for 48 hours. Gas formed in lauryl tryptose broth within 48h verifies the colony as a coliform. Inclusion of EC broth inoculations for 44.5±0.2^{o}c incubation verifies the colony as faecal coliforms (APHA, 1998). Generally, in the present study, the efficiency of SSF in clay pot in removing TC, TTC/FC and turbidity were tested. A total of 240 (40 x 2 (inf. & effl.) x 3) water samples were collected from the influent and effluent of slow sand filtration in clay pot taking triplicate water samples from each point. All samples were analyzed for bacteriological qualities and turbidity.

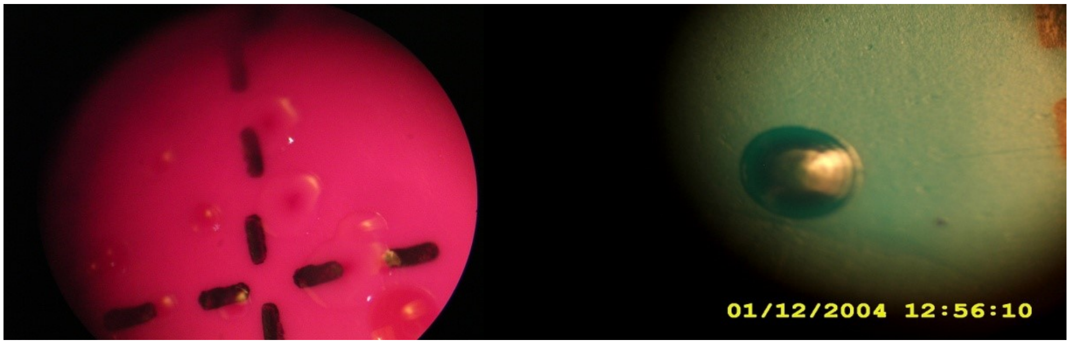
Total and Thermotolerant/Faecal Coliform Colonies Identification



a) b)

Figure 4.Total coliform colonies in membrane filtration (a) and Faecal coliform colonies in membrane filtration (b).

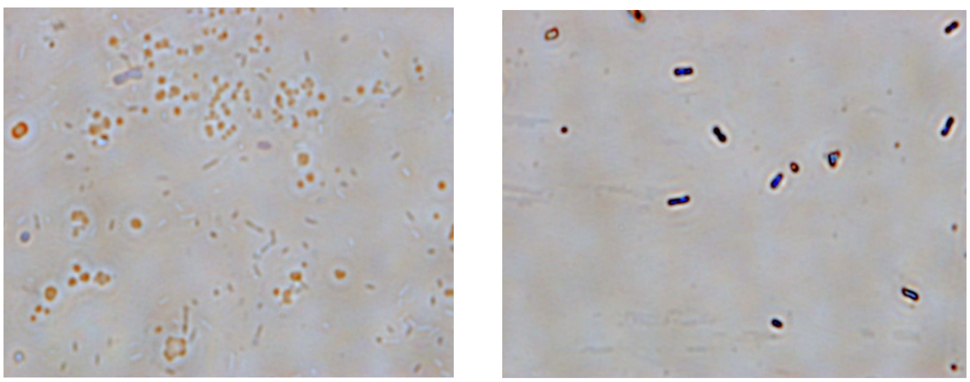
Bacterial colonies were identified using membrane filtration techniques. Colors of total coliform bacterial colonies were pink to dark red with sheen, using a low-power (10 to15 x magnifications) binocular wide-field-dissecting microscope, with a cool white fluorescent light source for optimal viewing of sheen as shown below in figure 5 (a).Where as colors of thermotolerant/ faecal coliform bacterial colonies were blue as shown below in figure 5 (b).



a) b)

Figure 5. Total coliform colonies (a) and Faecal coliform colonies (b) with (10 to 15 x) microscope magnification.

Further identification of total and thermotolerant/ faecal coliform was made by examining the colonies under an epifluorescence microscope (Olympus BX51, Japan) attached to a CCD camera. Analyses Docu soft-ware (cc12 Docu, Germany) was used for image acquisition of the respective colonies as shown below in figure 6(a) and 6(b).



(a) (b)

Figure 6. Epiflorescence microscopic examination of Total coliform bacteria (a) and thermotolerant/ faecal coliform bacteria (b).

Statistical Analyses of Data

The 40 households with SSF in clay pots were selected by ILRI in collaboration with the peasant association. All 40 households with a clay pot filter were included in the study, representing 5 % of the 796 households in the area. Half of these, 20 households were located in the highland part of the area, using a spring as their major water source. The other 20 were located in the low land part and used a river. Results of water analyses were compared against standards set by World Health Organization and Federal Democratic Republic of Ethiopia, Ministry of Water Resources for drinking water qualities (WHO, 2004b). The data were analyzed using the statistical software SAS version 9.1 for windows.

RESULTS

Total Coliform (TC), Thermotolerant/Faecal Coliform (TTC/FC) and Turbidity (TR) Removal by SSF in Clay Pots

Table 1 below shows mean analyses of water samples for TC, TTC/FC and turbidity from influent and effluent of SSF in clay pot for spring users. The results revealed that average TC from influent was 888.9 cfu/100_ml where as from effluent it was 5.5 cfu/100ml. Moreover, average TTC/FC from influent was 289.4 cfu/100ml where as from effluent it was 2.5 cfu/100ml. Similarly, average turbidity from

Table 1. Analyses of water samples for TC, TTC/FC and Turbidity (TR) from influent and effluent of SSF in clay pots *for spring users (n = 20).*

H H. No	Influent TC	Effluent TC	Influent FC	Effluent FC	Influent TR	Effluent TR
1	780.7	11.3	256.0	4.7	6.0	0.8
2	1016.3	12.3	260.0	4.3	6.3	0.7
3	1030.3	13.3	340.0	5.7	4.7	1.0
4	926.0	7.3	176.0	6.7	4.7	0.8
5	803.0	5.3	340.0	3.0	11.0	1.0
6	706.7	11.7	283.0	7.0	6.3	1.3
7	1036.0	13.7	360.0	4.7	4.3	1.0
8	773.7	11.0	256.0	5.7	6.7	0.7
9	810.0	4.0	290.0	7.3	6.3	0.8
10	1013.0	5.6	210.0	6.0	6.3	0.7
11	780.7	7.7	280.0	1.7	5.3	1.0
12	956.0	12.7	240.0	4.7	8.0	0.5
13	970.3	2.3	376.0	3.0	6.3	1.0
14	933.0	10.7	300.0	7.3	4.0	0.8
15	770.7	2.3	273.0	7.3	6.7	0.8
16	863.0	2.0	360.0	5.0	6.0	0.8
17	1020.0	2.3	176.0	8.3	6.0	1.0
18	763.3	11.7	296.0	2.7	7.0	0.8
19	893.3	7.3	456.0	1.0	5.7	0.8
20	933.7	7.0	260.0	5.7	6.7	1.0
Mean	**888.9**	**5.5**	**289.4**	**2.5**	**9.0**	**0.9**
S.D	**339.2**	**0.9**	**49.4**	**0.4**	**1.5**	**0.2**

The effectiveness of SSF in clay pot in removing microbial pathogens from water was based on TC and TTC/FC colony counts from the influent water samples versus samples taken from the effluent. Table 2 below shows removal efficiencies for each SSF in clay pot for spring users. The result showed that an average removal efficiency of SSF in clay pot were 97.4 % and 96.9 % for TC and TTC/FC bacteria, respectively, while the removal efficiency for turbidity was 92.9 % were found.

Table 2. Removal efficiencies of each SSF in clay pots for TC, TTC/FC and Turbidity, per 100 ml of water samples for spring users (n =20).

Removal efficiency (%)			
HH No.	TC	TTC/FC	TR
1	99.0	97.5	84.6
2	98.7	98.3	84.5
3	97.9	98.4	98.3
4	94.3	93.2	81.9
5	99.3	99.3	85.0
6	98.5	95.5	97.1
7	93.0	98.4	95.0
8	93.5	96.4	82.6
9	99.3	97.4	86.2
10	96.3	94.7	89.0
11	99.1	99.2	96.9
12	95.7	97.8	93.7
13	99.7	99.3	82.9
14	98.8	97.5	99.4
15	96.3	95.0	87.7
16	97.2	98.2	96.1
17	99.7	95.1	82.5
18	98.5	93.1	87.3
19	99.2	97.8	94.2
20	94.1	97.7	84.1
Mean	**97.4**	**96.9**	**92.9**
S.D	**15.9**	**15.8**	**15.2**

Table 3 below shows mean results of analyses of water samples for TC, TTC/FC and turbidity from influent and effluent of SSF in clay pots for river users. The result revealed that average TC from influent was 824.0 cfu/100ml where as from effluent it was 4.8 cfu/100_ml. In addition, average TTC/FC from influent was 267 cfu/100ml, and from effluent it was 2.0 cfu/100ml. Similarly, average turbidity from influent was 8.4 NTU and from effluent it was 0.9 NTU. Again the results of TC, TTC/FC and turbidity from effluent of SSF in clay pot are at acceptable level which meets the standards set by the World Health Organization and the Federal Democratic Republic of Ethiopia Ministry of Water Resources (WHO, 2004b).

Table 3. Analyses of water samples for TC, TTC/FC and Turbidity (TR) from influent and effluent of SSF in clay pots for river users (n =20).

H H. No	Influent TC	Effluent TC	Influent FC	Effluent FC	Influent TR	Efflu-ent TR
1	850.0	7.0	156.7	2.3	7.3	0.8
2	756.7	11.7	200.0	5.3	6.0	0.8
3	876.7	3.0	153.3	3.7	4.3	0.5
4	1126.7	16.3	160.0	7.3	8.3	0.5
5	716.7	5.7	276.7	7.7	7.3	1.0
6	796.7	5.3	333.3	3.0	9.3	1.7
7	613.3	8.7	396.7	5.3	6.7	1.2
8	730.0	8.7	353.3	8.7	7.0	1.3
9	980.0	11.3	276.7	3.0	6.3	1.3
10	800.0	10.7	360.0	8.7	6.7	0.7
11	1020.0	7.0	296.7	8.3	5.7	1.3
12	756.7	5.7	236.7	4.3	6.7	1.0
13	833.3	7.0	163.3	1.7	7.0	1.2
14	480.0	4.0	286.7	5.3	6.0	1.3
15	766.7	10.0	313.3	9.0	5.3	0.8
16	876.7	14.0	243.3	10.7	6.7	0.7
17	870.0	6.3	330.0	3.0	5.0	0.8
18	876.7	10.7	313.3	9.0	4.0	0.7
19	906.7	9.0	256.7	1.0	6.7	1.2
20	846.7	11.7	233.3	3.0	6.0	0.8
Mean	**824.0**	**4.8**	**267.0**	**2.0**	**8.4**	**0.9**
S.D	**140.5**	**0.8**	**45.5**	**0.3**	**1.4**	**0.2**

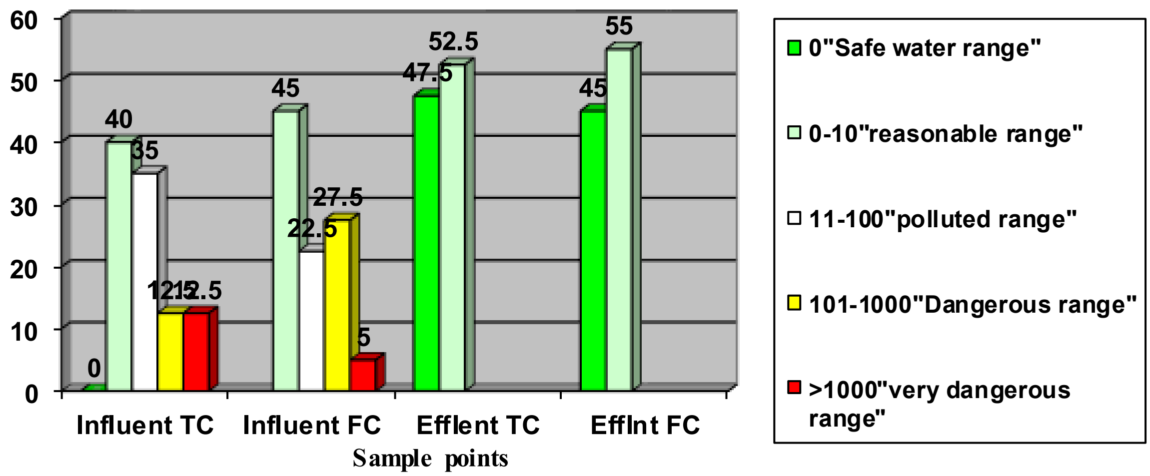
Table 4 below shows removal efficiencies for each SSF in clay pots for river users. The result showed that an average removal efficiency of SSF in clay pots were 97.9 % and 96.5 % for TC and TTC/FC bacteria, respectively, while the removal efficiency for turbidity was 93.1 %.

Table 4. Removal efficiencies of each SSF in clay pots for TC, TTC/FC and TR, per 100 ml of water samples, for river users (n =20).

	Removal efficiency (%)		
HH No.	TC	TTC/FC	TR
1	99.1	98.6	88.2
2	96.4	96.9	95.4
3	99.6	97.4	87.8
4	99.1	95.4	93.9
5	99.2	93.5	86.3
6	95.4	98.9	81.9
7	98.5	98.3	81.9
8	98.3	97.5	99.7
9	98.8	94.9	97.9
10	98.7	97.2	90.3
11	97.2	97.1	95.2
12	98.9	93.5	84.7
13	99.1	98.5	80.3
14	93.2	96.6	97.5
15	98.6	95.7	80.2
16	98.4	95.6	99.8
17	99.3	98.5	83.3
18	94.7	94.5	90.6
19	98.9	95.8	82.5
20	98.3	97.4	84.6
Mean	**97.9**	**96.5**	**93.1**
S.D	**16.7**	**16.4**	**15.9**

Figure 7 below showed the distribution of water samples in each range of TC and TTC/FC from influent and effluent of SSF in clay pot for both spring and river users. The results in Figure 4 revealed that 16 (40 %) of water sample taken from the influent had 1 to 10 TC (cfu/100ml) which is 'a reasonable quality', 14(35 %) had 11 to 100 TC (cfu/100ml) found in the 'polluted' range, 5(12.5 %) tested 101 to 1000 TC (cfu/100ml) which is 'dangerous' range, while 5(12.5 %) were over 1000 TC (cfu/100ml) which is found in 'a very dangerous' range according to the standards set by the World Health Organization and the Federal Democratic Republic of Ethiopia, Ministry of Water Resources (WHO, 2004b). Similarly, 18(45 %) of water sample taken from the influent had 1 to 10 TTC/FC (cfu/100ml) which is 'a reasonable quality', 9(22.5 %) tested between 11 to 100 TTC/FC (cfu/100ml) found in 'polluted' range, 11(27.5 %) tested 101 to 1000 TTC/FC (cfu/100ml) 'dangerous' range, while 2(5 %) were over 1000 TTC/FC (cfu/100ml) which is found in 'a very dangerous' range. Whereas 19(47.5%) of water sample taken from the effluent had Zero TC (cfu/100ml) which is 'safe water' and 21(52.5%) tested 1 to 10 TC (cfu/100_ml) 'a reasonable quality'. In addition, 18(45%) of water sample taken from the effluent had Zero TTC/FC (cfu/100ml) 'safe water' and 22(55%) tested 1 to 10 TTC/FC (cfu/100ml) which is 'a reasonable quality' range according to the standards set by the World Health Organization and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (WHO, 2004b).

Figure 7. Ranges of TC and TTC/FC from influent and effluent of SSF in clay pots



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. More than half of the world's population lives in villages in rural areas and most of those without access to safe drinking water supply or basic sanitation are rural dwellers (Howaard *et al*., 2003).

Several qualitative studies on the evaluation of the effectiveness of SSF in removing coliform bacteria and reduction of turbidity have been carried out in various countries; however, this is the first report on the evaluation of the effectiveness of SSF in clay pot in removing TC, TTC/FC and of turbidity from drinking water in rural areas of Ethiopia.

In the present study, the result of TC, TTC/FC and turbidity from effluent of SSF in clay pot is in a reasonable water quality range according to the standards set by the World Health Organization and the Federal Democratic Republic of Ethiopia, Ministry of Water Resources (WHO, 2004b). The analyses of water samples from influent and effluent of SSF for total and faecal coliforms and turbidity conducted in rural district of Chikwana in southern Malawi (Huisman and Wood, 1974). The result showed that analyses from effluent of SSF for all parameters 6.5 cfu/100ml, 3.0 cfu/100ml and 0.8 NTU were found, which meets the standards of World Health Organization while from influent of SSF were not met, which is found to be similar with the present study. A study on analyses of water quality from influent and effluent of SSF for faecal coliforms and turbidity conducted by Huisman and Wood showed that analyses from effluent of SSF were 2.5 cfu/100ml and 0.8 NTU, which meets the standards of World Health Organization, which is found to be similar with this study (Hijnen, 2007; Kuypers, 2007; Grice *et al*., 2008; Rittmann, 2010; Wooley, 2010; Zhu, 2010).

In a study of the performance of a low cost household In a study of the performance of a low cost household slow sand filtration system carried out in Haiti, it was reported that the system achieved 95.8% removal of coliform bacteria and a reduction on turbidity from 11.2 to 0.9 NTU (Duke and Baker, 2005), which is found to be similar with the present findings. In agreement to the present study, a study conducted in The Hague, Netherlands, suggested that SSF can achieve between 99 and 99.9 % reduction of coliform bacteria (Van Dijk and Ooman, 1978). However, removal efficiencies may be somewhat site specific as there is some variation in the findings from several authors.

The variation in bacteria removals can be attributed to differences in source water quality conditions and filter operational conditions. In the present study, SSF in clay pots was efficient due to increased biological maturity of the filters as well as increased biological treatment resulting from warmer water temperature. This resulted in a stable effluent quality. In addition, the increase is because of physical and biological layers in slow sand filtrations which are responsible for removal of microorganisms. The biological layer, known as biofilm, is mainly responsible for the removal of microorganisms from raw water. The growth of the biofilm increased the 'stickiness' of the filter medium and the specific bed surface, and thus raised the filtration efficiency value. Among the several biological processes occurring within slow sand filter beds, predatory action, maturity of sand bed, and biofilm development are very important for water purification. Pathogenic microorganisms including bacteria and viruses, and cysts of enteroparasites may be effectively removed by SSF (Burman, 1962; Pointer and Slade, 1977). This is partly explained by the slow filtration rate of water and fine sand used, but also attributed to biological mechanisms in the biofilm and within the upper layers of the sand bed (Huisman and Wood, 1974).

Turbidity is one of the very important quality parameters. Turbidity may not have a direct health impact, but is more associated with the social acceptance of water. In the present study, water sources which are found in the study area especially produced water with high turbidity levels due to suspended particles. The filters under study were found very excellent in terms of turbidity removal. The water quality standards of the World Health Organization emphasize to have the turbidity of drinking water below 5 NTU (WHO, 2004b); thus, results of the clay pot filters meet the standards.

Conclusion

The improvement of water quality is closely associated with man-environment relationships. There should be a dialogue between all stakeholders and the community when undertaking water and sanitation activities. Water analyses from the effluent of slow sand filtration in clay pot showed that it is safe for drinking purpose from bacteriological point of view. In light of results obtained so far, following conclusions are drawn**:**

- The study findings indicated that slow sand filtration in clay pot was found to be excellent to have a significant average removal efficiency of 97.4 % and 96.9 % for TC and TTC/FC bacteria, respectively, while the removal efficiency for turbidity was 92.9 % for spring users.
- Moreover, slow sand filtration in clay pot was found to have a significant average removal efficiency of 97.9 % and 96.6 % for TC and TTC/FC bacteria, respectively, while the removal efficiency for turbidity was 93.1 % for river users.
- Perceptions of the householders regarding: (**a**) the taste, smell and appearance of the filtered water, (**b**) ease of use of the filter, (**c**) health protection, and (**d**) sufficient quantity of water produced by the filter for the entire family, indicate high levels of overall satisfaction.
- Observations revealed that the filters were durable, and that most were well-maintained, and functioning properly.
- Major problems of slow sand filter users were plugging of the filter due to suspended solids in the influent. In addition, the users lack knowledge regarding maintaining the filter to remove plugging material and to restore flow rate.
- The study findings suggest that when considering the development and protection of any water source, improvement of environmental sanitation and hygiene promotion program should be one of the issues to be considered as top priority.
- Finally, the baseline information generated from this study may contribute to develop similar programs and also pave the way for further studies.

Acknowledgments

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A comparative study of the water quality of Hare, Kulfo and Sile River using Water Quality Index.

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ABSTRACT

This paper deals with the quality of Hare, Kulfo and Sile Rivers located at Arba Minch area, Ethiopia. To know the general water quality status and whether they are suitable for drinking purposes or not which is easily understandable by the decision makers and public users. In this study, two sampling station were selected for each Rivers and water samples were collected bimonthly from March to June, 2016. DO, pH, TSS, turbidity, total coliform, nitrate, phosphate, temperature and BOD_5 were analyzed for the determination of national sanitation foundation (NSFWQI) and weighted arithmetic water quality index (WAWQI). According to the findings, the NSFWQI of Hare River are 70.09 and 62.43, Kulfo river are 63.85 and 57.85 and Sile River are 70.84 and 63.17 for upstream and downstream sampling stations. Based on these values, the upstream of Hare and Sile river fall under good water quality and the upstream of Kulfo River fall under medium water quality. However, the downstream stations of each river fall under medium water quality. WAWQI results of Hare River are 44.21 and 60.73, Kulfo River are 68.54 and 87.94 and Sile River are 36.19 and 46.60 for the upstream and downstream sampling station. Based on the above value, the upstream of Hare and Sile river fall under Excellent water quality and the upstream of Kulfo River fall under good water quality. But, the downstream of Hare and Kulfo River fall under good water quality and the downstream of Sile river fall under excellent water quality. Both indices show, the upstream sampling stations of the rivers have better water quality than the downstream sampling station. The water quality decreased at downstream because of the influence of human activity, agriculture and urbanization. From the finding Kulfo River quality was lowest than the other two rivers, first it has the highest catchment and larger population settlement; second the downstream water quality was lowest because of 100,000 population settled Arba Mich town influence. Therefore, water quality index easily showed the extent of pollution of rivers and influence of human activity and general public can easily compare and behavioral change can be implemented.

Key words: Hare, Kulfo, National sanitation foundation, physicochemical parameters. Sile, Sub index, Water Quality Index, Weighted arithmetic.

INTRODUCTION

Over the years of time, river has been subjected to human interference regularly and water quality was to be getting deteriorated greatly. Major anthropogenic activities practiced in and around the river: intensive agriculture, abstraction of water for irrigation, bathing, washing cloths open defecation and solid waste disposal activities along the river were generating serious peril to the biota by altering the physicochemical and biological concentration of the river system (Vankatesharajuk et al., 2010). Polluted river water means affected physicochemical parameters, which will have severe negative impact on the health of community residing in the nearby area and using this water for various purposes.

So, it is a must to monitor river water time to time to observe its pollution status and pollution causing factors. Such studies can be of much significance in making the mass aware of deteriorating river water quality and about their use of water for various purposes (Khanna, et al., 2013). Assessment of surface water quality can be a complex process undertaking multiple parameters capable of causing various stresses on overall water quality (Katyal, 2011). Water quality index is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. The objective of this study is producing a water quality index which define the water quality of Hare, Kulfo and Sile Rivers which is comprehensible and understandable by the public. Water quality index was first formulated by Horton (1965) and later on used by several workers for the quality assessment of different water resources (Mohammed & J.K.Pathak, 2011).

Water quality index can also be used to aggregate data on water quality parameters at different times and in different places and to translate this information into a single value defining the spatial and temporal variation involved (Shewta et al., 2013). Water quality index method (WQI) is one of the most widely used ways to assess the quality of surface as well as underground water. Many researchers have used this method worldwide to assess the quality of water in various fields such as rivers and surface waters (Babak et al., 2009). In Hare Kulfo and Sile Rivers various studies were done based on water quality parameters (Tiruneh, 2005; Urgessa, 2015). But a number of water quality parameters is not easily understandable by the decision makers and public users. So, it is important to study the water quality of these rivers based on water quality index.

To study the water quality of Hare, Kulfo and Sile Rivers, water samples were collected from two stations for each of Hare, Kulfo and Sile rivers. In defining the physical, chemical, and biological parameters DO, turbidity, TSS, nitrate, phosphate, TC, water temperature and pH were analyzed. However, individual water quality parameters are not easily understandable because large in number. Therefore, WQI has the capability to reduce the bulk information into a single value to express the data in a simplified and logical form and demonstrate annual cycles, spatial and temporal variation and trends in water quality Shewta et al (2013). So, for easy and simplest interpretation of the parameters water quality index was essential. In this study, NSF and WAWQI were used to show the water quality status of the rivers.

National Sanitation Foundation WQI is the one of the most widely used for comparing the water quality of various water sources and define the overall status of the rivers based up on nine water quality parameters. For each test, the numerical value or Q value is multiplied by weighting factor and its used in the calculation of WQI (Shewta et al 2013). Weighted Arithmetic water quality index also used to classify the water quality according to the degree of purity by using the most commonly measured water quality variables (Chowdhury et al., 2012). This index mainly was used to know whether the rivers used for specific purposes like drinking, recreation and agriculture or not. The aim of this study is generating a Water Quality Index which define the water quality of Hare, Kulfo and Sile Rivers using some selected physicochemical and bacteriological parameters in order to know the general water quality status and suitability of water for drinking purposes which is easily understandable by decision makers and public users.

2. MATERIALS AND METHODS

2.1- Study area

Hare, Kulfo and Sile River are located in Ethiopia, Southern Nation Nationality at Arba Minch area. It is situated on the geographical coordinates between $37_o\,15'$ and $37_o\,18'$ easting longitude, and $5_o\,53'$ and $6_o\,15'$ northern latitude (Figure 2.1). These rivers drain in to the Abaya and Chamo Lakes which is the part of Ethiopian rift valley basin. The Abaya Chamo drainage basin is a sub basin of the rift valley that crosses through Ethiopia midway in the north south direction. From different perennial rivers Hare river is the one which flow in to lake Abaya. However, Kulfo and Sile are the major drainage rivers which flow in to lake Chamo.

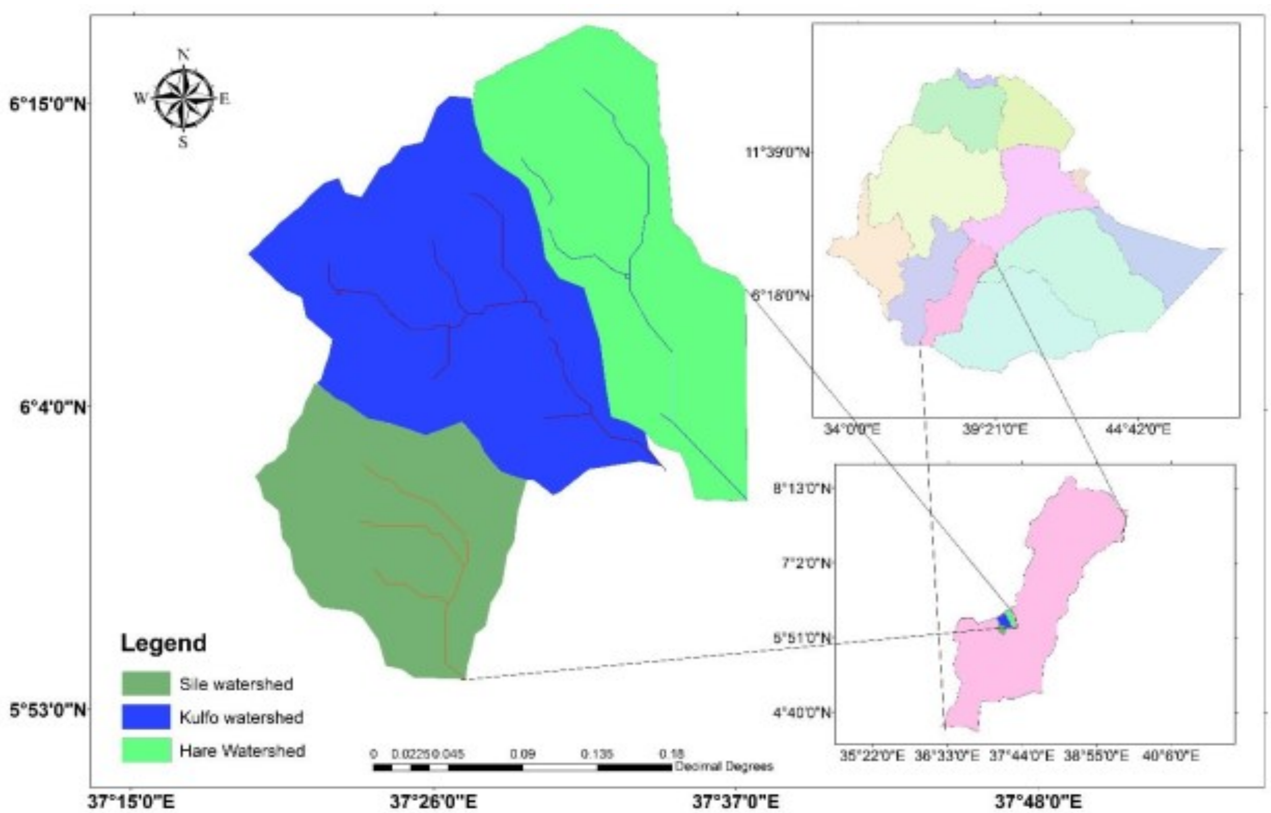

Figure 2.1: - Geographical location of the study area

2.2 Sampling and sampling points

Water samples were collected from two sampling stations for Hare, Kulfo and Sile Rivers by composite sampling. The sampling frequency were done bimonthly interval from March up to June, 2016. Water samples were collected in one litre polyethylene bottles for physicochemical analysis and with sterilized glass bottles for Bacteriological analysis. These samples were transported to the laboratory with an ice box. The samples for physicochemical and Bacteriological parameters were preserved in ice before transporting to the laboratory for analysis. For transportation of samples dark colored ice box were used in order to avoid the exposure of samples to sunlight variations in temperature. The two sampling points were selected to see the major impact of the human activity on that rivers.

Table 2.1: Sampling point on Kulfo, Hare and Sile Rivers.

Rivers	stations	Coordinate		Location
		Northing	Easting	
Hare	H1	6^0 8'16.55"	37^0 33'9.26"	5 kilometres in the upstream direction from the gauging station.
	H2	6^0 5'14.44"	37^0 34'47.62	3.5 Km downstream from the diversion weir
Kulfo	K1	6^0 05'30.40"	37^0 30'43.79"	Upstream of Arba minch prison
	K2	$6^0$00'50.83"	$37^0$34'.5216"	Next to the Kulfo Bridge in the Nechsar National Park
Sile	S1	5^0 56'14.69"	37^0 26'21.31"	2 kilometre upstream from Mele town
	S2	5^0 53'52.48"	37^0 30'22.92"	3 Km downstream Arba Minch Jinka road Bridge

2.2 Sample analysis method

DO, pH and water temperature were measured at site and TC, BOD_5, turbidity, total suspended solids, phosphate and nitrate were analyzed at water quality laboratory as per standard methods (APHA, 2012).

2.3 Water Quality Index computation using NSFWQI and WAWQI

2.3.1 National Sanitation Foundation Water Quality Index (NSFWQI)

NSF WQI is an excellent management and general administrative tool in communicating water quality information. This index has been widely field tested and applied to data from a number of different geographical areas all over the world in order to calculate WQI of various water bodies.

The mathematical expression for NSF WQI (Behamnesh, 2015) is given by;

$$\textbf{NSFWQI}= \sum_{i=1}^{p} W_i Q_i$$

Where; W_i:-is the weightage associated with i_{th} water quality parameter; Q_i: - is the sub-index for i_{th} water quality parameters and P: - is the number of water quality parameters.

Table 2.2: - The assigned weightage values for each parameter.

Parameters used	Unit	Weightage Value
DO	mg/lit	0.17
Total coliform	CFU/100ml	0.16
pH		0.11
BOD_5	mg/lit	0.11
Temperature	^{O}C	0.10
Po_4^{3-}	mg/lit	0.10
No_3^-	mg/lit	0.10
Turbidity	NTU	0.08
Total Suspended Solids (TSS)	mg/lit	0.07

Table 2.3: - Water Quality Index scoring and water quality status using NSFWQI.

Water Quality Index Scoring level	Water Quality status
90-100	Excellent water quality
70-90	Good water quality
50-70	Medium water quality
25-50	Bad water quality
0-25	Very bad water quality

2.3.2 Weighted Arithmetic Water Quality Index (WAWQI)

In most water quality studies WAWQI were used to classify water quality of water body for specific uses like: drinking, Irrigation, recreation and aquatic system. In this study WAWQI is mainly used as to know the water quality of Hare, Kulfo and Sile Rivers whether they are suitable for drinking purposes or not. In this method, different water quality components are multiplied by a weighting factor and are then aggregated using simple arithmetic mean. The WAWQI method (Brown, et al., 1972) has been used for the calculation of water quality index of the water body in the following steps: -

i **Calculation of Sub Index of Quality Rating (Q_i): -** The value of Q_i is calculated using the following expression.

$$Qi = 100 * \frac{[V_a - V_i]}{[V_s - V_i]} \quad \text{(Eq 1)}$$

Where: - Q_i = Quality rating for i_{th} parameter for a total of a water quality parameter; Va = Actual value of parameter obtained by lab analysis; Vi = Ideal value of Water quality parameter; all ideal value of taken as Zero except pH=7 and DO = 14.6 and Vs = Recommended standard (WHO)

ii **Relative unit weight calculation (Wi)**

The Relative (Unit) Weight (Wi) was calculated by a value inversely proportional to the recommended standard (Si) for the corresponding parameter using the following expressions.

$$wi = {}^{K}/_{si}$$

Where Wi= relative weight for i^{th} parameter; K = Constant of proportionality and Si = Standard permissible value for n_{th} parameter.

$$\text{Constant of proportionality (K)} = \frac{1}{\frac{1}{S_{i1}} + \frac{1}{S_{i2}} + \dots + \frac{1}{S_{in}}} \quad \text{(Eq 2)}$$

iii The
Overall Water Quality Index

The overall WQI was calculated by aggregating the Water quality rating (Qi) with the relative unit weight (Wi) linearly by using the following equation.

$$\text{WQI} = \frac{\sum \text{Qi Wi}}{\sum \text{Wi}} \quad \text{(Eq 3)}$$

Table 2.4 Water Quality Index classification using WAMWQI (Mophin & Murgesan, 2011; Ahmed, et al., 2015)

Water Quality Index Scoring level	Water Quality Status
0-50	Excellent water quality
50-100	Good water quality
100-200	Poor water quality
200-300	Very poor water quality
Above 300	Unsuitable for drinking

3 RESULTS AND DISCUSSIONS

3.1 **The pollution extent of Hare, Kulfo and Sile Rivers**

Temperature, Turbidity and Total Suspended Solids, pH, DO, BOD, Phosphate, Nitrate and Total Coliform have been analyzed. According to the analysis of this parameters the average value was shown in Table 3.1.

Table 3.1 Analyzed average value of each parameter.

Parameters	**Standard value**	**Average value**		**Average value**		**Average value**	
		Hare upstream	**Hare Downstream**	**Kulfo upstream**	**Kulfo downstream**	**Sile upstream**	**Sile downstream**
Temperature		18.54	19.6	19.54	20.5	17.61	19
DO	> 5 mg/lit	7.04	6.6	6.75	6	7.12	6.7
pH	6.5-8.5	7.79	8.1	8.06	8.5	7.96	8.2
TSS	50 mg/l	654.63	932.6	1256.63	1550.6	311.13	429.5
Turbidity	50 mg/l	111.25	127.1	163.01	192.6	41.66	66.4
TC	0 CFU/100ml	6	12.6	10	18.3	6.38	13.4
Nitrate	45 mg/lit	16.67	22.7	20.7	29.7	18.47	25.6
Phosphate	0.1 mg/lit	0.15	0.1	0.25	0.1	0.19	0.1

From all analyzed parameters temperature, DO, pH, and nitrate are with in WHO 2008 standard permissible limit. However, the parameters like turbidity, TSS, total coliform and Phosphate (at upstream station) are above permissible limit.

The parameters which is above recommended permissible value caused by, the upper catchment of the rivers deforested that increases in TSS and turbidity due to high runoff. The downstream sampling stations of the rivers have lower water quality than the upstream sampling stations. This is due to at the outlet of each river there are settlement, urbanization and irrigation activity which directly affect the water quality of the rivers followed by high runoff that reach the rivers.

From all rivers, the pollution extent of Kulfo River higher than Hare and Sile Rivers because of the catchment of Kulfo river more deforested due to agricultural land expansion and at the downstream of this river there is urbanization which affect the water quality of the river due to poor sanitation practice, solid waste removal and urban storm runoff that inter the river after rainfall.

3.2 Classification of the Rivers based on NSF and WAWQI.

To Classify and rank Hare, Kulfo and Sile Rivers, according to their quality NSF WQI and WAWQI were used. The classification of this rivers was done by using index scoring level and water quality status that described on the methodology section in Table 3.3 and 3.4.

3.2.1Classification of the upstream and downstream of Hare, Kulfo and Sile Rivers using NSF water quality index.

NSF WQI classifies the upstream water quality of Hare, Kulfo and Sile Rivers as GOOD, MEDIUM and GOOD water quality respectively. This classification shows the upstream of Sile and Hare Rivers has better water quality than Kulfo River. This is due to, some of the analyzed parameters like Turbidity, TSS, and phosphate are higher in Kulfo River than Sile and Hare River. However, the value of NSFWQI at the downstream sampling station revealed that, all rivers fall on MEDIUM water quality. Figure 4.3 shows the classification of Hare, Kulfo and Sile Rivers on their water quality at both station.

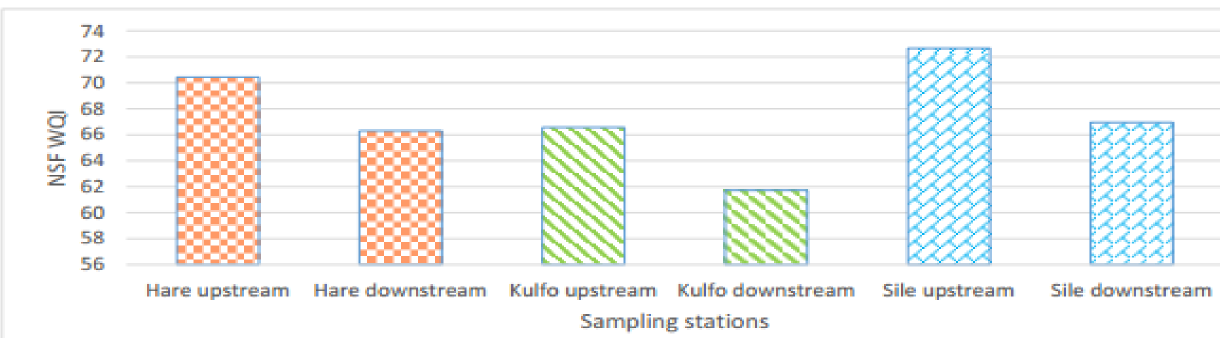

Figure 3.1 Water quality status of Hare, Kulfo and Sile river and their rank using NSFWQI.

3.2.2 Classification of the upstream and downstream of Hare, Kulfo and Sile rivers using WAWQI.

From all upstream sampling station of rivers, the scoring level of WAWQI indicates Kulfo River shows good water quality level at both stations. However, Hare and Sile River classifies under EXCELLENT water quality. This is due to some of analyzed parameters which affect the calculation of water quality index are above permissible limit. The downstream sampling station of Hare, Kulfo and Sile Rivers, the classification shows Kulfo earnings the least place. The following Figure 4.4 shows the classification of Hare, Kulfo and Sile Rivers on their water quality at both station using the Weighted Arithmetic water quality index.

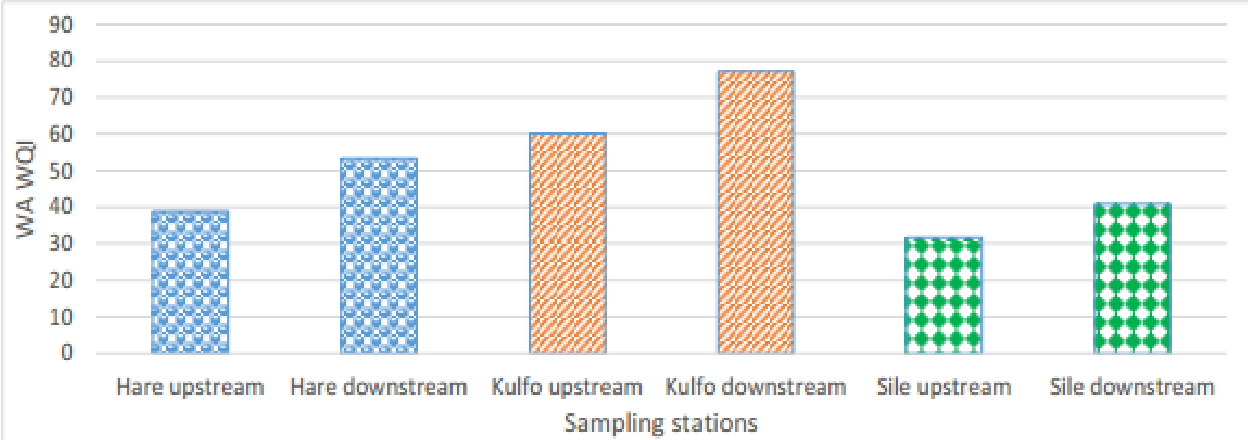

Figure 3.2 Water quality status of Hare, Kulfo and Sile river and their rank using WA WQI.

Hare River has a better water quality than Kulfo River, however Sile River much better water quality than Kulfo but better water quality than Hare River. This is because of the downstream of Kulfo River highly degraded than Hare and Sile due to the impact of urbanization and agricultural practice.

3. CONCLUSIONS

On the basis of nine parameters analyzed in this investigation, it was concluded that the pollution extent of Kulfo river was higher than Hare and Sile Rivers. However, Sile river shows lower pollution extent.

By using NSFWQI and WA WQI spatially, the upstream sampling stations of the rivers have better water quality than the downstream sampling station due to some parameters increased at this station. Temporally the lowest water quality level observed at March and the best water quality observed in June. WAWQI revealed that Sile and Hare River at both stations and upstream of Kulfo Rivers was suitable for drinking purposes with conventional and advanced treatment methods. However, the downstream of Kulfo River needs an advanced treatment method.

4. ACKNOWLEDGMENT
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Water quality and phytoplankton dynamics of physico-chemical characteristics of Legedadi Reservoir

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Abstracts

The seasonal dynamics of Physico-chemical water quality parameters of Legedadi Reservoir were investigated at monthly intervals. The study was conducted for about a year at three study sites in the reservoir. All physico-chemical parameters were measured using standard techniques. Transparency of the reservoir was extremely shallow and (always <10cm) and showed both seasonal and spatial variations (8$\pm$0.56) due to erosion and resuspension of sediments. The pH was around neutral throughout the study period with small temporal and spatial variations(7.8$\pm$0.24). The reservoir is moderately turbulent and characterized by unusually high turbidity throughout the study period (with most values > 400 NTU).
The conductivity and TDS values were within the range that drinking water should have. Both TDS and conductivity varied temporally with strong correlation ($r = 0.9$, $p<0.05$). Total alkalinity was found to be low (0.84$\pm$0.27)indicating that even a small amount of acid can cause a large change in pH or an increased risk of acidification meaning that the reservoir's water has low buffering capacity. Carbonate hardness varied both seasonally with most maximum values recorded during the rainy season (mean value of 46.5$\pm$6.7). It is fairly high but within the range of drinking water can have. All plant nutrients showed significant temporal variations with most maximum values recorded since March to the rainy seasons associated with intermittent and continuous rains. Phytoplankton biomass significantly varied seasonally (mean 37.4$\pm$20.5) with maximum values recorded during the most dry seasons most water quality problem incidences occurred. Throughout the study period 35 species of phytoplankton were identified, blue green algae being the dominant with 12 species and accounting more than 85% of the abundance. As a conclusion, the most important water quality problems are probably due to the variability in the major water quality parameters and their interactions which resulted in the dominancy of the blue green algae.

Key words: Water quality, Reservoir, Physico-chemical, Legedadi

Introduction

Fresh water bodies including reservoirs are finite resources essential for agriculture, industry, and human consumption. Among the freshwater bodies, reservoirs are much more susceptible to changes and this in turn affects the aesthetics, the cost of drinking water treatment and the public health.

Water quality of reservoirs is deteriorating due to both natural and anthropogenic factors.Agriculture, industries and urban settlements adjacent to, or in the drainage basin of reservoirsbecome the major contributors to the deterioration of reservoirs' water quality and human health problems by releasing contaminants, through the discharge of waste waters in to these water bodies or their source water.

Legedadi Reservoir, which provides the largest proportion of drinking and house hold water supply for the city of Addis Ababa has suffered, during the last three decades or so, from various problems includ-ingsmell, color, excessive chemical consumption and nuisance algal blooms. Reports showed that the reser-voir water has repeatedly failed to meet the world health organization's (WHO) requirements for potable water supply in turbidity and color (Lehmusluoto, 1999; AAWSA, 1994) from intermittent samplings. In spite of these serious problems, there have been no long term studies conducted. There haven't been any studies conducted how the physico-chemical parameters behave seasonally. Although proliferation of algae isan obvious phenomenon, the community structure, their seasonal dynamics and the underlying factors of community structure changes haven't ever been studied.

The objective of this study is, therefore, to investigate the seasonal dynamicsof the major water quality pa-rameters and the temporal changes in phytoplankton community structure in the reservoir.

Materials and Methods

Study Site

The reservoir under investigation is Legedadi, situated about 30 km northeast of Addis Ababa, the capital of Ethiopia (Fig.1).

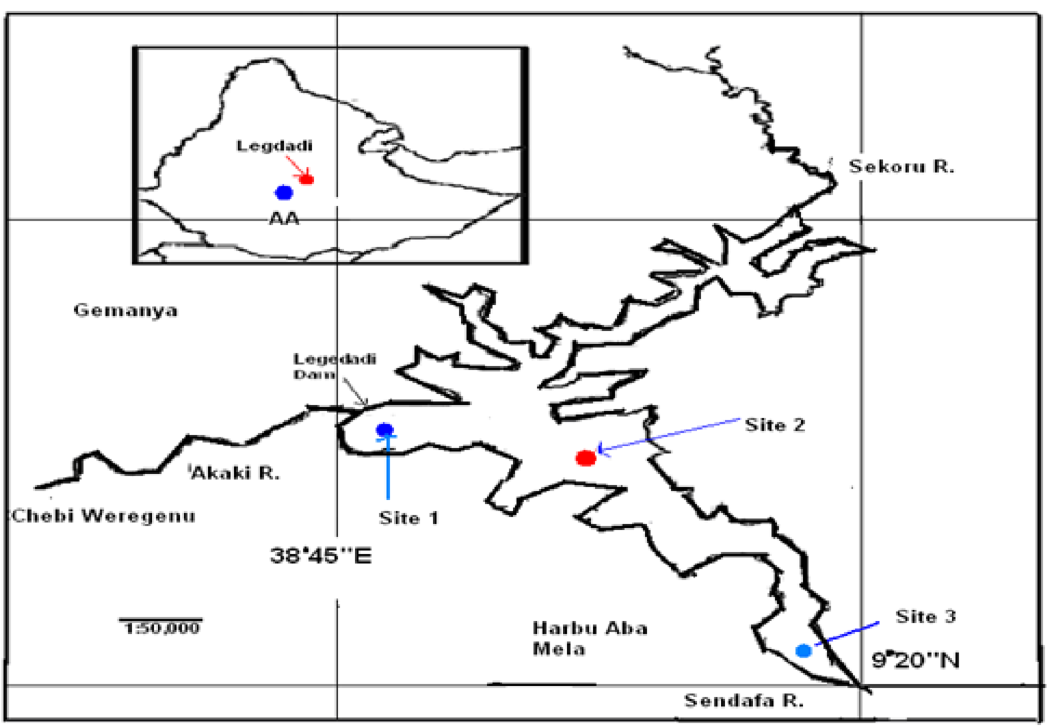

Fig. 1 Map of Legedadi Reservoir with sampling sites indicated

Some geographic and morphometric features of Legedadi Reservoir and its catchment area are given in Table 1.

Table1: Some morphometric and geographic features of Legedadi Reservoir and its catchments.

Features	**Measurement values**
Latitude	$9^{0}20'$ N
Longitude	$38^{o}45'$ E
Altitude (m, a.s.l)	2450
Area [ha (Km^2)]	452 (200)
Volume (m^3)	50×10^3
Maximum depth (m)	34
Mean depth (m)	4
Catchments area, [ha (Km^2)]	20 560 (9 097.35)
Catchments altitude (m, a.s.l)	2460-3200

Study Design and Sampling

For this study, three sampling stations were chosen: stations 1, 2 and 3. Station 1 is located close to the dam, deepest and site of algicide application; station 2 is situated around the middle of the reservoir, characterized by less disturbance and medium depth; and station 3 is established at the rear side of the reservoir characterized by its shallowness, the site of intermittent river discharge and high human activity (Fig. 1).From these stations, water samples were taken every month and majorphysico-chemical parameters and limiting plant nutrient measured. Phytoplankton species composition identified and biomass as *chl a* measured. Finally, the data from the three stations were pooled to an average data for the reservoir.

Measurement of Physico-chemical parameters

Water level of the reservoir was taken from the installed elevation gauge at the dam site. Water transparency was measured with a standard black and white secchi disc of 20 cm in diameter. Turbidity was measured using direct reading HACH Kit (DR/4000 spectrophotometer).

PHand electrical conductivity of the surface water was measured *in situ* with a portable digital pH and conductivity meters respectively (Hanna 9024). Alkalinity due to carbonate and bicarbonate ions was determined by titration technique. Total hardness as calcium carbonate ($CaCO_3$), total dissolved solids, nitrate, ammonium, SRP and SR silica were analyzed using a Hach Kit (DR/4000 spectrophotometer).

Phytoplankton species identification, estimation of abundance and biomass

Samples were collected with a plankton net of 10 µm mesh size from the near- surface region of the reservoir, stored in brown bottles and preserved using Lugol's solution (Wetzel and Likens, 2000) and placed in a refrigerator. The samples were examined with an inverted microscope and the identification to genus or species level was made using different keys. Aliquots of the preserved samples were used, after sedimentation, for the estimation of the relative abundance ofphytoplankton with a Sedgwick-Rafter cell under an inverted microscope.

Phytoplankton biomass was estimated as chlorophyll *a* concentration spectrophotometrically at 665 nm from 90% acetone extracts of the particulate material remaining after filtration through Whatman glass fibre filters (GF/C) and centrifugation. The absorbance was corrected for turbidity by subtracting the corresponding readings at 750 nm.

Result and Discussion

Changes in water level as a function of rainfall

The reservoir's water level declined continuously throughout the dry season with a maximum decline of about 2m during May, when the yearly hottest weather prevailed (Fig. 2). The water level increases only during two heavy rainy months of the year (July and August).However, the total annual increase in the year was less than the annual decrease resulting inthe decrease of the volume of the reservoir. The fluctuation will have negative attributes not only to the raw water quality but also it makes the treatment process very difficult and hence affects the potable water quality.

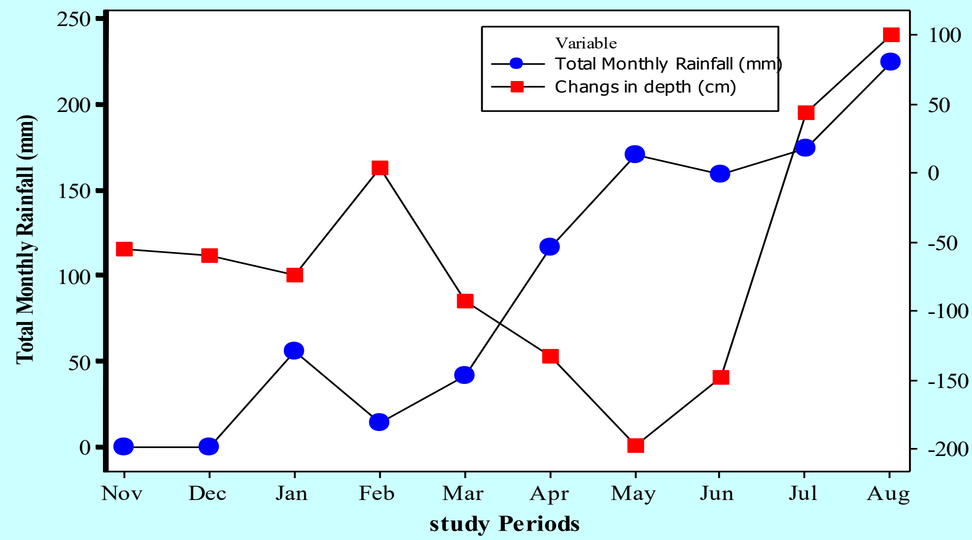

Figure 2: Total Monthly Rainfall and Changs in the water level of Legedadi Reservoir

Seasonal changes in physico-chemical parameters

Surface water temperature of the reservoir temporally varied significantly ($\pm$2.4°C) with the maximumand minimum values recorded during the dry (March–May)and rainy (July–August) seasons respectively (Fig. 3).

Transparency of the reservoir was found to be very low with mean value of 7.97 cm ($\pm$0.6)(Fig. 4). The observed differences between months can be explained by the prevailed weather conditions and feeding behavior of the fish. The year-round low transparency of the reservoir shows that the high turbidity is not only due to the influx of sediment during run off but also the resuspension of sediments by the water turbulence and bottom feeder fish. The high turbidity of the reservoir obviously makes the drinking water treatment very expensive.

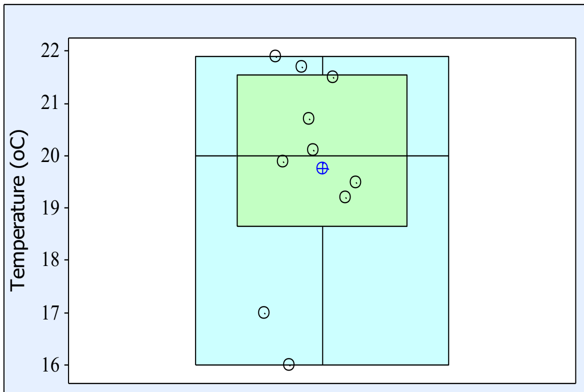

Figure 3: Variations in surface water temperature

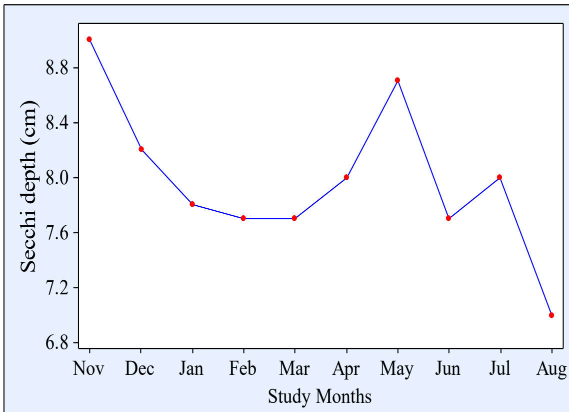

Figure 4: Seasonal variations in transparency

Seasonal variations in pH and alkalinity

The pH was around neutral throughout the study period with small temporal variations with in the range of the highest desirable pH levels (6.5-9.5; WHO, 1996) (Fig. 5). However, it wascloser to the upper boundary of the range of values within which most raw water lays (6.5-8.5).

Total alkalinity was found to be low with less temporal variations (0.84±0.27meq/L) (Fig. 6). Compared with previous studies, the variation in alkalinity was found to be very low. Moreover, compared to the TA of most acceptable water supply sources, 0-8 meq/L(Bailey and Bilderback, 1998) and to the expected total alkalinity values in nature, 0.4-40 meq/L(Lind, 1979), the TA is low and close to the lower boundary values.

Seasonal changes in turbidity, TDS, hardness and conductivity

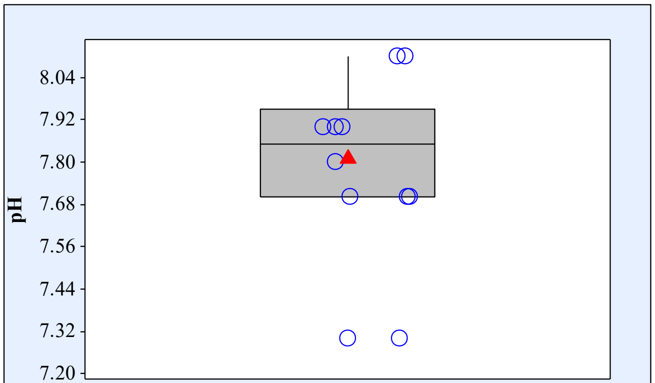

Figure 5: Seasonal variations in pH

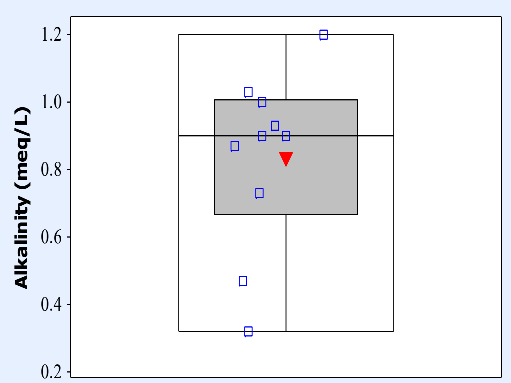

Figure 6: Variations in alkalinity of the reservoir

Turbidity varied significantly (332±138.8 NTU) with maximum values during the intermittent rains of the dry months and throughout the rainy season. These make the reservoir among the most turbid in tropical regions. The high turbidity could be attributable to the influx of particulate materials from the catchments through runoff, the fairly high photosynthetic biomass and the re-suspension of inorganic (silt and clay) and organic particles by the frequent wind-generated mixing.

The conductivity values were almost similar to those reported previously by AAWSA (125±22.3 µS/cm). The values were always more than 100 µS cm^{-1}during the dry months of the study period and this may be due to evaporative concentration of ions (Fig.7). The mean TDS values showed small temporal variations (45.6±7 mg/L) with maximum values recorded during March and April (Fig. 7). The correlation between conductivity and TDS for the reservoir was positive and very strong ($r=0.9$, $p<0.05$) similar to many Ethiopian lakes (Wood and Talling, 1988).

The positive correlation, between TDS and hardness ($r=0.76$, $P<0.05$), probably due to the presence of calcium and magnesium as important components of the TDS.

Hardness measurements, with slight seasonal variations, lay in the range that drinking water can have (10-500 mg/L; WHO, 1996) and a water with hardness always less than 60 mg/L of $CaCO_3$ is considered as soft water according to WHO (1996).

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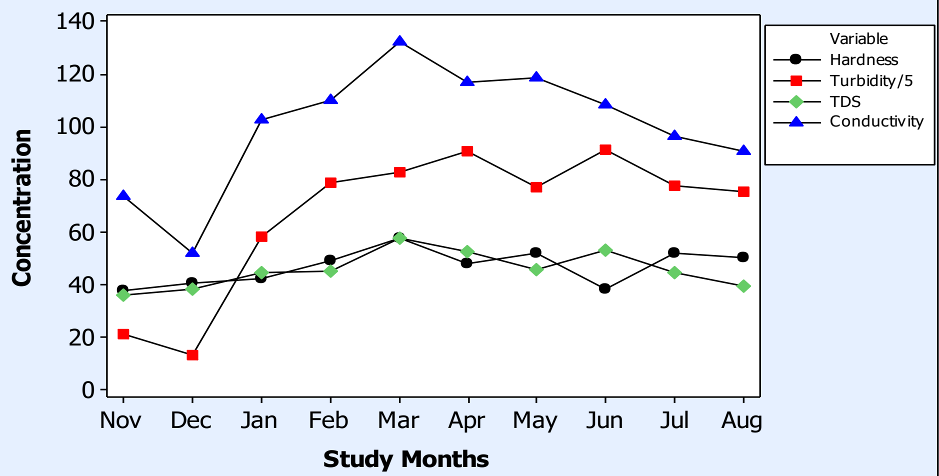

Figure 7:Variations in hardness (mg/L), turbidity (NTU), TDS (mg/L) and Conductivity (µS/cm)

Seasonal variations of nitrate, ammonium, orthophosphate and reactive silica

Nitrate varied from a minimum of less than 400 µg/L to always more than 500 µg/L during the dry months of the year (March to June) (Fig. 8). Marked temporal fluctuations of nitrate (540.1$\pm$160 µg/L), often coinciding with fluctuations in phytoplankton biomass, were observed reflecting the greater importance of nitrogen in determining changes in phytoplankton biomass ($r= 0.63$, $p<0.05$). The peak nitrate levels observed during periods of short rain periods and rainy seasons seem to be associated with the increased inputs through run off from the surrounding agricultural lands and the feeder-rivers.

Ammonium varied irregularly throughout the study period. The concentration of NH_4-N in well-oxygenated water is usually low relative to other forms of inorganic nitrogen due to its prompt oxidation (Kalff, 2002) and rapid and preferential uptake by phytoplankton (McCarthy, 1980). Most peak values were observed following periods of high phytoplankton biomass probably suggesting the release of NH_4 -N from the decomposition of bloom material.

According to Kalff (2002) a temporary rise in NH_4-N concentration can be observed following the collapse of algal blooms and during increased mixing (Fig.8).

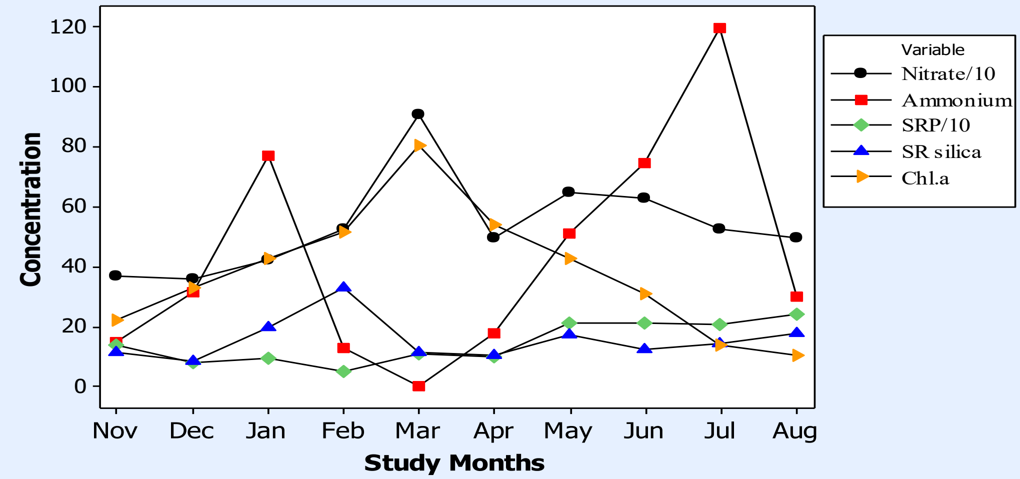

Figure 8: Nutrient and phytoplankton dynamics

Soluble reactive phosphate (SRP) significantly varied seasonally (147$\pm$66 µg/L) with higher values recorded during intermittent and rainy seasons (Fig.8).The remarkably high concentrations of SRP seem to be associated with the intensive human activities carried out in the catchments area. Reactive Silica was found to vary seasonally (15.1$\pm$7 mg/L). High concentrations of silica were not necessarily correlated with high phytoplankton biomass probably reflecting the fact that diatoms are minor components of the planktonic algal flora of the reservoir.

Phytoplankton biomass, composition and relative abundance

Phytoplankton biomass remarkably varied seasonally (37.4$\pm$20.5 mg/m^3) with minimum and maximum values recorded during the rainy and dry months of the year respectively (Fig.8). Phytoplankton biomass recorded in this study was higher than those observed in previous investigations (MelakuMesfin and Amha Belay; Lehmusluoto, 1999) for the same reservoir and many other tropical reservoirs (Hunt *et al*, 2003).

The observed temporal variations in phytoplankton biomass were clearly associated with the input of nutrients through runoff during the rainy season and mixing during the dry season.

The minimum values of phytoplankton biomass during the rainy months could be due the result of the cumulative effect of reduced underwater irradiance due to increased abiogenic turbidity, shorter residence time of phytoplankton in the euphotic zone and hydraulic washout.

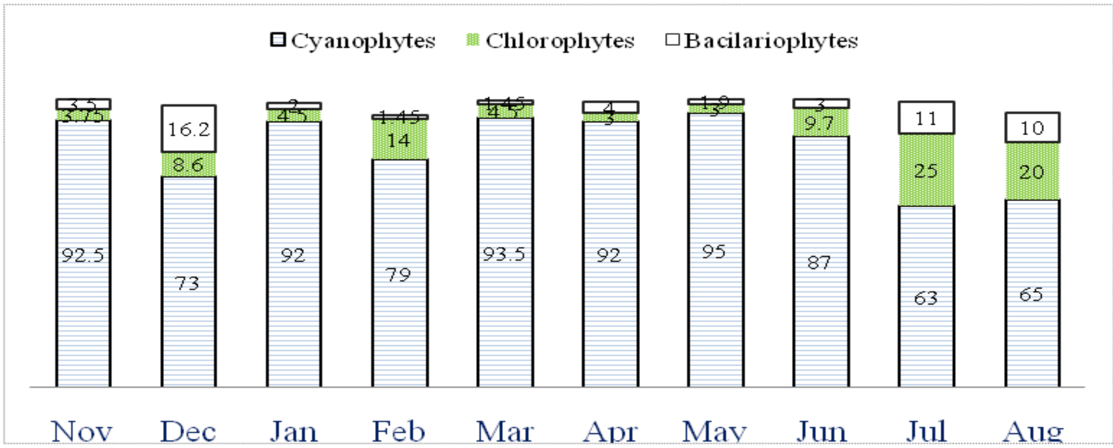

Figure 9: Relative abundance of major phytoplankton algal groups

A total of 35 species of phytoplankton were recorded during the study period. Blue-green algae with 12species were the most diverse and dominant taxonomic group. Marked seasonal changes in abundance was very common with blue green algae accounted for more than 70% throughout the year except during July and August (Fig. 9). Temporal changes in the relative importance of the different taxonomic groups to the abundance of phytoplankton in the reservoir were observed, although blue-greens were the most abundant and persistent (Fig.9) showing a shift from green algae dominancy recorded previously (AAWSA, 1994).

Among the blue-greens, *Microcystis* and *Anabaena*, were the most important in terms of both species diversity and percentage contribution to the total phytoplankton abundance. *Microcystis*and *Anabaena* are among the troublesome genera that commonly form blooms in lakes and reservoirs and are taken as signs of water quality deterioration and aging process in reservoirs.

The inter-annual variations in the relative importance of different taxonomic groups of phytoplankton and the timing of their dominance should be expected in light of the irregular pattern of climatic conditions and long-term changes in the physico-chemical conditions of the water column in the reservoir. Cyanobacterial dominance, a salient feature of Legedadi Reservoir, can be associated with several environmental factors such as low turbulence, low light, high temperature, low carbon dioxide or slightly high pH, high total phosphate, phosphorus storing strategy, ability to minimize grazing, buoyancy and low euphotic to mixing depth ratio.

Conclusion

The year-round high levels of turbidity and unusually shallow transparency of the reservoir together with the high levels of limiting plant nutrients gave a competitive advantage and favorable environment to cyanophytes, particularly for microcystis and anabaena species over the others. These conditions obviously lead to the deterioration of the water quality of the reservoir.

Seasonal variations in TDS, TA, pH, hardness and conductivity of the reservoir were clearly evident but with regard to water quality requirements, all of the parameters lay within the acceptable range. Therefore, the intermittently recurring water quality problems including color and odor can be related to the high and temporal dynamics of phytoplankton community.

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Multivariate Analysis of Water Quality Along APollution Gradient: An Outlinefor Selection of Environmental Monitoring Indices

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ABSTRACT
A study was conducted to analyze the water quality parameters and macro in vertebrate community change along a pollution gradient for Gidabo River of Ethiopia. One upstream sampling site free from coffee-waste impact served as control, and three downstream sampling sites affected by coffee-waste were selected for contrast. Analysis of water samples taken at different time spans revealed an elevated organic pollution as it showed high concentration of biochemical oxygen demand (BOD_5)(9.37, 391.75mg/l, $p<0.01$), phosphate (1.75,10.1mg/l, $p<0.05$), nitrate (0.81,87.25mg/l, $p<0.01$) and total dissolved solids (TDS) (45.61,346.4 mg/l, $p<0.01$) during operation and non-operation seasons of the mills respectively. Along these pollution gradients, the distributions of macro in vertebrate communities were examined using Shannon–Wiener (H), Margalef Diversity (D), and Hilsenh off Family-level Biotic (FBI) indexes. The results showed that in Gidabo River, the Shannon–Wiener index (H) is 2.96-3.33, the Margalef diversity index (D) is 1.88–3.75, and Hilsenh off Family-level Biotic Index (FBI) is 9.91-7.5. The Multivariate principal component analysis (PCA) well explained the correlation between the biotic indices and the physicochemical water quality parameters. Hence, this study strongly suggests the onsite use of the above three biotic indices for rapid water quality monitoring of Gidabo River. The indices has been recommended as a pollution monitoring tool for the implementation of ecologically sustainable coffee-processing sector in coffee-growing Districts of Ethiopia.

Keywords: *Multivariate; BOD5; environmental monitoring; macro invertebrate; index; PCA*

INTRODUCTION

Gidabo Watershed (6.09^0 and 6.6^0 N latitude and 38.0^0 and 38.38^0 E longitude with an area of 3342.37 square kilometers) is located in the Rift Valley Lake Basin of Ethiopia. The total length of the watershed is measured about 76 kilometers with the highest flow distance of about 117 kilometers. The length of the longest river in the basin is about 38 kilometers, and the maximum stream slope is 0.15 percent.

Coffee is a major export commodity for Ethiopia, with a share of 61% of the country’s annual commodity exports(Alemayehu & Ranni, 2008). Due to the country’s suitable altitude, rainfall, temperatures and fertile soil, the potential of coffee production in Ethiopia is very high.About half a million hectares of land are covered by coffee plantations, with a total production of 0.42 million metrictons of clean coffee in 2015 (CSA, 2015).

From field to cup, coffee goes through four processing steps. Primary processing involves on field harvesting and sorting of the cherries among different quality groups. Secondary processing entailsthe separation of the green beans from the harvested cherries. Tertiarycoffee processing engagesroasting the dried beans and making it ready for boiling. The last processing step involves boiling and serving on a cup.Each processing step dischargesdifferent quantities and qualities of waste as a by-product.

In the secondary processing, coffee can be processed in two ways either dry (natural) and wet (washed) processing. Wet processing is held with the help of water, especially to remove the red outer skin and the white fleshy pulp (Wintgens, 2009). The amorphous gel of mucilage around the beans is removed by fermentation with the use of high-quality water. Wet coffee processing can be done in a batch system, as most of the processing plants do in Ethiopia. Currently, there are advanced processing methods being practiced at some parts of the world (Adams, 2006).

These technologies are increasing the quality of the product while safeguarding the environment from pollution (ECIUT, 2010).

Wet Coffee processing is widely accepted for selection of ripe coffee fruit that is essential for producing good quality coffee beans (Rodrigo, 2003). It yields coffee pulp, mucilage, and wastewater as a by-product and green coffee beans with hulls on the main product line(Antonio et al., 1999). Once separated from the pulp, the coffee beans are transported hydraulically to fermentation tanks for mucilage break-down and removal. Fermentation time is varies depending on the altitude and temperature of processing sites. This process is almost anaerobic in nature and carried out for 36-72 hr(Braham et al., 1973; Braham & Bressani, 1979).Secondary wet coffee processing mills are anticipated to contain the waste (solid and liquid) generated during their operation. However recent survey conducted by the *Natural Resources Development and Environmental Protection Office of Southern Region of Ethiopia* reported a potential waste release from the mills; where the owners of the mills rejected the contention.

Despite thecoffee sector positive contribution for food security, secondary coffee processing wet mills may have negative impacts on the environment. Environmental protection authorities shall profoundly consider to evaluate whether the existing secondary processing wet mills are working according to the required level of environmental quality to make the sectorsustainable.Most studies on secondary coffee processing wet millsfocuson technical feasibility,but the better availability of resourcesalone is not a sufficient condition while several factors determine to maximize high-quality coffee production thereby improving better export earnings(Mihret et al., 2013). So far;very little is known about theenvironmental issues of wet coffee processing wet mills in Ethiopia. Even though the contributions of the coffee sector for export earning and livelihood diversification in Ethiopia ishighly significant, there is no conclusive information available about the impact on the environment, particularly on biota.

Developing an understanding on the potential environmental impact of secondary wet coffee processing mills on the ecosystem is very urgent and helps to take appropriate measures on the ongoing extensive coffee sector development program of the country(Mihret et al., 2013). Therefore, the general objective of this research was to understand the present and future environmental impacts of secondary coffee processing wet mills through careful analysis of cases from Gidabo watershed. The specific objectives of the study were to:

- Identify physicochemical and biologicalimpact assessment indicators;
- Assess and characterizesecondary wet coffee processing wet mills in their level of environmental impacts,and
- Evaluate environmental situations of four selected sites and extracting lessons for other secondary coffee processing wet mills.

MATERIALS AND METHODS

Sampling sites

Four sampling sites are chosen based on their respective locations on the Gidabo River, as presented in Table 1.

Table 1.Sampling sites locations

$$H=-\sum_{i=1}^{S}P_i(\log_2^{p_i}),P_i=\frac{n_i}{N}$$

No	Location	Reference	Upper-stream	Middle-reach	Lower-reach
		S_1	S_2	S_3	S_4
1	Northing	758343	746571	708019	712485
2	Easting	439213	431182	419521	419192
3	Site	Teremesa	Aposto	Bedessa	Bridge
4	District	Shebedino	Dale	DilaZuria	Dilla-Dara

Table 1.Sampling sites locations

Community structure and biotic indexes

Benthic macroinvertebrates have been frequently used for the assessment of the health of the aquatic ecosystem in environmental monitoring and assessment (Reynoldson & Metcalfe-Smith, 1992). In this research,a sampling of benthicmacroinvertebrateswas carried out during early summer of 2014 three months after wet coffee mills started operation.Sampling was conducted with a 25cm-by-25cm modified rod operated Peterson Grab bottom sampler (Barbour et al., 1999). The collected samples were sorted-out using 500µm sieve, and then transferred to aclean white bucket for further analysis (Chapman, 1996). The collected organisms were stored in 70% ethanol and brought to the laboratory for counting (Barbour et al., 1999).

Shannon and Wiener developed the Shannon-Wiener Index (H) in 1949 (Liu et al., 2014) and it is used here to calculatethe aquatic biodiversity (Eq.1). Proportional abundance of individual species in a given biological community is the foundation block of the equation(Camargo, 1992).

$$H=-\sum_{i=1}^{S}P_i(\log_2^{p_i}),P_i=\frac{n_i}{N} \tag{1}$$

where: N is a total number of individuals; P_i indicate the species fraction and and n_i is number of the species *i*. *S* is numbers of family encountered. Refer Table 2 for value implications.

Table 2.Interpretation of the index values

Values	FBI	H	D
0-1.00	Clean	Heavy pollution	Heavy pollution
1.01-2.00		Moderate pollution	Moderate pollution
2.01-3.00		Light pollution	Light pollution
3.01-3.75		Clean	Clean
3.76-4.25	Slight organic pollution		
4.26-5.00	Some organic pollution		
5.01-5.75	Fairly substantial pollution		
5.76-6.50	Substantial pollution		
6.51-7.25	Very substantial pollution		
7.26-10	Sever organic pollution		
Reference	(Hilsenhoff, 1988)	(Liu et al., 2014)	(Ren et al., 2011)

Margalef diversity index(Liu et al., 2014)is used to normalize the observed number of species to that of the the total individuals (Eq.2).The empirical relationship assumeslinearity between species richness and abundances(Camargo, 1992).

$$D = \frac{S-1}{\ln(N)} \tag{2}$$

where D is Margalef diversity index. Refer Table 2 for value implications.

Hilsenhoff Family-level Biotic Index (FBI) is calculated by multiplying the number of individuals of each family by an assigned experimental tolerance value(Sharifinia et al., 2016).

$$FBI = \sum \frac{T_i}{N} n_i \tag{3}$$

where FBI is Hilsenhoff Family-level Biotic Index. T_i is experimental tolerance value from literature. Refer Table 2 for value implications.

Water quality analysis

Sampling procedures

Water samples (approximately 500 ml) were collecte data each site where, benthic organisms were collated and transported to the laboratory for chemical/physical analysis. A total of eight water quality parameters in November 2014(season of high pollution load) and March 2015 (season of low pollution load) from four sampling locationson the river were collected to investigate the water quality status of the river and tributaries. The sampling sites were purposely selected based on the relative importance, location and magnitude of wet coffee processing industrial influences. Grab sampling was done in the four selected sampling sites at twelve noon,30cm from surfaceand 1m above the bottom of the river. WHO wastewater guideline (WHO, 2006), and American public health association guideline(APHA et al., 1998)were used to collect samples. All samples were triplicates every round of sampling. Mean values are used for analysis.

Water quality indicators

The indicators presented in Table 3 were used to assess environmental performance of secondary wet coffee processing mills. The indicators were selected according to the context of this investigation, major anticipated impacts and the cost of data collection and processing(Asit, 1985; Mihret et al., 2013). They are also based on the monitoring criteria of environmental impact assessment guidelines for industries for the Federal Democratic Republic of Ethiopia(EEPA, 2003; Mihret et al., 2013).

Variables	Apparatuses
EC, pH, TDS	pH(pH meter, ELE international) & conductivity meter (SANXIN SX713, Shanghai San-Xin Instrumentation Inc.)
PO4-3, NO3⁻	Photometric measurements using Paqualab Photometer, ELE international
DO	DO analyzer JPS-J-605, Ningbo Biocotek Scientific Instrument Co., Limited
Turbidity	Turbidity meter, ELE international

Table 3. Other Indicators used for investigation

Statistical analysis
Analysis were conducted using SPSS 20 and spread sheet 2010. Two-tailed t-testat a significance level of $\alpha<0.01$and 0.05; were used to compare the data (on and off-coffee season water quality). Principal componentand canonical correspondence analysis was conducted to correlate environmental parameters with biota.For better homogeneity of the variances, the data were log-transformed with the function $Log_{10}(x+1)$.

RESULTS AND DISCUSSION

Benthic macroinvertebrates

The macroinvertebrates at different reaches of Gidabo River is shown in Table 4.

Table 4: Composition and distribution of macro invertebrates in Gidabo River

	Reference	Upstream	Middle-reach	Lower-reach
Arthropoda				
Ephemeroptera				
Ephemeridae	6	0	5	0
Baetidae	2	0	6	0
Caenidae	1	0	0	0
Trichoptera				
Trichoptera larvae	4	0	2	0
Odonata				
Anisoptera	4	0	3	0
Anisoptera	4	1	9	0
Anisoptera	1	0	1	0
Zygoptera	12	32	76	154
Hemiptera				
Hydrometridae	0	0	10	0
Naucoridae	32	65	53	94
Nepidae	2	2	2	0
Notonectidae	9	24	16	91
Diptera				
Culicidae	0	0	3	0
Chironomidae	9	15	3	2
Coleoptera				
Haliplidae	7	6	6	24
Hydrophlidae	2	3	4	6
Dyticidae	3	15	3	0
Arachnida				
Water spider	0	1	3	2
Water spider	0	4	18	0
Acari				
Hydracarina	0	1	1	0
Mollusca				
Gastropoda				
Bullinus sp.	0	77	89	92
Mellanoides	23	51	48	60
Biomphalaria	0	0	2	20
Lemnia sp.	0	0	0	19
Nematoda				
Nematoda				
Roundworms	0	2	0	14
Annelida				
Hirudinae				
Piscicola	0	2	0	8
	16	**16**	**22**	**13**
H	**3.33**	**2.97**	**3.26**	**2.96**
D	**3.75**	**2.63**	**3.56**	**1.88**
FBI	**6.41**	**6.92**	**6.91**	**7.51**

A sum of 23 species of benthic macro invertebrates belonging to the 11 genera of 4 phyla were found. The macro invertebrates include *Arthropods* larvae (20 species of 8 genera), *Nematoda*, *Mollusca*, and *Annelida* (1 species of 1 genus) each, accounts for 63.02, 1.17, 35.08 and 0.73% of the total species, respectively (Fig.1).

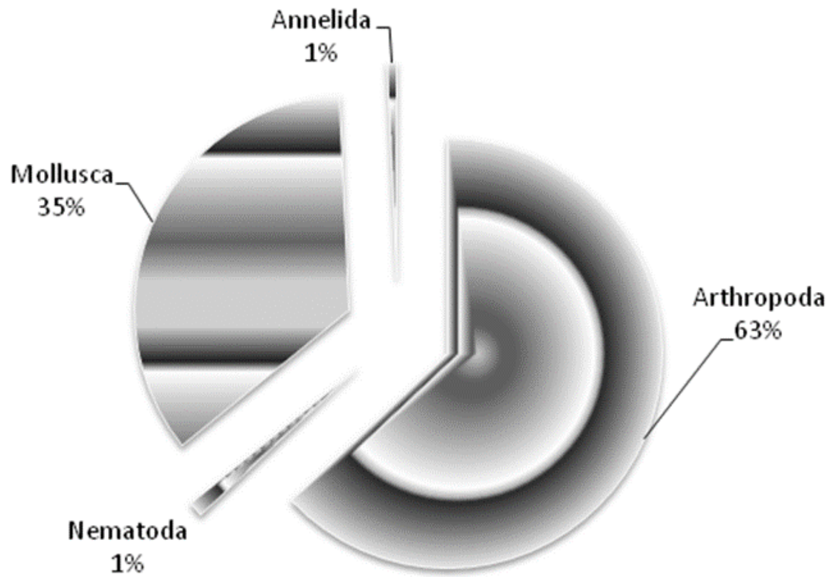

Figure 1: benthic macro invertebrates species composition of Gidabo River

Table 4 and Fig.1 shows that the benthic macro invertebrates' composition of the Gidabo River varies at different reaches, in which the middle-reach of the river had more species than that of the other reaches.

Assessment of macro invertebrate indexes

The Shannon–Wiener index (Table 4) of macro invertebrates (H) in the Gidabo River also varies at the different reaches. Higher values are measured at the reference site and the middle-reach of the river, having the values of 3.33 and 3.26, respectively, than those of upper stream (2.97) and lower-reach (2.96). These results indicated that the reference site and middle-reach of the river are clean whereas the upstream and lower reaches are lightly polluted. The Margalef diversity index of benthic macro invertebrates (D) (Table 4) at the Gidabo River also varies at the different reaches. Higher values are measured at the reference site and middle-reach of the river having the values of 3.75 and 3.56, respectively, than the upper stream (2.63) and lower-reach (1.88).

These observations indicated that the reference site and middle-reach of the river are clean whereas the upstream and lower-reach are "*lightly polluted*" and "*moderately polluted"* respectively. Results of the Hilsenhoff Biotic Index, a measure of overall tolerance/intolerance of the assemblage, ranged from a low of 6.41 in the reference site to a high value of 7.51 in the lower-reach (Table 4). On the other hand, the FBI values of macroinvertebrate samples collected at the upper stream and middle streams are comparable (6.92 and 6.91, respectively). According to the corresponding rating for the degree of organic pollution, the lower-reach of the river have *"severe organic pollution"*. Likewise, both middle-reach and upper stream had *"poor"* water quality with the resultant grading of *"very substantial pollution"*. Moreover, the valuation of the reference site revealed that it is comparatively the least affected with *"fairly poor"* water quality that is regarded as a spot with *"substantial pollution."*

Water quality parameters

The water quality data of Gidabo River during November 2014 to March 2015 is presented in Table 5.

Table 5:Water quality of Gidabo river at different locations in 2014 (mean±stdev)

Indicators	Reference	Upstream	Middle-reach	Lower-reach
Temperature (^{0}C)	24.6±0.57	25.85±0.21	14.8±1.00	18.3±0.42
pH (power of H^+)	6.±1.6	5.045±0.01	5.85±0.63	4.6±0.00
TDS(mg/l)	317.3±283	521.65±0.49	174.75±149.13	372.05±47.73
EC(µS/cm)	460.8±398.3	750.55±2.05	253.65±212.63	533.55±67.10
Turbidity(NTU)	233.8±30.1	501±21.21	39.95±7.57	168.15±103.03
Nitrate(NO_3^-)(mg/l)	126.5±103.9	96.5±68.60	67.4±88.53	80±28.28
Phosphate(PO_4^{-3})	20.29±28.6	11.075±15.45	4.66±5.78	4.375±4.42
BOD_5(mg/l)	277±32.5	346±65.05	471±97.58	473±179.61

It shows the $NO3^-$-nitrogen, PO_4^{3-}-phosphate, and BOD_5 of the reference site are 126.5, 20.29 and 277 mg L^{-1}, respectively. The BOD_5 of upstream, middle-reach and lower-reach sites are 346, 471 and 473 mg L^{-1}, respectively. The NO_3^--nitrogen of all the sites are greater than 67.4mg L^{-1}, which is atrophic and the source are both point and nonpoint from the wet mils and surrounding agricultural fields. The results also show that the TDS of all the sites is high, and the average TDS of Gidabo River is 346.4 mg L-1(Table 6).

Table 6. Physicochemical indicators observed during coffee milling and none milling seasons of 2014 and 2015

Physicochemical parameters	Sampling Time	Ranges	Values (mean±stdev)	Change
Temperature (^{0}C) ^{ns}	2014/10^a	14.1-26	20.89±4.86	1.16^{ns}
	2015/03^b	18.3-24.6	19.725±1.43	
pH (power of H^+)*	2014/10	4.6-7.48	5.45±0.98	-1.31*
	2015/03	6.62-7.5	6.75±0.11	
TDS(mg/l) **	2014/10	69.3-522	346.4±180.4	300.83**
	2015/03	26.7-87.25	45.61±11.68	
EC(µS/cm) **	2014/10	103.3-752	499.64±256.54	408.41**
	2015/03	53.4-174.5	91.23±23.44	
Turbidity(NTU) ^{ns}	2014/10	20.6-516	235.73±216.65	148.48 ^{ns}
	2015/03	25-225	87.25±44.64	
Nitrate(NO_3^- N)(mg/l) **	2014/10	4.8-200	92.6±63.32	91.79**
	2015/03	0.2-1.7	0.81±0.36	
Phosphate(PO_4^{-3}-P)*	2014/10	0.08-40.5	10.1±14.36	8.35*
	2015/03	0.14-16.2	1.75±2.09	
BOD_5(mg/l) **	2014/10	254.00-600.00	391.75±121.51	382.38**
	2015/03	3.2-13.8	9.37±2.78	

*** One way ANOVA test of Significance at P<0.001, ns- non significant, a - time of wet coffee processing, b-off season*

Water quality data collected during the coffee milling season (2014/10) and off season (2015/03) (Table 3) shows that the majority of the quality indicators are significantly different between the two seasons and imply that the variation of the river quality mainly attributed to the operations of the wet coffee milling industries. All the parameters are increased (Table 6) leading to the reduction of the pH level. The water quality analysis of 2014–2015 show that the Gidabo River is totally in a *"moderate pollution"* status.

Correlation of the indexes and water quality parameters

Correlation analysis of the water quality parameters and selected macroinvertebrate indices were analyzed and presented in Table 7. Shannon–Wiener index is positively correlated with pH and negatively associated with TDS, EC, Turbidity, Nitrate, Phosphate and BOD_5 ($P<0.05$). The Margalef index is positively correlated with pH ($P<0.05$) but negatively correlated with TDS, EC, Turbidity, Nitrate, and Phosphate. Hilsenhoff Biotic Index was only negatively correlated with pH. These observations entail that Shannon–Wiener's index is better in revealing the level of contamination of the Gidabo River to that of the Margalef and Hilsenhoff Biotic Index (FBI).

Table 7: Correlation of the indexes and water quality parameters

**Indicates significance at level of p<0.05*

Indices	Temperature	pH	TDS	EC	Turbidity	Nitrate	Phosphate	BOD_5
H	-0.23	0.97*	-0.90	-0.90	-0.86	-0.66	-0.95	-0.50
D	-0.07	0.94*	-0.78	-0.77	-0.59	-0.61	-0.76	-0.25
FBI	-0.38	-0.90	0.47	0.46	0.43	0.19	0.58	-0.14

Principal component analysis (PCA) of pollution in Gidabo River

PCA of macroinvertebrates indexes and water quality parameters were done using SPSS 20. The PCA table (Table 5) revealed that, the total Eigen-value of Component 1 and Component 2 are greater than 1 (Table 5), and cumulatively 95.205% of the physicochemical and biological information of the river is explained by these two components. It implies that the water quality of Gidabo River is accurately represented by the two components.

Table 8: PCA results

	Initial Eigen-values			Variables	Component r	
Component	Total	% of Variance	Cumulative %		1	2
1	7.867	71.515	71.515	TDS	0.989	0.140
2	2.606	23.691	95.205	EC	0.986	0.158
3	0.527	4.795	100.000	Phosphate	0.968	-0.054
4	6.416E-16	5.833E-15	100.000	Shannon	-0.957	0.288
5	3.098E-16	2.816E-15	100.000	Turbidity	0.901	0.064
6	2.032E-16	1.847E-15	100.000	pH	-0.864	0.501
7	1.544E-16	1.404E-15	100.000	Margalef	-0.836	0.460
8	-5.15E-18	-4.69E-17	100.000	Nitrate	0.833	0.417
9	-1.52E-17	-1.38E-16	100.000	BOD_5	0.721	0.681
10	-1.47E-16	-1.34E-15	100.000	Temperature	0.498	0.853
11	-2.36E-16	-2.15E-15	100.000	FBI	0.587	-0.802

If r=±0.5 is chosen as a dividing point (Table 8), the first factor involves all physicochemical and biological indices except temperature. The second factor involves temperature, FBI, BOD_5, and pH. Therefore, the three macroinvertebrate indices and the seven physicochemical quality parameters are suitable to reflect pollution status of Gidabo River as a biological water quality indicators (Table 4) and the physicochemical water quality parameters (Table 5).

Comprehensive evaluation of PCA

Comparative assessment (Table 9) of the level of pollution at different reaches of the Gidabo River turned out to be the "reference site" is < "middle-reach" < "upstream site" < "lower-reach" of the river. The main causes of pollution during the coffee milling season was mainly from the deposition of pulping and fermentation wastewater, and solid waste from wet mills .

Table 9: Comprehensive evaluation of pollution at Gidabo River (factor analysis with SPSS 20, using PCA)

Area	F_1	Ranking	F_2	Ranking	Component	Ranking
Reference	-1.1542	4	0.207838	2	-0.77619	4
Upstream	0.592539	2	1.179813	1	0.703258	2
Middle	-0.48042	3	-1.24249	4	-0.63792	3
Lower	1.042076	1	-0.14516	3	0.71085	1

The field survey explicitly depicted that pulping wastewater and fermentation/washing wastewater are the two forms of liquid waste generated from wet coffee processing mills. Different studies implicated the direct release of these wastes to the aquatic system as the cause for the river pollution. Wastewater from the pulping process has a high content of sugar and enzymes derived from the bacteria on the coffee cherries (Elias, 1979). Depending on the method involved, the fermentation/washing wastewater forms thick effluents composed of fermented organic matter and living cells (Von Enden & Calvert, 2002b). Hence, the pollution of Gidabo River stems from the living cells and the organic matter set-free during pulping and fermentation (Von Enden & Calvert, 2002a). The layer, particularly the difficult-to-degrade mucilage surrounding the beans, is the main source of organic matter (rich in proteins, sugar, and pectin) (Von Enden & Calvert, 2002a; Braham & Bressani, 1979). The pectin layer makes the slick mucilage components through polymerization of galacturonic acid that derived from sugars (Von Enden & Calvert, 2002a). The sugars will be swiftly fermented to alcohol and CO_2, while the alcohol is rapidly transformed into acetic acid that lowers the pH to about 4 or less (Von Enden, 2002). The wastewater from the fermentation process contains a certain amount of sugars, but its apparent thickness comes from the vintage pieces of torn beans and the undigested mucilage (Von Enden & Calvert, 2002b). The final washing wastewater from the fermentation tanks appears to have less concentrated organic pollutants.

Trace of toxic substances such as alkaloids (caffeine), tannins, and polyphenol are also reported from the wastewater (Murthy & Naidu, 2012). These substances intricate the biological digestion of organic maters (Von Enden & Calvert, 2002b). As a result of the lower pH during fermentation, the digested mucilage will flocculate from the solution and build a thick crust on the surface, black on top and viscous orange/brown below (Von Enden & Calvert, 2002a). If it is not separated from the wastewater; the crust will quickly block oxygen transfer and further contribute to anaerobic conditions in the system.

This study indicates that benthic macroinvertebrate indices are a useful tool in assessing the state of the water quality of Gidabo River. This is consistent with studies (Reynoldson & Metcalfe-Smith, 1992)that demonstrated the feasibility of the use of benthic macroinvertebrates to evaluate water quality. It is verified that the communities of benthic macroinvertebrates reveal the overall ecological quality and aggregates the effects of different stressors to provide a large extent of their impact (Liu et al., 2014). There have been many studies for the use of benthic macroinvertebrates in environmental monitoring and assessment (Aklilu, 2011). However, the current research is the pioneer in the watershed and shall be better to be integrated into the current environmental monitoring system of Ethiopia.

It was pointed-out that different indices have different applicability depending on the the concepts behind their formulation (Cao et al., 1997). According to the current observation, proportional abundance of individual species assumed in the case of Shannon-Wiener Index and Hilsenhoff Family-level Biotic Index could be better in reflecting the pollution status of Gidabo River than the Margalef Diversity Index. The Hilsenhoff Family-level Biotic Index shows Gidabo River is between "substantial" to "severe" organic pollution levels. According to the PCA of the benthic macroinvertebrates and water quality, it can be found that the pollution in the lower-reach of the river and the upstream location was comparatively higher than that in the middle-reach and reference site.

Environmental implications

The socio-economic issues observed during the coffee processing seasons includes respiratory infections, aesthetic impairment, odor problems, and over insect beading typically the abundant *Diptera spp.* in the localities (Table 4). Environmental impacts of the observed physicochemical parameters include impairment of optimum plants and animal productivity, corrosion of civil structures, reduced water availability in the watershed, dispersion of soil structure, and aquatic life toxicity at different reaches of the river. This indicates that the ecosystem in the Gidabo River is under intense pressure and has a weak self-regulating capacity particularly during the coffee processing seasons. Thus, environmental monitoring and control is immediately required. In summary, it was observed that the Gidabo River is moderately polluted based on a set of macroinvertebrate indices together with selected physicochemical water quality parameters. In addition, these results imply that the Gidabo River pollution is derived from agro-industrial activities. It is suggested that Ethiopian Environmental Protection Authority should implement strict monitoring and controlling activities using the suggested minimum rapid biological monitoring indices for the realization of a sustainable coffee production sector in the watershed.

CONCLUSIONS

The current assessment indicated that Gidabo River pollution is resulted from wastes released from wet coffee processing mills. It is observed that agro-industrial point sources and agricultural non-point sources of pollution were the main sources of pollution in the Gidabo River. Particularly the pollution released by wet mill is significant. There are about 286 wet coffee processing mills in Gidabo watershed alone (November 2015 survey). Most of them are concentrated in the upstream location with the demand of clean, unpolluted water. These mills consume an average of 63.32 liters of clean water to produce a kilogram of green beans (current survey, 2015). Most of these mills lack a water recycling system. They together consume 36.6 million m^3 of processing water annually with an average pollution emission of about 14 342.75 tons a^{-1} of BOD_5, 3390.27 tons a^{-1} of NO^-_3-Nitrogen and 369.78 tons a^{-1} of $PO4^{3-}$-Phosphorus. Hence, this study strongly suggests onsite use of Shannon–Wiener index (H), Margalef diversity index (D), and Hilsenhoff Family-level Biotic Index(FBI) for rapid water quality monitoring of Gidabo River, to realize a sustainable coffee production sector in the watershed.

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THEME FIVE

EMERGING CHALLENGES

water 12 (1)

Rangeland Water Requirement Satisfaction Index in Semiarid Environment of Jigijiga District, Eastern Ethiopia: Implication for availability of feed resources

Abstract

Rainfall is highly variable in the study district and is likely to influence rangeland water requirement index. A study was conducted to assess rangeland water requirement satisfaction index (WRSI) using long-term mean annual rainfall in Jigijiga pastoral district in eastern Ethiopia. The time serious data (1984-2015) was obtained from National Meteorological Agency of Ethiopia, whereas, the future rainfall trend was predicted using MarkSim software (Representative Concentration Pathways 4.5 General Circulation Model). The temporal rangeland water requirement values were processed from LEAP software (Version 2.61). The results revealed that mean annual rainfall anomaly had a strong positive correlation with rangeland WRSI in Jigijiga pastoral areas. Similarly, short and long rainy seasons had positive association ($P<0.001$) with rangeland WRSI. The base period rainfall (1984-2015), as well as the predicted annual rainfall showed variability in amount and distribution. The mean annual rainfall anomaly is correlated with the rangeland WRSI. Moreover, the future rainfall trend analysis indicated that variability of rainfall would be expected in 2030, 2050 and 2080. Thus, the future rainfall variability (CV=30.5%) would limit future rangeland WRSI values, leading to critical shortage of feed resources availability via its effect on the rangeland ecosystems. We suggested the need for using the findings as an early warning planning to minimize potential livestock feed insecurity, and the severity of drought condition.

Keywords: LEAP software, pastoralist, rangeland water requirement, trend analysis

whole. The major causes of food insecurity are mainly poverty, drought, and floods. The two areas that underpin food security deal with either challenges of food access by communities in both rural and urban areas as well as poor production as a result of deficit rainfall (Peter and Sandro, 2012. Rangelands are dependent on water, and water is scarce in many developing countries. Especially in semi-arid countries water is the most important factor determining rangeland yield. Rangelands play a significant role as a primary source of feed for livestock and wild animals in semi-arid areas, in addition to reducing the concentration of atmospheric carbon dioxide (IPCC, 2007). However, under the ever increasing environmental changes, the impact of rainfall variability on the productivity and vegetation dynamics of rangelands and availability of water both for human and livestock are the great challenges that pastoral communities are facing at present. As a result, the carrying capacities of most rangelands in arid and semi-arid ecosystems do not sustain livestock production (IPCC, 2014; Shine and Dunford, 2016).

Previous assessments highlighted the important connections between rainfall variability and vegetation cover and greenness in semi-arid ecosystems.

For instance, according to Adler and Levine (2007), under the ever increasing environmental changes, vegetation productivity, basal cover and species composition in arid and semi-arid rangelands are strongly associated with rainfall availability. The alteration of rainfall distribution associated with long-term climate variability is expected to influence plant productivity and species diversity (Cheng, 2011). As a result, the rangeland vegetation cover and its potential productivity could be limited by the long-term rainfall variability and its distribution in arid and semi-arid ecosystems (Cheng, 2011). Accordingly, for the sustainable utilization and management of rangelands, as main feed resources for both domestic and wild herbivores, monitoring of climatic risk through the development of rangeland water requirement satisfaction index is very crucial in arid and semi-arid ecosystems (Peter and Sandro, 2012). Rangeland water requirement and satisfaction index (WRSI) is defined as the amount of water that is required to replenish water that is lost through evapotranspiration (ET) processes, and it is calculated using a water stress index scheme that helps to determine whether a given vegetation had sufficient water to achieve its potential yield or not in a particular season that would help with feed estimation for early warning purposes and it was then that the water requirement index (WRSI) was used to relate to yield to moisture condition (Peter and Sandro, 2012; Senay *et al.,* 2011).

Although many studies have been conducted on rangeland vegetation and productivity under the influence of grazing and other biotic factors in semi-arid ecosystems in Ethiopia (e.g., Angasa and Oba, 2007; Kassahun *et al.,* 2008; Tessema *et al.,* 2011), information on the effect of long-term rainfall variability on rangeland WRSI is scanty. Moreover, it is also important to assess the current rainfall amount and distribution with the expected future rainfall scenarios to minimize stresses on rangeland vegetation and livestock production, as a result of rainfall variability (Thornton *et al.,* 2009). Therefore, we assessed the association between rangeland WRSI and long-term mean annual rainfall and its future predicted rainfall scenarios in relation to feed availability in Jigijiga district.

Materials and methods

Description of the study areas

The study was conducted at Jigijiga district of eastern Ethiopia. The average (1984-2015) annual rainfall in the study area was 606 mm with a coefficient variation of 30.8%) the average annual temperature was 18^{o}C. Under normal condition, Jigijiga receives its highest rainfall amount during long rainy season (June to September) while the short rains prevail from March to April. The dry season sometimes extends from October to May or June when the short rainy season fails. Rain falls over the study district only for few months, where dry conditions with highly variable rainfall prevail during substantial parts of the year. As a result, recurrent drought is a major problem in the study areas. Topographic orientation of the study area varies from typical lowlands to midlands. The altitudinal variation for Jigijiga ranges between 500 and 1600 ma.s.l. The district is dominated by agro-pastoral production system, where livestock feed is mainly dependent up on communal grazing systems on rangelands as feed resources.

Cattle, sheep, goat and camel are the major livestock types owned by the pastoralists and agro-pastoralists in Jigijiga district.

Data source and sampling techniques

The gridded (10 km x 10 km) rainfall data covering from 1984 to 2015 were obtained from the National Meteorological Agency of Ethiopia (NMA). Rainfall data collected were organized into seasonal and annual and then plotted against their long-term means and fitted with trend lines to observe the overall tendency of each dataset. All the temporal rangeland WRSI pattern over Jigijiga district was processed using LEAP software version 2.61 (Peter and Sandro, 2012).

The LEAP system is an innovative food security early warning – early action tool, developed in 2008 by World Food Program (WFP). The software uses agro-meteorological monitoring data to estimate crop and rangeland production. Satellite rainfall estimates have been used as input to a geospatial crop and rangeland water balance model that evaluates the availability of moisture to a crop relative to its needs over the course of the growing season. Beside the index the software calculated the actual evapotranspiration, water storage in the soil, water excess and water deficit at various phonological stages. The LEAP model followed the AgroMetShell (AMS) program. The development of AMS started in the 1980's to try and find a tool that would help with yield estimation for early warning purposes and it was then that the WRSI was used to relate to yield to moisture condition. However, the effect of water deficits on crop yields has been actually established long before. At that time, the tool was referred to as FAOINDEX. It is this tool that has now been developed further into what is now known as the AgroMetShell. AMS has extra tools among which the tool to calculate evapotranspiration is one of them. The software computed the rangeland WRSI for periods of 5 dekads, with normal evapotranspiration kept at potential level (KC=1) and an assumed water holding capacity (WHC) of 50 mm. Similar to moving averages, the value assigned to a dekad corresponds to the five-dekad period centered about that dekad. Thus 3 for dekads 1 to 5, 4 for dekads 2 to 6... (Mukhala and Hoefsloot 2004).

The potential evapotranspiration (PET) and actual evapotranspiration (AET) data for a reference crop is calculated according to the Penman–Monteith equation (Shuttleworth, 1992). It is calculated as the ratio of seasonal actual evapotranspiration to the seasonal rangeland water requirement.

$$\text{WRSI} = [\text{AET}/\text{WR}]\text{x}100,$$

$$\mathbf{WR} = \mathbf{PET} + \mathbf{Kc} \quad (1)$$

Where WR is rangeland water requirement, from Penman-Monteith Equation (Shuttleworth, 1992), PET is potential evapo-transpiration, and AET is actual evapo-transpiration, representing the actual amount of water withdrawn from the soil water reservoir, Kc is crop coefficient.

Statistical analysis

Analysis of current rainfall patterns

Mann-Kendall's test was used to assess the current and future mean annual rainfall trend for Jigijiga district for the time period 1984-2015 by using XLSTAT software. Mann-Kendall's test is a non-parametric method, which is less sensitive to outliers and test for time sequential order (Partal and Kahya, 2006; Yenigun et al., 2008; Gebrie et al., 2013; Tsegaye et al., 2015).

Analysis of rainfall variability

Rainfall variability and its characteristics were analyzed with CV (Ayalew et al., 2012, Gebre et al., 2013; Tsegaye et al., 2015). Coefficient of Variation was analyzed by the ratio of the standard deviation to the mean. It is calculated as:

$$CV = \frac{SD}{X} * 100 , \quad (2)$$

where CV is coefficient of variation, SD is standard deviation and X is the long term mean. The CV values categorized as less variable (<20%), moderate variability (20-30%) and high variability (>30%) (ABM, 2010). Regression coefficient analysis using SAS software (SAS, 2008 Ver. 9.1) was used to determine the associations between rainfall variability and rangeland WRSI.

The future climate scenario analysis

The World Climate Research Program's (WCRP's) Coupled Model Inter-comparison Project phase 5 (CMIP5) developed outputs from many GCMs. Representative Concentration Pathways 4.5 (RCP 4.5) was used to predict the future rainfall scenario of Shinile district. Therefore, future scenarios of indices of rainfall projections in Jigijiga district was done by downscaling global circulation model outputs and downloaded from http://www.ccafs-climate.org/patternscaling/ MarkSim-GCM (Jones and Thornton, 2013). For the study area data of future rainfall (2020 - 2099) was down scaled. Future rainfall changes was analyzed for three time slot centered in 2030 (2020-2049), 2050 (2040-2069) and 2080 (2070-2099) and compared its trend and variability with the base period rainfall data (1984-2015).

Results and Discussions

Annual and seasonal rainfall trend and variability

Mann-Kendall trend analysis has indicated that the annual and seasonal rainfall data have shown insignificant changes in amount in both annual and seasonal rainfall amount (Table 1). On the other hand, there was huge annual rainfall variability in Jigijiga (CV=30.8%) district. There was also seasonal rainfall variability in the study district. However, increasing and decreasing trend was not significant (P>0.05). In the study district, year 1984 and 2000 were relatively found to be the driest years, while years 1996 and 2010 were found the wettest years (Figure 1). Similar results were recorded by others. For example, Gebre *et al.* (2013), where the annual and seasonal rainfall in northern region of Ethiopia were variable and statistically insignificant. Ayalew *et al.* (2012) also confirmed variability of rainfall in Amhara region of Ethiopia. This rainfall variability or fluctuation might be associated with the Sea Surface Temperature (SST) changes in the Atlantic and pacific oceans which leads to shift rainfall direction and suppress rainfall distribution to Ethiopia (Korecha, and Sorteberg, 2013). Viste *et al.* (2013) also confirmed rainfall variability.

Table 1 Trends of annual and seasonal rainfall for the period 1984-2015 in pastoral, production systems of Jigijiga district of eastern Ethiopia

	Annual		Long rainy season		Short rainy season	
	Z_{MK}	Slope	Z_{MK}	Slop	Z_{MK}	Slope
Jigjiga	0.12ns	+8.73	-0.11ns	-4.16	0.22ns	8.62

Z_{MK} is Mann-Kendall trend test, Slope (Sen's slope) is the change (mm)/annual/seasonal; ns is non -significant trend at 0.05. The mean seasonal and annual rainfall trend recorded during 1984-2015, increasing (+).

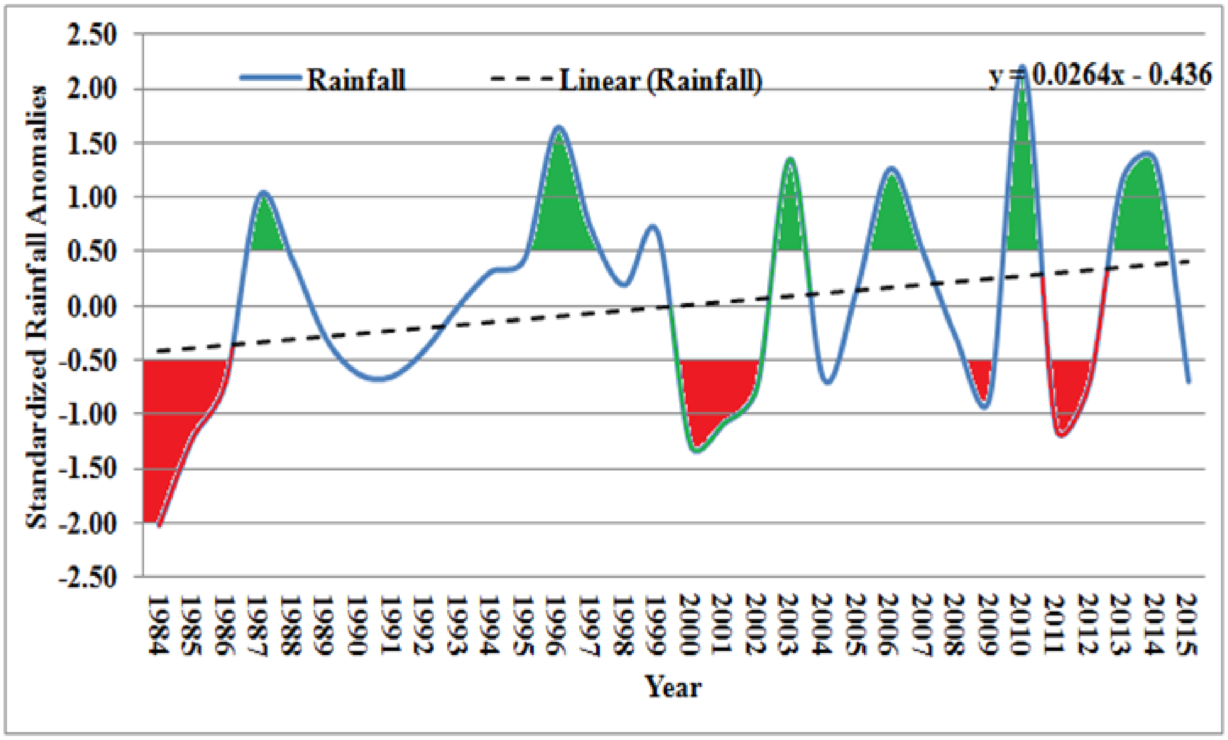


Fig. 1. Mean annual standardized rainfall anomalies and trend for Jigijiga district over the period 1984-2015. The red color (below average) indicated moderate to extreme drought periods, whereas the green showed (above average) moderate to extreme wet years.

Response of rainfall variability to rangeland water requirement satisfaction index

In the last three decades, high to moderate rainfall variability observed in Jigijiga was manifested in unevenly coverage of an annual rainfall over the rangeland portions of the study district. The computed statistical values revealed that rainfall distribution and rangeland WRSI values are positively associated ($P<0.001$) (Table 2). As it can be seen from figure 1 the years 1984, 1998, 2000, 2002 and 2009 were the drought years and attained below average rainfall amount and the values of corresponding rangeland WRSI (Figure 2) were also negatively deviated from the normal climatology. Senay et al (2011) reported that there was a major decline of rangeland WRSI in 2000, 2001 and 2005 for Kenya, Ethiopia and Somalia respectively. In contrast, above rainfall amounts that were observed in 1996, 2006 and 2010 (Figure 1) substantially resulted in above average rangeland WRSI value (Figure 2). In most cases, there is a strong association ($P<0.001$) between, rainfall and rangeland WRSI for mean annual and seasonal rainfall time scales (Table 2). This may be associated with moisture, which is needed for range vegetation as rainfall is the major water source for natural resources.

Furthermore, the short and long rainfall in the study district also positively associated to their respective rangeland WRSI. For instance, short rainy season helps to initiate the vegetation to grow, which in turn result in immediate increment of rangeland WRSI values. High vegetation coverage in long rainy season was because of sufficient amount of rainfalls over the rangelands.

From annual quantitative analysis of vegetation coverage, there was variation in rangeland WRSI among years depending upon rainfall distribution. For instance, year 1984 was the lowest in rangeland WRSI; similarly lower vegetation coverage was recorded in year 2009 (Figure 2) due to rainfall deviation from normal. This is possibly due to the availability of lower soil moisture. Significant positive association between rainfall and rangeland WRSI were recorded, which is an indication of strong relation between rangeland WRSI and rainfall intensity.

Results from this study indicated that the trend of rainfall and rangeland WRSI showed a direct correspondence of anomalies in most years. Similar studies by Adler and Levine (2007) and Cheng *et al.* (2011) showed the presence of strong association between vegetation greenness and rainfall distribution. Similar to this study, Senay et al (2011) also indicated year-to-year rangeland WRSI differences in relation to rainfall distribution for Kenya. Moreover, Yete (2012) (unpublished, MSc thesis) also confirmed the direct relationship of the spatial-temporal analysis of rainfall and vegetation greenness in the north-western part of Ethiopia by using Normalized Difference Vegetation Index. In most wet years the rangeland WRSI value was above average. Furthermore, in dry years, the rangeland WRSI value was deviated below average, indicating that rangeland WRSI mainly depend on rainfall amount. Humberto Alves (2011) also indicated that grassland vegetation cover and biomass is directly related with rainfall suitability. Therefore, in the study district, annual and seasonal rainfall was positively associated to the corresponding rangeland WRSI.

Table 2. Coefficient of regression for annual and seasonal rainfall (predictors) and rangeland WRSI values (dependent variable) for the period 1984–2015 in Jigijiga, district of Eastern Ethiopia

Study areas	Annual and rangeland WRSI	Short rainy season and rangeland WRSI	Long rainy season and rangeland WRSI
Jigjiga	0.80***	0.61***	0.69***

WRSI- Water Requirement Satisfaction Index, *P<0.05, ***P<0.001,

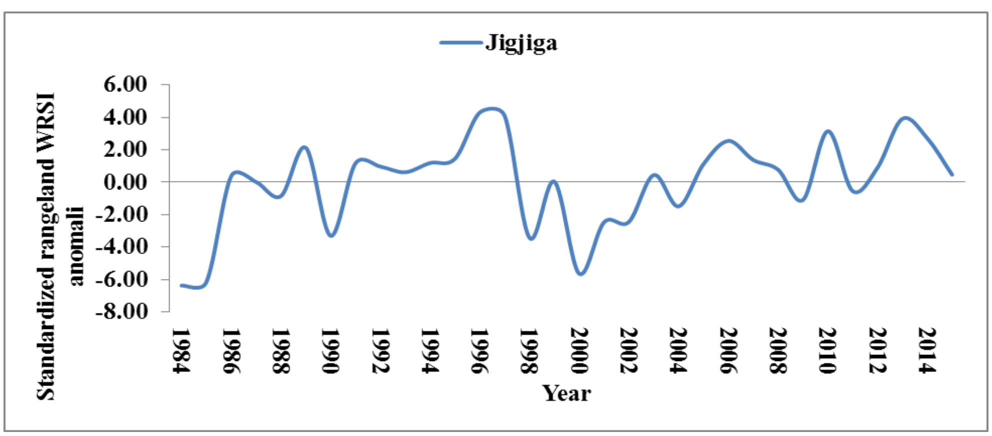


Fig. 2. Mean annual standardized rangeland WRSI values and trends for Jigijiga district over the period 1984-2015

Predicted future climate scenarios

The results of predicting the future rainfall for 2030's, 2050's and 2080's using MarkSim along with current rainfall status for comparison was indicated at figure 3. As compared to the current rainfall amount annual rainfall would increase in the study pastoral district by 2030, 2050 and 2080s under RCP 4.5 scenario (Table 3). In Jigijiga the annual rainfall is expected to increase by 11.1, 0.72 and 0.56% in 2030s, 2050s and 2080s respectively. However, the increase was insignificant ($p>0.05$). The future annual rainfall is also predicted to be variable. The result indicated that the annual rainfall at Jigijiga, is expected to be moderately variable.

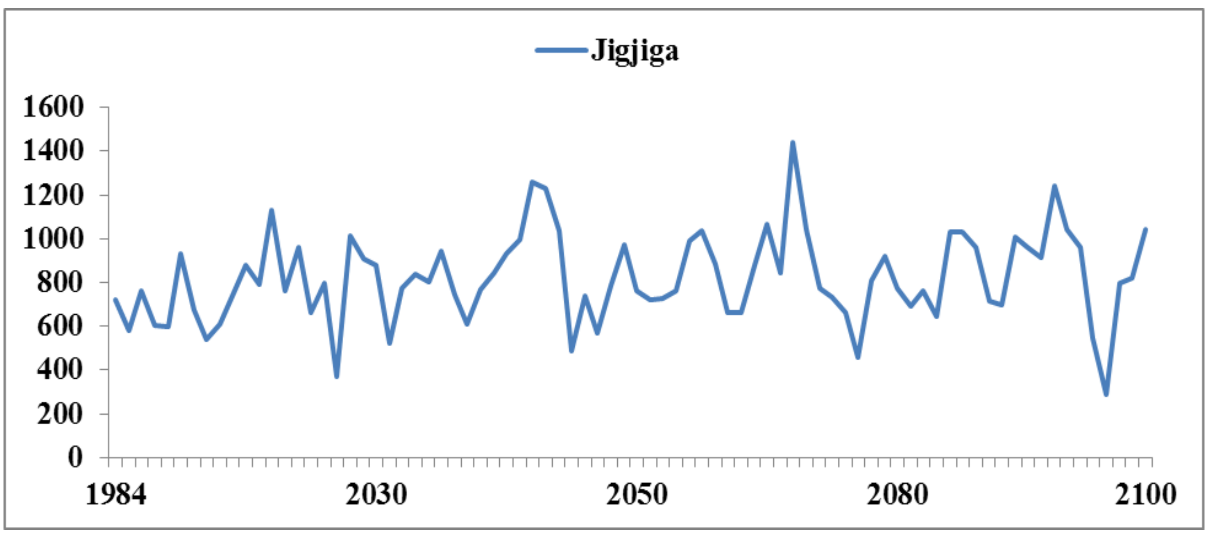
Table 3. Trends of annual rainfall for the period of 2030, 2050 and 2080 in pastoral production systems of Jigijiga districts of eastern Ethiopia1984-2015

Study areas	Annual (2030)		Annual (2050)		Annual (2080)	
	Z_{MK}	Slope	Z_{MK}	Slop	Z_{MK}	Slope
Jigjiga	0.319ns	14.28	0.03ns	0.61	0.08ns	1.79

Z_{mk} is Mann-Kendall trend test, Slope (Sen's slope) is the change (mm)/annual; ns is non-significant trend at 0.05. The mean annual rainfall predicted trend, a negative value represents a decreasing trend and positive values are an indication of increasing trends.

Fig. 3. Trends of current and future mean annual rainfall for Jigijiga districts for the period 1984 – 2100.

Expected future rainfall conditions revealed that the annual and seasonal rainfall most likely increase in the



study pastoral district in the predicted years. On the other hand, there was a report by IPCC (2007) which stated that there was increasing rainfall in parts of east Africa, which coincide with the study areas. In contrast, Tsegaye *et al.* (2015) reported a decrease in the future trend of annual rainfall in Adami-Tulu Jido-Kombolcha district of Ethiopia by using HadCM3 A2 and B2 scenarios.

These different reports could be due to the types of GCM used to generate future rainfall trend (Sarr, 2012), differences in topography, temperature, altitude, vegetation cover, atmospheric interaction and land use management. Although the future rainfall prediction is indicating its increment ($P>0.05$); the variability may be a great problem for altering the rangeland WRSI similar to what is happening today. Accordingly, the annual and seasonal predicted rainfall variability expected to limit the future rangeland WRSI values in Jigijiga district pastoral and agro-pastoral communities.

Conclusions and recommendations

Our study indicated that rainfall trend and variability directly reflected the pattern of rangeland WRSI in Jigijiga district of eastern Ethiopia. The future rainfall trend analysis indicated that there is an increase in annual and seasonal rainfall in 2030's, 2050's and 2080's, but its variability may limit future rangeland water requirement satisfaction index. Based on our study, it can be concluded that the rangeland WRSI is more important for decision making tools beforehand to reduce the resulting feed insecurity. We suggested the need for using the findings as an early warning planning to minimize potential livestock feed insecurity, and the severity of drought condition.

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Retrospect and Prospect of Hydro Diplomacy; Ethiopia's collaborative approach to dealing with the Nile basin management.

By Getachew Mekonnen

Abstract

Presently, the agenda of water development holds a paramount place in the perception of policy makers as well as ordinary Ethiopians. Ethiopia has been repeatedly stressing on just cause based on the principle of equitable and reasonable use of shared resources under international law and co- operation with Egypt and Sudan. Indeed, co- operation is the only way to get the people of the Nile basin out of underdevelopment, poverty and hunger. The diplomatic relations of Ethiopia with riparian counties calls for negotiation and dialogue (Hydro diplomacy). The paper tends to take stock what has been done in the past because Nile basin is not totally immune from the influence of the past which plagued the present and future cooperative processes. These processes include the recast of Ethiopia's hydro diplomacy, the role of Nile basin initiative which is transitional co- operative arrangement ,negotiation and signing of Comprehensive framework agreement (CFA),.By analyzing the past agreements ((1929,1959) and Comprehensive Framework Agreement which are the driving factors for negotiations among Nile riparian countries the paper has come up with different scenarios, ,among others, Sudan will sign CFA, both Sudan and Egypt will sign CFA ,Sudan and Egypt could refuse to sign CFA, CFA alliances, delay in the ratification of the signatory states or failure to do it altogether. The main objective of the paper is to examine retrospect and prospect of Ethiopia's collaborative Approach to dealing with the Nile basin management. In order to achieve this objective Qualitative research Methodology has been selected. The finding of this study reveals that in view of optimistic scenario of hydro diplomacy of the Nile, Egypt and Sudan will continue to engage themselves with Ethiopia with a new level of confidence. The finding also reveals that Ethiopia, being the water tower of North eastern Africa posses far greater potential to pursue and develop foreign policy instruments for sustainable co- operation and regional security.

Introduction

The Nile is renowned as one of the cradles of ancient civilizations. Today the Nile basin encompasses North eastern and central Africa, comprising 11 riparian countries- Burundi, the Democratic republic of Congo , Eritrea, Ethiopia, Kenya, Rwanda, Tanzania , and Uganda are in the Upstream, Eritrea, South Sudan , and Sudan occupy the midstream, while Egypt is the most downstream country. While 86%of the Nile waters originate in Ethiopia through Abbay, Baro Akobo and Tekeze sub systems in Ethiopia, the remaining 14 %emanates from the other six upstream countries. Presently, the 11 riparian countries are more intensely engaged on the Nile questions and the agenda of water development holds a paramount place in the perception of policy makers as well as ordinary Ethiopians. Ethiopia has been repeatedly stressing on just cause based on the principle of equitable and reasonable use of shared resources under international law and co- operation with Egypt and Sudan. Indeed, co- operation is the only way to get the people of the Nile basin out of underdevelopment, poverty and hunger. The diplomatic relations of Ethiopia with riparian counties calls for negotiation and dialogue (Hydro diplomacy).

The paper tends to take stock what has been done in the past because Nile basin is not totally immune from the influence of the past which plagued the present and future cooperative processes. These processes include the recast of Ethiopia's hydro diplomacy, the role of Nile basin initiative which is transitional cooperative arrangement ,negotiation and signing of Comprehensive framework agreement (CFA), By analyzing the past agreements ((1929,1959) and Comprehensive Framework Agreement which are the driving factors for negotiations among Nile riparian countries and the tripartite consultations among Ethiopia, Egypt and Sudan on the renaissance dam, the paper has focused with different scenarios, ,among others, Sudan will sign CFA, both Sudan and Egypt will sign CFA ,Sudan and Egypt could refuse to sign CFA, CFA alliances, delay in the ratification of the signatory states or failure to do it altogether.

Retrospect and Prospect of Hydro Diplomacy; Ethiopia's collaborative approach to dealing with the Nile basin management.

A recast of Ethiopia's Nile Diplomacy

Hydro diplomacy is a modality of riparian interaction over the use, management and protection of shared water resources, Lingering tension and upstream and downstream discord prevailed in the Nile basin complicating hydro diplomacy among the riparian countries. The current problem over the use and management of the Nile waters stems a great extent from the pre-colonial, colonial and post colonial legacy of downstream hegemony over the Nile and the Egyptian aspiration to maintain this hegemony. Egypt and the Republic of Sudan have rejected the proposed Cooperative Frame Work Agreement claiming that the instrument doe not accommodate the exclusive rights of the two downstream sates as provided in the 1929 and 1959 agreements. On the other hand both agreements effectively excluded the upstream countries from their rights on the waters of the Nile. The regional and international drivers of hydro diplomacy have met the blockage of the status quo at the heart of which is the fallacy of historical and natural rights to downstream countries at the expense of the upstream interests. Prior to the creation of the NBI , Nile was dominated by unilateral pursuits of the riparian states leaving hydro diplomacy barely non –existence or kept in the margins of Egypt's hegemony.

The geopolitical expression of downstream hegemonic aspiration was questioned and rejected by Ethiopia from the very early on , Ethiopia on several occasion and consistently rejected the maximum grabs and unilateral deals of the downstream countries , as for instance , at the time of bilateral negotiation for the 1959 agreement between Egypt and Sudan . To that effect the Ethiopian government served aide memoire to the diplomatic community in Cairo explaining the country's legitimate interests on the waters of the Nile in the following terms;

…… just as in the case of other natural resources on its territory, Ethiopia has the rights and obligations to exploit the water resources of the empire (Ethiopia)….. for the benefit of the present and future generations of its citizens ….. In anticipation of the growth in population and its expanding needs the Imperial Ethiopian government …. Reassert and reserve now and the future, the rights to take all such measures in respect of its water resources ….. namely those waters providing so nearly the entirety of the volume of the Nile…..

Criticizing the downstream governments for their unilateral measures on the Nile question band rejecting their exclusionist tendency towards Ethiopia and other upstream countries the Ethiopian government reiterated its plan for developing Nile waters at the same time offering a cooperative proposal outlining as follows;

.. the waters of the Nile 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 friendly nation neighboring up on her, for the life and welfare of their people……

The offer shows Ethiopia's cooperative stance, which was not heeded by downstream states. The offer represents a hydro diplomacy *par excellence* in the context of the Nile basin. Indeed Ethiopia's proposal can be reckoned as setting a constructive and a far reaching contribution for hydro diplomacy in the broader region of North eastern Africa. This sets a tone that Ethiopia was willing to share and cooperate with downstream states over the numerous water systems that flow out of the country in all directions of its frontiers. Paradoxically, however, Hydro diplomacy was totally estranged in the official statements of Egyptian leaders. As evident I have cited some instances where threats of and conflict laden statements issued by Egyptian leaders and politicians; Shortly after signing the US sponsored Camp David accord in 1979, president Anwar Sadat stated that ……. The only matter that could take Egypt to War is water (postel, 1991). Following the Camp David peace with Israel, Egypt's focus was to put as much pressure as she could exert upon the upstream countries. Immediately after the Camp David accord again Sadat intended to supply 400million cube of the Nile water per year to Israel Negev desert and to the Gaza strip in exchange for a Palestinian solution and to the libration of Jerusalem (Pompe, 1990 and Gartsen 1989). In fact when Mengistu, the then Ethiopian head of state, heard Sadat's plan he retaliated by saying that …..He will press ahead with hydraulic projects on the Blue Nile (Andresen, 1999), Sadat made a more confrontational statement in reaction to Ethiopia's protest against Egypt's project of diverting the waters of the Nile in to Sinai, and Sadat retorted that ….once I decided to divert the Nile waters into Sinai I will not try to get permission from Ethiopia. If they do not like our measures the can go to hell. Or there will be no alternative for us but to use force (African Reader, cited in Polachek, 1991).

When the belligerent president passed away the Egyptian policy on the Nile did not change. Another war drum was resounded when Dr Buthros Ghali, then the minister of the state of the Egyptian foreign ministry was quoted to have made an ominous remark that the next war in our region will be over the waters of the Nile not politics and added that the national security of Egypt is in the hands of other African countries in the Nile basin (Hafney, 1993). By so saying, Ghali was trying to underscore waters special roles in Egyptian life and international friction that could result if the change of the status quo is attempted.

In case Ethiopia and Sudan plan to build dams on the Nile (BBC, News on line march 1999). Being suspicious of Addis Ababa's design on the Nile , president Mubarke of Egypt threatened to bomb Ethiopia if the plan to build dams on the Nile. (BBC News October 1999). Very recently President Mohamed Morsi in response to a call by his own Ministers urging the country to take military action against Ethiopia over its construction of the Renaissance Dam; ―As president of the republic, I confirm to you that all options are open…If Egypt is the Nile‘s gift, then the Nile is a gift to Egypt….If it diminishes by one drop then our blood is the alternative (Aljazeera, 13th June, 2013). Egypt‘s political and military dominance lent certain credibility to repeated warnings of military intervention and made it a realistic option for Egyptian politicians so much so that all moves of Egypt can justify the realist thesis.

The Ethiopian strategy was based on its just case and that its uses of the Nile water are not for consumption, but rather for power generation only, and that the water that generates the
Energy goes back to the course of the Nile and continues to flow to Sudan and Egypt, which will not result in any damage to these two countries. Besides it took advantage of its political stability compared with the previous eras and used the element of surprise and choosing the right time and the time factor.

Ethiopia has presented   the case of the dam in international forums, conferences and workshops as a just cause based on the principle of equitable and reasonable use of a shared resource under the international law, and is based on cooperation with Egypt and Sudan. Ethiopia made an offer, in the first months of the construction of the Dam, to Egypt and Sudan to participatein the financing, ownership and management of the Dam with it. But Egypt and Sudan ignored that generous offer, which showed Ethiopia as a cooperative country and strengthened its arguments and positions in the international forums.
Sudan and Egypt missed the global forums which discussed the Nile water and the Great Ethiopian Renaissance Dam (GERD) issues. And the "self-proclaimed new international experts" in Egypt and Sudan thought that writing articles and airing television interviews in Cairo and Khartoum were enough to halt the construction of the Renaissance Dam.

In the meantime, some Ethiopian experts and international experts published articles in the three international periodicals specializing in water issues (The International Journal of Water, International Journal of Water Resources Development, International Water Policy) showing and explaining the right of Ethiopia in building the Great Ethiopian Renaissance Dam (GERD), and the Dam benefits to Sudan and Egypt. These three periodicals are the journals and forums of the international experts in water resources. In contrast, not a single article was published by an Egyptian or a Sudanese expert, or of any other nationality criticizing the Renaissance Dam.
And not a single Egyptian or Sudanese expert had appeared in any international forums to explain and defend Egypt and Sudan's refusal of the Dam.

While the Ethiopian experts were presenting their research and studies at the international conferences, and publishing their articles in international water academic journals, and showing the justice of their cause in the waters of the Nile, the new self-proclaimed Egyptian and Sudanese international experts were continuously making rhetoric statements in Egypt and Sudan. Whereas, one of those baseless statements said the Renaissance Dam will result in an earthquake that will crack the Ka,ba itself (the Grand Mosque in Mecca), and while Egypt was threatening to take military action against the Dam, Ethiopia was talking about cooperation and sale of the Dam electricity at the production cost to Egypt and Sudan.
Ethiopia has based its strategy on its just cause. Ethiopia is the source of about 86% of the Nile water, while its uses do not exceed 1% only of the Nile water. Ethiopia has been continuously citing the successive famines it faced especially the (famine of the years from 1983 to 1985 which claimed nearly one million Ethiopians), and the extreme poverty of its people. Ethiopia has also based its cause on the principles of the International Law, which adopts the principle of equitable and reasonable use of the waters of a shared basin.
Ethiopia has also continued to point to the Nile Waters Agreement of 1959, and how Egypt and Sudan refused its participation in the negotiations around it. Then Egypt and Sudan distributed all the Nile water between them, without leaving a single drop to any state of the other Nile Basin countries including Ethiopia. Besides, the agreement includes a provision that requires any other Nile Basin state wishing to use any amount of water to submit a request to Egypt and Sudan, which will decide in the request and can reject it. If the two accept the demand, they will determine the quantity of water for that state to use, while the Joint Technical Commission monitors to make sure that the state will not exceed the amount of water approved for it. Ethiopia has been repeatedly stressing in international conferences and workshops, and in its meetings with countries' delegations that this text of the agreement is exclusionary, which is contrary to the International Law and logic and the most basic rules of justice.

1.2 NBI and CFA in the hydro diplomacy of the Nile

The new cooperation process initiated in the mid-1990s would bring a novel approach to promote trans boundary cooperation in the hydro politically complex Nile Basin with two parallel tracks: a technical track, with the NBI as a transitional cooperative arrangement; and a political track, driving negotiations for a CFA, which would promote the establishment of a functioning basin-wide framework for legal and institutional arrangements. Despite the parallel tracks, the rationale was that once countries adopted the CFA, the NBI as a transitional arrangement would be replaced by a permanent river basin commission (Amare, 2000; Brunnee & Toope, 2002; Nile Basin Initiative, 2002; UNDP, 2006). The Nile Basin Initiative perceived that the question of water security of the Nile riparian countries would be resolved through the two pillar program that is shared vision program and subsidiary action program .The former envisions developing institutional mechanisms including negotiated agreements for cooperative use of the shared Nile waters , while the latter program strived to promote sub basin level cooperation on joint development scheme s. The shared Vision program engaged the riparian states in a decade long negotiation for the CFA. The subsidiary action program on the other hand enticed the Eastern Nile countries and Nile equatorial ones into joint multipurpose projects within their respective sub basins. Desiring a more sustainable resolution to the issue of water security the basin states strived to include a water security provision in the negotiated Nile CFA. Article 14(b) stipulates thus …….not significantly affect the water security of any other Nile basin state. All countries agreed to this provision except Egypt and Sudan who asked the following replacement for the provision which would read as ………..not to adversely affect the water security and current uses and rights of any other Nile Basin State.

The wrangling around water security provision is a clear indicative of far reaching implication in the hydro diplomacy of the Nile basin. what is stated as …………….not significantly affect the water security of any other Nile basin state satisfies the upstream states that have argued that historical rights claims must be included in the draft CFA document. On the other hand , being unhappy about the removal of the historical rights provision from the draft CFA instrument the two downstream states wanted to make sure that the water security provision to bear a similar meaning of historical rights . Hence, they proposed a replacement provision which would guarantee the status quo was established in the previous two agreements of 1929 and 1959. It became quite clear that Egypt and Sudan would not go to adopt the CFA document unless their water security of current uses and historical rights are not adversely affected.

Seeking to resolve the impasse on the question of water security, the Nile council of Ministers during their extraordinary meeting held in Kinshasa decided by stating …………….the unresolved article 14(b) is annexed to be resolved by the Nile river basin commission within six months of its establishment at the time of adopting and during the process of signing the CFA, juxtaposed views emerged and remain unresolved to date. In the meantime the riparian states have proceeded developing the Nile water resources in view of their respective national imperatives. One clear example in that regard is Ethiopia's decision to construct a huge hydro electric dam on the Abbay. It has become clear even for Egypt and Sudan that the upstream countries have nothing to do with historical rights claims of downstream countries.

Ethiopia's decision to move ahead in 2011 with the GERD as a national project can be considered an outcome of failed expectations under the two parallel cooperation tracks. A comprehensive legal agreement was not endorsed, nor had the NBI-identified investment projects achieved the implementation stage, partly because of the uncertain institutional and legal situation after 2010. As a result, the Ethiopian government moved ahead with one of its national projects; however, this did not preclude Ethiopia's continued engagement with and support for multilateral cooperation as the way forward to manage and develop the Nile's water resources. Indeed, Ethiopia has continued without interruption to provide political, technical and substantial financial support to the NBI and ENTRO, whilst reiterating the need for a guiding comprehensive framework agreement that can support equitable and reasonable utilization of the water resources in the Nile Basin (Ethiopian Herald, 2015a; Horn Affairs, 2013).

It was Ethiopia that pushed hard for the CFA to be signed by almost all upstream countries, and which played its diplomatic cards to bring this new type of upstream alliance to the fore, in spite of barriers. Ethiopia has aligned with the equatorial riparian countries and went ahead with CFA signature in spite of reservations expressed by its two downstream riparian neighbors. The official discourse of Ethiopia has hitherto been one of assuming leadership of the 'upstream bloc', namely having the prime minister declare that "the upper riparian countries that signed the Cooperative Framework Agreement are highly desirous for the Agreement to be ratified and implemented [and] Ethiopia has to be exemplary to other riparian countries by ratifying the agreement" (Horn of Affairs, 2013). Ethiopia was the first country to ratify the CFA, in June 2013. These are examples of how Ethiopia's bargaining powers have increased dramatically over the past decade (Zeitoun et al., 2014). But in discursive and ideational terms, the cooperation process has also provided Ethiopia an opportunity to sit at several negotiating tables.

Without renouncing the supremacy of the CFA as a mechanism for effective cooperation in the Nile Basin, simultaneously Ethiopia has leveraged its diplomatic strengths under the GERD process – and, indeed, has been able to transform an initially national-only project into a tripartite process with Sudan and Egypt .In both its multilateral and its bilateral/trilateral relations with neighboring riparian, it is possible to conclude that Ethiopia has substantially increased its capacity to influence the current state of affairs in the Nile Basin, and has done so through foregrounding two issues: the need for a new legal framework and the benefits of water infrastructure development upstream.

However, it is in terms of bargaining power, i.e. power to influence the negotiation process and outcomes (Zeitoun et al., 2011, 2016), that these changes are becoming more visible. The capacity of upstream countries to influence trans boundary negotiations and their outcomes is different from 20 years or even a decade ago, and two main trends are visible. On the one hand, the NBI and CFA processes have opened up the possibility of bringing issues onto the agenda and negotiating table(s) that were hitherto not possible. These include the issue of hydraulic development upstream and related benefits to downstream riparian and the long-avoided issue of a new legal framework agreement based on the principle of equitable utilization of resources (Cascão & Zeitoun, 2010b). Until the mid-1990s, a debate over these two topics would invariably encounter strong resistance from downstream riparian, Egypt and Sudan. On the other hand, and less anticipated, has been that the two cooperation tracks have also opened up the opportunity for a more complex set of 'sub'-alliances between upstream countries, and also an eventual alliance between Sudan and Ethiopia. An example of the first is the coalition of interests that brought together all the upstream riparian (except Congo) as signatories to the 2010 CFA. The other example is the growing alliance between Sudan and Ethiopia, based on increasing understanding of the substantial benefits that Sudan can reap in technical and economic terms (e.g. power trade, water for irrigation, sediment control, etc.) from cooperation with Ethiopia.

Scenarios on the Basis of CFA

The failure and/or success of concluding basin wide agreement over the issue of the Nile has always been associated with vibrant hydro diplomacy. The negotiation of the CFA that has ended in the refusal of the downstream states to sign and ratify it. Except the unity of upstream states against the downstream states hoping the ratification of the signatory states of the CFA in the near future, the changes witnessed in the basin remained as it has been for so long. Thus, focusing on the developments prevailing in the region, the following four scenarios' are identified and tried to explain along with their implications.

Sudan will sign the CFA

Taking into consideration the present position of Sudan towards the GERD project, it is possible to guess that Sudan may sign it. As opposed to the 1959 water agreement that demands both countries to have a common position whenever upstream states are developing hydraulic projects, Sudan's support to Ethiopia's big projects signals its detachment from the previous commitments. The presence of a very large irrigable land in Sudan has the potential to lift up its people from poverty. The secessation of South Sudan taking 75 percent of the oil is obliging Sudan to focus on the large agricultural potential it possesses. The dependence on agriculture might push them to consolidate their cooperation with the upstream states from where the water is coming from. The progressing economy of the country will further boost their capacity of implementing their ambition. The strong friendship the country has with China and the Gulf States will also make the task in relation to accessing finance for the projects an easy task. Thus, the availability of finance and technical skill to develop irrigation and dam projects might encourage Sudan to seek cooperation with the upstream sates and will sign the CFA.

Therefore, if all the above interests of Sudan are getting dominance in the near future, the question that should be raised will be on the implication of such interest up on Egypt, the other upstream states and the CFA and its future institution, the NRBC. In the first case, the signing of the CFA by Sudan will herald the climax of the breakdown of their alienation with Egypt that started by their support to the GERD. Given the role of the common position of the two countries up on the hydro politics of the basin, the separation of Sudan from the established hydro hegemonic group of the basin is going to be a huge blow for Egypt. By making Egypt alone in the confrontation against upstream states, the position of Sudan will further consolidate the bargaining power of upstream states in their future negotiations. Consequently, the rivalry between Egypt and the unified position of upstream states will be heading in favor of the later. In general, these developments will either force Egypt to come to the negotiation table or sign the CFA. Even if Sudan refuses to sign the framework, given the favorable economical and political situations in most of the upstream states, the power and dominance of Egypt in the basin will not be sufficient enough to block and prohibit the hydraulic projects of the unified upstream states as before. In other words, if all the countries ratified the framework agreement, the future works of hydro diplomacy will become easy.

Both Sudan and Egypt will sign the CFA

Though it seems to be more optimistic to think the realization of this scenario, if it happens, it will declare the high time in the relationship between the countries of the basin in their entire history. The rough upstream-downstream relation is going to be solved so that institution born out of such cooperation will have a favorable time to implement the joint vision enshrined in the NBI. Especially, as the major tag of war has been between Egypt and Ethiopia since the time immemorial, political commitment on the side of Egypt will avoid the long standing barrier between them for good. The cooperation spirit between the age old rivalry states will contribute for the smooth functioning of the basin's institutions working in Nile water. Given the less expected performance of HYDROMET, Undugu and TECCONILE, changes in terms of narrowing the gap between these states will decrease their hidden interest that overshadowed the cooperation in the basin. The hurdles put in place throughout the negotiation period of the CFA, mostly because of the disagreement between Egypt and Ethiopia is going to be replaced by cooperation.

In addition to the smooth functioning of the future works of hydro diplomacy, the signing of the CFA by the downstream states will avoid the acrimonious relationship between upstream and downstream states that for so long has been the reason for the rough relation among the basin states. The phobia that stronger upstream states might affect the water flowing downstream has been the reason for Egypt to interfere in the internal politics of most of the upstream states. Egypt's support to the opposition groups of Ethiopia, its interference in Sudan and South Sudan could reflect the intention of Egypt to keep these states unstable so that it will have the required flow of the Nile. The internal problems of these countries together with the interference of the relatively stronger Egypt have been responsible for the chaos prevailing in the region. As part of their intention to divide the position of upstream states, Egypt's support of financial and technical assistance to some of the upstream states is another barrier which in turn contributes for the worsening of the relationship among the states in general. Therefore, this optimistic scenario of downstream states position and the declaration of principles on the Renaissance Dam make future works of hydro diplomacy by signing the CFA is going to be smooth.

Sudan and Egypt could refuse to sign the CFA

It represents the current scenario of the Nile Basin. As was the norm, the refusal of the downstream states to sign the CFA reflects the continuity of the rough relation and upstream-downstream states division of the past. This type of relation has resulted in the loss of life of hundreds of thousands of people and instabilities across the region.

Though upstream states are getting more stable in their politics and economy, refusal of the downstream states to sign the framework is going to contribute for the continuation of the previous relationship that have been responsible to play the role of catalyst in the already unstable region. Let's assume that the recent positive developments are going to have dominance and thus overcome the influence of Egypt. The strength resulting from these positive developments in the upstream states will contribute for the increase in the number of unilateral hydraulic projects.

Given the increasing economic and political muscle of upstream states and the coming of China with the finance and technical skill to assist the ambitious projects, unilateral projects of states might affect the quality and quantity of the water of Nile reaching downstream. In the absence of a legal framework determining the utilization of their common resources and the high dependence of Egypt up on the river, unilateral projects of upstream states might end up in a conflict between upstream states and downstream states. In addition, if either of the options suggested above is not going to happen, the likely alternative left for Egypt is to make a bilateral agreement with any upstream state developing a hydraulic project. The example in this perspective is the recent agreement of downstream states with Ethiopia over the GERD. In general, all these developments are going to have a negative impact up on the future works of hydro diplomacy and the stability of the basin. Therefore, the only way out for the upstream states under this scenario will depend on keeping the strength and unity of these states. This is because- united position will make these states more strong in their negotiation despite the strength of Egypt and the continued strategic role to the major powers.

Delay in the Ratification of the Signatory States or failure to do it altogether

Though Ethiopia, Tanzania and Rwanda ratified the agreement in the five years time since the document was ready and put to signature, be it the bureaucratic parliamentary procedure of ratification process or out of less interest to ratify it soon among the signatory states, its delay will contribute for the continuation of a divided and weak upstream states. It will also make the playing field more comfortable for Egypt. Of course, as states for so long denied any kind of privilege from their own water and the fact that they rejected the previous Nile agreements, the probability of these states in ratifying the agreement which they once signed is more likely. However, given the current situation in some of the upstream states, one can put the realization of the ratification process in question. The unsolved homework in the , South Sudan and Somalia halt hydro diplomacy activities.

The CFA Alliances

As previously discussed, the CFA was signed by 6 countries, refused by 2 and awaiting signature by another 3 countries (namely South Sudan, DRC and Eritrea). Alliances and counter alliances have formed around the CFA, but this solidarity seems flexible. As stated, CFA alliance would stay stronger provided that their economic and national interests are protected in this partnership. The Sudanese demand for more water created doubt around whether Sudan would continue its alliance with Egypt or align with the upper riparian states. Sudan might position itself with the upper riparian countries for an opportunity to cancel some or all parts of the 1959 agreement, and its benefits from alliance with upper riparian countries. The 1991 agreement between Ethiopia and Sudan about the future use of the Blue Nile has set a precedent for cooperation. In that case, the power balance in the region would be 7 to 1, should Sudan join the CFA alliance.

The state of South Sudan came into existence in the middle of this tension. Eyes are on the newly independent South Sudan, wondering whether it will align with the upper or lower riparian countries. Which side, will South Sudan join in relation to the signature of the CFA? Will Egypt claim the country to be bound by the 1929 and 1959 agreements? Or will South Sudan reject all the previous agreements, invoking a Nye ere doctrine? These questions cannot necessarily be comprehensively answered in this paper, but without any doubt the position South Sudan will crucially affect both lower riparian and upper riparian countries. If South Sudan opts to side with the lower riparian countries, their ability to win out on the core disagreements of the CFA will be increased. Conversely, if South Sudan opts to align with the upper riparian sates, it would assist the CFA alliances in accomplishing the vision of the NBI- ratifying the CFA and establishing the Nile River Commission. The third option is for South Sudan to take a neutral position as a mediator in an attempt to resolve the Nile water question amicably.

Alliance with Super Powers

Seen as domestically or regionally, the power and influence of African countries, is based on their strong relations with the outside world. Egypt has had a prominent position in the world politics having a good relation with global super powers. Egypt’s hydro-hegemony was established first by British colonists in the 1929 and 1959 agreements, and later by the Soviet Union during the Aswan High Dam Construction. During the Cold War, Egypt and Ethiopia were located in opposite camps. During the Nasser regime, Egypt was a Soviet ally, while Ethiopia allied with U.S.A. However, following a change of regime in both countries, Egypt changed its allegiance to U.S.A., Ethiopia to the Soviet Camp. As a result, the U.S.A.

became Egypt's new global power ally, which helped Egypt to maintain her hydro-hegemony over the Nile water. But, after the end of the Cold War and the downfall of the military regime in Ethiopia (1991), Ethiopia again allied with the U.S.A. So both Egypt and Ethiopia came under one global super-power. Realists argue that from this position, "United States pressured both states, through the World Bank, to coordinate their positions" However, it appears that since the pro-democratic revolution (2010) in Egypt, U.S. foreign policy toward Egypt has begun to change. It seems that U.S has now turned its eyes to upper riparian countries like Ethiopia, Uganda and Kenya to carry out its mission in the fight against terrorism, particularly against al-Shabab in Somalia. This attention has allowed the upper riparian countries to be heard in international forums and helped them to challenge the Egyptian dominance over the Nile River. Despite its absence at the time of the signing of the CFA, its disadvantaged up-stream position would push its alignment to the rest of upstream states. As a state rejecting both the 1929 and 1959 Nile Water Agreement, there is a hope by many that South Sudan will accede to the agreement in the near future. As a testimony to such conclusion, they managed to ratify the CFA, but became unacceptable because of their failure to follow the right procedure. Again, by following the normal track, the CFA is waiting the parliamentary procedure to be ratified However, the potential of South Sudan to influence the upstream downstream relation following its independence remained a question. The half a century struggle to acquire independence from Sudan, though succeeded in 2011, but failed to achieve the required stability. Power struggle between the president (Salvakir Mayardet) and vice president (Riek Mechar) ended up in a severe civil war between the two dominant ethnic groups, the Dinka and Nuer. This contemporary development opens the room for the temporary changes in the relation of South Sudan with its neighbors' in the basin. Egyptians approach in securing military pact and financial support to build small dams with South Sudan is testimony to the changes in power asymmetry which temporarily over shadow the issues related to the Nile Water `In general, the Egyptians will do everything in their power to approach South Sudan to side them or remain indifferent. Their attempt to hinder the independence of South Sudan is a recent memory that justifies the fear that Egyptians expected following its independence. Besides, Egypt also wishes the continuation of the problem since a weak South Sudan will not raise a question of water for some time and hinders her alignment to the other upstream states. On the side of South Sudan, though survival is their utmost priority, their interest towards the water of Nile has not been forgotten., The unwavering position of South Sudan towards Nile issue was seen when the former independent fighters of Sudan People Liberation Army (SPLA), even before controlling power had managed to block the Jonglei Canal. The suspension of this project that was planned to augment additional flow to Egypt and Sudan clearly explains that their real intention over the issue of Nile is clear. This actions of South Sudan shows as there is little love left over with downstream states. Therefore, despite the unusual friendship between the two countries, when situations are getting better, there will be a probability for South Sudan to come back to their senses and ratify the agreement. The case of the other country, DRC, however, is different from South Sudan. Of course, the unresolved internal civil war and rough relation with its neighbors' since independence, makes DRC to have a similar situation with South Sudan. However, the fact that DRC interest in the Nile is very minimal is the main reason that differentiates it from South Sudan. This is due to the small contribution of the tributaries of Nile emanating from DRC, i.e., Semiliki River to the development needs of the country. Rather, it is the Congo River which is 16-18 times bigger in terms of the volume of the flow to the Nile River, that DRC is highly dependent for its developmental needs. Therefore, as a country which failed to utilize other precious resources for the good of the country, it is very unlikely for them to focus on the water of Nile that might spark problems with other basin states .

The argument of DRC to sign the CFA when there is a unanimous support from all the basin countries including Egypt and Sudan shows their lack of interest to sign it. In addition, by signing the CFA, which has little relevance for their development, they do not want to endanger their relation with Egypt. Most importantly, it is the interference of Rwanda and Uganda which has been responsible for the worsening of the civil war that ravaged the country's economic and political stability. Therefore, it is natural for DRC not to have much interest in signing the agreement to support her enemy neighbors' and further complicate their relation with Egypt.

Chinese Involvements in Development Projects

Studies show that the growing magnitude of Chinese involvement in investment throughout Africa has been "under-theorized aspect of the new geography of war and peace in Africa" (Hintjens and Pavan 2011). The Chinese involvement in the Nile River basin has been creating a steady shift in power balance from unipolarity to multipolarity. Egypt's hydro-hegemony has also been faced practical challenges stemming from unilateral development projects by upper riparian states undertaken with the Chinese government, and increasing cooperation among the upper riparian states. Can Egypt stop the upper riparian states from taking unilateral development projects as it was in the past? Can Egypt prevent the upper riparian countries obtaining development funds from international financial institution as it had been?

It is obvious that Egypt had been the guardian of the Nile; and without Egypt's prior consent it had been impossible to take any development projects on the Nile River. The country had also successfully blocked project funds from the world financial institutions and donor countries to the upper riparian countries (Cascão 2009b). Nowadays, with the involvement of China, World Bank and other international institutions, and individual countries' involvement in the development of the Nile River, the nature of Egyptian control over the Nile River has changed. claims that "China and its economic might have provided the possibility of securing alternative external support to the Upper Nile riparian countries for large water development projects" (2011). Cascao argues a similar point that upper riparian states' access to alternative financial support is coming "mainly from China, a key external player in the basin. Such support was not available a decade ago. Such dynamics may significantly affect the relations between the Nile riparian and challenge Egypt's enduring hydro-hegemonic position in the basin" (Cascão 2009b). Chinese involvement in upper riparian countries, particularly in Sudan33 and Ethiopia, has increased. Chinese interest in Sudan is in project areas like oil refineries, highway construction and large dams, and in infrastructure, telecommunications, and hydropower in Ethiopia (Swain 2011). As a result of investment, the upper riparian countries have been encouraged undertake unilateral investment projects on the Nile in spite of the 1929 agreement which obliges them to seek consent from Egypt.

Conclusion

It became clear that the old unilateral approach to trans boundary water development strategy was to change and increasingly to give way for cooperative initiatives at basin wide level. The current level of hydro diplomacy in the Nile Basin is remarkable .Establishing shared benefit mechanism and instituting mutually acceptable cooperative frame work through the rubric of shared vision was officially embarrassed by all Nile riparian states. Issues to be addressed through the new diplomatic platform included overcoming longstanding tension between downstream stance for maintaining the status quo and the upstream quest for a new agreement based on the main principle of equitable and reasonable use of the Nile waters, An environment of more trust and mutual confidence in ones capacity and on the capacity of other co- riparian nations has increased , and this will likely be the most realistic way forward for the hydro politics of the Nile in general and hydro diplomacy in particular.

Ethiopia's longstanding plea for cooperation did not receive Egypt's attention under the hegemonic complacence and due to apparent geopolitical advantage. On the other hand Ethiopia's indomitable assertion of sovereignty over her part of the Nile lacked a level of influence to help change the Status quo . Ethiopia's clout on hydro politics of the Nile has been reactivated through the recast of hydro diplomacy which has been driven by the country's decision to construct Grand Ethiopian Renaissance Dam in April 2011. In this regard Ethiopia has gained three diplomatic achievements ; Coalition of the upstream nations with Ethiopia, Sudan's support of GERD and Egypt's willy-nilly choice to negotiate with Ethiopia over the use and management of the Nile waters.

In view of optimistic scenario of hydro diplomacy ,Egypt and Sudan will continue to engage themselves with Ethiopia with a new level of confidence. In any case , the upstream – downstream relations in the Nile basin will not any longer be determined by the frozen politics of colonial agreements or post colonial geopolitical machination.

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Economic Impact of Climate change on Agricultural production in Central Rift Valley of Ethiopia

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Abstract

Agricultural production remains the main source of food and income for most rural communities in Ethiopia. Climate change is critically affecting agriculture and leading to famine. Adaptation of the agricultural sector to the impact of climate change is vital to reduce household vulnerability to drought induced famine and ensure climate resilient livelihood of farmers. However, scientific information is lacking on magnitude of climate change, impact on agricultural crops and existing and possible coping up strategies. This study is, therefore, to analyse climate variability and its economic impact on agricultural crop productivity, and adaptation strategies in Arsi Negele district, central Rift Valley of Ethiopia. The study analysed observed climate variability, downscaled future projection (2046–2065 periods) with reference to base line station data from 1981-2009 using self-organising maps downscaling (SOMD) technique. This study also employed Ricardian econometric model to analyze marginal effects of temperature and rainfall on agricultural crops based on farm data generated from 174 farmers. Annual crop net revenue was regressed on climate and socioeconomic variables. The result obtained from metrological data indicated that, in both stations, climate variability was observed and the minimum temperature was more variable than maximum temperature while rainfall pattern was more variable in Langano station than in Arsi Negele stations in the period of (1981-2009). The future simulated result indicated that climate variability will be observed both in Arsi Negele and Langano stations for the projection period of (2046–2065). The magnitude and variability of both maximum and minimum temperatures will be increased in magnitude than the rainfall patterns. Detailed analysis of rainfall projection showed that at Arsi Negele station, main rainy season (Jun, July, Augest and partly September) is expected to decrease while short rainy season (March, April and May) is expected to increase. In Langano station, the future simulated result indicated as main and short rainy season rainfall patterns are expected to decrease while autumn rainfall will increase to some extent. However, in both Arsi Negele and Langano stations, the month July is expected to have higher precipitation than other months. Regressing of net revenue on climate, socioeconomics and soil variables showed that these variables recorded as a significant impact on the farmers' net revenue per hectare. The result from marginal analysis showed that a 1°C increase in temperature during main and dryseasons reduced the net revenue by 5179.65 and 704.19 ETB (Ethiopian Birr) per hectare respectively while a1°C increasing temperature marginally during the short rainy season and autumn seasons increase the net revenue per hectare by 1081.81 and 1542.65 ETB respectively. Increasing precipitation by 1mm during the main rainy season and dry season reduced net revenue per hectare by 1184.00 and 328.9ETB respectively. Household interview results showed that farmers were aware of climate variability and changes, and devised coping up strategies including soil and water conservation, tree planting and crop diversification. The findings suggested that the need to support farmers' adaptation capacity and improving their crop production efficiency to overcome future scenarios of climate change and impacts.

Key words: Climate variability, Climate change, Marginal effect, downscaling, adaptation and perception.

Introduction

Global warming is considered to be major threat for life on our planet. Observations show that global mean temperature at the earth's surface has substantially increased over the twentieth century [IPCC, 2007].This global warming and its multifaceted impacts are affecting the whole world in various forms. Several scientific studies have suggested that developing countries in particular are suffering from the burden of the ever changing climatic conditions (UN-OHRLLS, 2009). Many low income countries are located in tropical, sub -tropical region, or in semi-arid zones, that are particularly vulnerable to shifting weather patterns and rising temperature (Joachim, 2008). Widespread research findings have revealed that climate variability and change have significant impacts on global and regional food production systems particularly on the performance of common staple food crops in the tropical sub-humid climatic zone (UN-OHRLLS, 2009). Climate variability and change have been implicated to have significant impacts on global and regional food production particularly the common staple food crops performance in tropical sub-humid climatic zone. For example, the most food insecure regions and most climate change vulnerable regions in Ethiopia are those that experience both the lowest and most variable rainfall patterns (UN-OHRLLS, 2009). Many African countries are vulnerable to climate change because their economies largely depend on climate-sensitive agricultural production system (Temesgen, 2000).This is particularly true in low-income countries like Ethiopia where adaptive capacity is low.

Ethiopia is characterized by diverse topographic features that have led to the existence of a range of agro-climatic zones each with distinctly variant climatic conditions which in turn have resulted in the evolution of a wide variety of fauna and flora and agricultural production systems. Among these agro-climatic zones, the lowland (kola) that receives the lowest and most erratic rainfall rates notably the Central Rift Valley (CRV) region experiences frequent natural hazards such as sudden flooding, recurrent droughts and chronic water stress that are aggravated by climate change and its variability. Climate variability of erratic rainfall and its uneven sequential and spatial distribution is creating frequent flooding and drought in these areas (Lai *et al*., 1998).

In the central rift valley of Ethiopia, fluctuations in precipitation and temperature rates are directly affecting the production and productivity of the agricultural systems (Deschenes & Greenstone, 2006). Climate variability is indirectly affecting the agricultural production of the area through influencing the emergence and distribution of crop pests, livestock diseases, aggravating the frequency and distribution of adverse weather conditions, reducing water supplies and enhancing severity of soil erosion among other impacts (Watson et al, 1998). Climate variability and its associated impacts are inducing frequent crop failures, and declining livestock production and productivity leading to aggravated rural poverty in the region. Scientific evidences suggest that higher temperatures and changing precipitation levels as a result of the changing climate will further depress agricultural crop yields in many arid-and semi-arid parts of Ethiopia over the coming decades (Bezabih et. al; 2010).

As a result farmers in many arid- and semi-arid areas of the central rift valley will be more vulnerable to climate change for their economies largely depends on climate-sensitive agricultural production systems (Temesgen, 2000). This is particularly true for the low-income and marginalized central rift valley areas such as the Arsi Negele districts where adaptive capacity is low. Several evidences show that high temperature and chronic water stress caused by climate change has already affected the Ethiopian agriculture especially the crop production and livestock raring (EARO, 2002). Many regions in northern and central rift valley of Ethiopia have been severely affected by climate change. Current climate predictions indicate that crop production in the central rift valley would be extremely vulnerable as a result; food security of the country will be at risk unless effective adaptation and mitigation mechanisms are put in place (Karim et al., 1996).

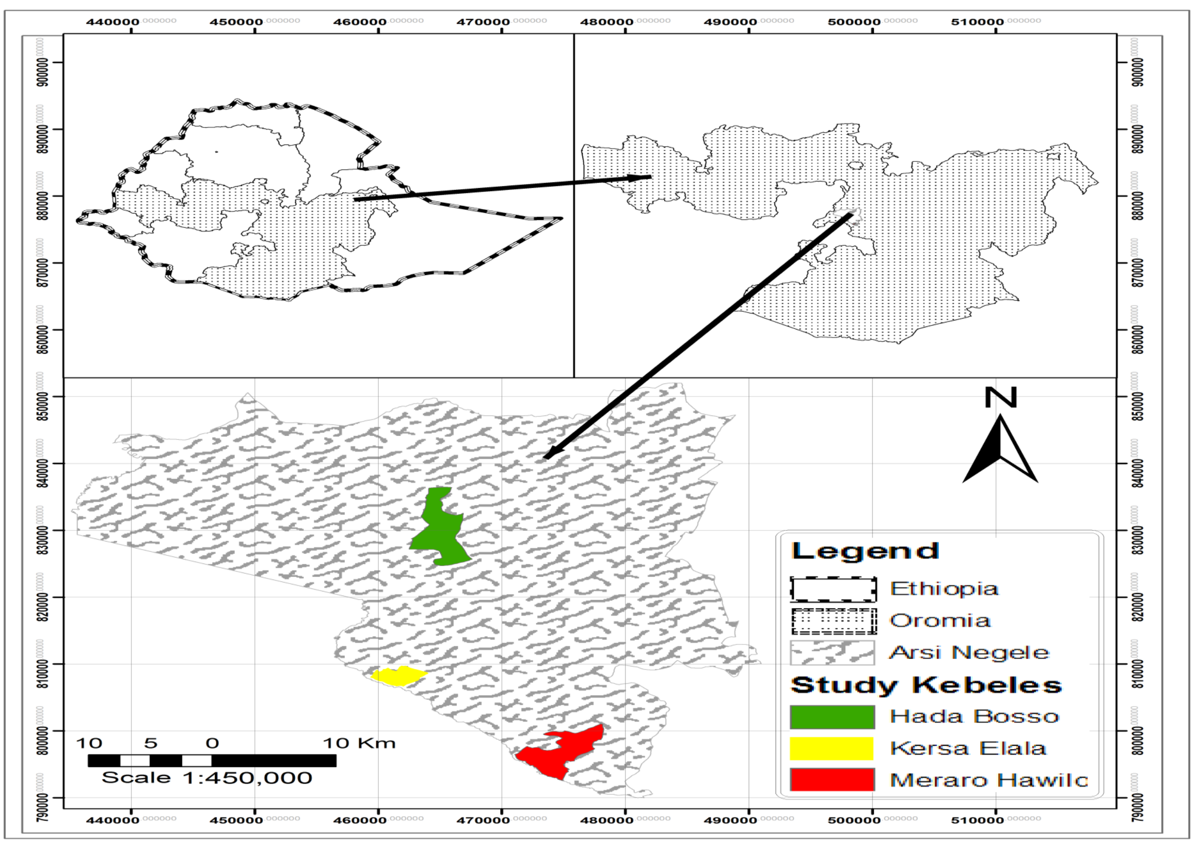
In effect, ongoing national development efforts that are aimed at increasing food production through the expanding irrigation, flood protection and modern agricultural technologies to achieve food self-sufficiency will be at risk. Therefore, scientific investigations and applied researches on climate variability and its economic impact on the production levels and productivity of agriculture is critical to develop effective and locally-adaptive agricultural production systems in the face of the increasing climate change and variability (Karim et. al., 1994). However, despite a handful of empirical studies, in-depth analysis and well-established scientific evidences on the nature and extent of climate variability, magnitude of climate change impact on agricultural crops and the likely socio-economic consequences on the livelihoods and food security of the rural poor in the area is virtually lacking. The study is designed to investigate climate variability and its economic impact on crop yield in the Arsi Negele area. This study was therefore conducted analyzed the change of climate variability and assess its economic impact on crop productivity in the study area.

Methodology

Description of the Study area

Arsi-Negele district is located in West Arsi zone of the Oromia Region State about 225 km south of the capital Addis Ababa. Geographically, it is situated in the Ethiopian central rift valley system of 7 ^{0}09'-7^{0}41' N and 38^0 25'-38^{0}54' E. It is bordered in the south by Shashamene district, in the southwest by Bulbula woreda which separates it from Seraro, on the west from the Southern Nations, Nationalities and Peoples Region, on the north by Adami Tullu and Jido Kombolcha with which it shares the shores of Lakes Abijatta and Langano, and on the east by the Arsi Zone (ORS, 2004).

Figure 3.1 Map of the study area



Climate and Agro-ecology

The study area covers three agro-ecological zones (low, mid and high land) based on temperature, rainfall, altitude and vegetation and that ranges from 1500-2300 m.a.s.l. (ICRA, 2002). The high altitude zone occupies the largest area followed by mid and low altitude climatic zones respectively. Average annual temperature varies from 10-25 C^o while annual rainfall varies between 500-1000mm (ORS, 2004).

Sampling Design and Sample Size

In order to collect the robust data needed to achieve the objectives of the research, a multi-source data collection method through stratified random sampling (SRS) was employed. In the first stage, the Woreda was classified into three strata of Lowland (kola), Midland (woyna-dega) and Highland (dega) agro-ecological zones. From each agro-ecology one target kebele was selected in such a way that the kebeles represent the Woreda in biophysical, agricultural and socio-economic aspects. Most importantly the kebeles were selected so that they represent the main farming practices, crop varieties, socio-economic status, climate problems and disasters besides topographic features. Accordingly, Hada Boso, Kersaylala and Meralo-hawilo kebeles were selected from the three zones respectively.

In the second phase the number of households in each target kebeles was identified and sample size was determined for the random sampling. Accordingly, Hada Bosso kebele consisted of 580 households, Kersa elala kebele consisted of 520 households and Meralo-hawlio kebele consisted of 640 households making a total of 1,740 target households. A 10% sampling intensity was used from each kebele accounting a total of 174 sample households. Proportionately distributing the sample size to the three kebeles; 58 households from the Hada Bosso, 52 households from the Kersaylala and 64 households from the Meralo-hawlio was sampled. Finally, the respective sample households from each kebele were identified and contacted for the socio-economic study. GPS points of farmlands of each household were also located for the interpolation of the cross-section climate data at farm level.

Data Source and Data Collection Method

Three sets of primary data namely: climate and soil data (temperature and precipitation and soil characteristics), socio-economic and agricultural production data, and data on traditional climate change adaptation mechanisms were collected. The first group of data (climate data) was obtained from the National Metrology Agency. The second group of data (socio-economic and climate adaptation) were collected from household survey. Additionally, valuable secondary data were also collected from various sources including previous scientific studies and reports from Woreda level agricultural bureau and other concerned organizations. Detailed description of the data collection methods used for each group of data type are presented below.

Climate data

The observed data on climate variables mainly temperature and rainfall, from 1981-2010, of the study area was obtained from the National Metrology Agency of Ethiopia. The data were later downscaled and future projection was administered with the help of Climate System Analysis Group (CSAG) through the climate information portal (CIP) with the help of University of Cape Town, South Africa. Accordingly, monthly rainfall and temperature data were collected from all the metrological stations in the district in collaboration with the National Metrological Station.

In order to impute the cross-section household farm level rainfall and temperature values, the spatial interpolation method were used using latitude, longitude, and elevation parameters of each household farm. The spatial interpolation method is a physically based interpolation scheme for arbitrarily spaced tabulated data. The Spline surface represents a thin metal sheet constrained not to move at the grid points, which ensures that the generated rainfall and temperature data at the weather stations were exactly the same as data at the weather station sites that were used for the interpolation (Wahba, 1990; Yesuf et al., 2008).

Socio-economic data

An in-depth household survey by using a semi-structured questionnaire and in-person interview was employed to collect both the detailed socio-economic data and the traditional climate change adaptation and coping mechanism of the households. Farm households' cross-sectional data were obtained from a household survey of farmers during the 2011/12 production year in Arsi Negele district.
Prior to conducting the household survey, key informants and elite community leaders were identified for focus group discussions with the help of the woreda agricultural bureau and local development agents.

Accordingly, one focus group discussion was carried out at Kebele level which contained 5-8 farmers in a particular kebele. After conducting the discussion, these farmers were the key informants of the kebele. The focus group discussions have played great role for the study to find out the problems of the farmers at the local level and see a real situation on-ground and also to explore and understand farmers' knowledge, perceptions, awareness and climate change impacts on their agriculture practices and adaptation strategies practicing by the local farmers. Then one key informant discussions was also carried out at Kebele level to generate general information on the main research problem.

Following the key informant discussions, the semi-structured questionnaire already prepared for the study was amended before the actual household survey. A very important part of the data collection process was the pre-test i.e. in order to check the validity and appropriateness of the semi-structured questionnaire, three households from each kebele that are outside the research sample were identified and interviewed for a pre-test prior to the actual interview of the total sample households. Consequently, the questionnaire was amended. Data collectors/ enumerators and research assistants who have better knowledge of the local tradition and language were contacted and trained before conducting the survey. In addition, a separate semi-structured questionnaire was prepared and presented to professionals and agricultural officers working in the study area.

Soil data

The soil data for this study came from the same survey mentioned above. There are different soil types in the study areas. These soils are traditionally classified by its colors and some of the color types are sandy, clay, black and red. One should note that although these soils seem to be more prominent in the district, this does not imply that all of are important for crop farming activities. Rather expected effect of these soils is depending on the level of fertility or the type of soil (FAO, 1996).

Econometric model Specification

The empirical models employed for this study follow the works of Mendelsohn et al. (1994) and Ouedraogo et al. (2006). The models examine how long-term farm profitability varies with climate (temperature and precipitation) and soils while controlling for other factors. Relevant socioeconomic variables are also assessed to see the extent to which they control the impact of climate change on crop agriculture. Two main models are formulated: 'without' adaptation model and 'with adaptation models. The former include only climate and soil variables, while the latter in addition to these variables include relevant socio-economic variables such as cropland area, livestock ownership, distance to nearest market for obtaining inputs and selling products, access to extension, access to credit, household size, years of education of the household head and farming experience. These two models estimated for sample farms that represent central rift valley Ethiopia .The model without adaptation options includes only the physical variables (temperature, precipitation and soils): The model with adaptation includes the previous variables and farms characteristics (Kurukulasuriya & Mendelssohn, 2006).

It is not obvious how to represent monthly temperature and precipitation data when Ricardian regression model is applied (Kurukulasuriya & Mendelssohn, 2006). The correlation between adjacent months is too high to include every month. This study explored several ways of defining three-month average seasons. Comparing the results, defining summer or main rainy season (the average for June, July and August), winter or dry season (the average for December, January and February), spring or short rainy season (the average for March, April and May) and autumn (the average for September, October and November).

In my study the dependent variable (R) indicated in equation-1 is measured as crop net revenue per hectare of cropland. Crop net revenue is the gross crop revenue which is the product of total harvest and price of the crops (Maize, Wheat, Teff, wheat, Sorghum, Barley and Haricot been (the value of crop production) total associated cost of production calculated for each agricultural household. The independent variables include the linear and quadratic terms of temperature and precipitation and only linear terms of soils and farm characteristics

Variables	Variable description	Expected sign
Crop net revenue	It is continuous variable measured in Birr per hectare	
Summer temperature	It is continuous variable that measured in ^{o}c	-/+
Winter temperature	It is continuous variable that measured in ^{o}c	-/+
Spring temperature	It is continuous variable that measured in ^{o}c	-/+
Autumn temperature	It is continuous variable that measured in Millimeter	-/+
Summer precipitation	It is continuous variable that measured in Millimeter	-/+
Winter precipitation	It is continuous variable that measured in Millimeter	-/+
Spring precipitation	It is continuous variable that measured in Millimeter	-/+
Autumn precipitation	It is continuous variable that measured in Millimeter	-/+
Sandy soil	It is a dummy variable that represent by 1/ 0 ,sandy soil=1 Otherwise=0	-
Black soil	It is a dummy variable that represent by 1/ 0, Black soil=1, Otherwise= 0	+
Red soil	It is a dummy variable that represent by 1/ 0, Red soil=1 Otherwise= 0	-
Cultivated land size	It is continuous variable that measured in Hectare	+
Livestock ownership	It is continuous variable that measured in tropical livestock unite (TLU)	+
Distance from input market	It is continuous variable that measured in Kilometer	-
Distance from output market	It is continuous variable that measured in Kilometer	-
Household farming experience	It is continuous variable that measured in a year	+
Access to credit	It is a dummy variable that represented by 1/0 Access to credit=1 Otherwise =0	+
Access to extension	It is a dummy variable that represented by 1/0 Access to extension =1, Otherwise =0	+
Household family size	It is continuous variable that contain total family size members of a household	-
Educational status of household	It is continuous variable that measured in a year	+

Table 3.5 Description of variables specified for the regression model

Analysis of econometric Approach: The Ricardian cross sectional Model

In the last few decades, few statistical and econometric models have been developed to analyze and establish a logical relationship between climate variability and revenue from agricultural crop production. For this study, a linear regression model was used to estimate the economic impact of changing climate variables on agricultural crops yield. The Richardian Econometric model statistically analyzes the relationship between farms inputs (climate) and outputs (agricultural production) through regressing a set of climate variables (rainfall and temperature) and other socioeconomic variables with revenue from agricultural productions.

In doing so, the model measures the contribution of each independent factor to the outcome of agriculture production and impact of climate change on agriculture (Mendelssohn et al. 1994).

The Ricardian approach is based on the observation of David Ricardo (1772–1823) that land rents reflect the net productivity of farmland and it examines the impact of climate and other variables on land values and farm revenues. This approach has been found attractive because it corrects the bias in the production function approach by using economic data on the value of land. So, the Ricardian approach accounts for the direct effects of climate on the yields of different crops (Mendelsohn et al. 1994). It is also attractive because it includes not only the direct effect of climate on productivity but also the adaptation response by farmers to local climate.

In essence the Ricardian approach is a cross-sectional model applied to agricultural production. It takes into account how variations in climate change affect net revenue or land value. Following Mendelsohn et al. (1994), the approach involves specifying the productivity function of the form.

$$R = \sum P_i Q_i (X, F, Z, G) - \sum P_x X \text{.........}(1)$$

where R is net revenue per hectare, Pi is the market price of crop i, Q_i is output of crop i, X is a vector of purchased inputs (other than land), F is a vector of climate variables, Z is a set of soil variables, G is a set of economic variables such as market access and Px is a vector of input prices. The farmer is assumed to choose X to maximize revenues given the characteristics of the farm and market prices. The standard Ricardian model relies on a quadratic formulation of climate.

$R = B0 + B1F + B2\ F^2 + B3\ Z + B4\ G + u$………………….. *(2)*

Where u is an error term, and F and F^2 confine levels and quadratic terms for temperature and precipitation. The introduction of quadratic terms for temperature and precipitation reflect the non-linear shape of the response function between revenues and climate. From the available literature, we expect that farm revenues will have a concave relationship with temperature. When the quadratic term is positive, the revenue function is U-shaped, but when the quadratic term is negative, the function is hill-shaped. For each crop there is a known temperature where that crop grows best across the seasons, though the optimal temperature varies by crops. Crops consistently exhibit a hill-shaped relationship with annual temperature, although the peak of that hill varies with each crop. The relationship of seasonal climate variables, however, is more complex and may include a mixture of positive and negative coefficients across seasons (Mendelsohn et al. 1994).

From equation (2), we can derive the mean marginal effect of a climate variable on farm revenue. Thus, the expected marginal effect of climate variable on farm revenue evaluated at the mean is:

E [dV/dfi] = b1, i + 2*b2, i *E[fi] ……………………………… (3)

The original Ricardian studies used land value for the dependent variable. In many developing countries, however, land value is not available. Annual revenue per hectare can be used instead, since land value is the present value of future revenue (Dinar et al., 1998).

Statistical analysis

Appropriate statistical software's such as STATA11 and Microsoft Excel were used to analyze the data from the household socio-economic survey in order to underlying socio-economic variables determining the perception and traditional knowledge of the local communities on climate change and its impacts as well as their adaptation measures. Finally, the results of the data analyzed were summarized and presented in various forms including: frequency tables, percentages, histograms, graphs, software outputs as well as narrative summaries as shown in the next section.

Result and Discussions

Estimated marginal effect of temperature and precipitation on crop net revenues

The Ricardian approach estimates the importance of climate and other variables on the value of farmland. Net revenues were regressed on climatic and other control variables. This study explores two main sets of the Ricardian model indicated in model one and two. The first model includes only climate and soil variables and is referred to as without adaptation model. The second model includes climate, soil and relevant socio-economic variables and is referred to as with adaptation model. These additional variables are used to assess the extent to which these additional variables increase or decrease the effect of climate on crops. These socio-economic variables are good policy instruments for policy makers to explore as tools for controlling or taking advantage of climate effects. They are useful to see the importance how these variables explain crop net revenue (Benhin, 2006).

The regression results indicate that most of the climatic, household and soil variables have significant impacts on the net revenue per hectare (Table 4.1). This table shows that while the coefficients of dry season and main rainy season temperature are both negative, those of short rainy season and autumn season are positive. The coefficients of main rainy season are negative, whereas for dry season, short rainy season and autumn seasons are positive. The interpretations of the signs and magnitudes of impacts are further explained under the marginal analysis.

The education level of the head of the household and the livestock ownership are positively related to the net revenue per hectare. The effect of distance to input market place is negative, as farmers incur more cost in terms of money and time as the market place becomes further from their farm plots. The household size is negatively related to the net revenue per hectare because there are many dependent and unproductive people in rural Ethiopia (such as children, elderly and sick). Access to extension service helps improve crop net revenue which is statistically significant. Access to credit also affects crop net revenue positively. The effect of black soils on crop production is positive which may be explained by the fertility level and water retention capacity of the soils. However; some of them have negative effects.

Table 4.1: Regression results of model with adaptation: climate, soil and socio-economic variables

Independent variable	coefficient	T-statistics
Summer temperature	-5525.09 *	-1.711
Summer temperature sq	172.72 *	1.82
Winter temperature	-733.3	-0.68
Winter temperature sq	14.42	1.01
Spring temperature	-1190.57 **	-2.47
Spring temperature sq	54.37 **	2.22
Autumn temperature	1538.95**	2.04
Autumn temperature sq	4.36 *	1.97
Summer precipitation	-1544.24 *	-1.74
Summer precipitation sq	180.12 *	1.54
Winter precipitation	-344.42	-0.83
Winter precipitation sq	7.76	1.07
Spring precipitation	229.46 *	1.73
Spring precipitation sq	-1.087 **	-2.11
Autumn precipitation	-473.64 *	-1.65
Autumn precipitation sq	57.42 *	1.55
Clay soil	Reference group	
Sandy soil	-216.87	-0.70
Black soil	5987.43 *	1.63
Red soil	3855.88	1.24
Land size	134.59	1.46
Livestock ownership	777.66 ***	3.32
Distance of input market	-376.04	-1.49
Distance of output market	-43.58	-0.81
Farming experience	161.41	1.02
Access to credit	18839.42***	4.71
Access to extension	6869.53 *	1.66
Family size	-565.46 *	-1.8
Year of educational household head	533.00 *	1.87
Constant	-74442.76 *	-1.88
F	6.73	
R squared	0.51	
N	**174**	

Note: * Significant at 10% level ** Significant at 5% level * Significant at 1% level**

Results from both models shown that there is a quadratic relationship between climate variables and net revenue per hectare. For example, the coefficient of short rainy season temperature in with adaptation model is negative but the coefficient of the short rainy season temperature squared is positive. In short rainy season temperature, climate variables have a ***U shaped*** relationship with net revenue. This suggests that short rainy season temperature has a negative effect on net revenue until a turning point is reached, beyond that value; it has a positive impact on net revenues whereas in without the adaptation model, the coefficient of spring temperature is positive and it has a ***hill-shaped*** relationship with net revenue. This means, spring temperature has a positive effect on net revenue until a turning point is reached, beyond that value; temperature has a negative impact on the revenue. The coefficient of **squared values** tells both the direction and steepness of the curvature (a positive value indicates the curvature is upwards while a negative value indicates the curvature is downwards).

The independent variables in this study included the linear and quadratic temperature and precipitation terms for the four seasons: main rainy season, dry season, short rainy season and autumn season. As it shown from (table4.1and 4.2), one can see that the effects of the seasonal climate variables across the two models. Both linear and squared terms are significant in certain seasons, implying that climate has a nonlinear effect on crop net revenues.

The effect of quadratic seasonal climate variables on crop net revenue is not obviously determined simply by looking at the coefficients, as both the linear and the squared terms play a role rather the climate coefficients will be interpreted based on the marginal effects of climate variables (Kurukulasuriya & Mendelssohn, 2006).

Table4. 2: Regression results of model without adaptation: climate and soil variables

Independent variable	coefficient	T-statistics
Summer temperature	2134.72 *	1.69
Summer temperature sq	-61.98 *	-1.86
Winter temperature	-941.79*	-1.50
Winter temperature sq	105.34*	1.73
Spring temperature	300.75	1.39
Spring temperature sq	-22.16	-1.06
Autumn temperature	5497.96 **	2.40
Autumn temperature sq	-124.69 **	-2.07
Summer precipitation	164.16	1.30
Summer precipitation sq	-10.32	-1.00
Winter precipitation	29.78	-1.07
Winter precipitation sq	-3.52	1.30
Spring precipitation	137.06	1.01
Spring precipitation sq	-5.49	-1.40
Autumn precipitation	- 516.79 *	-1.57
Autumn precipitation sq	55.02 *	1.70
Clay soil	Reference group	
Sandy soil	-1884.35	-0.51
Read soil	4737.23	1.25
Black soil	4805.59 **	2.34
Constant	-106350.2	2.34
F	4.15	
R squared	0.22	
N	**174**	

Note: * Significant at 10% level ** Significant at 5% level

The estimated marginal impact analysis was undertaken to observe the effect of change in temperature and rainfall on Arsi Negele farming. Table4.3 and 4.4 showed the marginal effects of a 1°C increase in temperature and 1mm increase in precipitation on crop net revenues for farmer in adaptation and without adaptation model respectively. For example, with adaptation model, a 1°C increasing temperature during main rainy season and dry seasons significantly reduces the net revenue by 5179.65 and 704.19Birr per hectare respectively (table 4.3). How- ever, a 1°C increasing temperature marginally during the short rainy season and autumn seasons increase the net revenue per hectare by 1081.81and1542.67Birr respectively (table4.3). During short rainy season, a slightly higher temperature with the available level of precipitation enhances germination, as this is the planting period. During autumn, a higher temperature is beneficial for harvesting. It is important to notice that most crops have finished their growing period by autumn, and a higher temperature quickly dries up the crops and facilitates its harvesting so, it has a positive effect on net revenue (Mendelsohn R & Dinar A, 2003).

Increasing precipitation by1mm during the main rainy season reduces net revenue per hectare by 1184.00Birr but 1 mm increase winter precipitation reduces the net revenue by 328.9Birr. The reduction in net revenue per hectare during the main rainy season is due to the already high level of rainfall in the country particularly in central rift valley. During this season, increasing precipitation results in flooding and damage to field crops but in Ethiopia January and February are a dry season, so increasing precipitation slightly with the already dry season may encourage diseases and insect pests. During the period of (mid-September, October and November) a 1 mm increasing precipitation increases net revenue per hectare by 227.29Birr (table-4.3). As explained earlier, with slightly higher temperature and available precipitation (soil moisture level), crop germination is enhanced. Marginally 1mm increasing precipitation during the autumn also reduces net revenue per hectare by 358.80Birr (table-4.3). The reduction in net revenue per hectare with increasing precipitation during this season is due to the crops' reduced water requirement because it is commonly known as harvesting season. More precipitation damages crops and may reinitiate growth during this season (Polsky C & Esterling W, 2001).

Table 3:4 Marginal effects of climate variables on crop net revenue based on coefficients for model with adaptation (Birr)

Climate variables	Main rainy season	Dry season	Short rainy season	Autumn season
Temperature	- 5179.65	-704.19	1081.81	1542.67
Precipitation	-1184.00	-328.9	227.29	-358.80

For the model without adaptation, a 1°C increasing temperature during main rainy season and dry season seasons significantly reduces the net revenue by 2010.76 and 731.11 respectively while 1°C increasing temperature marginally during the short rainy season and autumn seasons increase the net revenue per hectare by 256.41 and 5248.54 Birr respectively (table-4.4).\

Increasing precipitation by 1 mm during the main rainy season and dry season increase net revenue per hectare by 143.52and22.74 Birr respectively. During the short rainy season a 1mm increasing precipitation increases net revenue per hectare by 126.00Birr. Marginally a 1 mm increasing precipitation during the autumn also reduces net revenue per hectare, by 406.00Birr. As it is explained above, the reduction in net revenue per hectare with increasing precipitation during the autumn (mid-September, October and November) is due to the crops' reduced water requirement during the harvesting season and more precipitation damages crops (Deressa et al., 2008).

Table4. 4: Marginal effects of climate variables on crop net revenue based on coefficients for model without adaptation (Birr)

Climate variables	Main rainy season	Dry season	Short rainy season	Autumn season
Temperature	-2010.76	-731.11	256.41	5248.54
Precipitation	143.52	22.74	126.00	-406.00

Adaptation has an advantage of the positive effects of climate change while reducing the negative ones. In table-4.3 one would expect that, inclusion of adaptation related variables (socio-economic variables) will increase the relationship between climate variables and crop net revenues for positive values and reducing the negative values. Thus including adaptation variables may help reduce the negative effects and take advantage of the positive effects of high temperatures. For example, in adaptation model, the negative effects of the dry season temperature have decreased while without adaptation model the negative effect of temperature increase from-704.19 birr to -731.11Birr respectively. However, for main rainy season temperature, the inclusion of adaptation related variables rather aggravates the negative effects of increased temperature, the estimated negative effect is -5179.65Birr whereas without adaptation model with the negative effects was estimated as -2010.76Birr reduced per hectare. According to (Dinar et al., 2008) findings, even though the adaptation related variables are important in helping to control climate effects, if they are not properly implemented they may rather aggravate the problem. One can see that how the inclusion of socio-economic variables improved the model, as is it indicated the R-squared values from without and with adaptation models as that indicated the relative higher R-squared for the two models ranging from 22% to 50%. This implies that the socio-economic variables are important in explaining better for crop revenues.

Farmers' perceptions and adaptation to climate change

The survey instruments were designed to capture farmers' perceptions and understanding of climate change as well as their approaches to adaptations. From the three kebeles, the farmers were asked about the trends of climate parameters of temperature and rainfall is shown below.

Table 4.5: Households' perceptions on climate change over the last two decade (Percentages).

	Hadha Boso kebel (LL) (%)		Kersa Ilala kebele (ML) (%)		Meraro kebele (HL) (%)	
Directions	Rainfall	Tempera-	Rainfall	Temperature	Rainfall	Temperature
Increasing	18.97	65.97	26.92	60.46	28.13	53.13
Decreasing	70.69	17.69	61.54	29.62	46.88	34.38
The same	10.34	16.34	11.54	9.92	24.99	12.49
Total	100	100	100	100	100	100

As one can see from (table 4.5), 77.59% of selected households have perceived as climate is changing while the corresponding response 22.41% of the rest didn't perceived for this climate change in the last two decades. Regarding the direction of the change of temperature and rainfall in the three kebeles, Hada Boso, Kersa and Meraro, 65.97%, 60.46%, and 53.13%, of the sample households perceive an increase temperature and 17.69%, 29.62%, and 34.38% decrease temperature respectively. With regard to rainfall as mentioned above 18.97%, 26.92% and 28.13% of respondents answered that rainfall is increasing while 70.69%, 61.54% and 46.88% of respondents answered rainfall is decreasing respectively. However, 10.34%, 11.54%, and 24.99 of Hada Boso, Kersa, and Meraro sample household did not observe any change of rainfall and temperature respectively. The agro-ecological setting of farmers influences the perception of farmers to climate change. According to Diggs (1991) findings, farmers living in drier (lowland) areas with more frequent droughts are more likely to describe the climate change to be warmer and drier than farmers living in relatively highland areas with less frequent droughts. In Ethiopia, particularly central rift valley, lowland areas are drier with higher drought frequency than other areas (Bezabih et. al; 2010). Thus, it is hypothesized that farmers living in lowland areas are more likely to perceive climate change as compared to midland and highlands. In general, increased temperature and declined precipitation are the predominant perceptions in the study areas.

Traditional adaptation mechanisms of climate change by local farmers

In central rift valley of Ethiopia, particularly in Arsi Negele district, farmer's ability to adapt climate change is limited due to lack of knowledge and economic resources, and their vulnerability is put emphasis on by heavy dependence on the climate, because farmers depend on the rain fed agriculture system. Given the diversity of the constraints they faced, the general capacity to cope to climate changes is currently very low. There are no good national action plans which take into account short or long term climate changes.

The extended increasing temperature, combined with the declining of the rain fall and the frequency of the drought, as well as deforestation and land degradation of the soils, have resulted in decline of crop yields. According to Deressa et al. (2008) findings, crop yield was declined by 32.8% as result of shocks such as drought and flood etc. Farmers therefore trying to develop their own strategies to cope climate change impacts. Maddison (2006) argued that adaptation to climate change is also a two-step process that involves perceiving that climate is changing, and then responding to changes through adaptation strategies.

The adaptation methods most commonly cited in the literature include the use of new crop varieties irrigation, crop diversification, mixed crop, livestock farming systems, changes of planting dates, diversification from farm to nonfarm activities, increased use of water and soil conservation techniques, and trees planted for shade and shelter (Mukheibir and Ziervogel, 2007).

In the case of Arsi Negele district farmers were asked about their perceptions of climate change and their actions to offset the negative effects of climate change. As responded by farmers one can deduce that farmers actions were driven by climatic actions and the result were similar to the findings of (Mukheibir and Ziervogel, 2007).

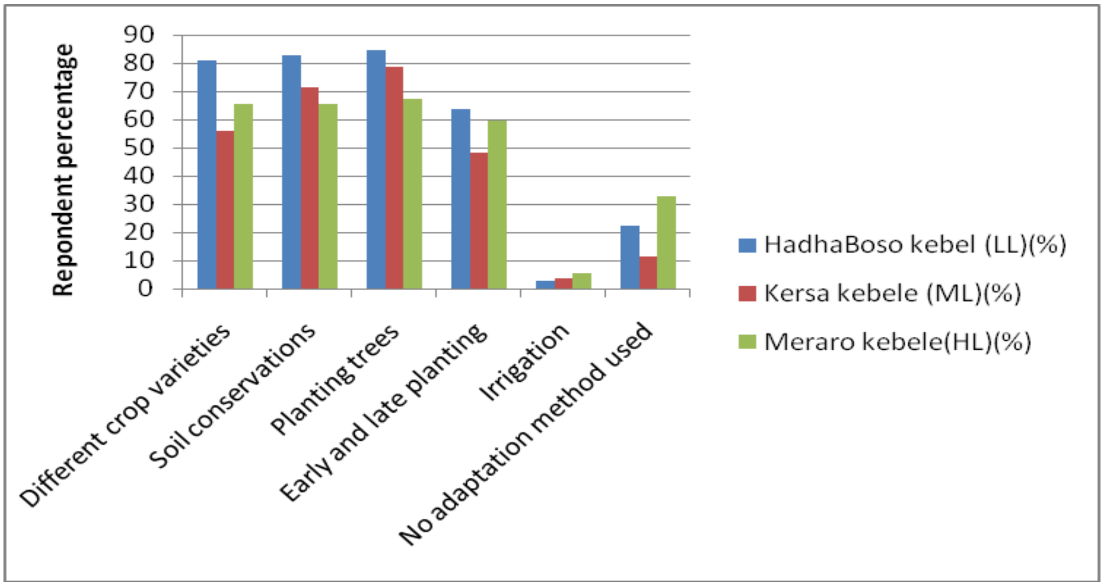


Figure 4.14: Adaptation methods in the study site

As shown in figure-4.14, most of the farmers did at least something in response to climate changes. This indicated that they are aware of the changing climatic conditions. Some farmers did not use any adaptation option. For example, 22.41%, 11.54, and 32.81% of Hadaboso, Kersa and Meraro kebeles respondents were not used any adaptation option for a number of reasons (see fig-4.15). From fig.14 one can see that the adaptation strategy in the three kebeles is most commonly used plant trees (in the three kebeles about 84.48%, 78.85%and 67.19% respectively). Other adaptation strategies farmers were used soil conservation techniques (82.76%, 71.15%, and 65.63%), using different crop varieties (81.03%, 55.77%, and 65.63%), early and late planting (63.79%, 48.08%, and 59.38%) and irrigation (2.86%3.85%, 5.44 %,) of Hadaboso, Kersa and Meraro kebeles farmers used respectively.

The various adaptation strategies being used by farmers in response to changing climatic variations in high land and the low land areas of the kebeles were as follows. In the lowland (Kolla) kebeles are more vulnerable to climate variability and change due to water stressed and also constraints related with alternative livelihood engagements aggravate the problem and limits their adaptive capacity. As a result the following coping strategies have been used by the community. If the drought period is short, they usually try to cope using various mechanisms being in their localities such as late and early planting, using crop diversification and sometimes irrigation and however, if the drought continues, short-term movement to the highland areas is common. Besides human population increment that cause shortage of grazing land, production of livestock per household in drought period is reducing. So, storage of crop residues (maize straw) as an emergency feed for drought periods was common practices in the area.

In addition, reserving some crops until the coming season, crop diversification, and using short rotation crop varieties were some of adaptation mechanisms in the study area.In highland area, farmers have used various coping strategies; some of those are as follows. Adopting of fruit trees, soil and water conservation practices, practice of using crop residues as livestock feed, community level forest conservation and management, using Enset crops for both source of food and feed were some of the coping strategies being used by highland farmer.

Analyzing adaptations made by all respondents revealed that an integrated farming system was considered to be one of the most important adaptations in response to climatic variability. This greater use of planting trees is mainly attributed to provide natural shades for their livestock when the temperature is hot. Soil conservation techniques may be attributed to avoid the risk of flooding. The use of different crop varieties as an adaptation method could be associated with the lower expense and ease of access by farmers. The use of early and late planting adaptation strategies by farmers depending on adequate information service to ensure that farmers receive up to date information about rainfall and temperature varaibilities. The limited use of irrigation could be attributed to the need for more capital and low potential for irrigation or lack of access to water. However, most of the farmers did not have any of these adaptation strategies mainly because of money constraint, information, supervision and technologies.

The decision makers should integrate the strategies actually adopted by farmers to help in the improvement of agriculture. The development of research to create new varieties adapted to climate context should be given a high priority attention. Given the high percentage of households without any adaptation, the government should develop a strong system for the provision of information and sensitization of farmers to show them the importance of having strategies for adaptation to climate change (Molla, 2009).

Major constraints of climate change adaptation in the study area

Summary statistics indicate that there are main constraints to adaptation that are identified by the respondents of Hada Boso, Kersa and Meraro kebeles. These are lack of information (72.41%,69.23% and 64.06%), lack of money(81.03%,80.77%,and 45.31%), shortage of labor (25.86%,26.92%,and 31.25%), shortage of land (20.69%,36.54,and 42.19) and poor potential for irrigations (27.59%,40.38,34%and 38%) while 22.41%13.46% and 28.13% did not constrained to adaptation of climate change respectively. Figure-4.14 shown that the major constraints to adaptation perceived by farmers in the study site.

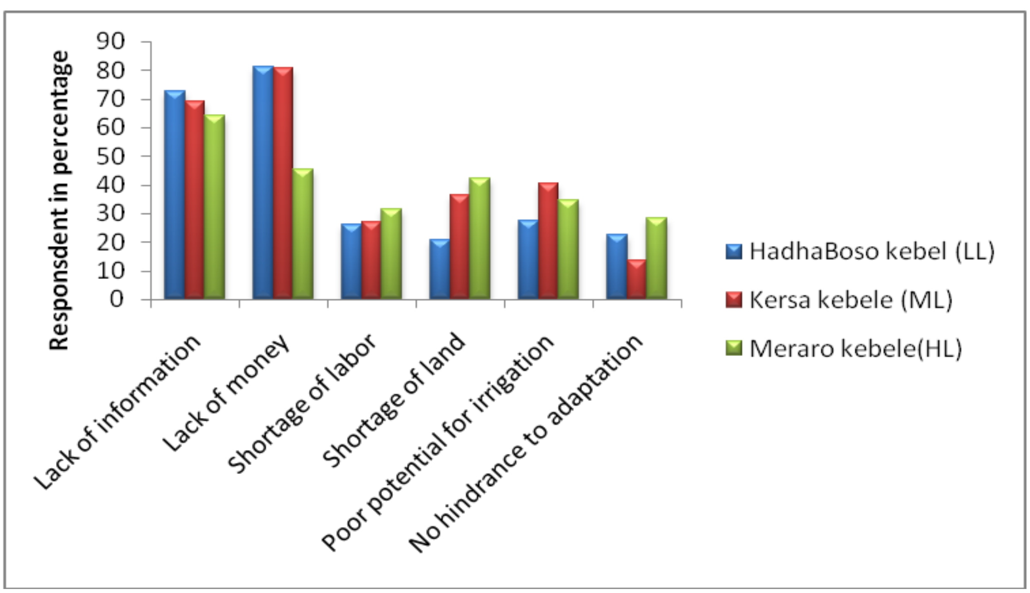


Figure4. 15: Constraints to farm-level adaptations

Most of these constraints shown in the figure-4.15 were associated with poverty. Lack of information on appropriate adaptation options could be attributed to scarcity of study gape on climate change and adaptation options. Lack of money hinders farmers from getting the necessary agricultural inputs and technologies that facilitates adapting to climate change. If farmers do not have sufficient family labor or financial means to employ labor, they cannot adapt. This is true because adaptation to climate change needs some financial and technological supports. Shortage of land has been associated with high population pressure, which forces farmers to intensively farm a small plot of land. Poor irrigation potential is most likely associated with the inability of farmers to use the water that is already there due to technological incapability. The reasons of farmers not did the farm level adaptations options illustrated in figure-4.15. Lack of awareness about climate change is the major constraints.

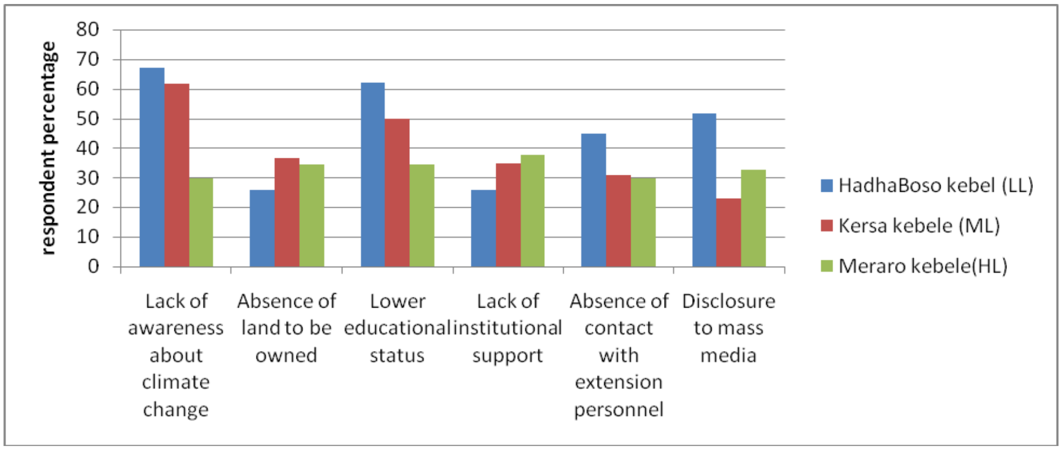


Figure 4.16: Barriers to adaptations identified by local farmers

Major effects of climate change on agriculture in Arsi Negele

From the figure-4.17 below, one can see that the summary statistics of the effect of climate change on agricultural practices in the three study kebeles based on the household interviewed results.

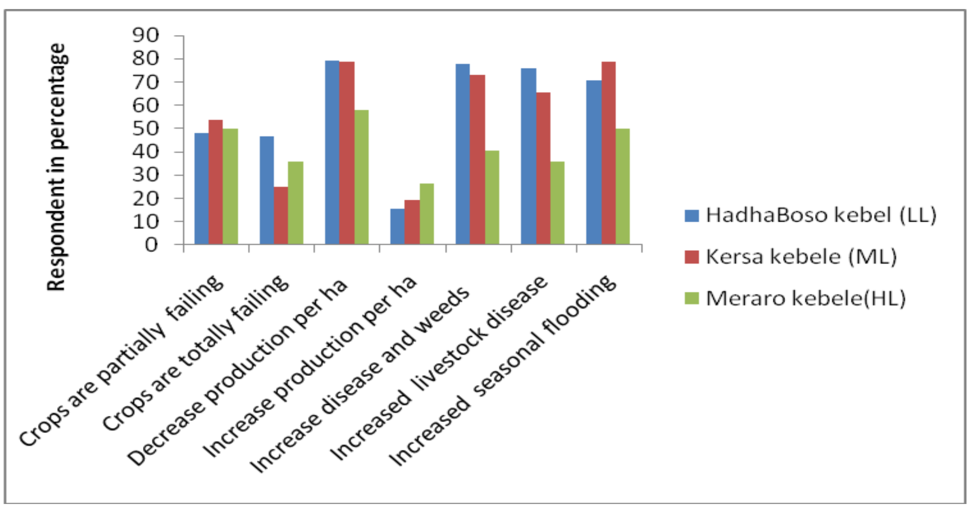


Figure4. 17: Major effects of climate change on agricultural production in study area

According to figure-4.17, the various effects faced by farmers due to climatic change are presented. For example, respondents, 48.28% lowlands 53.85% of mid land and 50.00% in highlands were answered that crops were sometimes failing.

On average 46.55% of low land 25.00 % of mid land and 35.94% highland faced crops are totally failing, on average 79.31 %of lowland 78.85%of mid land 57.81%of high land responded that due to climate change, production per hectare is decreasing. As interviewed farmers claimed that there were reductions of crop yields because due to changes in rainfall temperature patterns. From the interviewed households as indicated in figure-4.17, the 15.52% 19.23% and 26.56% of respondents from low land, mid land and highland respectively answered production per ha is increasing. Thisi might be because of using different adaptation mechanizes that can increase their production against temperature and rainfall variation.

Conclusion and Recommendation

Conclusion

This study investigated the degree of observed climate variability, downscaled future projection, as well as marginal effects of temperature and rainfall on crop productivity. It also assessed farmers' perception and adaptations mechanisms employed by farmers in response to climate variability in Arsi Negele district.

The results obtained from analysis of meteorological data indicated that there has been considerable variability in climatic elements both in Arsi Negle and Langano stations. The rate of change of maximum and minimum temperature found to vary in both stations and minimum temperature variability increased more than maximum temperature does. On the other hand, rainfall found to be more variable in Langano station than in Arsi Negele station.

The future climate scenario analysis indicates that the magnitude and variability of both maximum and minimum temperatures will increase more than the rainfall in both stations. With regard to rainfall projection at Arsi Negele station, rainfall in the main rainy season will be decreasing meanwhile, it will be relatively increasing in the short rainy season. Whereas at Langano station, the future simulated rainfall amount during the main and short rainy seasons will decrease meanwhile the autumn rainfall will increase relatively. However, in July both Arsi Negele and Langano stations will have high precipitation as compared to other months of the year.

The estimated results indicated that climatic variables mainly temperature and precipitation are very relevant for agricultural activities, and to some extent, climate impact also found to have non-linear relationship with net revenue. Climatic variables, especially temperature and precipitation, are useful to crop production but turning out to be negative beyond a certain limit. The estimated results obtained from analysis of marginal effect indicated that there is significant effect of climate change on the magnitude and fluctuation of crop productivity. Interpretations of results obtained from this study indicate that increasing temperature and decreasing rainfall generally have negative impact on crop productivity. However, at local level, some farmers experienced positive effects from increased precipitation while others experienced negative effects as results from interviewing farmers suggested. This is a reflection of the unclear impact of change in precipitation on crop activities in the area. It is also a reflection of the high degree of variability of the rainfall experienced in the recent past.

The socio-economic and/or adaptation related variables in controlling climate effects play a crucial role for the betterment of agricultural practices. The size of cropland area is an important factor, especially for large family size households, since a larger area enable them to spread their risk from adverse climate effects and thereby to reduce the net effects from the change. Larger cropland area may provide better opportunities for efficient use of resources and the possibility of growing different crop types. Livestock rearing was also found to be a possible adaptation option especially in dry areas. Livestock farming is better practice in response to adverse climate effects because in most cases they have limited alternatives. Easy accessibility of markets relatively helps farmers get higher prices for their products. This helps them to cover additional costs caused by the adverse effects of climate change. Accesses to extension and credit services have positively influenced farming activities.

The study also assessed farmers' perceptions of climate change and the extent to which these perceptions have influenced their current practices with respect to adapting with changes in temperature and precipitation. Most of the interviewed farmers for the studied kebeles perceived that they have observed the changing temperature and precipitation, such as reduced amount of rainfall (59.7%), increasing temperature (60%), shift in the timing of rainfall and shortened period of raining days.

They also stated that these changes have been affecting their farming activities. Given this perception and depending on the farming system, farmers have practiced several adaptation mechanisms.

Recommendation

- On the basis of this study, the following recommendations have been drawn to reduce the effect of climate variability within the study area:
- There is a need to support farmers' adaptation capacity and improving their crop production efficiency to overcome future scenarios of climate change impacts.
- Provision of training to farmers on various modern farming rearing becomes quite important. Proper and efficient extension services are also possible adaptation options. Hence, it is, therefore, important to revisit the extension services provided to farmers and improve their efficiency of crop production.
- High rate of deforestation is common in the study area. Therefore, due consideration should be given to afforestation, reforestation and maintenance of the remaining forest.
- Irrigation activities should be implemented in the plain areas where rivers can be used best, as this helps to overcome the hazards created on agricultural sector in the periods of rain shortage particularly in low land part of the district.
- There should be promotion activities to enhance farmers' participation on awareness creation activities as it is highly needed in the field of climate variation or weather forecast.
- Additional meteorological stations are needed to exactly record the climate variables and assist to determine any changes in long term climate variations with full confidence since the numbers of available climatic stations in the study area are few in number.
- The results in this study are based on general agricultural crops produced by farmers. Given that different crops have different climate requirements, future studies need to focus on specific crop responses and adaptations strategies.
- The full impact of climate change on crop production would be better assessed with time series climate data. Long term changes in agricultural production may better reflect the impact of long term climate change than one time estimates of production. So, continuous climate data collection and recording should be maintained.

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