Water

Ethiopian Journal of Water Science and Technology

Special Issue

Proceeding of the 14th Symposium on Sustainable Water Resources Development Held at Arba Minch University from June 27-28, 2014 Arba Minch

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Content

Editor's Foreword

Nature has provided us with the water, the most essential resources for our life and all-round development. However, with increasing population and unwise utilization of land and water resources, the water quality and quality is increasingly impacted. Climate change and variability is also becoming areas of concern in relation to water availability. These all call for considering the principles of sustainable development in water resources management and utilization. Sustainable development is the centerpiece and key to water resource quantity and quality. By acting under the principles of sustainable development, decision making to meet the demands of economic growth will take into account the ecological imperative to protect the environment and social equity imperative to create equal access to resources and minimize human distress. With increasing development needs, utilization of our resources including water resources becomes of top priority. Nevertheless, utilization of resources has to consider the principles of sustainability. Sustainable development is becoming increasingly on the top of development agenda.

Arba Minch University is organizing this annual symposium on "Sustainable Water Resources Development" for the last fourteen consecutive years. Organizing this symposium has started in 1996 with the objective to create a platform to enable researchers, academia, practitioners with the involvement of development partners in the water sector and policy-makers come together and present research findings and best practices, share ideas and experiences. The proceedings of the symposia have been published and distributed to shareholders free of charge. Although, the organization of this symposium has started with the support of GTZ, within the framework of the Project "Germen Support for Capacity Building of Arba Minch Water Technology Institute", Arba Minch University has managed to sustain this platform for the last one and half decade.

Series of symposia organized by Arba Minch University have been addressing challenges and opportunities of sustainable development of water resources. There are six broad thematic areas covered in this 14th cycle of the sysmposium. These are: Hydrology and Integrated Water Resources Management, Irrigation and Food Security, Water Supply and Sanitation, Renewable Energy, Sociopolitical Aspects of Water Resources and Emerging Challenges, Dam Safety and Reservoir Sedimentation.
This proceeding contains papers presented, discussed and reviewed during the symposiums. We believe the information contained in this proceeding are of paramount importance for readers' reference. We thank all contributors to this symposium.

Editors
Dr. Mekonen Ayana, Director, Water Resources Research Center
Zerihun Anbesa, Research Coordinator, Arba Minch Institute of Technology

Welcome Address

By Dr. Negash Wagesho, Scientific Director, Arba Minch Institute of Technology

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

On Behalf of Arba Minch Institute of Technology and myself as well I would like to welcome you all to this 14th symposium on Sustainable Water Resources Development hosted by Arba Minch University, Arba Minch Institute of Technology.

Arba Minch University has been organizing and hosting the sustainable water resources development symposium in series for the last fourteen years. Its contribution while sharing various scientific research outputs among researchers, academic communities and related stakeholders from home and abroad has been becoming manifold. The academic forum brings new and emerging scientific developments to the attention of the wider scientific community supporting the academia. Moreover, it addresses some of the key problems associated to water and environment while maintaining sustainable utilization of available resources without degrading the physical environment. The Sustainable Water resources Development symposium remain unique in its kind at national level and given top priority by the University and its close partners over the last decade plus years while ensuring academic and research excellence in water resources engineering sector. This has been testified from the vast majority of high caliber research papers contributed every year. The current series of symposium is supported/ sponsored by Federal Water Works Design and Supervision Enterprise, German Agro Action and Southern Regional Design, Construction & Supervision Enterprise. **Our two-days symposium is focusing on the following Six thematic areas**

- Hydrology and Integrated Water Resources
- Irrigation and Food Security
- Water Supply and Sanitation
- Renewable Energy
- Socio-Political aspects and emerging challenges
- Dam Safety and reservoir operation

With this brief introduction I would like to invite Dr. Agena Angulo, Vice President for Academic Affairs, to deliver opening speech.

Thank you.

Opening Speech

Dr Agena Angulo, Arba Minch University Vice President for Academic Affairs

Dear Workshop Participants
Ladies and Gentlemen,

It gives me a great pleasure to deliver an opening speech for this important event "14th Symposium on Sustainable Water Resources Development.

Water is a source of life upon which all lives depend and is the most valuable resources. The importance of water cannot stressed enough. Globally, there is plenty of water but only limited amount is available for use. The availability and accessibility of this vital natural resource is further treated by lack of technical and economic capability to harness the available water in some regions and scarcity and quality constraints in other regions. Ethiopia belongs to regions where lack of technical and economic capabilities is limiting the development of water resources.

Ladies and Gentlemen,

Today almost half of the world population is still going through a great hardship because of water related problems. In particular, in the horn of Africa millions of people have been severely affected by recurrent floods and droughts. As one of the poorest country, Ethiopia is the most vulnerable countries to such extreme hydrological events. Millions of people are still facing food insecurity, making food security a primary objective for the nation. The largest proportion of the population relies on agriculture for their livelihoods, and increasing droughts and flooding are causing major rural crises. In particular, droughts in 2003, 2009, and 2011 showed once again how vulnerable the population is.

Ethiopia's agricultural system is primarily rain-fed, but parts of the country are prone to droughts and flooding. Our capacity to project the severity and frequency of drought and flood events is low. According to predictions of the climate experts, it is likely that, in the coming future, we will be faced with an increasing number of floods and droughts. It is in addition expected that climate change will have an effect on the water cycle and biodiversity.

To tackle these challenges, Ethiopia has been implementing the principles of "grow green" as described in its strategy for climate resilient green economy. The goal of this strategy is to quickly improve the living conditions of our people by reaching a middle-income status by 2025 based on carbon-neutral growth. With huge untapped resources potential like water, we have good prospects to grow. According to its climate resilient green economy strategy, Ethiopia is planning to develop the green economy based on four pillars:

1. Improving crop and livestock production practices to increase food yields, hence food security and farmer income, while reducing emissions
2. Protecting and re-establishing forests for their economic and ecosystem services, including services as carbon stocks
3. Expanding electric power generation from renewable sources of energy fivefold over the next five years for markets at home and in neighboring countries
4. Leapfrogging to modern and energy-efficient technologies in transport, industry, and buildings.

This strategy is designed to address both climate change adaptation and mitigation objectives. As underlined by our late Prime Minister Meles Zenawi " green growth is a necessity as well as an opportunity to be seized. It is an opportunity to realize our country's huge potential in renewable energy and a necessity so as to arrest agro-ecological degradation that threatens to trap millions of our citizens in poverty".

Ethiopia has huge natural resources to generate all the clean energy it needs and to decouple its economy from the fluctuating prices and unsustainable nature of the oil-based economy. Our country is well positioned and moving fast to contribute to developing a green global economy.

The implementation of mega development projects such as Ethiopian Grand Renaissance Dam and many others implemented and planned hydro-electric power plants as well as nationwide afforestation activities are signifying our commitment to green growth.

There are also many other water centered development projects in the pipeline like large-scale sugar estate irrigation projects that will have significant contribution not only to the national economy but also create employment opportunities for ten-thousands of people.

Large-scale projects are created with huge investment and hence they are expected to operate over several years. However, with the current land use practices which is characterized by increased deforestation, overgrazing, over-cultivation and so on as well as the resulting land degradation and soil erosion, the useful life of many projects will be treated.

In many areas, we are facing silting-up of water storage structures like dams and reservoirs as well as irrigation canals. There are watershed development endeavors here and there throughout the country in the form of soil and water conservation activities. Managing water is about managing land and its uses. Therefore, there is a need for integrated development and management of resources to sustain the positive impacts of our projects.

Ladies and Gentlemen,

Our country is making enormous progress in capacity building through education, training and technology transfer. Lack of capacity has been hindering the country from utilization of its resources. Now this history is in the course of change. We are launching several projects useful for generation by own capacity in all sectors. Universities have crucial role in this arena. They represent center of knowledge and technology vital for economic development the country. The barrier between university and industry need to be removed. Research results and technologies generated by universities need to reach end-users and translated to development.

Arba Minch University has been organizing such symposium for last 14 years. Sustaining this event over these years shows how the university is committed to create platform for sharing experiences and research results among professionals in the water and related sectors.

I am aware that several research papers addressing various areas of water resources management are selected and ready for oral and poster presentation. I hope, these research results and professions gathered here will provide an opportunity for sharing ideas and experiences in water resources management.

Ladies and Gentlemen,

Finally, I would like to thank the financial contribution of Water Works Design and Supervision Enterprise, German Agro Action and South Design, Construction Supervision Enterprise.

I thank also the organizing committee of this symposium who has worked hard to make this important event a reality.

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

Thank You.

Closing Remarks

Dr. Feleke Woldeyes, Arba Minch University President

Dear Speakers,

Invited guests,

Symposium participants

Ladies and Gentlemen,

Water is crucially needed in all aspects of Human life. Ethiopia is characterized as a country with huge physical water resources. However, it is constrained by economic and technical water scarcity. As a result the country could not utilize its natural resources for socio-economic development of its nation. While some regions of the country are suffering from recurrent droughts other parts are affected by flood. Rain-fed based economy of the country is highly vulnerable to climate variability.

Lack of capacity has been considered as one of the major bottlenecks for our inability to use our natural resources. In recent years the country is committing huge investment in capacity building. We can already see the fruits of these endeavors. The facts that the country is implementing several projects by its own capacity are evidences for this. The role of water in all development sectors is crucial. This is why efficient utilization of water of water is given due attention in all of our development strategies. The commitment of the country to build climate resilient green economy is one of such strategies. Ethiopian Grand Renaissance Dam is part of the implementation of this "grow green" strategy.

We have stated to develop our natural resources in an environmental friendly and emission neutral way. These are just encouraging starts and by no means reason for satisfaction. Still our water supply and sanitation coverage is low (with lots of schemes malfunctioning). Irrigation and hydropower development is also low. Watershed degradation, soil erosion and declining of soil fertility are threatening agricultural production and hence food security. Apart from agriculture, other water use sectors such as industries and municipality are growing. All these suggest that there is a need for integrated and sustainable development and management of our resources.

Universities, as center of creation and incubation of knowledge and technology are expected to aggressively contribute to these development endeavors of the country. We need to develop culture of sharing ideas, knowledge and experiences.

Arba Minch University has been organizing such symposium on Sustainable Water Resources Development for the last consecutive 14 years. The objectives, as you can see on the publications, is to create a platform for researchers, professionals from wider ranges of disciplines such as water resources, energy, environment, agriculture, and climate change as well as practitioners, decision-makers and development agents to come together and share experiences and knowledge by presenting papers, displaying products and technologies that address sustainable water resources management and development.

Ladies and Gentlemen,

I am informed that during these two days, a total of 23 papers (19 as oral presentation and 4 as poster presentations) were communicated and discussed. I hope this platform has provided you an opportunity to come together and share ideas, experiences and knowledge. After passing through reviews, the papers are published and distributed for wider use.

Finally, I would like to thank the financial contribution of Water Works Design and Supervision Enterprise, German Agro Action and South Design, Construction Supervision Enterprise. I appreciate also the organizing committee of this symposium who has worked hard to make this important event a reality.

Now I declare that the 14th Symposium on Sustainable Water Resources Development is officially close.

Wish you safe journey back home.

Thank you .

Panel Presentation

Major Challenges and Prospects for Sustainable Water Resources Development in Ethiopia

Professor Tenalem Ayenew, School of Earth Sciences, Addis Ababa University

Presentation outline

- General Issues
- Overview of Ethiopia's Water Resources
- Status of Water Resources Utilization in Ethiopia
- Major Challenges for Sustainable Development
- Prospects and Development trends
- Conclusions

General

- Water Resources: Surface water (lakes,, rivers) and groundwater (baseflows, water from wells and springs)
- Water Uses (Utilization) – Community water supply, industrial, irrigation, energy generation, navigation, beautification and as hosts for biological resources
- Sustainability – The quality of not being harmful to the Environment or depleting natural resources, and thereby supporting long-term ecological balance
- Challenges for Sustainable Utilization - comes from man-made and natural factors

Overview of Ethiopia's Water Resources

- Ethiopia is considered by many as the water tower of Northeast Africa
- Ethiopia has enormous water resources potential (lakes, rivers, groundwater) – However, it is unevenly distributed, with water quality challenges and complex geology
- It has many large untapped rivers draining to neighboring countrives (over 110 billon m^3 annual flow)
- Little known large groundwater potential (2.5 – 35 billion m^3)

Water uses in Ethiopia

- Ethiopia has economic water scarcity but not physical water scarcity
- Water resources development in Ethiopia is at its infancy. However there is encrouging development trends in some sectors
- Groundwater is the most important water supply source for community (both urban and rural)
- Except the most notable example of the Awash basin irrigation system there are no large commercial farms using irrigation system
- The water supply coverage is rapidly increasing (recent figure for rural areas reach 70% and for urban >90%)
- Industrial water use is also extremely low (mostly extracted from groundwater)

Major challenges (man made)

- Uncontrolled pumping of lakes (Abiyata, Haromaya, Afdera)
- Potential environmental changes of some lakes and rivers (eg. Tana, Abaya, Akaki, Meki etc.)
- Groundwater mining (Akaki well field and Aynalem well fields)
- Erosion and sedimentation (siltation of lakes and reservoirs)
- Uncontrolled release of water in irrigation fields and expansion of lakes and infrastructural damages
- Salinization of irrigation fields
- Pollution of lakes and rivers

- Pollution of lakes (agricultural and industrial)
- Inappropriate workmanship in water resources development projects
- Poor quality construction materials
- Limited capacity in operation and maintenance
- Limited capacity in monitoring systems (especially groundwater)
- Limited private sector involvement

Major challenges (natural?)

- Climate change (Extreme events)
- Poor water quality (fluoride, salinity, temperature, heavy metals, iron, etc.)
- Complexity in geology and geomorphology
- Urbanization, industrialization and agrochemicals
- Ethiopia's geographic position (hydropolitics)
- Limited private sector involvement and corruption
-

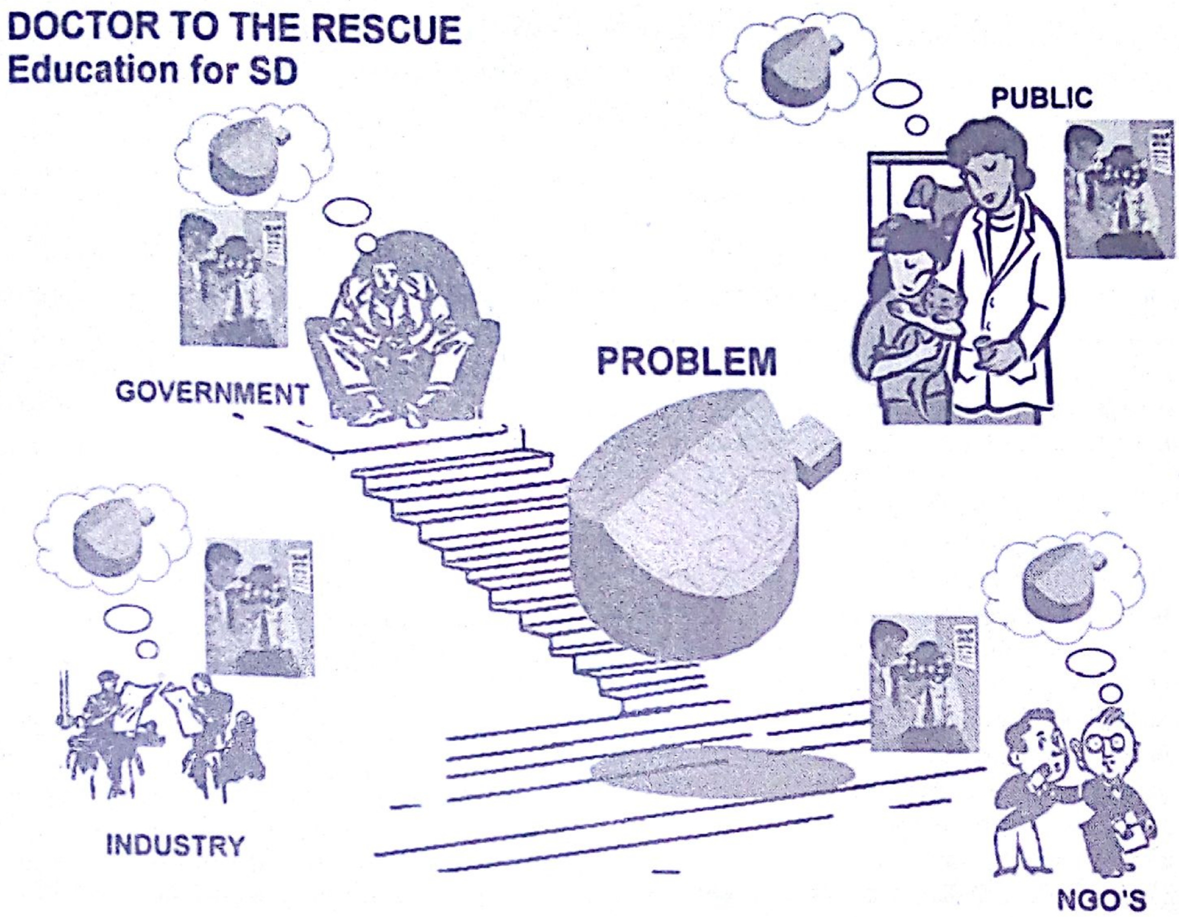
Encouraging development towards sustainable water resources development

- Policy and legal frameworks
- Construction of dams for hydropower (eg. GRD, Give 3, Tana-Beles, Tekeze)
- Large scale irrigation development (Kesem-Tendaho, Rib, Koga, Kuraz, Koga, Rib, etc.)
- Groundwater use for irrigation (eg. Raya-Kobo , Aysha-Dewole etc.)
- Better WASH coverage
- Growing capacity in groundwater drilling and delivery of construction materials
- Establishment of new RBOs
- National initiatives for large-scale soil and water conservation practices
- More trained man-power and establishment of national database and monitoring

Conclusions

- Water resources development and management in Ethiopia faces a number of problems which are aggravated by changes in climate change. Addressing this, requires an integrated approach
- IWRM is vital for sustainable water resources development. It links knowledge and understanding of the resource to the demand side of water resources development and management.
- Education and training (capacity building) along with increased private sector involvement in the water resources development activities are key issues
- Create effective system for collecting, storing and transmitting hydrological and hydrogeological data. This leads knowledge –based decisions
- A concreted effort has to be made to understand in detail the available water resources (mainly groundwater). But ultimately we have to go from understanding to proper management.

Integration and Sustainability



The road to success is to know weaknesses!

Seasonally Varied Model (SVM) Used for the Optimal Operation of Cascade Hydropower Reservoirs

Tilahun Derib Asfaw
Water Works Design and Supervision Enterprise
Addis Ababa, Ethiopia

Abstract

Seasonally varied model (SVM) is developed to operate a cascading of four hydroelectric power reservoirs with the concept of refills and depletes ranking orders. The aim is to maximize the total annual power generation of the scheme. The critical period is divided into four seasons. A specific model was developed for each season according to the state of the reservoirs. Annual power generated using SVM was compared to the long-term historically average (HA) generated. The result showed that with the same annual volume of release, the power generation using the SVM has improved the HA generation by 2%. This is equivalent to an additional of 4.56 MW per day.

Keywords: *Cascading Reservoirs, Hydropower, Seasons, SVM*

1. Introduction

The real-world reservoir operation is complex [1], [2]. Moreover, the operation of cascading reservoirs are the most complex because of recapturing of flows [3]. Some of the main reasons that arises the complexity of reservoir operation are conflicts between objectives, stochastic nature of hydrological events, and dynamic nature of demands. Hence, optimal management and careful planning is necessary [4]. Rule curves are guidelines for long-term reservoir operation [5]. Different models and algorithms were developed to find reservoirs operation rules [6]. Dynamic programming neural-network simplex model to develop refill operation [7], an integrated rough set approach [8], and hedging rule [9], [10] were some of the methods employed. Researchers have developed and verified reservoir operation models using various optimization techniques.

This paper emphasizes the development of seasonally varied model (SVM), and it was applied on the operation of the four Perak cascading hydroelectric power reservoirs namely Temenggor, Bersia, Kenering and Chenderoh from upstream to downstream respectively, which are located in the state of Perak of Malaysia. The objective was to maximize the total annual hydroelectric power generated from the cascading scheme. The model is developed with the concepts of refills and depletes ranking orders of the reservoirs. In addition, the critical period (CP) is classified into various seasons according to the state of the reservoirs. CP is the longest time over which a full reservoir goes to empty and to full again [11]. The length of operational period was equivalent to the length of CP. To study the CP, the long-term historical data of the headrace level variation of the most upstream reservoir, i.e. Temenggor was used since the inflow of the other three downstream reservoirs mainly relied on the release of the preceding reservoir.

2.. Background

Perak cascading reservoirs were located in the state of Perak of Peninsular Malaysia. The reservoirs were constructed along the Perak River; it is the second longest river in Peninsular Malaysia. Along the river Temengor, Bersia, Kenering and Chendroh reservoirs were constructed in cascade from upstream to downstream respectively. The distance between Temenggor to Bersia is 19 km, Bersia to Kenering is 51 km and Kenering to Chenderoh is 48 km. The main purposes of the reservoirs are to generate hydroelectric power and to mitigate flood. The total cascading potential is 578 MW; it constitutes about 27.7% of the total country's hydroelectric power developed up to the year 2008 [12]. The entire four reservoirs had different generation and storage capacity. The largest storage and generation capacity plant is Temenggor. Its storage capacity is 6050 Mm3 with a generation potential of 348 MW. The smallest storage capacity among the cascading scheme is Bersia, 70 Mm3 and smallest generation capacity plant is Chenderoh, 38 MW. The largest storage capacity in the system is hundred times that of the smallest (Bersia).

The largest power plant generation capacity is about nine times the smallest (Chenderoh).

3. Methods

3.1. Development of SVM

The general statistical tests were conducted to analyze the overview of the long-term historical data of Perak cascading reservoirs operation. Fig. 1 shows the flowchart used to develop SVM. The missing data were filled with various techniques. Specifically the missing rainfall data were filled with inverse weighting method. Moreover, z-score, box-plot and eyeball methods were used to detect and to correct outliers' data. Twenty years (1991-2010) daily data of the headrace level variation of Temenggor reservoir was used. It showed four distinct states of the reservoirs. The first state was a continuous refill of the reservoir. After reaching at a relatively peak level, the second state stayed at peak level for a certain period. The third state was depletion. When the reservoir reached at minimum operation level, it was maintained at that level for a certain period until refill starts. This period was referred to a fourth state of the reservoirs. Accordingly each state is known as a season. The seasons are termed as; the refill season (RS), followed by upper level operating season (ULOS), the third is deplete season (DS) and the last is lower level operating season (LLOS). All seasons repeat themselves once per year in the order of RS – ULOS – DS – LLOS.

RS and DS require ranking order to optimize and to manage the inflow volume. The refill ranking was made with the consideration to enhance the total annual energy storage in the reservoirs and to minimize the expected volume of spill. The refill ranking order of the four Perak cascading reservoirs was developed using the concept found from Jain and Singh [13]. The ranking was accomplished by considering of the reservoirs storage capacities and the sensitivity of power production to the change of storage volume (that affects the headrace level of the reservoir). The change of headrace per storage was determined with the addition of a constant inflow volume to the reservoir. In addition, the headrace level was computed from the stage-storage relationship curve. The refill began from the higher value of power production with storage volume, and followed by the next lower value. It was based on the descending orders of the value of unit change head per change in storage. Moreover, the depletion order was accomplished with the adjustment of the release rate. Hence, the question was which reservoir depletes first and in what order depletion can be accomplished? Deplete ranking order set the priority of the reservoirs level that to be lowered first. The aim of deplete ranking was to find the optimal effective headrace level during the period of low flow. With deplete ranking order; reservoirs enhance the capacity of recapturing of inflow within the operation period.

Deplete ranking was determined using storage effectiveness ratio (SER). SER was evaluated separately for each reservoir. Depletion of a reservoir was accomplished in order from the lowest to highest SER value.

3.2. Optimal power generation based on ranking order

The seasonal water balance of each reservoir was evaluated on weekly basis. The change in storage volume is equal the product of average of water surface area between the two elevations and the corresponding change in headrace level (1). The value of change of headrace level was positive during RS and negative for DS, while it was nearly zero during LLOS and ULOS. The change of headrace level with respect to time during a specific season was a predetermined value. The value depends on the length of the season and the range of operating head of the reservoir. A seasonal constant was introduced to analyze a small incremental of headrace level in a week. The seasonal constant was varied between negative one and positive one. Initially analysis was conducted with the assumption of the current rate of release less than the permissible maximum value. Equation (3) was used to compute the rate of the release based on the assumed condition. If the assumption is valid, the computed rate of release is the actual value. Otherwise, the alternative condition is used (2). The total seasonal power generated is the sum the entire power generated from each plant in the cascading system (4). Equation (5) was used to compute the average annual hydroelectric power generated, P. The result found from SVM was compared to the HA operated values. The performance of the model was presented in accordance of the comparative results.

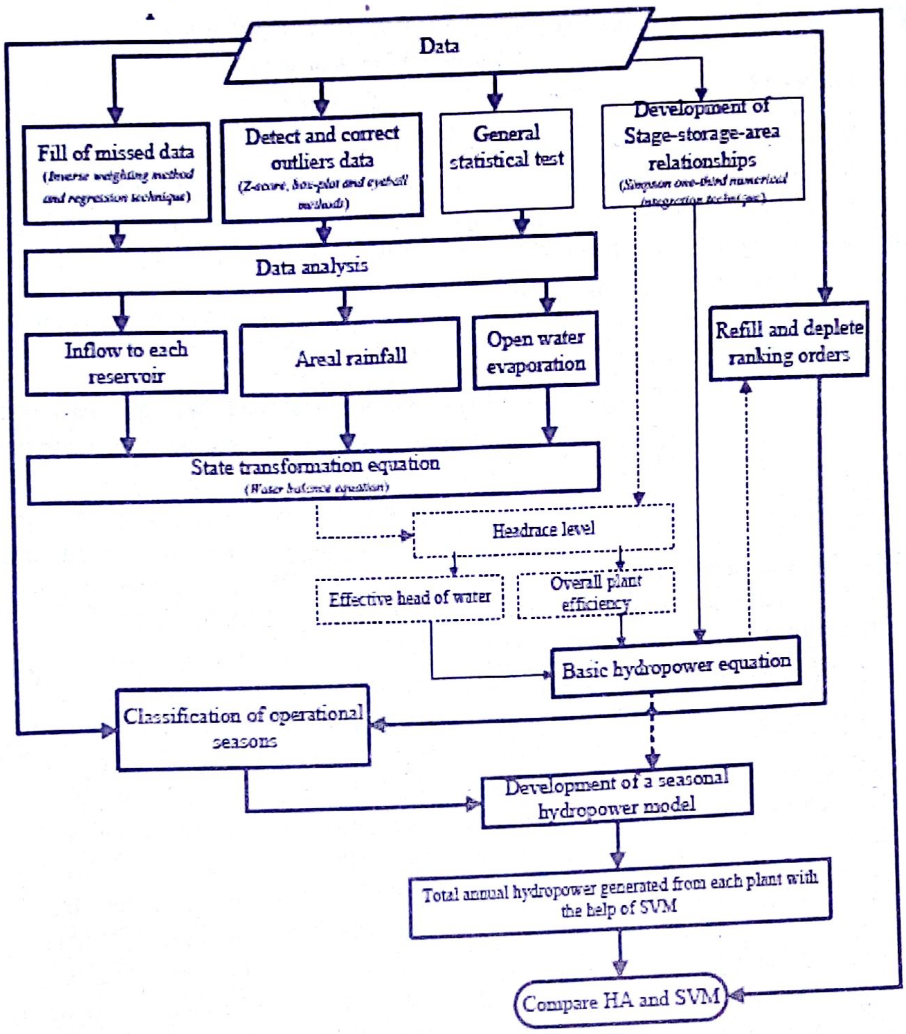


Figure 1: Flowchart of SVM

$$S_{it} - S_{i(t-1)} = \left(\frac{A_{it} + A_{i(t-1)}}{2}\right)\left(h_{it} - h_{i(t-1)}\right) \tag{1}$$

$$= k_1 \Delta t \left(I_{it} - R_{it}\right) + k_2 \Delta t \left(F_{Rit} - E_{it}\right)\left(\frac{A_{it} + A_{i(t-1)}}{2}\right)$$

$$C_{it} = h_{it} - h_{i(t-1)} = \begin{cases} w_{ij}\Delta h_{i\max} & \text{if } R_{it} \le R_{i\max} \\ w_{ij}\Delta h_{i\max} + 2\Delta t\left(\dfrac{R_{it} - R_{i\max}}{A_{it} + A_{i(t-1)}}\right) & \text{if } R_{it} > R_{i\max} \end{cases} \tag{2}$$

$$R_{it} = \begin{cases} I_{it} - C_{it}\left(\dfrac{A_{it} + A_{i(t-1)}}{2}\right) & \text{if } R_{i\min} \le R_{it} \le R_{i\max} \\ 0 & \text{if } R_{it} < R_{i\min} \end{cases} \tag{3}$$

$$P_{it} = \gamma \sum_{i=1}^{4} \sum_{t=1}^{q_i} \eta_i R_{it} \left(\left(\frac{h_{it} + h_{i(t-1)}}{2}\right) - h_{ri}\right) \tag{4}$$

$$P = \sum_{i=1}^{4} \sum_{t=1}^{52} P_{it} \tag{5}$$

Where S_{it}, A_{it}, h_{it}, I_{it}, R_{it} and P_{it} are the storage volume, the water surface areas, the stage, the rate of inflow, the rate of release and the power generated for reservoir i during the period of t respectively; w_{ij}, $\Delta h_{i,max}$, h_{ri}, η_i, $R_{i,min}$ and $R_{i,max}$ are the season constant, the difference between warning level and minimum operating level, the tailrace level, the overall plant efficiency, the minimum and the maximum rate of turbine release of reservoir i respectively during the season j; Δt and q_j are the time-step of analysis and the total length of the season j.

4. Results and Discussions

4.1. Optimal Strategy of the Seasonal Operation

The approach used for operating Perak cascading reservoirs based of seasonally varied model (SVM) has improved the annual average hydroelectric power generated. Fig. 2 shows the SVM rule curve for each reservoir. A relative stage (ordinate of Fig. 2) of zero indicates the minimum operating level, while value of one shows the warning level of the respecting reservoirs. The rule showed, Temenggor reservoir continuously depleting from February to August and the refill starts from the mid of September. Generally, the rule on Temenggor reservoir indicated that maintaining at higher level (above warning level) does not led to optimal condition. Moreover, the period that Temenggor reservoir stayed at LLOS was small. However, Bersia stayed the longest period at both ULOS and LLOS compared to any others reservoir.

4.2. Variation of Headrace Level and Release Rate

The headrace level and the rate of turbine release were found to be the governing parameters on hydroelectric power generation. Even though the sensitivity of both parameters depended on the stage-storage relationships of a reservoir, the increment of both values was of significant advantage to the power production. Fig. 3 and 4 show the variation of headrace level and the corresponding turbine release rate decision using SVM and HA respectively.

The result of headrace level using HA was over the corresponding of SVM in most periods of the operation. The rate of release using HA was varied between 100 and 250 m3/s, whereas for SVM between 50 to 250 m3/s. According to SVM, refill was accomplished with the reduction of the rate of release. However, for HA case the refill was practiced during high inflow period. From February to August, the results of SVM showed the rate of release for all reservoirs was above 150 m3/s; moreover, the headrace level was below the corresponding of HA during that period.

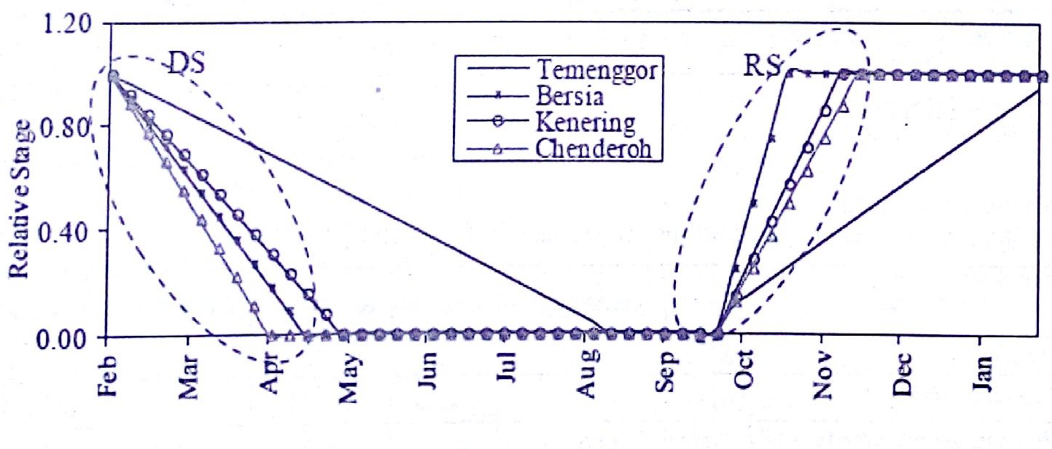


Figure 2: Reservoir rule curve using the concept of refill and deplete ranking orders

4.3. Hydroelectric Power Generated with SVM

SVM has improved the annual average hydroelectric power generated from the cascading system by 2%. This is equivalent to 4.56 MW per day. Table 1 illustrates the comparative results of hydroelectric power generated of SVM and HA. A higher improvement was found from Chenderoh plant, 13.77% (4.16 MW per day); while a reduction of 1.21% (0.69 MW per day) was observed at Kenering plant. The reason was due to the limitation of Chenderoh reservoir operation. In general, with the reduction of 0.69 MW per day of Kenering plant, the power generated from Chenderoh plant was boosted by 4.16 MW per day. Hence, SVM that was developed with the concept of refill and deplete ranking orders of the reservoirs apparently led to a better operation rule compared to HA.

The economic advantage of the additional hydroelectric was evaluated. With a transmission efficiency of 95%, the additional power is equal to 4.332 MW (103,968 kWh). the known electric utility company in Malaysia is 0.218 in Ringgit Malaysia (RM). This rate is for domestic consumption that utilizes up to 200 kWh per month only. Hence, the total benefit from the extra power generated using SVM is equal to RM 22,665 per day. The benefit indicated the gross income gained from the extra power generated. The design is conservative since it considered the minimum electric selling price of the utility.

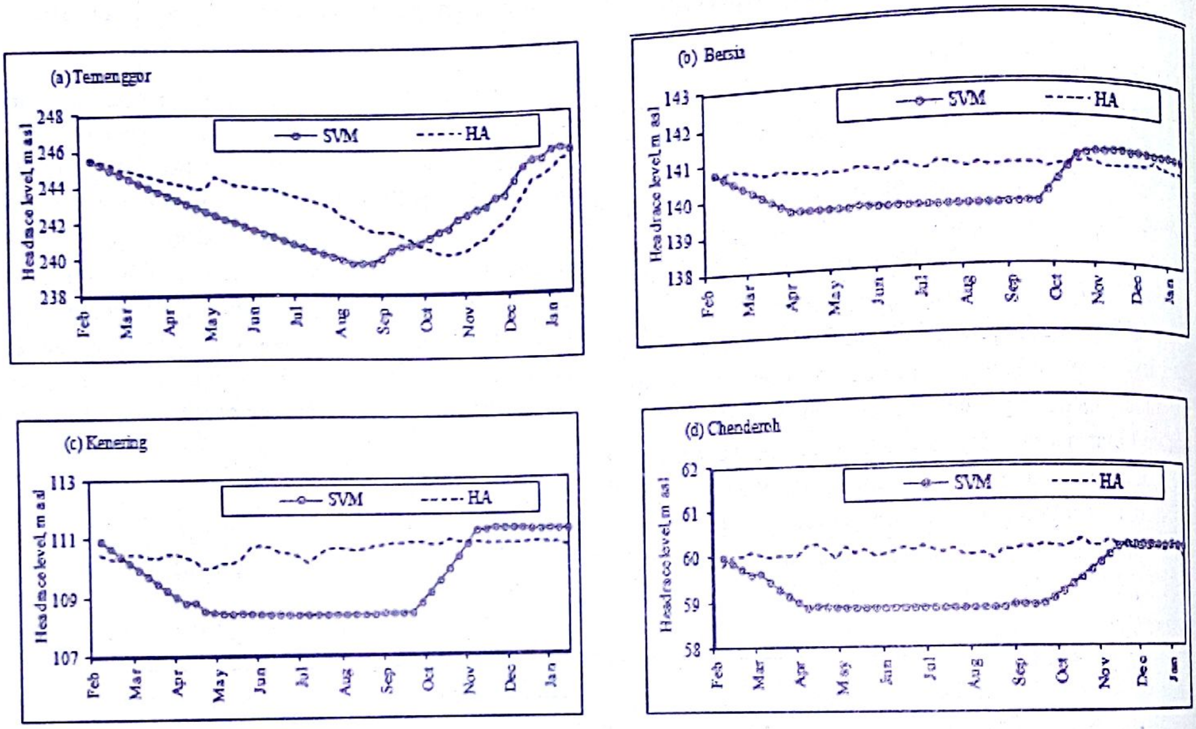


Figure 3: Variation of headrace level

Table 1: The comparative hydroelectric power generated using HA and SVM

Criteria	Unit	Temenggor	Bersia	Kenering	Chenderoh	Total
Potential = (a)	MW	348	72	120	38	578
HA generated = (b)	MW	109.57	31.39	56.90	30.21	228.07
SVM generated = (c)	MW	110.04	32.01	56.21	34.37	232.63
Power increment = (c-b)/b	%	0.43	1.98	-1.21	13.77	2.00
Plant Factor (HA) = b/a	%	31.49	43.60	47.42	79.50	39.46
Plant Factor (SVM) = c/a	%	31.62	44.46	46.84	90.45	40.25

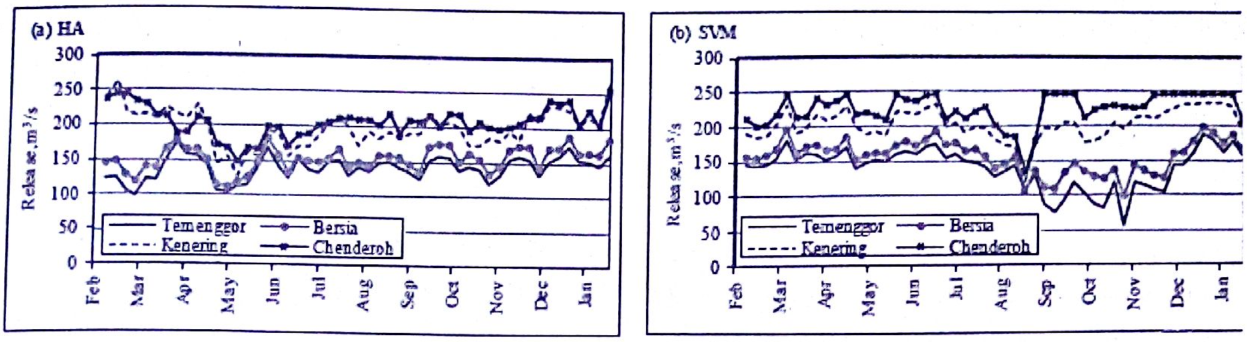


Figure 4: Release decision of SVM and HA

5. Conclusions

The length of each season directly influences the total annual power generated from the cascading scheme. Operation of reservoirs using seasonally varied model (SVM) requires the decision on the start and the end period of each season. The exact starts and ends period require the subjective judgment of the operator and the prevailing hydro-metrological conditions of the catchment area. The most important periods which highly influence the maximization of the total hydroelectric power generation from cascading plants were the refill season (RS) and the deplete season (DS); the reason was both seasons had a great impact on the effective head of water. Effective head of water was one of the major parameters in hydroelectric power generation. Generally, the change of headrace level with change of storage volume was higher for smaller reservoir. Moreover, the change of power generation with the change in storage volume was also high for smaller reservoir.

SVM has improved the total average annual power generation from Perak cascading plants. Table 1 indicates that, with the exception of Kenering plant, the power generated with SVM has generally improved. The main reason was due to the limitation of Chenderoh reservoir operation. According to the rule, the release from Kenering reservoir is not greater than the sum of maximum turbine release and available storage space of Chenderoh reservoir. If the available storage capacity of Chenderoh reservoir is small, then the release made from Kenering will be forced to reduce. The rule showed the release of preceding reservoir relied on the capacity of the succeeding reservoir.

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Shallow Groundwater Irrigation in Dangila Woreda of Amhara Region in Ethiopia: Situation Analysis

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Abstract

Shallow groundwater is a commonly preferred source of water by rural households as it provides individual access to water. It is less sensitive to climatic fluctuation and enables crop production in dry season. As a result, shallow groundwater use for household irrigation is an important strategy to alleviate poverty. Dangila is one of the woredas in Ethiopia with some experience of shallow groundwater use for household irrigation. However, distribution of the resource is uneven across the woreda. In 2013, the total number of hand dug wells in the rural kebeles was 2281 which suggests one well per 11 households on average. Depth of hand dug wells in Dangila varies between 6 and 23 meters. According to the plan of woreda agriculture office, each household should irrigate at least 0.125 ha of its backyard using a hand dug well. This plan, however, does not recognize that not all households are situated in shallow groundwater potential area. A critical concern is also whether the available groundwater can sustainably meet demands of various users such as domestic, livestock and environmental water demands. Currently, there are some individual households with up to eight wells in their backyard. This is an early indication that overexploitation is eminent unless the resource is allocated and managed wisely. Some of the concerns of shallow groundwater development in Dangila can be addressed by hydro-meteorological monitoring, resource assessment, introducing adaptive management tools and improved access to technology (well drilling, water lifting and water saving).

1. Background

Groundwater is a strategic resource to leverage poverty alleviation and economic growth. Smallholder groundwater irrigation (GWI) is seen as an important vehicle to promote (especially rural) poverty alleviation, food security (at various scales, from local to global), land and labor productivity, rural employment, general economic development and adaptation to increasing climate variability (Ngigi, 2009). Farmers prefer groundwater as it offers individual mode of access to users and flexible water application – readily available on demand. As a result, GWI users are involved in less conflict with other users of the resource. To utilize groundwater for irrigation, farmers do not necessarily need to have farmland close to a river. Compared with surface water sources, groundwater is less sensitive to effects of climate variability and change. It is known to be a reliable source of water in both dry and wet seasons. As a result, GWI helps to cope with current vulnerabilities of rain-fed agriculture and enhance adaptive capacity of smallholder farmers.

Promoting groundwater use for irrigation is a major part of the strategy of the government of Ethiopia to alleviate poverty and boost agricultural productivity. The Agricultural Transformation Agency (ATA) of Ethiopia projects that household irrigation technologies can lead to over 500,000 ha irrigated land (doubling existing irrigation); >650,000 farming households to become agricultural entrepreneurs, increase of family income and food security for almost 5 million Ethiopians; and addition of $600 million USD and 30,000 jobs to the national economy (www.ata.gov.et/). Development of shallow groundwater for household irrigation is crucial in this regard.

Villholth (2013) identifies Ethiopia as one of the promising countries in Sub-Saharan Africa with rapid current GWI development yet with untapped physical potential. Some parts of the country are already benefiting from shallow groundwater by new trees, plants, and cultivating of highly valued crops, improvement of the households feeding habits and generation of regular income; and introduction and adoption of water lifting technologies (Tadesse et al., 2008).For many parts of Ethiopia, however, access to technology is one of the major barriers of GWI development. For instance, groundwater lifting and crop watering requires considerable household labor and time since water is often hand lifted. This can affect the size of irrigated land and type of crops grown.

There are complex issues involved in the debate about the use of shallow groundwater for irrigation. Some countries already experienced intensive groundwater irrigation and its consequences. First of all, it is a "highly decentralized resource" as groundwater wells are often owned by individuals. Some refer to existing groundwater developments as "Silent Revolution". There is little planning and management of groundwater development. Impacts of poor management and planning of groundwater use include overexploitation, deterioration of water quality, and ecological impacts such as river reaches are converted from "gaining" reaches to "losing" reaches. Research on GWI in SSA more generally has remained fragmented, anecdotaland focused on certain geographic regions or topics (Villholth, 2013). Research on vulnerability of shallow groundwater is limited in Ethiopia. As a result, impacts of various pressures (climate change, land cover change and water abstraction) on the shallow groundwater resource are not known to the desired extent.

In this study, we assess the existing situation of shallow groundwater irrigation (SGI) in Dangila woreda. The situation is assessed based on field visits, key informant interviews and well inventories made by the woreda agriculture and water offices. This information was collected as part of Adaptive Management of Groundwater Resources for Small Scale Irrigation in Sub-Saharan Africa (AMGRAF) project which had lasted for one year in 2013/14. AMGRAF aimed at improving the evidence base on groundwater availability and management in Sub-Saharan Africa (SSA). Dangila was selected as a pilot area for AMGRAF as it is one of the Agricultural Growth Program (AGP) woredas as of Ethiopia and since there is some experience of shallow groundwater utilization.

2. Study area

The top-down administrative structure of Ethiopia follows Region-Zone-Woreda-Kebele respectively. Dangila is one of the woredas of the Awi Zone Administration of Amhara region. Dangila has 27 rural kebeles among which 16 kebeles have perennial access to river water. It is located at 36.847 degrees longitude, 11.254 degrees latitude and 2140 m.a.s.l. altitude. It is situated along the Addis Ababa-Bahir Dar road at a distance of about 80 km southwest of Bahir Dar town. There are three major towns along the road between Bahir Dar and Dangila. These towns are Merawi, Wotet Abbay and Durbete. The two nearest towns to Dangila on the road to Addis Ababa are Addis Kidam and Enjibara.

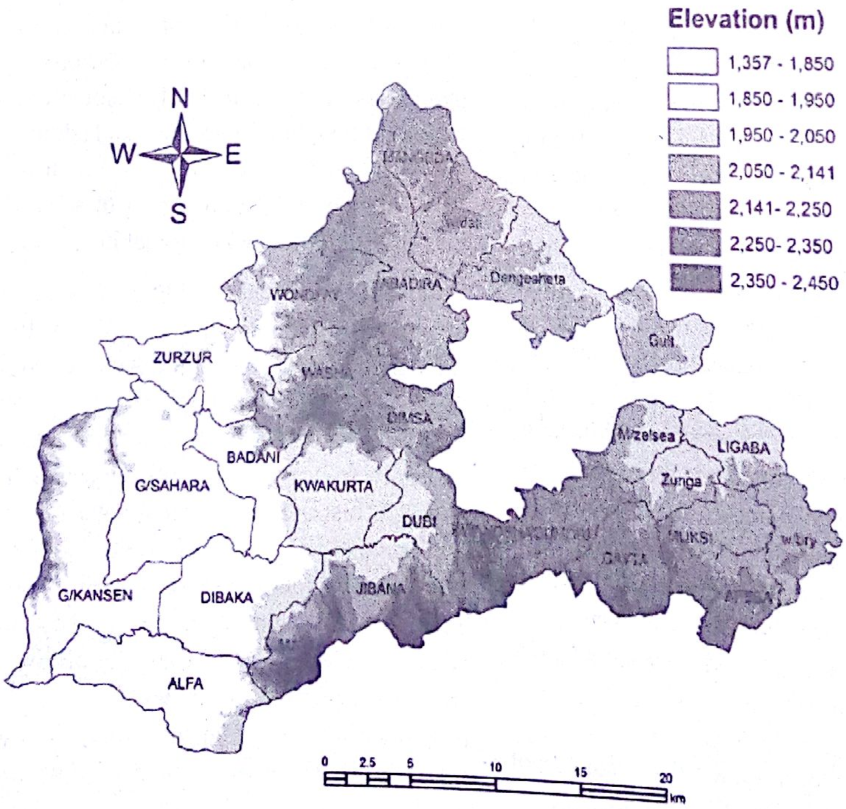

Figure 1: Administrative boundary of the rural kebeles of Dangila woreda

Dangila has a sub-tropical ("Woina Dega") climate. Daily minimum and maximum temperature show weak seasonal variation. The annual average of minimum, maximum and average daily temperature is 8.4, 24.3 and 16.4 degree Celsius respectively. Its annual rainfall amount is between 1400 – 1800 mm (Figure 1). Its terrain is undulating with lowest elevated areas situated in the western part.

The major geological outcrops in Dangila area are tertiary and quaternary volcanic rocks and alluvial deposit mainly along water courses. In some places, the alluvial deposits are thick enough to store water for household irrigation and domestic water supply. Different lineaments predominates Dangila and neighboring woredas. Linear features provide pathways for groundwater movements.

Reports of well drilling for the town water supply indicated outcrops of weathered and vesicular basalt along the river northeast of Dangila town, vesicular basalts on the flat lands, and vesicular and fractured basalts around 2 km north of the town.

3. Data

The situation analysis presented in this paper is presented based on a field work which was undertaken from September 15 to 20 of 2013. The purpose of the field visit was to identify villages ("kebeles") to pilot the AMGRAF project. The villages were identified through: (i) field assessment to investigate availability of shallow groundwater resource and experience of its use for irrigation and (ii) discussion with experts from the Dangila Agriculture and Water Bureaus. The experts have more than a decade working experience in the woreda and therefore have great knowledge of SGI in the study area.

A checklist that guided the discussion with stakeholders was prepared ahead of time. The experts of the Dangila Agriculture office and the research team revisited the checklist in order to add missing issues that were not initially included. The main information gathered based on the experts inputs included household characteristics; landholding; access to market; small scale irrigation experience; sources of irrigation water; use of water lifting and saving technologies; and groundwater well information. Annual or quarterly reports of the agriculture and water offices were also found helpful to complement the information provided by the experts.

The criteria that guided the selection of potential intervention kebeles included (i) access to market and road type as proxy to adoption of groundwater irrigation; (ii) experience with small scale irrigation and SGI; (iii) ease of digging wells; and (iii) shallow groundwater potential. These criteria were evaluated based on experts' knowledge of the study area. We also estimated terrain slope and wetness index of each kebele based on the Digital Elevation Model (DEM) of the study area which has a resolution of 90 m x 90 m. These two variables can serve as a proxy to shallow groundwater potential. The wetness index sets catchment area in relation to the slope gradient. The wetness index (w) is the natural logarithm of flow contributing area divided by tangent of terrain slope. It represents spatial distribution and zones of saturation or variable sources for runoff generation.

4. Shallow groundwater irrigation

The Amhara Regional State Bureau of Water Resource Development classifies groundwater wells into three classes based on depth of wells and the type of well drilling technology. These classes are (i) hand dug wells, (ii) shallow wells, and (iii) deep wells as presented in Table 1.

Hand dug wells have a depth of less than 25 m and often provide access to the unconfined aquifer. Shallow wells have a depth between 25 and 75 m. Excavation of these types of wells cannot be done by human labor and therefore requires hiring machinery. To our knowledge there are only three shallow wells in Dangila which are drilled in Gumederi, Afesa and Dubi kebeles.These shallow wells are used only for domestic water supply. In this study, the terms hand dug wells and shallow wells are used interchangeably with both referring to manually dug wells with depths less than 25m.

Table 1: Classification of groundwater wells as defined and used by the Amhara Regional State Bureau of Water Resource Development as of 2014

	Depth below ground surface (m)	Current Use	No. of Wells in Dangila woreda	Remark
Hand dug wells	< 25	Irrigation and Domestic water supply	2281	Well digging is by human labor
Shallow wells	25-75	Domestic water supply	3	Well drilling is by complicated and expensive drill rig under the supervision of the Water Bureau
Deep wells	>75	Domestic water supply	11 (includes non-functional)	Well drilling is by heavy machineries under the supervision of the Water Bureau who hires contractors for drilling

4.1. Terrain slope and wetness index

Topography data is the most readily available source of information that can be used to assess runoff generation and groundwater availability. For instance, terrain slope can affect runoff generation, groundwater recharge and discharge. Infiltration is generally low and runoff is high over steep terrain. This may result in low recharge and deep groundwater table. However, water table can be shallow in flat areas as a result of upward movement of groundwater in response to a shift from steep to flat terrain. There exists large slope variation across Dangila woreda suggesting spatial differences in shallow groundwater potential (Figure 2). The slope values range between 3.7% and 20.66%. Dengeshta and Zurzur have slightly steeper terrain (3-4%) while the slope of other Kebeles exceeds 4% with Jibana, Quakurta and Wondfay having >15%.

The Topographic Wetness Index (TWI) has become a popular and widely used way to infer information about the spatial distribution of wetness conditions (i.e. the position of shallow groundwater tables and soil moisture) (Grabs et al., 2009). TWI integrates flow contributing area and terrain slope which is used as a measure of subsurface lateral transmissivity. It is based on the assumption that groundwater table and movement are controlled by surface topography. High values of wetness index suggest high shallow groundwater potential (Figure 3). Dengeshta, W/Dati, Washa and Zurzur have the highest shallow groundwater potential as inferred from their high wetness index. However, Abadira, Jibana, Q/quakurta, Wondfay has the lowest potential.

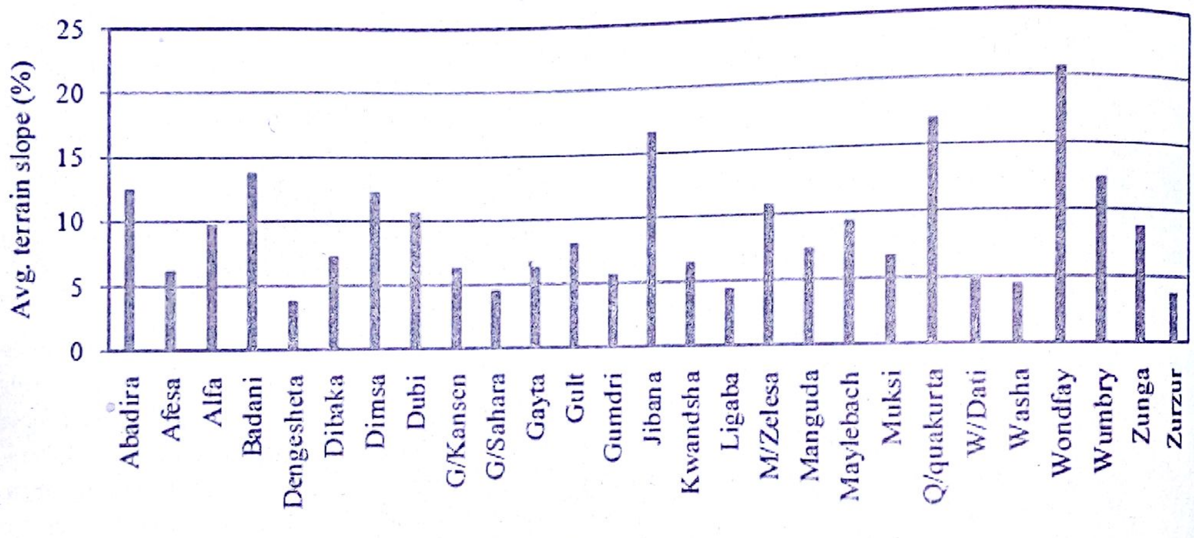

Figure 2: Average terrain slope of the rural kebeles in Dangila

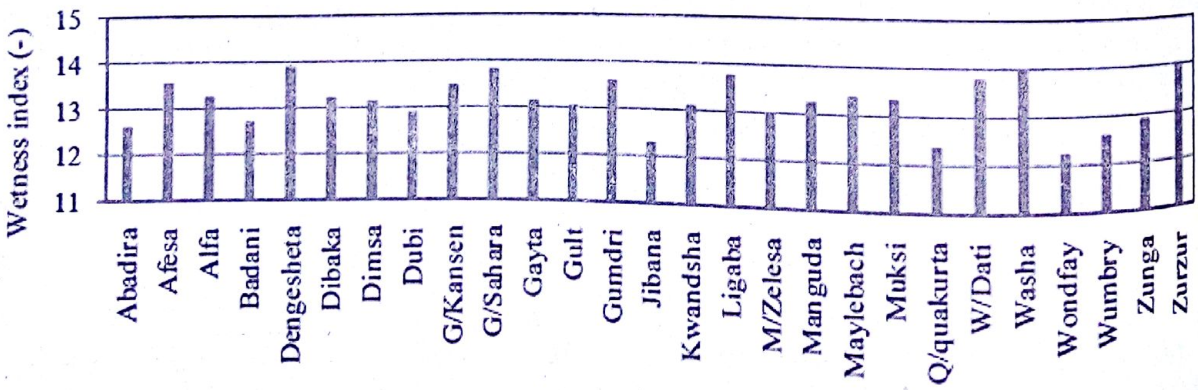

Figure 3. Wetness index of the kebeles in Dangila

4.2. Groundwater in Dangila woreda

In Dangila, groundwater occurs in both confined and unconfined aquifers which are separated by fresh basalts and clay layer. The highly weathered and fractured basalts are interconnected to allow groundwater movement and storage. Some deep well drillings for the town water supply indicated that sufficient groundwater is available at different depths. In 1987, for instance, the North Western Region Water Works Construction Office drilled a 120m deep well for the town's domestic water supply. Their finding indicates that there are productive aquifers at 9-15m, 60-67m, 108-116m depths which provided a total saturated thickness of 23 meters. The groundwater yield of the well was within the range of 1 to 6 liters per second. The groundwater quality in Dangila is considered the best for drinking as well as irrigation. However, further investigation is required.

Households in Dangila have a rich experience of using hand dug wells particularly for domestic water supply with some experience of irrigation. Digging of wells commonly takes place during the driest months in order to avoid false alarms which commonly occur when construction takes place in the wet season. Women and sometimes children are also involved in manual digging. The total depth of the dug wells is about one meter below the water level of the driest months in order to allow a buffer for water level fluctuation.

During our field survey period, the total number of hand dug wells in Dangila rural kebeles was 2281 which suggests one well per 11 households on average. Not all households have equal access to the shallow groundwater resource due to its fragmented availability. Some villages have a massive rock near the ground surface which resulted in minimal or no access to groundwater.

As a consequence of this and many other factors, the number of existing hand dug wells shows a considerable spatial variation from 18 to 198 wells per kebele with an average of 84 wells. This can be translated to one well every 3 (Gult kebele) to 58 (G/Kansen kebele) households showing the uneven development of the resource (Figure 4).

Residents expressed that the deeper the well the less reliable it is. Figure 5 shows the median depth of hand dug wells in each kebele. The depth data was too small to estimate the median depth forKwandsha and Maylebach. The median depth of the existing wells in Dangila is 11 mm. However it shows large variation across the kebeles (6 to 23 meters). Some wells provide perennial source of water while other wells become dry intermittently particularly in the driest months.

4.3. Shallow groundwater irrigation in Dengeshta kebele

After comparing the 27 rural kebeles in consultation with woreda level experts, we selected three kebeles for further investigation: Dimsa, Dengeshta and Gult Kebeles. We visited Dimsa and Dengeshta to assess the type of wells, their use and the land scape. In Dimsa, there is an experience of surface irrigation through stream water pumping.

However, the yield of the perennial streams is now significantly declining to the extent of hindering irrigation practice. We speculate that the river water pumping has a negative impact on the shallow groundwater resource as a result of groundwater-surface water interaction. However, this requires further scientific investigation possibly through continuous monitoring and hydrological modeling.

In Dengeshta, we observed the existence of extensive unprotected grazing lands. The topographic nature (as shown by high values of wetness index) and the relatively high soil moisture content after the rainy season suggest availability of shallow groundwater. This also requires further investigation as other factors such as hydrogeology affect groundwater resource availability.

The hand dug wells that we visited were excavated manually using shovels and other similar tools. The shallow wells differ in their diameter (50 cm to 1 m), depth, and top cover. A common feature is that all have a rounded shape, which compared to other shapes, provides the largest amount of water with least labor and time (Figure 6). The wall of the wells is intact and stable without any lining due to the firm (clay) nature of the soil. Protection for the top surface is provided using clay pot, barrel, corrugated sheet or wooden material (Figure 2). We observed that some wells remained unprotected without a top cover while women were washing clothes very close to the wells. Contaminants can easily get into most wells since the well top is at the same level as the ground surface and the top cover is not water tight.

Currently, most households in the study area irrigate about one-sixteenth of a hectare per hand dug well.

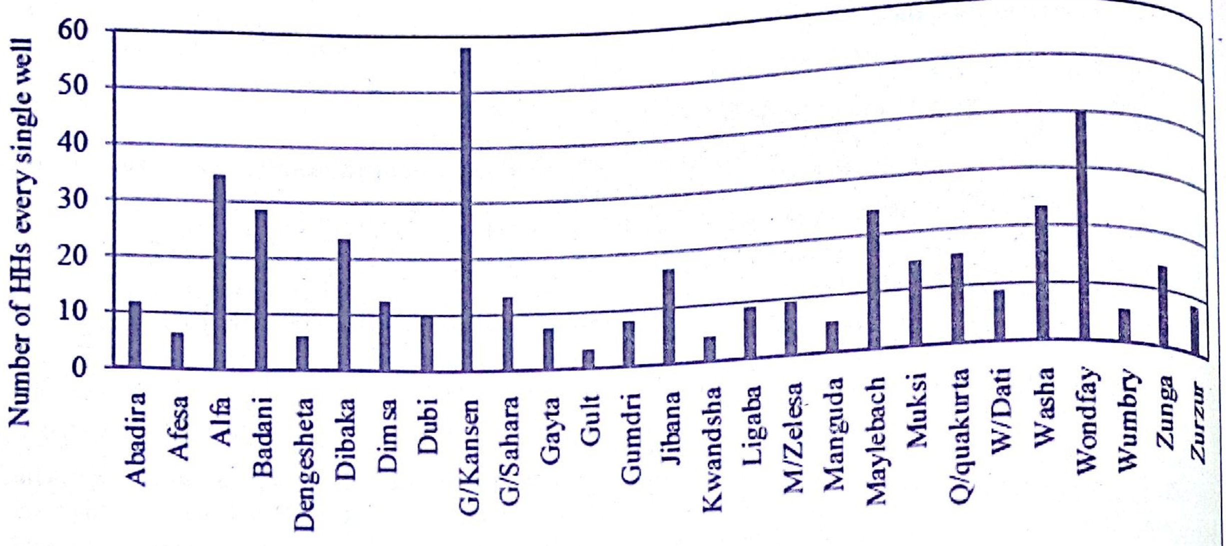

Figure 4: Number of households (HHs) every single hand dug well in Dangila

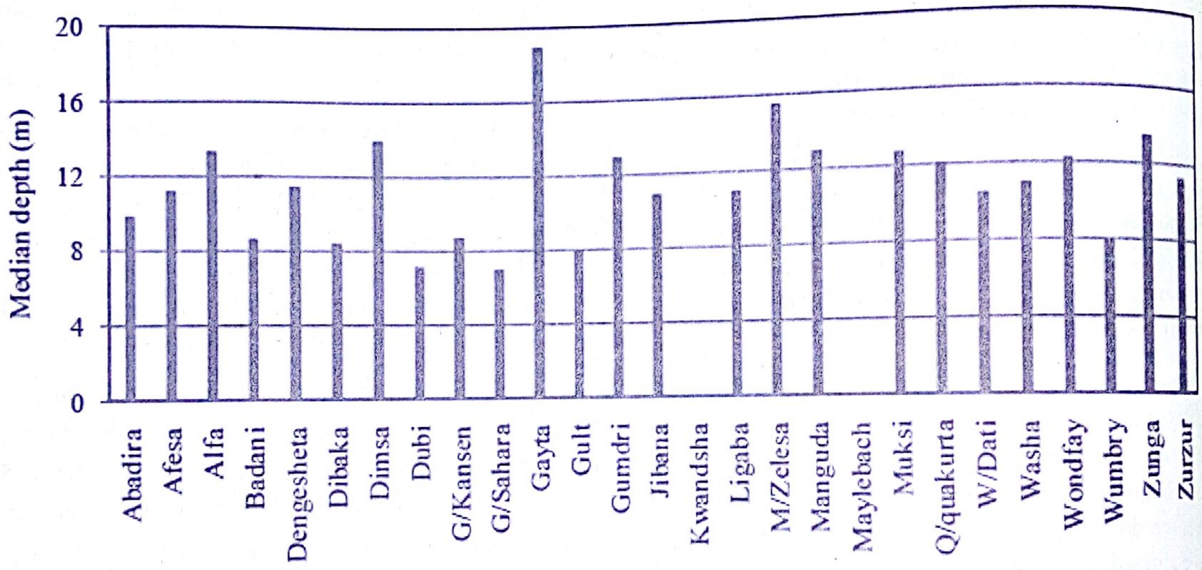

Figure 5: Median of the depth of hand dug wells in each kebele of Dangila

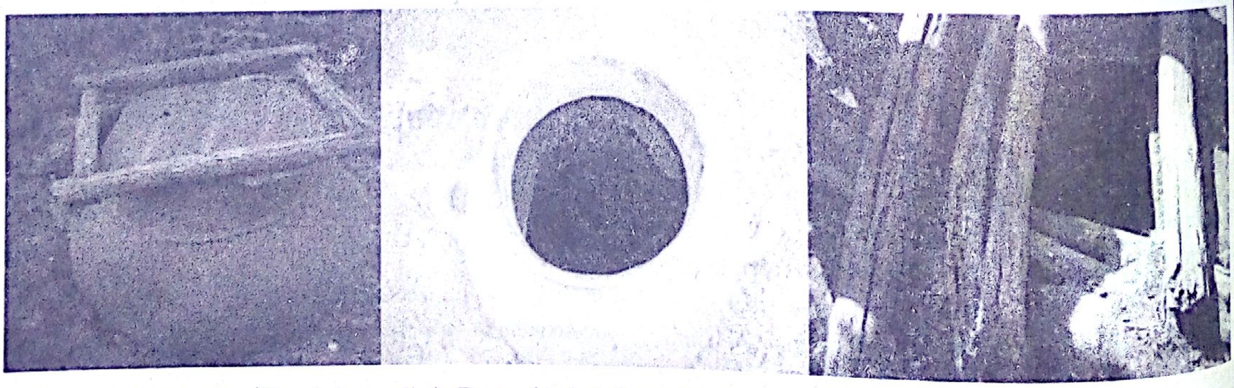

Figure 6: Top cover of hand-dug wells in Dengeshta kebele used for backyard irrigation and domestic use

The main constraints to expand irrigated land were identified by farmers as (i) labor intensive water lifting, (ii) land scarcity, and (iii) seed shortage. Women are exclusively responsible for lifting water and irrigating crops from the wells. The most commonly used lifting mechanism is rope and bucket. Peddal pumps have limited capacity and there is a perception that they are easily damaged. As a result, they are not preferred particularly by women. The preference is towards rope and washer pumps though these are note not being widely used in Dangila. The concern with these pumps is overexploitation as a well dried out in Dengeshta in the past due to excessive pumping with rope and washer pump. Motor pumps may lead to overutilization of the groundwater resource. It may even not be possible to use centrifugal motor pumps as the water level in the wells often drops deeper than 8 meters.

Crop selection is mainly dictated by water availability and ease of water application. Women prefer to produce profitable crops such as onion, cabbage, garlic, carrot, beet root, and tomato. However, these require considerable household labor and time to irrigate. As a result, tree crops are preferred for ease of water application and water saving by targeting individual crops during water application. Irrigated crops by hand dug wells in Dengeshta include coffee, sugarcane, avocado, mango, cirrus, chat, green pepper, soya bean, and potato.

In Dengeshta, some individuals own multiple hand dug wells (up to eight wells). For some farmers, owning multiple wells is a source of pride. There are also conditions where farmers own multiple wells to increase their irrigated land size. Overall, there exists lack of knowledge about the impact of well interference which is caused by having multiple wells in small area. Farmers do not receive any advice on well sitting and such knowledge is lacking at the woredas agriculture office.

4.4. Beneficiaries of SGI

Mr. Yihenew Sileshi who is a resident of Dengeshta kebele is one of the groundwater users for backyard irrigation and domestic water supply. During our field visit, he had two hand dug wells (~15 m deep) and was digging an additional well (~8.5m deep). The water table of his wells shows large seasonal variation. The three wells are separated by only few meters but differ in their yield. His irrigated crops include high value crops such as 'Chat', Ginger, Banana, Red pepper, Onion, and Coffee. In addition, Yihenew benefited from groundwater irrigation by selling 40 thousand seedlings of eucalyptus tree over one year period (2012/13).

Mr. Fantahun, a neighbor of Yihenew, also owns a hand dug well but uses it only for domestic water supply. His first attempt of well digging was not successful. However, he was able to hit the groundwater table at a depth of ~8.5 m in his second attempt at few meters away from the location of his first attempt.

5. Conclusions and recommendations

Hand dug wells are being used in Dangila to irrigate backyard crops as well as to meet domestic and livestock water demands. However, shallow groundwater potential and level of development differs among and within kebeles as availability of the resource is fragmented. Even though SGI is not well developed yet, there are some evidences that overexploitation may happen in the future. The woreda agriculture office has set an ambitious target to expand shallow groundwater irrigation (SGI). The target is for each household to irrigate 0.125 ha using hand dug wells. However, full achievement of this target is questionable since the actual groundwater potential of Dangia is not well known. Development of SGI will also affect water allocation for domestic, livestock and ecological water demands.

Future research in the area should identify, demonstrate and evaluate the right technologies or practices that could enable farmers to access the shallow groundwater resource and use it for irrigation. The technologies include water drilling, water lifting and saving technologies. In addition, adaptive management of the resource should be introduced to the area in parallel with SGI development. Training should be arranged to extensions agents about shallow groundwater well construction and maintenance so that they will be in better position to support farmers. In addition, woreda experts and the community can learn from experience sharing visits to other parts of Ethiopia with a good experience of SGI.

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Assessment of Fish Production Potential and pProductivity of Bira dam, Bati wereda, Amhara Region, Ethiopia

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Abstract

Bira dam was constructed in Bati district in 1986 through the aid of International Red Cross Association for food security purpose. The study was conducted from January to September 2013.The objectives of the study were, to estimate fishery production potential, assess physico-chemical parameters and check the status of the already stocked Nile tilapia (Oreochromis niloticus) fish species in Bira dam. Current total area, average depth of the reservoir were measured using GPS and rope respectively, fishery and physico-chemical parameters were taken monthly from January to September 2013 from three sites. Reed boat, gillnet of mesh size of 4-10 cm, measuring board, dissecting kit were used to collect fishery data. Digital Multimetres were used to measure pH, Temperature, conductivity and Turbidity value. Empirical model (Henderson and Welcome, 1974) was used to estimate annual fish production potential of the dam .SPSS Version 16 was used to analyze the collected data. Univarate test was used to test the physico-chemical parameters difference among sites and months. The mean value of pH, Temperature ,Turbidity and conductivity 7.02, 24.11^{0}C , 24.60 NTU and 399.00µS/cm respectively .There was no significant difference in all physico-chemical parameters among sites (P>0.05).There was significant difference in water Temperature, Turbidity and conductivity by month (P<0.05).The total Nile tilapia fish species collected were 33,of these 17 were female and the rest 16 were male. The minimum and the maximum total length of the fish were 13.5 and 20 cm respectively. From empirical model estimation the annual yield of the reservoir is nearly 141.2 Kg/ha/year and its total production is 2542.12 kg /year. The current total area of the dam is 18 hectar which was 42 hectar when the dam was constructed; the depth also reduces from 20 to 4.33 m. For better fishery production of Bira dam, common carp has been brought from Lake Maybar and introduced in the dam and has showed better adaptability. Since the watershed of the dam is highly degraded, the dam will be totally dried if the situation continues. The water quality of the dam and its productivity is less therefore watershed of the dam should be properly managed though full participation of dam users.

Key words: *Oreochromis niloticus, productivity, Reservoir*

1. Introduction

Ethiopia is uniquely rich in water resources. It has numerous water bodies including ponds, lakes, rivers, reservoirs and wetlands. Based on the estimation of FAO (2001) the surface area of major lakes and reservoirs is 7,334 Km^2 and the length of rivers is 7,185 km.

Ethiopia could be called a water tower of Eastern Africa in a continent where its most part is arid. The inland water body of Ethiopia is estimated at about 7,400 km2 of lake area and about 7,000 km total length of rivers (Wood and Talling, 1988). These water bodies contain large population of commercially important fish species. However, the territory of Ethiopia seems to be among regions of the African continent which are least explored in ichtyofauna perspectives (Golubtsov et al., 1995).

The estimated potential yield is important information required for fisheries exploitation and mangment. The actual yield of the fisheries is compared with estimated potential yield. It is on the basis of this comparison that management plans are made. In the absence of historical catch effort data covering several years, empirical models can be used to obtain a quick estimate of potential yield.

The development of aquatic life (flora and fauna) in surface waters is influenced by a variety of environmental conditions that determine the species as well as the physiological performance of individual organisms. The flora and fauna present in specific aquatic systems are a function of the combined effects of various hydrological, physical and chemical factors (UNESCO/WHO/UNEP, 1996). Aquatic ecosystems are dynamic and their trophic state is controlled by physical and chemical conditions. Thus, monitoring and evaluating the trophic state of lakes have become an essential prerequisite to develop control mechanisms. Expanding human population brought about by the opportunities of good water supply, irrigation, fish production recreation and navigation offered by Reservoirs has put enormous pressure and stress on the quality of water impounded by the reservoir. The impact of human activities in and around the reservoir is felt on the unique physical and chemical properties of water on which the sustenance of fish that inhabit the reservoir is built as well as to the functions of the reservoir. Water quality is determined by the physical and chemical limnology of a reservoir (Sidnei et al., 1992) and includes all physical, chemical and biological factors of water that influence the beneficial use of the water. Water quality is important in drinking water supply, irrigation, fish production, recreation and other purposes to which the water must have been impounded.

Water quality deterioration in reservoirs usually comes from excessive nutrient inputs, eutrophication, acidification, heavy metal contamination, organic pollution and obnoxious fishing practices. The effects of these "imports" into the reservoir do not only affect the socio-economic functions of the reservoir negatively, but also bring loss of structural biodiversity of the reservoir. Djukic *et al.* (1994) have used the physico-chemical properties of water to assess the water quality of a reservoir. The use of the physico-chemical properties of water to assess water quality gives a good impression of the status, productivity and sustainability of such water body. The changes in physical characteristics like temperature, transparency and chemical elements of water such as dissolved oxygen, chemical oxygen demand, nitrate and phosphate provide valuable information on the quality of the water, the source(s) of the variations and their impacts on the functions and biodiversity of the reservoir.

The quality of surface water has deteriorated in many countries in the past few decades. As a result of the growing population, increasing industry, agriculture, and urbanization, the inland water bodies are confronted with the increasing water demand, as facing with extensive anthropogenic inputs of nutrients and sediments, especially the lakes and reservoirs (Kondratyev,1998) To handle this problem, it is necessary to carry out water quality assessment, planning, and management, in which water quality monitoring plays an important role (Seker,2003)

This study aimed at assessing the water quality of Bira dam used for irrigation, livestock watering and fish production using some selected physico-chemical parameters. The results will form the baseline for monitoring and tracking changes in the water quality as a result of the dam's natural dynamics over time and impact of men's activities on the dam and its water shed.

2. Objectives

General objective

The main objective of the study was to assess physico-chemical parameters of Bira dam, status of the stocked Oreochromis niloticus and estimate fishery production potential of the dam using empirical formula and recommend sustainable utilization of Bira dam.

Specific objectives

- To assess physico-chemical parameter of Bira dam
- To assess the stocked Oreochromis niloticus before 20 years
- To estimate fishery production of Bira dam using empirical formula

3. Materials and Methods

3.1. The study area

Bira kebele is one of the kebeles of Bati Woreda where Bira dam is found that was constructed for irrigation purpose by Red Cross. The dam at the beginning when it was constructed had a depth of 15 to 20m and a total area of 42 hectare, but recently its area reduced to 18.33 hectares due to siltation (Figure 1). Bati is one of the districts in Oromia zone that has different culture attracting tourists especially on market day, Monday. The economy is based on crop production (sorghum, teff and maize) and livestock rearing. Livestock production is constrained by lack of grazing and access to fodder. Local agricultural labor, migration labor and firewood sale are important income generating activities particularly for poorer households (ALZR, 2007).

3.2. Methods

Physico-chemical parameters

Physico-chemical parameters Conductivity in µs/cm, pH, Turbidity in NTU and temperature in °C were measured using Digital multimetres in three sites, S1, S2 and S3 from January to June 2013

Fishery data

Gill net of mesh size from 4-10cm were used to sample the already fish species, Oreochromis niloticus in three selected sampling sites, littoral with and without vegetation and Pelagic .To set these different mesh sized gill-nets papyrus boat was used. Fishery data were taken for six consecutive months from January to June 2013.

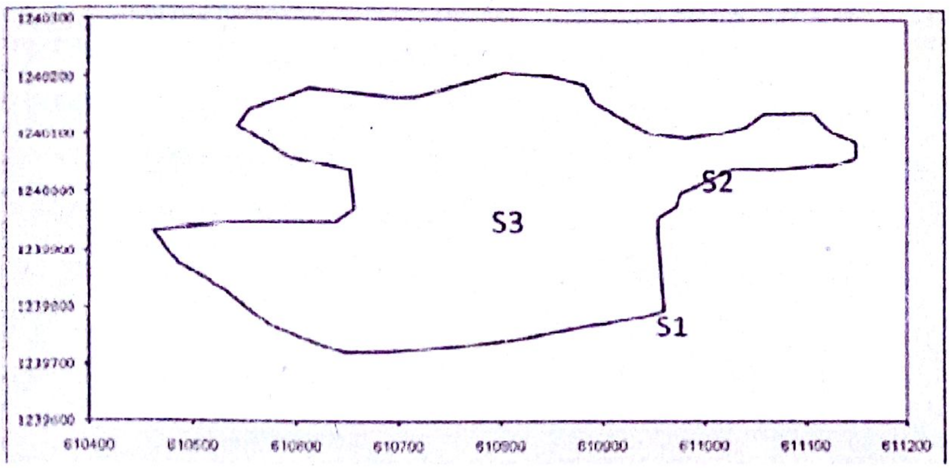

Figure1: Sketch of Bira dam drawn using the collected X-coordinate and Y-coordinate, Longitudes belongs to X-axis and Latitudes belongs to Y-axis. Site1(S1) is the littoral area without vegetation,Site2(S2),Littoral area with Typha latifola species coverage and Site3(S3),the open water, pelagic

Fish production potential

According to Henderson and Welcome (1974), Water bodies of fish production potential in tones per can be estimated using empirical formula stated below

$Y=14.3136*MIE^{0.4681}$

Y-yield in Kg/ha/year

$$MEI = \frac{Conductivity\ (\mu S.cm^{-1})}{Mean\ depth\ (m)}$$

Data analysis

Descriptive Statistics (mean, graphs) and inferential statistics (Univarate analysis) were used through SPSS Version 16 application

4. Results and Discussions

4.1. Physico-chemical parameters

Most of the values of Physico-chemical water quality parameters during sampling months were in the optimum condition for fish production except for higher Turbidity value. As stated below in table 1, except pH, temperature, conductivity and Turbidity showed significant difference among sampling months ($P<0.05$). There were no significant difference in water quality parameters among the three sites ($P>0.05$) (Table 2)

Table 1: Physico-chemical parameters variation among the different sampling months

			Sum of Squares	Df	Mean Square	F	Sig.
pH * Month	Between Groups	(Combined)	1.346	5	.269	.328	.886
	Within Groups		9.846	12	.821		
	Total		11.192	17			
Tep * Month	Between Groups	(Combined)	62.518	5	12.504	22.574	.000
	Within Groups		6.647	12	.554		
	Total		69.165	17			
Turbidity * Month	Between Groups	(Combined)	1542.401	5	308.480	4.338	.017
	Within Groups		853.413	12	71.118		
	Total		2395.814	17			
Con * Month	Between Groups	(Combined)	12778.000	5	2555.600	48.989	.000
	Within Groups		626.000	12	52.167		
	Total		13404.000	17			

Table 2: Physico-chemical parameters variation among sampling sites during sampling months

site		pH	Temperature	Conductivity	Turbidity
Site1	Mean	6.9400	23.967	393.83	21.265
	Std. Deviation	.40714	2.4977	30.413	4.7235
Site2	Mean	6.6600	24.350	401.17	25.268
	Std. Deviation	.95714	2.0047	28.646	18.3661
Site3	Mean	7.4667	24.033	402.00	27.258
	Std. Deviation	.86832	1.8640	29.779	9.8578

4.2. pH

The pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body and all processes associated with water supply and treatment (APHA, 1995). In unpolluted waters, pH is principally controlled by the balance between the carbon dioxide, carbonate and bicarbonate ions as well as other natural compounds such as humic and fluvic acids. Changes in pH can indicate the presence of certain effluents, particularly when continuously measured and recorded, together with the conductivity of a water body. Dial variations in pH can be caused by the photosynthesis and respiration cycles of algae in eutrophic waters. The pH of most natural waters is between 6.0 and 8.5, although lower values can occur in dilute waters high in organic content, and higher values in eutrophic waters, Groundwater brines and salt lakes (APHA, 1995). The desirable pH range for fish is between 6.5- 9. Long term exposure to pH values beyond these limits slows fish growth and reduces health. Exceedingly alkaline water (greater than pH 9) is dangerous as ammonia toxicity increases rapidly. At higher temperatures fish are more sensitive to pH changes. The mean pH value of Bira dam ranged from 6.6 -7.3 almost similar with Tekeze dam and lower than Hashenge (8.4). The Bira dam pH value is suitable for fish production and its variation among sites described in Figure 2

4.3. Water temperature

Fish are exothermic, their body temperature is about that of the surrounding environment; and affects all metabolic processes. Cold water slows metabolism and warm water increases metabolic rate. Fish have adapted to a wide range of temperatures. Some cold water species can tolerate temperatures below 32^0 F.; while desert killifish can live in pools in Death Valley at temperatures in excess of 110^0 F. Native warm-water fish have a temperature tolerance range of about 34- 104^0 F. although many species will become stressed near either of these extremes. There Below 55^0 F. activity and feeding slow. Above 95^{0}F. many warm-water fish begin to reach upper lethal temperature tolerance limits. Tropical fish such as the tilapia, cannot tolerate cold water. They become stressed when water reaches 60^0 F. and die at water temperatures below 50^0 F. Trout and other coldwater fish will die when water temperature exceeds 70^0 F. Their optimum temperature is about 55-65^0 F. and they are active down to 40^0 F. Fish must adjust to temperature changes gradually. A warm-water fish may survive in 100^0 F. water if slowly

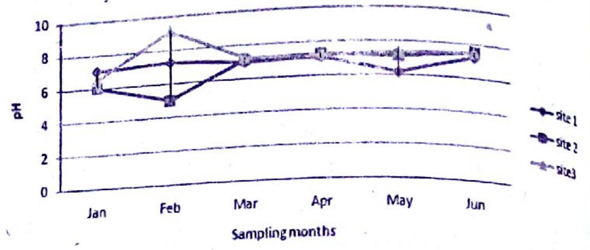

Figure 2: pH variation among sampling sites during sampling months

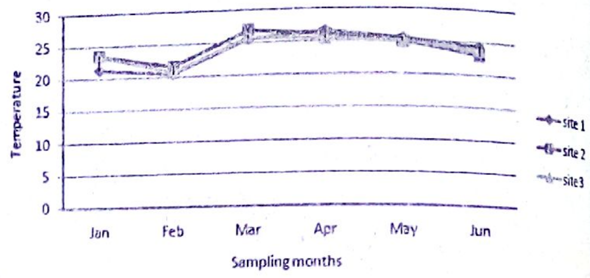

Figure 3: Water temperature variation among sampling sites during sampling periods

4.4. Turbidity

Water turbidity refers to the quantity of suspended material, which interferes with light penetration in the water column. In water bodies, water turbidity can result from planktonic organisms or from suspended clay particles. Turbidity limits light penetration, thereby limiting photosynthesis in the bottom layer. Higher turbidity can cause temperature and DO stratification in water bodies. Planktonic organisms are desirable when not excessive, but suspended clay particles are undesirable. It can cause clogging of gills or direct injury to tissues of aquatic organisms .Erosion or the water itself can be the source of small (1-100 nm) colloidal particles responsible for the unwanted turbidity. The particles repel each other due to negative -charges: this can be neutralized by electrolytes resulting in coagulation. It is reported that alum and ferric sulfate are more effective than hydrated lime and gypsum in removing clay turbidity. Both alum and gypsum have acid reactions and can depress pH and total alkalinity, so the simultaneous application of lime is recommended to maintain the suitable range of pH. Treatment rates depend on the type of soil. The turbidity value measured in NTU was higher(21.26-27.27) in Bira dam than Tekeze dam (8-11). The bigger difference might be duet to highly degraded watershed of Bira dam resulted higher siltation. Turbidity variation among sites during sampling periods is described in Figure 4.

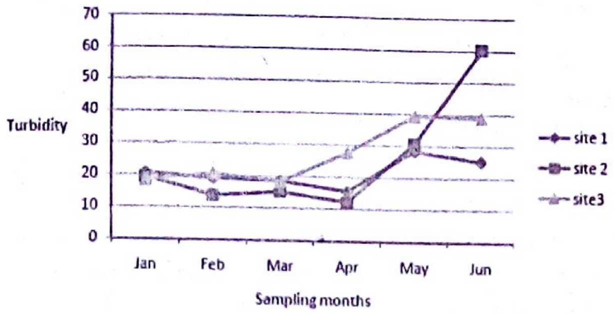

Figure 4:Turbidity variation among sampling sites during sampling periods

4.5. Conductivity

The values of Electrical conductivity (EC) ranged from 260 to 300 µS Cm-1 in Tekeze t. Total dissolved Conductivity is related to the concentrations of total dissolved solids and major ions. The conductivity of most freshwaters ranges from 10 to 1000 µS cm-1, but may exceed 1000 µS cm-1, especially in polluted waters, or those receiving large quantities of land run-off (APHA, 1995).The conductivity value measured in µS Cm^{-1} was higher (393.83-402.00) than Tekeze dam(260-300) and lower (569) Tendaho reservoir. The higher conductivity in Bira dam and Tendaho reservoir might be their geological characteristics containing many cations. The conductivity variation among sites during sampling duration showed in Figure 5.

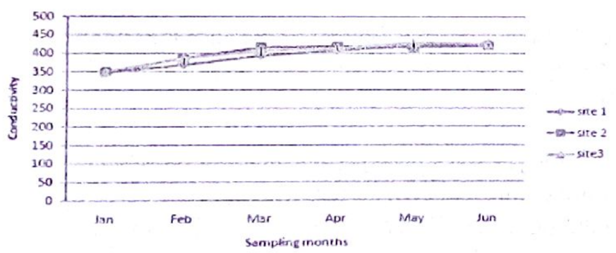

Figure 5: Conductivity variation among sites during sampling period

4.6. Fish data

Ethiopia is known to be rich in its water resources and favorable environmental conditions for the development of aquaculture. However, in spite of the presence such enormous resource and potential, the sector is known to be the least developed. So far the aquaculture activity in Ethiopia is limited to stocking of fish fingerlings to manmade or natural water bodies. Such practices have been made with the intention of producing fish for local consumption Most developing countries in Asia, South America and Africa have recognized reservoir fisheries as an effective way of increasing the supply of fish as food in rural areas, at an affordable price. Reservoir fisheries also provide additional income to rural farmers, thereby contributing to poverty alleviation. Reservoir fisheries have added advantages in that, unlike the more conventional aquaculture practices, they are less resource intensive and need less technical skills at farmers' level. These fisheries are also an effective secondary user of water resources in rural areas. Recognizing the importance of reservoir fisheries, the Ministry of Agriculture and Rural Development (MoARD) and the Sebeta Fish Culture Station now called the National Fisheries and other Aquatic Life Research Center (NFALRC) of the Ethiopian Institute of Agricultural Research (EIAR) have been made a huge effort for the development of fisheries in reservoirs and lakes such as Koka, Fincha, Melka Wakena, Small Abaya, Ashengie and several others could be mentioned as success stories.

According to Tadessie Negu, Kemissie Zonal Agricultural Senior Expert, Oreochromis niloticus (Nile tilapia) were stocked by South Wollo Rural and Agricultural Office in 1982. However, expect children practice for sport fishing in insignificant way, the local people are not benefited from the stocked fish species in Bira dam. The total number of Nile tilapia fish species collected within six month time were 33, of these 17 were female and the rest 16 were male. The monthly average fish catch in all the three sites were 5 tilapia. The minimum and the maximum total length of the fish were 13.5 and 20 cm respectively. Even the highest fish length recorded in Bira is the least compared with the size of the same species found in Lakes and reservoirs found in Amahara region in Particular and in Ethiopia in general. The Physico-chemical parameters value recorded in six consecutive months from January to June 2013 revealed that the dam is not suitable for Nile tilapia. Research conducted in East Gojjam by Alayu Yalew et al. (2009) confirm that common carp, *Cyprus carpio* will show better growth performance than Oreochromis niloticus. The present study agrees with Alayu Yalew (2009).

After Physico-chemical and fish stock assessment for six consecutive months, Common carp species has been introduced in the dam that has been brought from Lake Maybar. After 5 months adaptability of the carp species were checked in October and December 2013 using Gill net having mesh size of 4-10cm.This preliminary assessment showed that the common carp has adapted well.

Fish production potential

Water bodies fishery potential can be estimated using different empirical formulas that consider the different physico-chemical parameters like TDS, temperature and volume, area or average depth of the water bodies. According to Henderson and Welcome (1974), Water bodies of fish production potential in tones per can be estimated using empirical formula stated below

$Y=14.3136*MIE^{0.4681}$

$$MEI = \frac{Conductivity\ (\mu S.cm^{-1})}{Mean\ depth\ (m)}$$ Y-yield in Kg/ha/year

399/3 = 133

Y=14.3136*9.87=141.2 Kg/ha/year

141.2*18 = 2542.12 kg/ha/year for the whole reservoirs

The amount of fish production in Tones per hectare in Bira dam (2542.12 kg/ha/year) is low than Dendeho Reservoir(1,345,000kg/y). The difference might be duet to conductivity ,depth and total area or volume of water of the dams.

5. Conclusions and Recommendations

Bira dam is used as source of irrigation water, livestock watering and water for washing clothes and basing. The excessive water extraction day and night with out regulation, degraded watershed and absence of buffer zone resulted in siltation are major problems affecting water quality and quantity of the dam. The average depth of the dam reduced from 20metre to 4.33m and its toral area from 42 hectares to 18 hectares. The dam littoral area mainly is devoid of vegetation that may support fauna and flora including fish species. The poor adaptability of Oreochromis niloticus fish species might be absence of feed and shelter during harsh periods. As a side line activity during data collection Bira dam user association has been established and training on sustainable water utilization and watershed management was delivered to these individuals. All members of the association should actively involve in watershed bira dam management for sustainable utilization of the resource. Further studies on major factors affecting growth performance of Nile tilapia and newly stocked common carop adaptability should be conducted.

Acknowledgement

The researchers would like to thank Organizations, Kemissie and Bati Agriculture and Rural Development Offices for positive response during request for transport facilities. We are also delighted to thank individuals, Mr. Tadesse Negu and Mr.Fisha Woldemariam for their unreserved effort during data collection in Bira dam and fingering collection from Maybar Lake

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Assessment of the Effects of Water Harvesting Technology on Downstream Water Availability Using SWAT Model, Case of Alaba Special Woreda, Ethiopia.

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Abstract

In hydrological cycle there are many water-related human interventions that modify the natural systems. Rainwater harvesting is one such intervention that involves harnessing of water in the upstream. Water harvesting used in upstream prevents water runoff on downstream mainly disturbance on biodiversity and ecosystems. The main objectives of the study are to assess the effects of water harvesting technologies on downstream water availability in the Woreda. To address the above problem, SWAT model, Cost-Benefit Ratio and Optimal control approach was used to analysis the hydrological and socioeconomic impact and tradeoffs on water availability of the community, respectively. The downstream impacts of increasing water consumption in the upstream rain-fed areas of the Bilate and Shala Catchment are simulated using the semi-distributed SWAT model. The two land use scenarios tested at sub basin levels (1) conventional land use represents the current land use practice (Agri-CON) and (2) in-field rainwater harvesting (IRWH), improving soil water availability through rainwater harvesting land use scenario. The simulated water balance results showed that the highest peak mean monthly direct flow obtained from Agri-CON land use (127.1m^3/ha), followed by Agri-IRWH land use (11.5mm) and LULC 2005 (90.1m^3/ha). The Agri-IRWH scenario reduced direct flow by 10% compared to Agri-CON and more groundwater flow contributed by Agri-IRWH (190m^3/ha) than Agri-CON (125m^3/ha). The overall result suggests that the water yield of the Woreda may not be negatively a□ ected by the Agri-IRWH land use scenario. The technology in the Woreda benefited positively having an average Benefit Cost Ratio of 4.2. Water harvesting for Domestic use was not optimal that the value of the water per demand harvested was less than the amount of water needed. Storage tanks, Series of check dams, gravel filled dams are an alternative solutions for water harvesting.

Key words: *Water Harvesting, SWAT model, Land Use Scenario, Agri-CON, Agri-IRWH, Trade off, Benefit Cost Ratio.*

1. Introduction

Water Harvesting is the accumulation and deposition of rainwater for reuse before it reaches the aquifer. In a hydrological cycle, there are many water-related human interventions, such as water storage, diversion, distribution, purification and other associated acts that modify the natural water systems. Rainwater harvesting, which involves harnessing of water in the upstream catchment and is designed for "on-site" gains, may have hydrological impacts on downstream water availability. Increased water consumption at upstream level is an issue of concern for downstream water availability, but it is generally assumed that there are overall gains and synergies by maximizing the efficient use of rainwater at farm level (Rockstrom et al, 2002). The expected upstream shifts in water flows may result in complex and unexpected downstream effects in terms of quantity and quality of water. In general, though, increasing the residence time of water in a catchment through rainwater harvesting may have positive environmental as well as hydrological implications/impacts downstream (Rockstrom et al, 2002). However, it may also result in uninformed decisions by policy makers.

Department in India ordered the destruction of community rainwater harvesting structures, fearing that it would threaten the supply of irrigation water to downstream users (Agrawal et al, 2001). Therefore, there is a need for further research and understanding on the possible impact of wider expansion of rainwater harvesting technologies. Water harvesting systems have been successfully utilized by people in some parts of the world where water shortage exists. The application of water harvesting techniques although potentially high but still low practice in Ethiopia. Hydrological performance of water harvesting technology requires use of hydrological modeling approaches that have been developed to simulate the impacts and consequences of land use changes on the environment in general and water resources in particular. One of these models is the Soil and Water Assessment Tool (SWAT). It was selected for the simulation of hydrological processes in arid watersheds with water harvesting practices, because (1) it simulates all water flows, water balance components and crop yields of different land units at various temporal scales,

(2) It allows easy representation and use of spatially variable data, processes and results through a GIS interface; and (3) it has a wide development and users' community with open access to the model documentation and source code.

2. Objectives of the Study

The general objective of the research is to assess the effect of water harvesting technologies on the downstream water availability and to find the viable options of surface water harvesting.

The Specific Objectives of the study are:

- To identify factors that affect the downstream like ground water, soil type, land use Scenarios.
- To identify cost-benefit analysis of Water Harvesting technologies
- To Evaluate tradeoff on upstream and downstream water availability of the society under water harvesting influence.
- To suggest an alternative methods of surface water harvesting for crop production, domestic uses and livestock.

3. Materials and Methodologies

3.1. The study area

The study was conducted at Alaba Woreda in the Southern Nations, Nationalities and Peoples' Region of Ethiopia. The woreda is located 310 km south of Addis Ababa and about 85km southwest of the southern nation's nationalities and people's regional (SNNPR) state capital of Hawassa and geographically located 7^0 17' N latitude and 38^0 06' E longitudes. The climate of the location is Weina Dega with the annual rainfall varies from 857 to 1085 mm, while the annual mean temperatures also vary from 17 ^{0}C to 20 ^{0}C with a mean value of 18 ^{0}C. The area receives a bimodal rainfall where the small rains are between March and April while the main rains are from July to September.

3.2. Method of the study

The methods used for Assessment of Water Harvesting technology effect on downstream water availability general steps followed in this study works are outlined below.

1. Input data collected for the study such as: socioeconomic data of the Woreda, The general progress of the Woreda supply, stream flow, digitized map of the study area and DEM data collected from MOWE, data collected from MOWE, meteorological data from NMA, physical characteristics of Pond on the Woreda.
2. Setting-up, calibration and validation of SWAT model with climate and stream flow data representing the current climate condition.

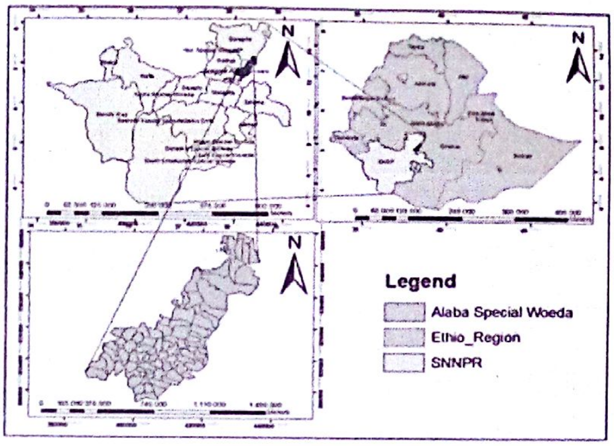

Figure 1: Location of the study Area (Alaba Special Woreda)

The methodology of this study is summarized in a form of a flow chart as shown in Figure 2. The flow chart depicts the steps followed in carrying out the modeling of the catchment level changes.

3.3. Data Analysis

Data was analyzed using descriptive statistics. Qualitative data were used to specify contexts of the study and enrich information generated from quantitative data analysis. To assess the economic viability of Water harvesting ponds constructed in Alaba Woreda by the community, Government and international NGO.

This study collected a large amount of socioeconomic and physical data from the community in the Woreda. Data collection activities involved the active participation of the local self-governments and members of the local community. The spatially distributed data (GIS input) needed for the Arc SWAT interface include the Digital Elevation Model (DEM), soil data, and land use data. Data on weather and flow is used for the prediction of water balance and calibration purposes respectively.

3.4. Cost benefit analysis (CBA)

It was used to assess the water harvesting technology in Alaba special Woreda for comparison of cost and benefit that accrues from a specific project. A CBA involves calculating and comparing all of the costs and benefits, which are expressed in monetary terms.

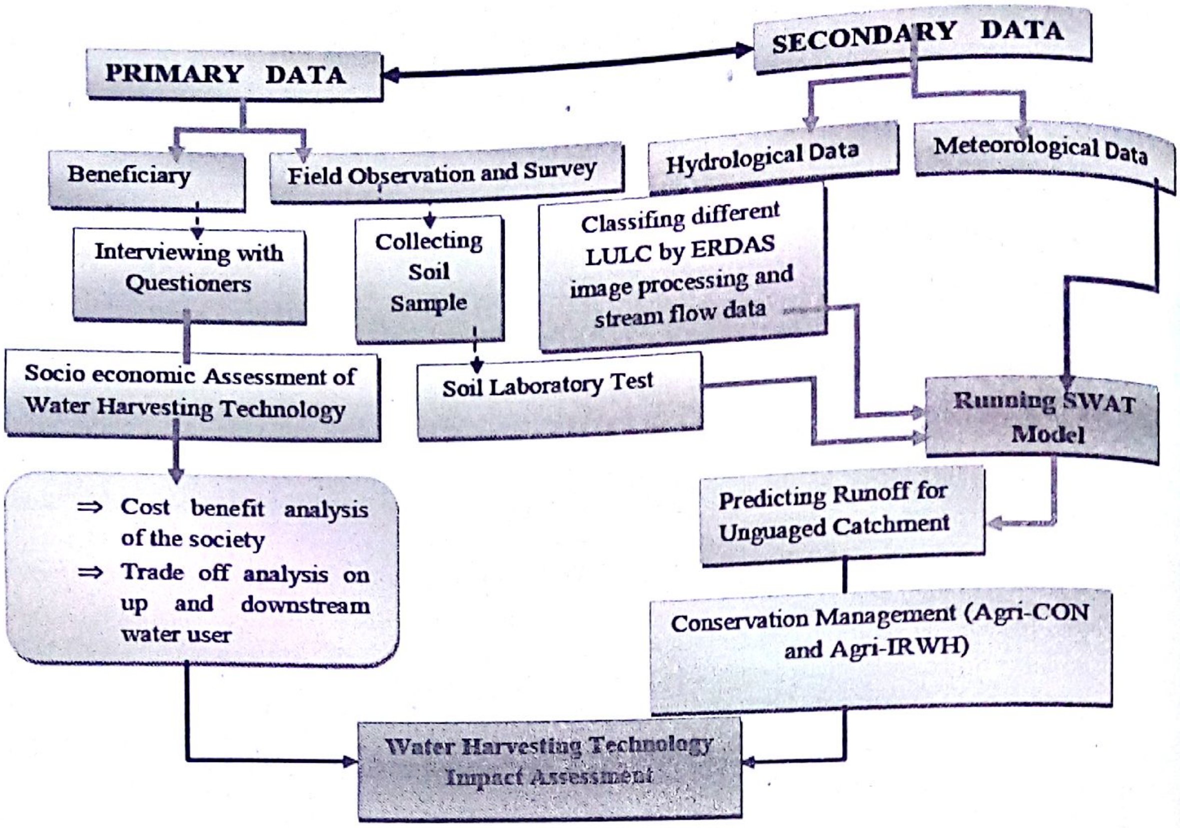

Figure 2: The flowchart of general methodology used in this thesis work

The benefit -cost ratio indicates the overall value for money of a project. If the ratio is greater than 1, the option is acceptable.

$$Benefit - Cost\ ratio = \frac{Total\ present\ value\ of\ benefits}{total\ present\ value\ of\ costs}$$

This method was used to evaluate the benefit cost analysis of the technology.

3.5. Hydrological Model

SWAT Model was used to assess the effects of water harvesting technology on downstream water availability. The model simulates the hydrology of a watershed done in two separate divisions. The land phase of the hydrological cycle and routing phase of the hydrologic cycle for this study land phase Hydrological components of SWAT was used.

SWAT model simulates hydrology of the area with watershed level. In this study the model simulate the area on two watersheds Bilate and Shala because the Woreda fall on the two catchments. Hydrological components simulated in land phase of the hydrological cycle canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow.

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_0 + (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

Calibration is modification of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, generated with the use of historic meteorological data, to recorded stream flows. The performance of SWAT was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Spatial analysis was carried out to describe land use land cover change pattern and overall land use changes with time. This is done after image classification of the three land use land cover maps (1973, 1984 and 2005) whose results for each analysis. The land-use of the Bilate and Shala Catchment based on data of 1973,1984 and 2005 which is reclassified by Arc SWAT005 version).

3.6. Optimization of the water use tradeoff (OCA)

An optimal control method was used to assess the conditions under which the management of the tradeoff between two water use activities, on domestic, is either optimal on the system level from the local decisions of multiple agents. The model extends a standard Domestic animal population growth model with Ricker type employment to include this natural supply effect. Supply is formalized as an addition of domestic water consumption from an external source of the water supply similar to other approaches investigating the effect of supply on take dynamics.

4. Results and Discussions

This section presents results of the study and discusses the result by giving an appropriate emphasis on the projected research objective.

The standard land phase hydrologic parameters used in SWAT were considered for annual water balance. For this study, Average annual water balance in the watershed for both calibration and validation period was done. The simulation result that largest portion of the average annual precipitation (66.63%) falling in the watershed is lost through Transmission losses. This value indicates that there is high sensitivity of Transmission losses to any change than any other hydrologic parameter governing the sub watersheds" water balance.

Figure 3shows the variation of the WY for the three land use data sets at the outlet of Bilate and shala catchment, the result was an average decrease of WY by about 42.76% over a period of 6 years (1997-2002) when land use data of 1973 was compared to the land use data with 1984 and also decrease of WY by about 52.6% when land use data of 1984 to 2005.

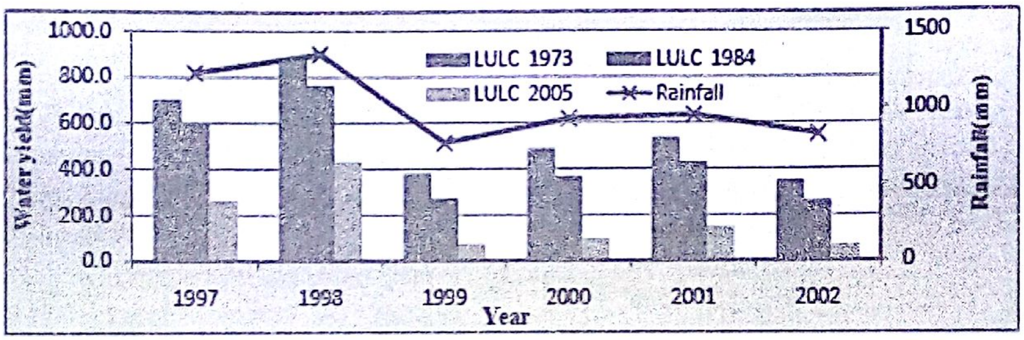

Figure 3: Comparison of the simulated average annual water yields for the period of 1997 to 2002 based on the three land use data sets on Bilate and Shala Catchment.

The impacts of the different land use scenarios on the components of the stream flow are presented. The mean monthly WY (DIRQ + GWQ) for the period of 1997 to 2007 showed significant differences in peak flow when pasture (LULC 2005) land on 0 to 3% slope was converted to Agri-CON and Agri-IRWH land uses.

The monthly mean peak WYs were 280 m3/ha 620 m3/ha and 290 m3/ha for LULC 2005, Agri -CON, and Agri-IRWH, respectively. The mean monthly WY on the Agri-CON land use scenario was higher than the other two scenarios during the rainy months of December to March only. Agri-IRWH showed a higher peak WY value than LULC 2005 probably due to the high ground water contribution by the IRWH technique during the same month as the occurrence of the peak flow.

The effect of the different land use scenarios on the water balance of Alaba Special Woreda is well verified by the direct flow component of the WY. The direct flow comprises the surface Runoff and the lateral flow, also known as interflow.

The other interesting result on the impact of land use change was related to the ground water (base flow) component of the WY. Figure 4 presents the ground water discharge to the stream flow.

Thus, the Agri-IRWH was found to recharge the ground water table better than the other two scenarios that , the highest mean monthly peak ground water flow was produced by Agri-IRWH amounting to 60.2 m^3/ha, followed by 56 m^3/ha and 48 m^3/ha by Agri-CON and LULC 2005 land use scenarios, respectively. The annual mean ground water flow was also found to be the reverse of the direct flow.

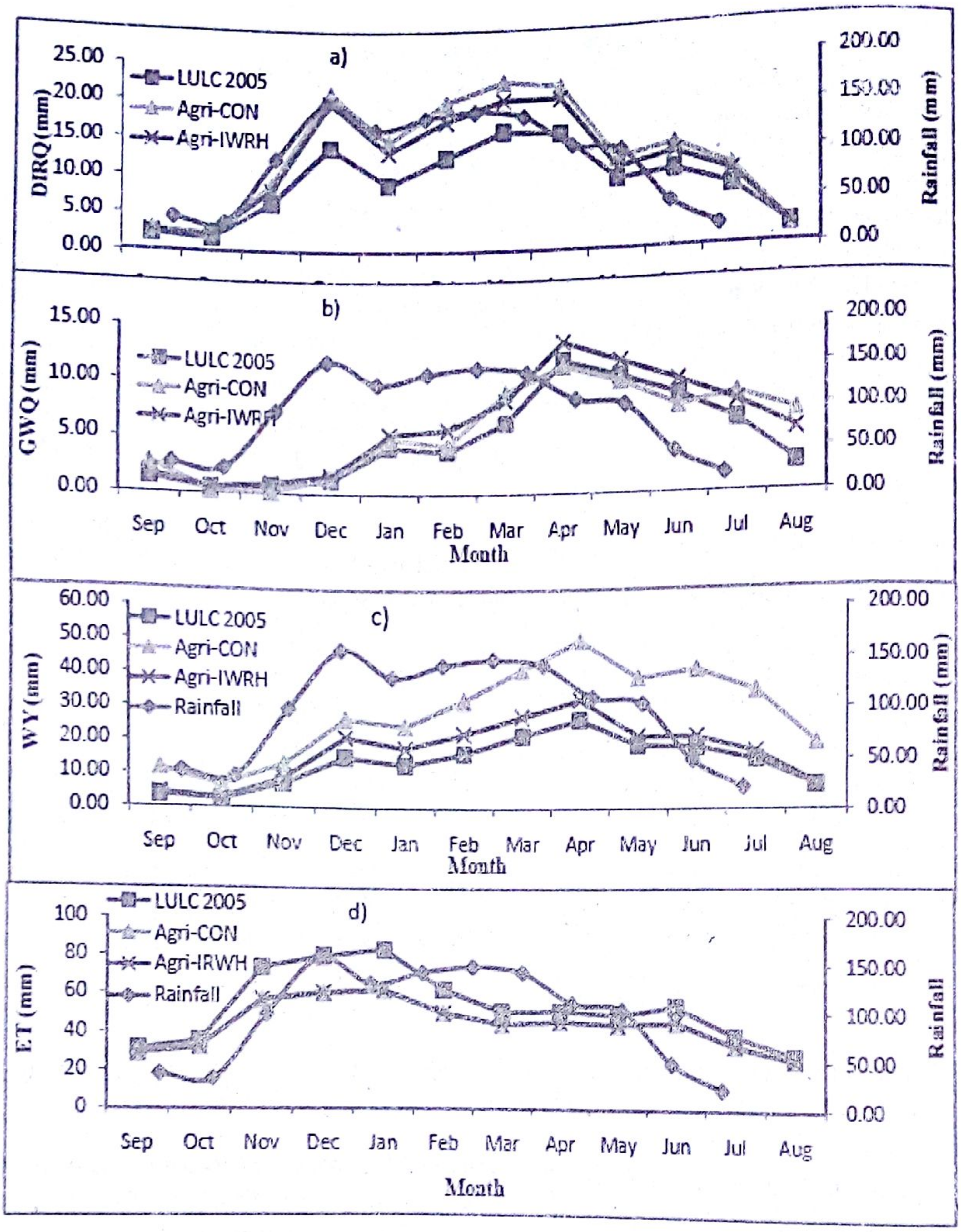

Figure 4: Water balance components of Alaba Special Woreda for three land use scenarios: Direct flow (a); Total water yield (b); Ground water flow (c) and Evapotranspiration.

The highest annual ground water flow was obtained from Agri-IRWH which was 352.5m^3/ha, followed by 283.4 m^3/ha on Agri -CON and 210.8 m^3/ha on LULC 2005 land use scenarios. The results demonstrate that there was high infiltration of water on Agri-IRWH and LULC 2005 than on the Agri-CON land use. The Agri-IRWH technique creates a pond of water inside the furrow that later infiltrates into the soil profile.

Moreover, Agri-IRWH and LULC 2005 scenarios were found to increase the residence time of runoff flow in a catchment which in turn had an effect on the occurrence of the monthly WY peak flows. Thus, the increased dry season WY under Agri -IRWH may have positive environmental as well as hydrological implications/impacts downstream.

Overall, the results suggest that the WY of Alaba Special Woreda may not be adversely affected by the Agri-IRWH land use scenario despite its design for surface runoff abstraction. It is expected that this result will assist in taking a practical measure regarding water resources management in general and a strategic allocation and use of water in particular.

The economic benefits of this improved water harvesting technology have two main components 1) Productive gained and 2) The value of any time saving that result from the installation of the new water resources. The economic value of time saving to households will vary greatly depending on local laber market conditions and economic opportunities.

The study calculate the time saving benefits by multiplying (1) an estimate of the time saving associated with the initial quant ity of water consumed; (2) an estimated of the market wage for labor (ranging from ETB 32 to ETB 40/ day); (3) a parameter less than one to denote the ratio of the value of time spent collecting water to the market wage (ranging from 0.1to 0.5). The estimates of the time saving assume that the time required to collect water from the improved source varies from 0.1 to 0.5h/20L water. Thus, it is possible in the model for there to be positive time costs to households using the new source instead of time saving.

With the optimization approach that delivering water to domestic is not optimal that the value of the water per demand harvested is less than the amount of water needed to domestic purpose.

Taking the advantage of the geological suitability of the area (a flood plain with alluvial soils of few meters deep), other alternatives such as storage tanks, sand filled dams and check dams for artificial recharge need to be given attention.

5. Conclusions and Recommendations

5.1. Conclusions

Based up on the results obtained in this study and the consequent comparative analysis, the models employing the SWAT technique have consistently outperformed the models using technique of regression analysis.

SWAT-WH allows a reasonable representation of the water balance components and processes of the different soil and land uses at the sub basin level; it does not allow the routing of surface runoff between different land units within the sub basins.

Therefore, to evaluate the long term hydrologic impact and the dynamics of the water -harvesting technologies, SWAT-WH could be coupled with a cell-based routing model at the sub basin level.

Overall, the results suggest that the WY of Bilate and Shala catchment will not be adversely affected by the Agri-IRWH land use scenario despite its design for surface runoff abstraction. It is expected that this result will assist in taking a proactive measure regarding water resources management in general and a strategic allocation and use of water in particular.

The investigative process and the results of the Cost-Benefit analysis (CBA) of the society under water harvesting technology have been extremely informative in Alaba Special Woreda. The CBA results have demonstrated that the average estimated benefits from all household groups are positive having Benefit Cost Ratio of Greater than one (BC Ratio 4.3).

Generally it can be concluded that the trade-off on the use water for both domestic and agricultural purpose is non optimal, that the technology implicated in the area are not enough and needs additional water harvesting ponds.

5.2. Recommendations

Based on field observation and physical measurements carried out on level of sedimentation, results, it can be concluded that the main factors contributing sedimentation are lack of timely removal of the sediment deposited in the silt trap structures and poor site selection, management problems. For instant sustainable use of floodwater from the rivers and temporally flows, there is a need to undertake a master plan study that leads to the construction of permanent structures, however this needs big investment. In this regard, if Government or other NGOs involve in preparation of the master plan, the above problem will be solved.

Most of the assessed rainwater harvesting ponds are technically suitable and one of the strategies for the achievement of the global and national level objectives. Therefore governmental and nongovernmental organization replicate community based rainwater harvesting project with community partial cost coverage principle to the achievement various global and national goals and objectives, such as those of the recent "Development and Transformation" plan of the Ethiopian Government.

Awareness creation for water professionals, policy makers, international financers and donors through workshops, meetings, publications such as brochures and the like are very important works to be under taken to improve the promotion of rainwater harvesting in the effort made to improve the low level safe water supply of the country.

At last to ensure the sustainability and safety of the Ponds strong extension system and responsible institution for training and operation are required.

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Microalgae to Biofuels: 'Promising' Alternative and Renewable Energy

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Abstract

Rapid growth of human population has led to mounting energy demands, projected to increase 50% or more by the year 2030. The natural petroleum can not catch-up the current consumption rate which is already reported to be 105 times faster than nature can create. Besides, the use of fossil fuels is devastating to our environment by the ***greenhouse gas*** *emissions and consequent global warming. Therefore, the search for* ***'clean' energy*** *has become one of society's most overwhelming challenges. Currently several alternatives are being studied and implemented including solar energy, hydroelectric, geothermal, wind, and* ***biofuels****, of which biofuels are seen as real contributors to reach a goal of replacing fossil fuels in the short term. Biofuels, fuels from living organisms, provide environmental benefits, since their use leads to a decrease in the harmful emissions of CO, hydrocarbons and particulate matter and to the elimination of SOx missions, with a consequent decrease in the greenhouse effects. Unfortunately, the present biofuel projections are based on feedstocks that are also food commodities and resources suitable for conventional agriculture. One possibility to overcome the problem is the cultivation of* ***micro-algae*** *and switching to third generation biofuels, which seem to be a promising source since algae are able to efficiently convert sunlight, water, and CO_2 into a variety of products suitable for renewable energy applications. Therefore, this review is intended to recapitulate current works on micro-algal biofuel production potential and disclose possible ways to put it into practice. This review starts by highlighting the advantages and various forms of micro-algal biofuels. Some of the micro-algal species proved to be suitable for biofuel production so far have been tabulated with details given for* ***Scenedesmus obliquus****. The recent attempts and achievements in improving the economies of production through genetic and metabolic engineering of micro-algal strains have been addressed. Other potential applications such as* ***wastewater treatment*** *and* ***CO_2 mitigation*** *that can be coupled with biofuel production are described. The opportunities of implementing microalgal biofuel production in Ethiopia have been highlighted. Finally, the promises and challenges of algae to biofuel industry are uncovered.*

Keywords/phrases: *Biofuels, renewable energy, micro-algae, transesterification, Green house gases, wastewater treatment and CO_2 mitigation*

1. Introduction

Rapid growth of human population has led to mounting energy demands, projected to increase 50% or more by the year 2030 (Maness *et al.*, 2009). The natural petroleum can not catch-up the current consumption rate which is already reported to be 105 times faster than nature can provide (Netravali and Chabba, 2003). Moreover, the use of fossil fuels is devastating to environment by greenhouse gas emissions and consequent global warming (Chist, 2007). Therefore, the search for 'clean' energy has become one of most overwhelming challenges (Mata, 2010). Following this, several alternatives including solar energy, hydroelectric, geothermal, wind, and biofuels are being studied and implemented. Of these potential sources of energy, biofuels are seen as real means of achieving the goal of replacing fossil fuels in short term.

Biofuels are fuels that contains energy from geologically recent carbon fixation i.e. living organisms. Biofuels can be produced from starch, vegetable oils, animal fats, waste biomass, or algal biomasses which are non-toxic, biodegradable and renewable (Song *et al.*, 2008). Based on the feedstock types used and their current/future availability, biofuels are categorized into 1^{st}, 2^{nd} or 3^{rd} generation biofuels (UNEP, 2008). They provide environmental benefits since their use leads to a decrease in the harmful emissions of carbon monoxide, hydrocarbons and particulate matter and to the elimination of SOx emissions, with a consequent decrease in greenhouse effects. In fact, burning biofuels adds less carbon to the environment than burning fossil fuels as the carbon released by burning biofuel already existed as part of the modern carbon cycle.

Unfortunately, the present biofuel projections are based on feedstocks that are also food commodities (REN21, 2009) and resources suitable for conventional agriculture (Hoogeveen et al. 2009). Satyanarayana *et al.*, (2010) have pointed out that the substitution of the diesel by the biodiesel would need the use of lands used to produce food and the fiscal incentives by governments are decreasing the lands available for food production.

To this effect, microalgae have attracted much global attention in recent years for the valuable natural products they generate, their ability to remediate effluents and their potential as energy crops. Algal fuel, also called oilgae or third-generation biofuel, is a biofuel which is derived from algae. Switching to third generation biofuels, seems to be a promising source for the production of biofuels as algae are able to efficiently convert sunlight, water, and CO_2 into a variety of products suitable for renewable energy applications (Hu *et al.* 2008; Dismukes *et al.* 2008; Satyanarayana *et al.*, 2010). Algae are also low-input, high-yield feedstocks to produce biofuels. Thus, microalgae seem to be the source of renewable biodiesel that has the potential to completely displace petroleum-derived transport fuels without the controversial argument "food for fuel". Nowadays, due to increased concern over fossil fuels, energy security, greenhouse gas emissions, and the potential of other biofuel feedstocks to compete for limited agricultural resources, worldwide interest in microalgal biofuels is rising (Pienkos and Darzins, 2009). Although not yet achieved, the combination of accumulated knowledge from the past, regulatory actions and market needs, sustained the quest for microalgal production at large commercial scale (Vieira, 2014).

2. Selection, production and processing of microalgae

Several features of algal physiology are relevant for evaluating their possible incorporation into renewable biofuel applications (Christi 2007; Dismukes *et al.* 2008; Hu *et al.*, 2008). These attributes can be summarized as follows (Christi 2007; Dismukes *et al.* 2008; Hu *et al.*, 2008): Firstly, the solar energy yield with algae could be up to 6–12 times that of terrestrial plants as they are inherently more efficient solar energy converters. Their intrinsic solar energy conversion efficiency is greater than the theoretical maximum for crops (3-8%). Secondly, the absence of recalcitrant biopolymers eliminates the need for pretreatments to breakdown cellulytic products. Thirdly, their metabolic and ecological diversity allows selection of taxa that are adapted for growth in locally available aquifers or have morphological features that allow cost-effective harvesting. Fourthly, the biosynthetic control of chemical composition by nutrient and environmental stresses enable to manipulate their end-products.

2.1. Criteria used for the selection of algae strains

Thousands of forms of algae have been identified, but certain algae strains are more suitable for biofuels use than others. The characteristics of the strain should be taken into consideration along with the climate in which the algae will be grown. The following properties are required of algal species for biofuel production based on the Aquatic Species Program and the experience of other research in algal production (Edwards, 2010): Production of high and constant lipid content; Continuous Growth by overcoming the stability problem common to algae cultures; Demonstrates high photosynthetic efficiency; Grows with seasonal climatic differences and daily changes in temperatures; Creates minimal fouling from attachment to sides or bottom of containers; and Easy to harvest and to extract lipids with soft or flexible cell walls.

Based on these, many microalgal species have been identified as a suitable feedstock for biofuel production. Each species of microalga produces different ratios of lipids, carbohydrates, and proteins (Table 1). Since the bulk of the natural oil prepared by microalgae is in the form of tricylglycerols (TAGs), which is the right kind of oil for producing biodiesel, microalgae are the exclusive focus in the algae-to-biofuel arena (Wen, 2009). In order to achieve better economic performance, the lipid content in the microalga need to be raised (Xu *et al.*, 2006).

Moreover, the techniques for the culture and enhancement of oil-rich, promising strains of microalgae has been a particular interest in the development of feedstock (Rodolfi et al., 2009).

Table 1: Chemical composition of biofuel source microalgae (% of Dry Matter)
(Gouveia and Oliveira 2009; Matta *et al.*, 2010; Satyanarayana *et al.*, 2010; Sivakumar *et al.*, 2010)

Strain	Lipids (%)	Proteins (%)	Carbohydrates (%)
Chlorophyceae			
Chlamydomonas rheinhardii	21	48	17
Chlorella emersonii	29		
Chlorella minutissima	31		
Chlorella protothecoides	55	10-52	10-15
Chlorella pyrenoidosa	2	57	26
Chlorella vulgaris	14-22/56	51-58	12-17
Chlorella sorokiniana	22		
Dunaliella bioculata	8	49	4
Dunaliella primolecta	23		
Dunaliella salina	6	57	32
Dunaliella tertiolecta	28		
Ettlia oleoabundans	35–54		
Botryococcus braunii	25–75		
Haematococcus pluvialis	25		
Monoraphidium minutum	~52		
Scenedesmus dimorphus	16-40	8-18	21-52
Scenedesmus obliquus	35-55	50-56	10-17
Scenedesmus quadricauda	1.9	47	
Spirogyra sp.	11-21	6-20	33-64
Tetraselmis maculate	3	52	15
Tetraselmis suecica	15–23		
Cyanophyceae			
Anabaena cylindrical	4-7	43-56	25-30
Spirulina maxima	6-7	60-71	13-16
Spirulina platensis	4—9	46-63	8-14
Synechoccus sp.	11	63	15
Bacillariophyceae			
Navicula saprophila	~51		
Nitzschia closterium	27		
Phaeodactylum tricornutum	20–30		
Skeletonema costatum (Greville)	21		
Thalassiosira pseudonana	20		
Chaetoceros calcitrans	39	58	10
Chaetoceros muellerii	33	44-65	11-19
Rhodophyceae			
Porphyridium cruentum	9-14	28-39	40-57
Dinophyceae			
Crypthecodinium cohnii	20		
Euglenophyceae			
Euglena gracilis	4-20	39-61	14-18
Prymnesiophyceae			
Isochrysis galbana Parke	21–38	30-45	7-25
Prymnesium parvum	22-38	28-45	25-33
Labyrinthulomycetes			
Schizochytrium sp.	50-77	n.d	n.a.

2.2. Production of microalgal biomass

Producing microalgal biomass is usually more costly than growing crops. The cost can be minimized if microalgal biomass productions rely on freely available sunlight although there are daily and seasonal variations in light levels. From this point of view, tropical countries like Ethiopia with abundant sunshine could be an ideal place for the cost-effective production of microalgal biomass. In fact, Rodolfi *et al.* (2009) reported that *Nannochloropsis* sp. has the potential for the production of more than 30 tons of lipid per hectare per year in sunny tropical areas whereas only 20 tons can be produced under the Mediterranean climate.

Thus, for commercial scale production of microalgal biofuel, we need to use our ingenuity and take advantage of existing resources such as agricultural runoff, wastewater effluent, emissions from coal-burning power plants, and even leftover material from the algal biodiesel production facilities (*Casey, 2009*).

A geothermal-powered and -heated plant built for biodiesel production from algae oil is another fascinating achievement that represents a cost-effective approach (Wagner, 2007). Li et al. (2007) reported the feasibility of expanding heterotrophic Chlorella fermentation for biofuel production at the industry level in a bioreactor, and suggested that high cell density cultivation strategy in bioreactors might help further cut down the cost. These authors found out that the lipid content was sharply increased by metabolic engineering in the course of heterotrophic growth of *C. protothecoides*. The recently proposed novel approach that involves the use of engineered respiro-fermentative metabolism for the production of biofuels and biochemicals from fatty acid-rich feedstocks (Dellomonaco *et al.*, 2010) may be used for further improvements of the economics of microalgal biofuel production. The proposed respiro-fermentative metabolism enables the efficient synthesis of fuels and chemicals from fatty acids. With these packages, microalgal biofuel production will ultimately be the most efficient biofuel production, both in terms of land use and energy conversion (Chisti, 2007).

2.2.1. Cultivation systems

Currently, two main microalgal cultivation systems are adopted: open ponds and photobioreactors (Cazzola, 2010, Table 2). Despite many attractive features, third generation biofuel production systems do also have a number of less desirable aspects. To address these drawbacks, a number of research works have been made for decades. Microbial production of natural products has been achieved by transferring product-specific enzymes or entire metabolic pathways from rare or genetically intractable organisms to those that can be readily engineered (Keasling, 2010). Production of unnatural specialty chemicals, bulk chemicals, and fuels has been made possible by combining enzymes or pathways from different hosts into a single microorganism and by engineering enzymes to have new function (Keasling, 2010).

Hellingwerf and de Mattos (2009) have proposed the photanol approach: Light-driven conversion of CO_2 and water into biofuel can be achieved by combining the elementary reactions of photosynthesis and the Calvin Cycle with a fermentative pathway from a chemoheterotrophic microorganism in one single chimera (an organism with at least two genetically different tissues resulting from mutation, the grafting of plants, or the insertion of foreign cells into an embryo) (see Figure 1). This would circumvent the need for converting CO_2 into the complex mixture of biopolymers (protein, nucleic acids, cell walls, neutral and phospholipids, etc.) and then applying a series of subsequent processing steps to convert this complex mixture into a specific biofuel with consequent increase in the overall efficiency of the biofuel production process.

Table 2. Algae Cultivation systems (Olenyi, 2009; Cazzola 2010; Mata *et al.* 2010)

Open ponds (raceways)	Photobioreactors (PBR)
♦ Accounts for > 90% of current worldwide production ♦ less expensive to build and operate, more durable ♦ Subject to a difficult control of temperature (day/night, seasonal) and evaporative water loss ♦ Subject to contamination from predator strains ♦ Require larger amount of nutrients (N, P, K) and use more energy to homogenize nutrients and the water level cannot be kept much lower than 15 cm (or 150 L/m^2) for the microalgae to receive enough solar energy to grow.	♦ excellent for high□ value products and lead to more concentrated solutions ♦ >100 times too expensive for biofuels ♦ offer better control over culture conditions and growth parameters (pH, temperature, mixing, CO2 and O2), prevent evaporation ♦ Offer a safer and protected environment, preventing contamination or minimizing invasion ♦ Allow easier and accurate provision of nutrients (N, P) and need larger amounts of energy for mixing and to maintain temperature ♦ flexible systems that can be optimized according to the biological and physiological characteristics of the algal species being cultivated, allowing one to cultivate algal species that cannot be grown in open ponds.

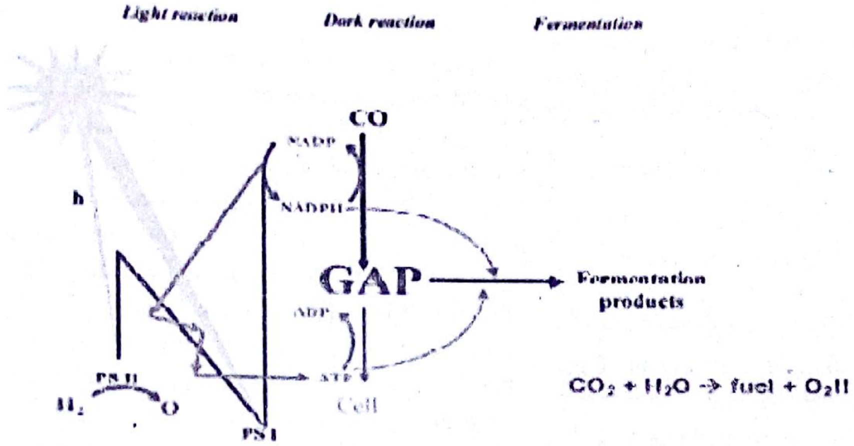

Figure 1: Schematic representation of Photanol process (Hellingwerf and de Mattos 2009)

2.2.2. Enhancing algal biology to improve production costs

Although biofuels made from microalgae hold the potential to solve many of the sustainability challenges facing other biofuels today, they are not economical to produce using the technology available and, the existing algal species could not be grown sufficiently cheaply and, at the same time, produce oil usable as a source of fatty acids for biodiesel (Ratledge and Cohen 2008). Based on conventional estimates, algal biofuels produced in large volumes with current technology would cost more than \$8 per gallon (in contrast to \$4 per gallon for soybean oil today) (Sheehan *et al*, 2008). Therefore, producing low-cost microalgal biodiesel requires primarily improvements of algal biology through genetic and metabolic engineering (Chisti, 2007). Concomitant use of tailor-made, rather than wild type, algal strains may shrink production costs to a level that could bring algal oil within reach of economic feasibility (Ratledge and Cohen, 2008).

The last few years have witnessed significant progress in the genetic engineering of eukaryotic algae. Transgenesis in algae is a fast-growing technology as selectable marker genes, promoters, reporter genes, transformation techniques, and other genetic tools and methods are already available for various species (Hallmann, 2007). Outstandingly, the commercial application of algal transgenics is beginning to be realized, and algal biotechnology companies are being established.

Genetic and metabolic engineering and transgenics offer the potential to increase the lipid productivity of microalgae and have impact on improving the economics of production of microalgal diesel (Sivakumar *et al.*, 2010). In this regard, many improvements have been realized, including increased lipid and carbohydrate production, improved H_2 yields, and the diversion of central metabolic intermediates into biofuels (Radakovits *et al.*, 2010). The transgenic *Chlamydomonas reinhardtii* is now being developed for various biotechnological applications, including the production of biohydrogen (Melis, 2002). In this species, mutant created by the genetic blockage of starch synthesis showed increased accumulation of lipids on a cellular basis during nitrogen deprivation. In an attempt to increase algal productivity through down-regulating expression of the light-harvesting antenna complexes in *C. reinhardtii*, the transgenic alga showed higher resistance to photo-oxidative damage with a concordant 30% increase in photosynthetic efficiency (Dismukes *et al.*, 2008). Another fascinating finding in this scenario is an engineered blue green alga (i.e. *Synechococcus leopoliensis*) equipped with the cloned bacterial cellulose synthase genes from *Gluconobacter xylinus*. This engineered alga produces extra-cellular deposits of non-crystalline cellulose, a polymer which is ideal as a feedstock for biofuel production of various alcohols (Hellingwerf and de Mattos, 2009). Furthermore, enhanced alcohol production via genetic engineering has been implemented in two independent cyanobacterial strains (*Synechococcus* sp.) through expression of pyruvate decarboxylase (pdc) and alcohol dehydrogenase II (adh) genes (Deng and Coleman, 1999). In general, molecular level engineering can be potentially useful to promote several desirable features of microalgae (Dismukes *et al.*, 2008): to increase photosynthetic efficiency to enable increased biomass yield; to enhance biomass growth rate; to increase oil content of biomass; to improve temperature tolerance to reduce the expense of cooling; to eliminate the light saturation phenomenon so that growth continues to increase in response to increasing light level; to reduce photoinhibition that actually reduces growth rate at midday light intensities that occur in temperate and tropical zones; and to reduce susceptibility to photooxidation that damages cells.

2.2.3. Scenedesmus obliquus as reference strain

The lipid content of *S. obliquus* is estimated at 40-55% DW of body mass (Table 1). Especially, the presence of palmitate and oleate as the main constituents the lipid in *S. obliquus* makes it an appropriate feedstock for biodiesel production (Mandal and Mallick, 2009). Like many other microalgal species, this species has the ability to manipulate its metabolism through simple manipulations of the chemical composition of the culture medium (Xin *et al.*, 2010b) with consequent high lipid productivity. Mandal and Mallick (2009) reported that lipid accumulation in *S. obliquus* could be improved under certain culture conditions. Optimizing nitrate, phosphate, and thiosulphate to maximize the lipid yield resulted in significant enhancement in lipid accumulation (Mandal and Mallick, 2009). Under N-deficient culture, the increase in lipid content reached 43% of its dry weight, in contrast to only 12.7% increase of the control (Mandal and Mallick, 2009). The likely explanation could be that under nitrogen limitations the existing nitrogen is utilized for production of enzymes and vital cell structures. Moreover, while the rate of production of all cell components is lower under nutrient malnourishment, oil production seems to remain higher, leading to an accumulation of oil in the cells (Sheehan *et al.* 1998). Therefore, any carbon dioxide subsequently fixed is converted into carbohydrate or lipid rather than protein. For instance, Sheehan *et al.* (1998) reported that under P-deficiency and thiosulphate supplementation, the lipid content increased up to 30% of the DW. Exposing algal cells to trace amount of ethyl-2-methyl acetoacetate (EMA) offers a feasible method to enhance the TAGs production in *Scenedesmus* sp. (Xin *et al.*, 2010a). Moreover, the growth and lipid accumulation properties of *Scenedesmus* species also show variation under different cultivation temperature (see Li et al. 2011).

Scenedesmus is also known to either take up or produce hydrogen gas depending on the partial hydrogen pressure. Hydrogen production occurs under anaerobic conditions both in the dark and in the light. Hydrogen production in the dark is supposed to be connected to fermentation. Wunschiers (2002) demonstrated the co-production of hydrogen and oxygen in anaerobic condition graphically as measured by gas chromatography (Figure 2). In the light, hydrogen production ceases directly and oxygen is produced by photosynthesis. In order to produce hydrogen in the bioreactor, the algae need to be anaerobically adapted. Adaptation to anaerobic condition can be done in two different ways: either by flushing the algae with nitrogen gas for 3 hours or placing them in the dark over night. In the former case the oxygen is simply replaced by nitrogen, in the latter the oxygen is used by the algae through respiration. After anaerobic adaptation, addition of some grams of sodium-dithionite to the culture is required so that it will remove the remaining oxygen and the oxygen produced by photosynthesis during the experiments. Although not yet clear, after anaerobic adaptation, it is postulated that changes of the redox environment activate the inactive hydrogenase, i.e. the thioredoxin affects the activity of the hydrogenase.

2.3. Types of microalgal biofuels and their processing

Microalgae can supply several different types of renewable biofuels such as biodiesel derived from microalgal oil (Sheehan *et al.*, 1998; Hu *et al*, 2008); biohydrogen produced photobiologically (Melis, 2002; Wunschiers, 2002); biomethane produced by anaerobic digestion of algal biomass (Spolaore *et al.*, 2006); bioethanol produced via fermentation and anaerobic digestion of the remaining algal biomass (Harun *et al.* 2010). The energy production from microalgal biomass involves biochemical, thermochemical, chemical, and direct combustion processes.

The first step in a conceptual process for producing microalgal oils is the production of microalgal biomass by using light, carbon dioxide, water and inorganic nutrients (Figure 3). The next step is the biomass-recovery stage, where the cells suspended in the broth are separated from the water and residual nutrients, which are then recycled to the biomass-production stage. In the third step, the algal oil is extracted from recovered biomass. Some of the spent biomass can be utilized as animal feed. In the fourth step, most of the biomass undergoes anaerobic digestion, which produces biogas to generate electricity. Effluents from the anaerobic digester are exploited as a nutrient-rich fertilizer and as irrigation water.

Most of the power generated from the biogas is consumed within the biomass-production process and any surplus energy is sold to grid. In this process, carbon dioxide emissions from the power generation stage are fed into the biomass production. Thus, ideally, microalgal biodiesel would be carbon neutral, as all the power needed for producing and processing the algae would come from biodiesel itself and from methane produced by anaerobic digestion of biomass residue left behind after the oils has been extracted.

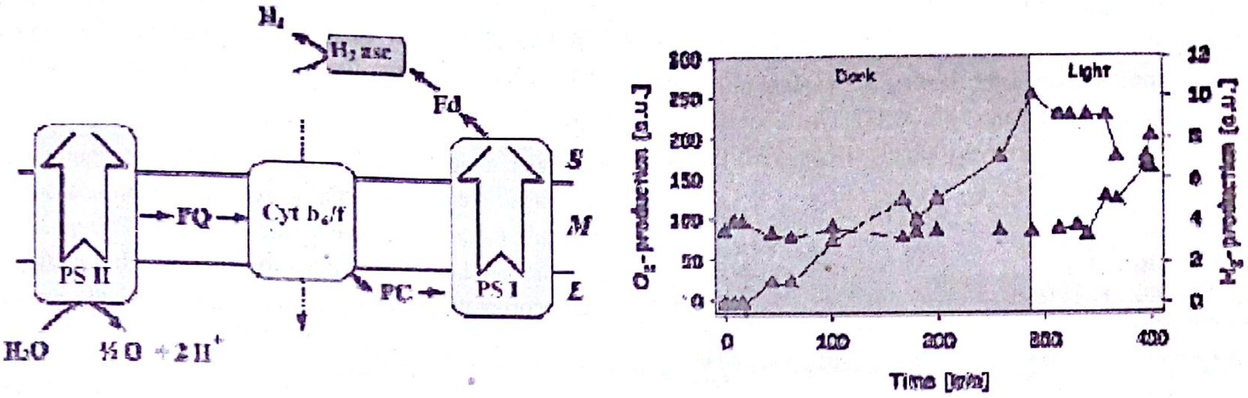

Figure 2: Representation of hydrogenase connection to the PSs (A) and H_2 production (B) (Wunschiers 2002)

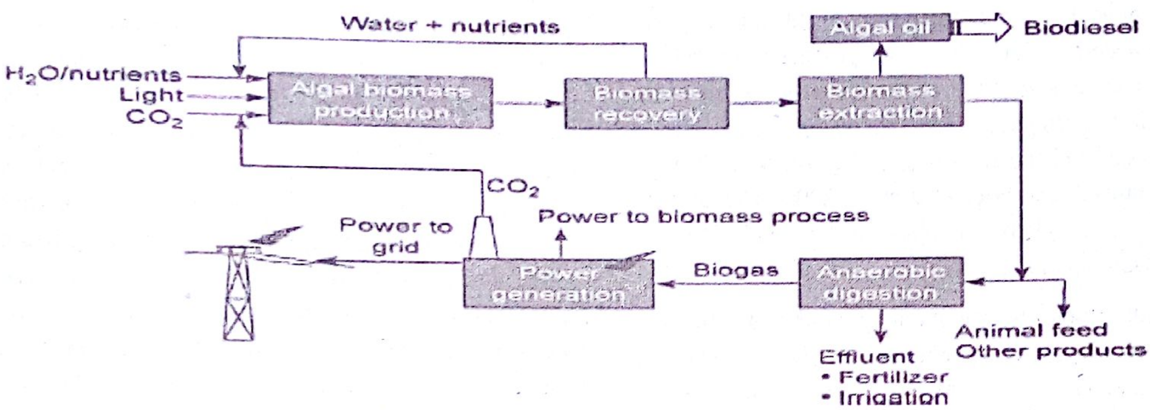

Figure 3: A conceptual process for producing microalgal products (Christ, 2008)

Oil productivity of many microalgae greatly exceeds the oil productivity of the best oil producing crops (Table 3). Moreover, while the lipid content of microalgae, on a dry cellular weight basis, varies between 20 and 40 %, lipid contents as high as 85 % have been reported for certain microalgal strains (Chisti 2007; Banerjee *et al.*, 2002). In an impressive contrast with the best oil-producing crops, biodiesel from microalgae seems to be the only renewable biofuel that has the potential to completely displace petroleum-derived transport fuels without adversely affecting supply of food and other crop products (Chisti, 2008). This is because algal ponds and bioreactors for algae production can be situated on non-arable land.

2.3.1. Microalgal biodiesel

One of the most efficient ways to prepare microalgal biofuel is through trans-esterification of the algal oils to produce biodiesel (Sheehan *et al.*, 1998). The biodiesel trans-esterification reaction is very simple (Deng *et al.*, 2009):

Biodiesel production involves mixing triglycerides, methanol, and catalyst (may be alkali such as potassium hydroxide or acid) in a controlled reaction chamber to undergo trans-esterification. The initial product is placed in a separator to remove the glycerine by-product; the excess methanol is recovered from the methyl esters through evaporation; and the final biodiesel is rinsed with water, pH neutralized, and dried (Xu *et al.*, 2006). Unlike petroleum fuels, the relative simplicity of biodiesel fabrication makes its production scalable. The residual biomass from biodiesel production processes, lipid-extracted microalgal biomass residues (LMBRs), is rich in carbohydrates and proteins. Thus, LMBRs are possible

Table 3. Yield per acre of various feedstocks

Source	Oil Yield	Area to produce
Corn	172	1540
Cotton	325	15002
Soyabean	446	10932
Mustard seed	572	8524
Sunflower	952	5121
Canola	1190	223
Rapeseed/Canola	1190	4097
Oil Palm	1892	2577
Jatropha	5950	819
Algae (10g/m^2/day	12000	406
Algae (50g/m^2/day	98500	49

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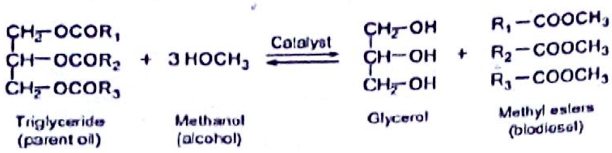

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The residual biomass from biodiesel production processes, lipid-extracted microalgal biomass residues (LMBRs), is rich in carbohydrates and proteins. Thus, LMBRs are possible substrates for dark fermentation to produce hydrogen. Yang *et al.* (2011) reported that it was difficult to directly convert LMBRs to hydrogen, probably because the complex oil extraction processes (dewatering, drying, destruction of the cell wall and extraction with solvents) caused them to resist biodegradation. They also argued that the thermo-alkaline pretreatment improved the LMBR solublization leading to an increase in hydrogen production. This form of converting LMBRs into hydrogen serves the dual role in renewable energy production and sustainable development of microalgal biodiesel industry.

Alternatively, the production of methane (CH_4) via the anaerobic digestion of microalgal biomass residues from the biodiesel production process has the potential to meet some of the energy requirements of the process of converting primary biomass to fuel. Otherwise, the residual biomass would be considered as waste with its disposal cost increasing the economics for biodiesel production from microalgae (Chisti, 2007). Therefore, the extraction of energy from the residual biomass could serve as a way to maximize energy production from microalgae, and reduce the overall process costs and wastes (Ehimen *et al.* 2009). Dimitrov (2007) also suggested that the non-lipid portion of the algal biomass may be an option for electricity generation. Furthermore, glycerol, the byproduct of biodiesel production through trans-esterification, can be used to produce hydrogen via anaerobic fermentation.

Biodiesel can be used as either direct substitute or as an extender to fossil diesel fuel in compression ignition engines and has the potential to reduce carbon dioxide, hydrocarbon and carbon monoxide emissions. The quality of the fuel product is equivalent to petroleum diesel and can be incorporated with negligible change into the existing fuel infrastructure (Campbell, 2008).

2.3.2. Biohydrogen from microalgae

Hydrogen gas is considered as a potential future energy carrier by virtue of the fact that it is renewable, does not evolve the CO_2 in combustion, liberates large amounts of energy per unit weight in combustion, and is easily converted to electricity by fuel cells. It is currently produced by fossil fuel-based processes which emit large amounts of CO_2, and relatively smaller amounts of other air pollutants such as sulphur dioxide and nitrogen oxides. Miyamoto (1994) noted that biological H_2 production has several advantages over hydrogen production by photoelectrochemical or thermochemical processes, and thus recently received renewed attention owing to air pollution and global warming concerns. Photosynthesis involves biological electrolysis; breakdown of water into hydrogen and oxygen. In normal photosynthetic pathway, the hydrogen is subsequently combined with carbon dioxide to form carbohydrate. But, in some algae and under certain special conditions, hydrogen is released instead of carbohydrate during photosynthesis (Sigfusson, 2007).

Several unicellular chlorophyta have the capacity to produce H_2 by using water and sunlight as an energy source (Figure 4). Nearly 70-years ago, Gaffron and Rubin (1942) discovered that green algae such as *S. obliquus* and *C. reinhardtii* could, depending on experimental conditions, either assimilate or photo-produce molecular hydrogen (H_2). They observed that the algae would sometimes switch from the production of oxygen to the production of hydrogen. But, they did not explain the mechanism for this change. In the late 1990s, Melis (2002) found that depleting the amount of sulfur available to the algae interrupted its internal oxygen flow, allowing the hydrogenase to produce hydrogen. Chochois *et al.*, (2009) described direct photolysis mechanism for hydrogen production in *C. reinhardtii* and discussed the possibility of sustainable production.

When *C. reinhardtii* cells are illuminated after adaptation to anaerobic conditions, electrons originating from water splitting at PSII are driven by the photosynthetic electron transport chain to ferredoxin and to a reversible iron hydrogenase, thereby enabling the production of H_2 from water and solar energy (Figure 4).

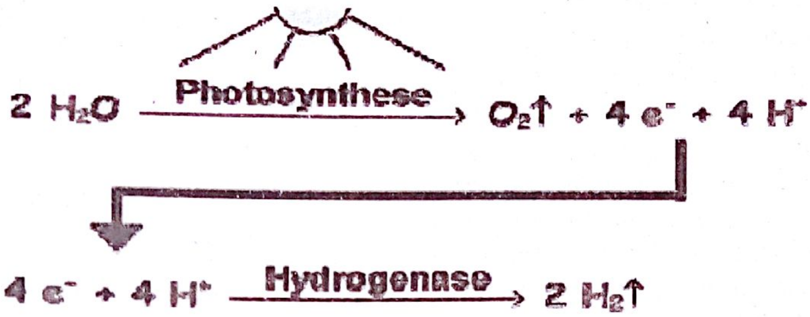

Figure 4. The reactions involved in photohydrogen production (Wunschiers, 2002)

2.3.3. Bioethanol from microalgae

Bioethanol, produced from renewable biomass such as sugar and starch materials, is believed to be one of the alternative energy sources, and it is currently being harnessed extensively. Nevertheless, the utilization of sugar and starch materials as feedstocks for bioethanol production creates a major competition with the food market in terms of land for cultivation, and this makes bioethanol from these sources economically less attractive. Harun *et al.* (2010) reported that microalgae (*Chlorococum sp.*) are suitable as a substrate for bioethanol production via yeast (*Saccharomyces bayanus*) under different fermentation conditions. In their study, Harun *et al.* (2010) found out that at the productivity level of 3.83 g L^{-1}, current production systems endorses microalgae as a promising substrate for bioethanol production.

2.3.4. Biomethanol from microalgae

The application of algae in search for sustainable renewable energy in the form of Biomethanol was proposed long ago. Golucke and Oswvald (1959) argued that hypothetical systems designed to overcome certain disadvantages of solar energy systems involved algae. According to Golueke and Oswvald (1959), the hypothesized systems involve the transformation of solar energy into the cellular energy of algae; the cellular energy of the algae would in turn be converted to the chemical energy of methane through the anaerobic fermentation of algae by bacteria. As a fuel, bio-methanol can either be blended with petrol, or it can be used as a feedstock for other environmentally friendly fuels.

Compared to other hydrocarbon fuels, burning methane produces less carbon dioxide for each unit of heat released. It is reported that, at about 891 kJ/mol, methane's combustion heat is lower than any other hydrocarbon; but the ratio of the molecular mass (16.0 g/mol) to the heat of combustion (891 kJ/mol) shows that methane, being the simplest hydrocarbon, produces more heat per mass unit than other complex hydrocarbons. Fermentation of Methane offers an effective means of pollution reduction, superior to that achieved via conventional aerobic processes.

3. Other Applications of microalgae coupled with biofuel production

Since the first use of microalgae (such as *Nostoc*) to survive during famine in China about 2000 years back (Spolaor *et al.*, 2006) and the first notion of application of microalgae in the production of biogas in fifties (Benemann, 2008), and later proposal as a source of different types of fuel, several application areas have been identified (Satyanarayana *et al.*, 2010). Combination of various applications like coupling the microalgal biomass production for biofuel with wastewater treatment and sequestering flue gases from industries will serve many purposes and can be more economical.

3.1 Microalgae in wastewater treatment

In wastewater-treatment facilities, microalgae can be used to reduce the amount of toxic chemicals needed to clean and purify water (Wen, 2009).)

This attribute is associated with the fact that the actively growing microalgae tend to be highly negatively charged on their surface and hence strongly adsorb polyvalent cations (Oswald, 2003). Thus, the algal biomass produced in the algal wastewater treatment ponds in relation to the concentration of heavy metals present in such systems can absorb and remove most of these metals from the system (Ramani 1974, cited in Oswald, 2003). Accordingly, microalgae can be cultivated in waste discharges to couple waste treatment with biodiesel production. Mandal and Mallick (2011) found out that in *Scenedesmus obliquus* the lipid pool accumulation was boosted to 1.0 g L^{-1} against 0.1 g L^{-1} for the control. Besides, the waste-grown *S. obliquus* showed an increase in the content of the saturated fatty acid pool, which is desirable for good-quality biodiesel. Therefore, wastewater fertilized algal pond offers multi-purposes: production of biomass for biofuel production; production of oxygen to support bacterial growth; nutrient uptake; adsorption of heavy metals and indirectly disinfecting water bodies. According to Oswald (2003), microalgal growth and CO_2 assimilation raises the pond pH to above 9 and dissolved O_2 concentration well above twice the saturation level resulting in the removal of coliforms and ova of parasites.

3.2. Microalgae in CO_2 mitigation

The huge amounts of potentially recoverable CO_2 released from industries and other various human activities necessitate the development of technologies for sequestering or, utilizing this CO_2. The microalgae are potential candidates for utilizing excessive amounts of CO_2, since when cultivated these organisms are capable of fixing CO_2 to produce energy and chemical compounds upon exposure to sunlight. CO_2 fixation by microalgae, coupled with biofuel production and wastewater treatment, may provide a very promising alternative to current CO_2 mitigation strategies. The photoautotrophic CO_2 fixation by algal cultures has the potential to diminish the release of CO_2 into the atmosphere, helping alleviate the trend toward global warming (Ono and Cuello, 2003). Microalgae are already known for their ability to fix CO_2 efficiently from different sources, including the atmosphere, industrial exhaust gases, and soluble carbonate salts (Wang *et al.*, 2008).

4. Microalgal biofuel production opportunities in Ethiopia

Ethiopia, as one of a fast growing country, needs to look for all possible alternatives of energy to meet its escalating demands. Since we have all the aforementioned merits and potential to develop microalgae biofuel, it would be valuable for the country like Ethiopia to embark in this industry. Above all, the country is located in tropics, receiving sunlight throughout the year, which is 'free' raw material for microalgal biomass production. Moreover, the freashwater bodies of the country are rich in microalgal species with biofuel production potential. Many of the Rift Valley Lakes harbor abundant population of algal species with this potential. For instance, *Scenedesmus* species are abundant in Lake Ziway (Wood and Talling, 1988) and Lake Chamo (Eyasu Shumbulo, 2004). They are also found in the largest lake of Ethiopia, Lake Tana, (Wondie Zelalem, 2013) and in some of the Debre Zeit Crater Lakes (Tamiru Gebre, 2006; Rediet *et al.*, 2014).

5. Promises and challenges in the algae-to-biofuel industries

Microalgal efficiency in converting solar energy (3-8%) into chemical energy, and production of higher biomass (20-60 $g/m^2/day$) and oil yield than conventional energy crops (only 0.5% efficiency with <10 $g/m^2/day$ yield) are good opportunities to embark on in this business (Lardon *et al.*, 2009). Owing to these features, recently worldwide attention is given to research activities related to microalgae and their production. The issue has attracted much courtesy of many scientists and government officials in a number of countries. Scientists are devoting much of their time in microalgal research and many governments are funding a considerable sum of money for projects related to microalgae (Francis 2006; Basque, 2009; IANS, 2010). Though many challenges remain in microalgal biodiesel production, more and more inventors are committed to believe that the rewards would eventually outweigh the risks and, so far, microalgae investments have reached over $900 million worldwide (Deng *et al.*, 2009).

Siobhan (2010) reported that aircraft runs on algal biofuel, which is a big promise/feedback to efforts made in the realm of algal research. He added that the use of algal biofuel made the aircraft 10% more efficient and fuel consumption was 1.5 liters per hour lower when compared to conventional fuel.

Although significant advances have been made in algal research and these have increased their industrial relevance, the application is still facing various challenges. Yet, significant scientific and engineering challenges remain to the full commercialization of microalgae-to-biofuel technology (Kumar *et al.*, 2010).

Once the biomass is produced, the next challenge is the dilute nature of microalgal culture, which puts a huge economic burden on the dewatering process of algal biomass especially on an industrial scale. Danquah *et al.*, (2009) found out that the tangential flow filtration concentrates the microalgae feedstock up to 148 times by consuming 2.06 kWh m^{-3} of energy reported to be better when compared to other methods. The latest finding reported by Matos *et al.* (2013) is to combine elctro-coagulation with centrifugation processes that proved to decrease significantly the energy demand for biomass recovery with >97% efficiency. But, still much lower energy consuming techniques are demanding. Furthermore, extracting and purifying oil from algae continues to be a significant challenge in producing both microalgal bioproducts and biofuel, as microbial oil extraction is relatively energy-intensive and costly (Mercer and Armenta, 2011). In this respect, developing economical and vigorous oil extraction and purification processes is a major challenge facing the microalgae to biofuel industries (Table 4).

The future trends of microalgal biofuel fate was summarized by Vieira (2014) as follows: the combination of Accumulated Knowledge, Regulatory Actions and Market Needs will sustain the quest for: microalgae for Food, Feed and Ceutical uses; specific biofuels from microalgae are possible; and research will continue its exponential growth.

Table 4: Some common extraction methods and their effectiveness at recovering lipids

Extraction Method	Organism	Recovered oil (%)	Fatty acid (% in Recovered oil)
wet milling	*Scenedesmus dimorphus*	25	
	Chlorella protothecoides	14.4	
Soxhlet	*Scenedesmus dimorphus*	6.3	
	Chlorella protothecoides	5.6	
French press	*Chlorella protothecoides*	14.9	
	Scenedesmus dimorphus	29.2	
solvent/saponification	*Botryococcus braunii*	12.1	oleic – 56.3 linolenic – 19.0
Bligh and Dyer (dry)	*Chlorella vulgaris*	25.5	
	Spirulina maxima	5.5	
	Mortierella alpina	41.1	oleic – 49.3; palmitic – 15.3
	Crypthecodinium cohnii	19.9	DHA – 49.5; palmitic – 22.9
solvent /transesterification	*Porphyridium cruentum*	59.5	EPA – 79.5
	Synechocystis sp.	7.3	palmitic – 59.2 oleic – 16.7
Solvent	*Phaeodactylum tricornutum*	96.1	EPA – 23.7; palmitoleic – 19.2
supercritical carbon dioxide extraction	*Spirulina platensis*	77.9	linolenic acid 20.2; palmitic 40
	Spirulina maxima	40	linolenic acid 13
	Nannochloropsis sp.	25	EPA – 32.1; palmitic – 17.8
	Crypthecodinium cohnii	8.6	DHA – 42.7; palmitic – 25.3
ultrasonic assisted extraction	*Crypthecodinium cohnii*	25.9	DHA – 39.3; palmitic – 37.9

6. Conclusions

Microalgal biofuels are promising to displace fossil fuels in light of their intrinsic efficiency to convert solar energy into chemical energy, and their significantly higher potential yield of oils suitable for biofuel production than terrestrial crops. A number of achievements in genetic and metabolic engineering of algal strains to optimize their production costs have been recoded during the last few years. In addition, many technical aspects have been upgraded in the course of algal biomass production and biomass processing techniques to yield biofuels. Yet, the production cost is challenging the efforts of algae-to-biofuel industries.

Nevertheless, owing to the current growing concern over fossil fuels, energy security, greenhouse gas emissions, and the potential of other biofuel feedstocks to compete for limited agricultural resources, there is mounting world-wide interest in microalgal biofuels. Therefore, employing engineered/transgenic strains in ponds or photobioreactors, accompanied by efficient harvesting /dewatering/ concentrating techniques and oil extracting mechanisms, microalgal production can be scaled-up to industrial level.

Furthermore, the availability of plenty of sunshine and favorably high temperature in the tropics, may favor the production of hydrogen in a low-cost system in a closed photobioreactor. Especially in the landlocked countries like Ethiopia, where there are "thirteen months of sunshine", the contribution of this to the economy should not be underestimated.

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Flood Water Management in Yanda-Faro Spate Irrigation System, Konso, Ethiopia

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Abstract

Life in a water scarce environment is challenging and crop production in such environment is unsustainable. In Konso, Yanda-Faro spate irrigation system, which is considered for this case study, is one of the areas with an arid climate in SNNPR State of Ethiopia. In Ethiopia in general and in the study area in particular, spate irrigation is foreseen as potential to reduce poverty and establish food security. This study focuses on understanding flood water management and the associated problem of crop production and livelihood improvement of the Yanda-Faro spate irrigation farming community. The research was done by involving both quantitative and qualitative data analysis based on available primary and secondary data. Livelihood improvements of the community and flood water management for spate irrigation were examined by structured questionnaires. Systematic soil and water analyses were also conducted to determine the impact of salinity and sodicity on sorghum and maize yields and the infiltration rate of the irrigated fields. The study revealed that the livelihood of Yanda-Faro spate irrigation farming community is based on agricultural activity which is influenced by rain fall availability at upstream for its flood water. To cope with the challenge of flood water management the farmers introduced key water management of water rights and rules and an effective enforcing organizational structure. The farmers" organization was effective in mobilizing the resources and in executing the maintenance work; protecting the rights of the downstream farmers and mitigating conflicts. In this study it has shown that the irrigated soil does not have yield loss due to soil salinity problem. Nevertheless, both crop production and livestock development characterized as poorly intensified and productivity is kept to a minimum.

1. Introduction

1.1. Background

Spate irrigation is a flood water harvesting and management system. The flood water is usually generated by heavy rainfall in upper catchments. In spate irrigation system, flood water from mountain catchments is diverted from river beds (wadie's) and spread over irrigated areas. Spate irrigation is practiced in parts of Africa, the Middle East, West India and Latin, America FAO (2011) irrigation and drainage paper 65. The uncertainty comes both from the unpredictable nature of the floods and the frequent changes to the river courses and beds from which flood water is diverted. Besides providing irrigation, the flood water in the spate system can recharge shallow aquifers (especially in river beds), they fill ponds and in some areas are used to spread water for pasture or forest land. Spate irrigation system requires strong local cooperation and agreement on how to distribute the common good which is unpredictable and uneven. The short duration floods on which it is based are often forceful in nature, requiring special techniques and special organization to manage and distribute the water.

In spite of the fact that spate irrigation is the oldest irrigation system dating back to 70 centuries, and it has been used until today as an important source to support the livelihood for the most marginal communities in Ethiopia and several other developing countries, it has received little attention from development agencies and researchers (Avelino, 2012).The importance of spate irrigation can not to be underestimated since it is the only method of irrigation in several areas for achieving sufficient crop yield.

1.2. Problem of Statement

In Ethiopia spate irrigation is recently promoted by the government and farmers' initiatives. Feasibility studies suggest that it can support many farmers in large command areas. Given the high relevance of food security for Ethiopia in general and for the study area in particular, spate irrigation is foreseen as having potential to reduce poverty and establish food security. Understanding the local irrigation practices and the major water management related elements and processes in the spate irrigation system; the approaches and participation of the community in the design, layout, construction, operation and maintenance of the infrastructure as well as the nature of land and water use rights and their enforcement mechanisms. Therefore, research focuses on understanding probassociated with operation and maintenance of existing structures of the system, water and land distribution and problem of soil salinization and sodicity in the spate irrigated field and livelihood basis of the community Yanda-faro spate irrigation command area is required.

2. Research Objectives

The general objective of the study was to assess and analyze the flood water management problem for crop production in Yand-afaro spate irrigation scheme and the livelihood opportunities of the community.

The specific objectives were

- To investigate soil physical and chemical property of Yanda-Faro spate irrigation command area.
- To understand rights and rules that entitles water and land to users of Yanda-Faro spate irrigation system.
- To understand the existing floods water management and water distribution in Yanda-Faro spate irrigation system. To evaluate livelihood opportunities of Yanda -Faro spate irrigation users.

3. Materials and

3.1. Description of the Study Area

The Konso, Yanda-Faro spate irrigation is found in the Konso woreda in Konso, SNNPRS, and is situated at $5^0 15'$ N latitude and $37^0 30'$ E longitude. Konso is bordered on the south by the Oromia Region, on the west by the Woito River which separates it from the Debub Omo Zone, on the north by the Derashe woreda, and on the east by Burji woreda. Based on the 2007 Census conducted, this woreda has a total of 44,902 households with a total population of 235,087, of which 113, 412 are men and 121,675 women (CSA, 2007). Konso has semi-arid and arid agro climatic condition with average monthly rainfall ranging from 13.97 to 53.18 mm and mean

daily temperature of about 28^0C. The livelihood of the Konso people is mostly based on agriculture and thus, crop production, animal husbandry and marginal trading are dominant economic activities.

3.2 Data Collection

This research involved both quantitative and qualitative data analysis of primary and secondary data sources. Field test and laboratory observations, were used to generate soil information and interviews, and focus group discussions were used understand the technical, institutional and legal framework of the Yanda-Faro spate irrigation system.

3.3 Field Test and Laboratory Observations

The soil physical characterization such as infiltration rate, textural classifications, bulk density, soil moisture holding capacity analysis were done by conducting field and laboratory measurements.

3.4 Laboratory observation of soil samples

The laboratory soil analyses were divided into two, the physical and chemical (salinity and sodicity) analysis. The physical analysis was conducted for the determination of soil water holding capacity, bulk density, porosity, and texture classification. Soil chemical analysis was conducted for checking soil reaction (salinity and sodicity).

3.5 Laboratory observations for soil physical properties

For this purpose soil samples from six sample points were collected – two in each of the upstream, midstream and downstream spate irrigation command area. For the determination of the dry bulk density undisturbed soil samples (at consecutive depths, 0-30cm, second 30-60cm and 60cm -1m depth) were used. The samples were collected using core samplers of 582-1046cm^3 capacity. The soil samples were saturated and weighed, then oven dried and again weighed. The water holding capacity (porosity) of the soil of Yanda-Faro spate irrigation command area was obtained using the gravimetric method, using wet mass of soil sample and mass of oven dry sample. The total porosity of the soil was determined by using the following relations:

$$n (\%) = 100*(1-Bd/Pd)$$

Where n is the porosity of the soil; Bd is the bulk density g/cm^3 and Pd is particle density g/cm3 where is approximately 2.65g/cm^3

The dry bulk density of the soil samples was determined

using the following relations

$$\rho_{bd} = \frac{M_{ds}}{V_T}$$

Where ρ_{db} is dry bulk density of the soil sample in g/cm3, M_{ds} is the mass of the dry soil sample in gm, V_T volume of soil cm^3

The soil texture of the Yanda-Faro spate irrigation command area was carried out using hydrometry method in laboratory. For this purpose soil samples from six sample points were collected – two samples in each of the upstream, midstream and downstream irrigation zones. At each sample point, two samples were collected each from the topsoil (0 to 30 cm depth) and the sub-soil (30 cm to1m depth). Then each soil sample was mixed thoroughly to form composite sample for the topsoil and the sub-soil. They were then subject to the standard procedure of the hydrometer method.

3.6 Laboratory observations for soil chemical properties

Soil samples were collected from 34 different sample points in spate irrigation command area from depths of 0-30 cm, 30-60 cm, and 60cm-1m at each point. The cations of the soil of the irrigated field were determined using flame-photometry, electric conductivity (EC) meter and titration methods U.S Salinity Laboratory staff (19540). Chemical quality (salinity and sodicity) of both surface and subsurface was analyzed.

To determine the soil salinity, soil samples from 34 sample points at 400m intervals were collected. Each soil sample was mixed thoroughly to get saturated paste extract. Putting on mechanical shaking machine for an hour for two hours, the saturated paste was extracted and the electric conductivity of the extract was determined with an EC -meter, calcium and magnesium ions by using titration method and sodium ion done using flame photometry techniques.

3.7 Group Discussion

Discussion with water user association and users has been used to prepare the flood water management system, land sharing and flood sharing system aspect of the study.

3.8 Interview

Randomly selected households were interviewed using structured questionnaires. Depending on the beneficiaries of Yanda-Faro spate irrigation alone and both Yanda-Faro spate irrigation and Segen-Sewate small scale irrigation, the respondents were stratified and a total of 265 households were interviewed. That is, after the stratification, 58 households from Yanda only users and 207 households from the users of both systems were randomly selected for interview from 3 villages, viz., Jarso, Dara and Birbirsa.

For unbiased data collection and smooth communication, it was decided to hire three enumerators who speak the local language. Therefore, three enumerators and one field coordinator were hired to complete the household interviewing. They were trained on code of conduct for data collection and interview approaches.

Yanda-Faro spate system users are unique in that majority of beneficiaries have farms in the Segen and they produce their crop by using Yanda spate irrigation and Segen small scale irrigation. Hence to examine livelihood of the Yanda spate irrigation user it required to interview the household that use only the Yanda spate system.

3.9 Data analysis

The data obtained from household survey through structured questionnaire were edited, coded and entered into SPSS (version 16) software for analysis. Descriptive statistics such as percentage, frequency, mean, maximum and minimum were used to analyze the data.

4. Results and Discussions

4.1. Physical and Chemical Properties of the Soils of Yanda-Faro Spate Irrigation Command area

4.1.1. Soil texture

Table1 the soil textural class's ofYanda-Faro farm

Most of the relatively coarser sediments might have settled in the upstream catchment of Yanda. This may be the reason why the silt content of the Yanda spate irrigation area is higher. The results obtained indicated that the top-soil samples taken from the Oneya (upstream), potota (midstream) and Tarakohoma (downstream) fields were found to be predominantly silty clay loam and silt loam whereas all the sub-soil samples were silty loam and silty clay.

Table1: the soil textural class'sofYanda-Faro farm

Upstream Oneya fields	% Sand	% Silt	% Clay	Texture class
Topsoil sample	19.28	59.28	21.24	Silt loam
Sub-soil sample	23.28	71.28	5.44	Silt loam
Midstream Potota field				
Topsoil sample	3.28	45.28	53.44	Silty clay
Sub-soil sample	9.25	51.28	39.47	Silty clay loam
Downstream Tarakohoma field				
Topsoil sample	21.28	68.28	3.92	Silt loam
Sub-soil sample	7.28	33.28	59.44	Clay

4.1.2 Dry bulk density

The dry bulk density, total porosity and the water content at saturation obtained by the methods and procedures discussed in the below are presented in Table 4.2 Saturation level corresponds to a 100% occupation of the total porosity with water. The results also indicate that the silty loam texture of the soil does not affect the overall water holding capacity of the whole irrigation field.

A bulk density of 1.6 g cm^{-3} affects root growth and of 1.8 g cm^{-3} severely restricts it. All the assessed Yanda fields have bulk densities lower than these values.

Table 2: Dry bulk density and porosity for Yanda-Faro irrigated area

Selected field and their texture	Bulk density (g/cm^3)	porosity (%)
Upstream Oneya fields		
Topsoil sample	1.2585	52.45
Sub-soil sample	1.31	45.1
Midstream Potota field		
Topsoil sample	1.111	53.05
Sub-soil sample	1.169	55.7
Downstream Tarakohoma field		
Topsoil sample	1.162	56.15
Sub-soil sample	1.217	54.05

4.1.3. Soil salinity and sodicity

Table 3 shows Measured cations concentration, SAR,Ec and ESP values in meq/l of Yanda-Faro soil samples of the saturation paste extracts of soil samples and sodiumcation from flame photometry.

Salinity and sodicity are among the major problems threatening the sustainability of irrigated agriculture; particularly in the arid and semi-arid regions of the world to which the Yanda-Faro area belongs. Generally, in irrigated areas, these salts often originate from a saline, shallow groundwater table (within 2 to 5 m of the surface), or from salts in the applied water.

There is agreed perception among the majority of the farmers and irrigation specialists that the flash floods supplied by the Yanda river is a source of good quality irrigation water, which does not cause soil salinization and sodicity to a level that would reduce the crop yield and limit soil infiltration rate.

4.2. Yanda-Faro Spate Irrigation Management System

4.2.1 The existing field water management practices

There are three improved intakes and a lot of unimproved diversions in Yanda-Faro spate system.

On the command area water is distributed through a well-laid network of main, secondary and tertiary canals. The shape of the main canal is rectangular, narrow and high. The preference of Konso farmers for this shape of canals relates to low sedimentations were taking place in the fast flowing canals.

A traditionally established farmers association is made responsible to assure equitable distribution of water within the canal network. Flood water isusually released into the fields surrounded by field bunds through the tertiary canals for about three hours and retained there for three to four days in order to let the water infiltrate into the soil. Field bunds are typically 40 to 60 centimeters high. The height of the bunds is fixed traditionally by farmers with the aim of holding as much water as possible.

Table 3: Cation concentration and salinity

Field category	Average sodium ion (Na^+) for	Average Calcium ion (Ca^{++})	Average Magnesium ion (Mg^{++})	Total cations	Average SAR	Averag e ESP	Ec (dS/m)
Upstream	14.95	47.17	23.86	85.99	2.83	2.82	0.416
Midstream	14.24	26.69	12.84	52.77	3.4	3.58	0.234
Downstream	18.33	76.49	26.24	121.4	3.12	3.21	0.69

It could be more effective if the height of the field bunds is fixed/designed considering the intake rate of the soil, and the stability of the bund under different water depths

4.2.2. Institutional set up and community management of spate irrigation in Yanda-Faro

In the studying area of Yanda-Faro spate irrigation, community manages their spate system under technical and financial support of EEMY-SWS. EEMY-SWS is a country based non-governmental organization, has been carrying out a number of integrated development activities, which include improving intakes, capacity building, specialized supplying, seedling production, different demonstration sight development, community water supply development in its program of Yanda-Faro Segon-Sawate Food Security Project.

Before improve intakes are constructed, all the beneficiaries are organized under their strong traditional organization system that is similar of Water User Association (WUA). After 1990 all the above local administration system tended to change in modern WUA systems. It is started after construction of improved intakes. Today all the users' are organized into committees, groups and subgroups. For each improved intakes 26 member of committee established, this committee has different sub groups: administration, purchasing, selling, judge, supervision sub -committee.

The major tasks of a sub-group leader are: mobilizing and supervising a team of farmers to work on main structures; implementing water distribution rules; reporting water related and other social conflicts; and messages and requests from individual farmers to the group leader. All main committee members are selected from users and divided into sub-groups and together form a committee of WUA, Which decides on, among other things: when and how a construction and maintenance of a structure should be done; the allocation and distribution of water.

4.2.3. Operation and maintenance system of Yanda-Faro spate infrastructure

Each flood flow has to be efficiently diverted in time with no or minimum damage to irrigation structures and canals networks while avoiding flow of water to loss. This is the first main objective of operation task for the Yanda-Faro farmer. The second main objective is that after each improved diversion of Yanda, the flood water has to be distributed to their farmlands within the command area of the Yanda-Faro. Similarly, maintenance of a system is another important management task for diversion weirs, irrigation structures and canal networks for Yanda-Faro farmers.

The more equitable distribution of water that comes with it makes collective work on maintaining the channel network in principle less problematic. In Yanda-Faro on each canal a small committee (usually three persons) is in place that handles the maintenance. Every year field bunds are maintained or renovated by removing the deposited silt and pushing it to the border.

4.2.4. Relationship between water rules and maintenance

The links between the water rights and rules, and the organization and execution of maintenance tasks in Yanda-Faro spate irrigation systems, were based on one's contribution to maintenance of main and branch canals and structures. If one fails to contribute in maintenance, he will be punished by WUA and but to be allowed to irrigate his field. Contributing labour was not a prerequisite for preserving one's water right. The minimum amount of labour and materials or money needed for maintenance. The fact that tail-end farmers were interested in sharing the burden of maintenance only if they would not systematically be deprived of their water right, made 'the critical mass factor' vital for serving as a check on an inequity in water sharing.

4.3. Land Ownership

4.3.1. Rights and rules on land demarcation

Demarcation rights and rules define the boundary of the area entitled to irrigation and set priorities to access water depending on the year of establishment of the different fields. Among others, changes in the course of rivers, breaching, silting up or scouring of canals, and rising of fields above irrigable command levels are frequent and can occur on a yearly basis. They often protect the prior rights of downstream landowners by restricting or even prohibiting new land development upstream, which could have resulted in the diversion of flood water to new territories and a redefinition of the group of shareholders.

4.3.2. Land sharing system in the community

Land distribution system in Yanda-Faro spate irrigation had done by strong local administration system in the area on communal land.

If the land was owned previously by private owner, then the administration has no right to distribute. If anybody that needs farming land near Yanda course then application is submitted to their established WUA that administrate a given intake administrations. Each association has seven committee that authorize land distribution, equitable water distribution, maintenance and operation activity for the intakes and canals that are whether improved or unimproved. This association has high responsibility to follow each activity flood irrigation system. They punish if anybody refuses to clear canals and maintenance of the systems or violet their flood irrigation turn or breaches by-laws.

Each farmer has land on upstream, middle and downstream (tail) irrigable area on the flood water conveyance systems. That means, one farmer has a piece of land on head, middle and tail part of a canal. This system of land sharing has advantages on equitable sharing of flood water. If the flood is short and stop after irrigation areas near the intake, then all of the farmers will get flood on their first plot. If the flood is enough for irrigating the head and middle areas and stops then everybody gets flood on first and second plot of land.

4.4. Livelihood Opportunities of the Yanda-Faro Farming Community

All Yanda-Faro community depends on agriculture for their livelihoods. As a result, agricultural production and productivity is highly influenced by rainfall availability and distribution in Yanda catchment, which ultimately controls the crop yields.

4.4.1. Structure of the households

Based on the sampled interviewers of 58 house hold heads in the Yanda community, the HHHs are at 100 % male and their mean age is 37years old. The HHHs are relatively young as 32 % of them are below 30 years old and 68 % of them are below 40 years.

With regard to education, 84.2 % of the HHHs have never attended school but 15.8% have received more than 7^{th}grade education.

5. Conclusions

This study focused on the analysis of flood water management for spate irrigation, livelihood practices and soil characterization for a better infiltration, soil texture, bulk density, soil water holding capacity, salinization and sodicity problem The study was developed for the Yanda-Faro spate system to enhance soil and water management experience. Some conclusions from this study are produced as follows:

- Collectively, the water rights and rules create a perception of fairness of water distribution between the upstream and downstream farmers, thus generating an atmosphere of cooperation between them. To perform these tasks, however, the water rights and rules must be observed by the majority of the farmers.
- The water distribution and maintenance is operated by local water rights and rules and they are sufficient
- Agriculture is the main economic and livelihood base in my study area, however both crop production and livestock development characterized as poorly intensified and productivity is kept to a minimum.
- The midstream irrigated fields have averagely silty clay soils. Its basic infiltration rate is 18mm/hr. which can be moderately slow class
- Unlike in perennial irrigation, in spate irrigation systems in, the water application period and the crop production season are not the same.
- The soil bulk densities of the fields are less than 1.5 g cm-3, which does not hinder root development.
- In the Yanda-Faro, however, salinity measurements conducted in thirty four randomly selected fields: Hence, it may be assumed that the actual irrigation field couldn't have yield reductions and no threat that minimize yield loss.

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Optimizing Reservoir Operation Policy Using Chance Constraint Non Linear Programming for Koga Irrigation Dam, Ethiopia

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Abstract

One of the typical problems in water resource systems modeling is the derivation of an optimal operating policy for reservoir to ensure water is used more efficiently. A reservoir operating policy is a sequence of decisions in operational periods specified as functions of the state of the system defined by the reservoir storage at the beginning of the period and the inflow to the reservoir during the period. This paper presents an optimization analysis to determine monthly operating policies for five scenarios of predetermined cropping patterns of the Koga irrigation scheme, Ethiopia. The objective function of the model was set to minimize the sum of squared deviation (SSD) from the desired targeted supply. Reservoir operation under different water availability and thresholds of irrigation demands has been analyzed by running a chance constraint linear programming model based on uncertain inflow data. The model was optimized using Microsoft Excel Solver. Based on reliability, vulnerability and SSD performance indices, the most reliable and the least vulnerable models at minimum thresholds of deficit irrigations were identified. It was concluded that the reservoir water was not sufficient enough to meet 100% of irrigation demand for all specified cropping patterns at 48% of irrigation system efficiency. The design command areas of 7000 ha could only be irrigated at 30% deficit irrigation if environmental flow is permitted for downstream areas and at 20% deficit if environmental flow is not permitted. The study also illustrated that the simplicity and flexibility of Microsoft Excel Solver in efficiently optimizing the dynamic operation policy for varying water supply and demand conditions. Therefore, the developed model could be used for real time reservoir operation decision making. Finally it was recommended to test the application and conveyance efficiency of the irrigation system.

Keywords: Exceedance probability; Nonlinear programming; Performance measures; Reservoir operation policy; Sum of square deficit

1. Introduction

Management of reservoir systems from planning to operation is very challenging for water resources planners and managers since the problem deals with many complicated variables such as storages, inflows, demands, etc. as well as considerable risk and uncertainty. The stochastic nature of reservoir inflows adds greatly to the complexity of the problem (Taghi *et al.*, 2009). In cases where real time operating policies are required, the decision makers face an even greater challenge in handling updated reservoir inflow forecasts (Fayaed *et al.*, 2013). Therefore, derivation of an optimal operating policy for reservoir to ensure water is used more efficiently is one of the classical problems in water resources systems modeling.

Real-time operation of river–reservoir systems requires specific operating rules. These rules are guides for water conservation and release policies prepared for reservoir operators. Several types of rules range from very simple and static to dynamic for considering the varying states of inflow and physical characteristics of a reservoir in each time period. One of the simplest rules for reservoir operation is the rule curve, which specifies the target storage at the end of each month (Karamouz *et al.*, 2003).

However, rule curves are static forms of operating policies that do not get any feedback from reservoir storage and current hydrologic situations such as predicted inflows to reservoirs in the following months (Karamouz *et al.*, 2003). Hence, rule curves are not very efficient policies, particularly when inflows and demands are highly varied, but they have been widely used because of their simplicity. Moreover, rule curves prescribe reservoir releases based on limited criteria such as current storage levels, season and demands (Khare and Gajbhiye, 2013).

In general, rule curves, do not allow a fine-tuning (and hence optimization) of the operations in response to changes in the prevailing conditions (Husain, 2012). Application of deterministic and stochastic optimization models for reservoir operation has led investigators to define non-static types of operating rules/policies (Jothiprakash and Shanthi, 2006; Karamouze, 2003; Singh, 2012).

The operating policy is a set of rules for determining the quantities of water to be stored or released from a reservoir or system of several reservoirs under various conditions (Wrubs, 2005). In reservoir operating policies, the decision variable (release) depends on variables representing the state of the system for each month, including: inflow to the reservoir, water demand, storage at the beginning of a month and inflow forecast for the next month (Karamouz *et al.*, 2003; Vedula and Mujumdar, 2005).

Therefore, the operation policies in optimization models are like the contents of a table in which various combinations of characteristic values for a state variable and the optimal release are presented in each row (Karamouz *et al.*, 2003). To define reservoir operating policies, several optimization models were used in the past. Linear programming (LP) model was used to evaluate the optimal performance of the Dam based on reservoir inflows (Sattari *et al.*, 2013).

A chance-constrained LP model was used for short term reservoir operation (Duranyildiz *et al.*, 1999). Monthly storage yield functions were developed using Stochastic Dynamic Programming Model (Ananda and Shrivastava, 2013). Sattari *et al.* (2009) investigated the efficiency of the dam release for irrigation and municipal water need. Stochastic dynamic programming (SDP) model was used to obtain optimal operating policy (Baliarsingh, 2010). Hajilal *et al.* (1998) developed Dynamic Programming mode for real-time reservoir operation. Genetic Algorithm and Excel Optimization Solver were used for optimal short term cascade reservoir operation (Asfawa and Saiedi, 2011).

Although many successful applications of optimization techniques to reservoir operation studies have been reported in the literature, no universally proven technique exists (Husain, 2012). Nandalal and Bogardi (2013) also added that there is no general algorithm for all reservoirs, and is to be tackled independently for developing the optimal operating strategies. Hence, reservoir operation still remains an active research field (Husain, 2012).

Dynamic programming also becomes computationally bounded on problems of moderate size and complexity. Linear programming cannot be applied when either the objective function or the constraints become non-linear. Due to complex relationships among different physical and hydrological variables or because of specific objectives being served by system (Rani and Moreira, 2010), nonlinearity exists in various reservoir systems operation problems.

Moreover, as future inflows or storage volumes are also uncertain, the challenge is to determine the best reservoir release or discharge for a variety of possible inflows and storage conditions (Loucks and Beek, 2005). Because of the uncertainty of inflows and non linearity of the reservoir systems, a chance constraint non linear programming (CCNLP) model which uses the statistical behavior and distribution of the inflows should be applied for development of optimal reservoir operation policy.

To illustrate the application of the CCNLP, the Koga irrigation reservoir in Ethiopia was selected. This reservoir has been operated using non-optimized fixed guiding curves relating reservoir water level and volume versus irrigable area (MM, 2008) and operator's subjective judgment. As a result reservoir water has been irrigating below 73.5% of design command areas which implies that either the reservoir water is mismanaged or insufficient to irrigate all command areas.

Moreover, as cropping pattern varies year to year in the Koga irrigation scheme due to farmers' preferences, socio-economic factors and government directives, the amount of reservoir releases varies too. Under these circumstances, development of dynamic optimal reservoir operation policy is mandatory.

Therefore, the objective of this study is to develop optimal reservoir operation policy for Koga Irrigation reservoir using a chance constraint NLP model. This would enable decision makers or reservoir operators to stipulate the desired monthly reservoir releases as a function of varying water supply and demand conditions.

2. Materials and Methods

2.1. Description of the Study Area

The Koga Irrigation dam is located at 37°08' E and 11°20' N, South of Lake Tana in the Blue Nile River Basin, Ethiopia (Figure 1). The Koga Dam is semi homogeneous earth fill dam of which its catchment lies in the Tana Basin between 11°10' and 11°22' North Latitude and 37° 02' and 37°17' East Longitude, and covers an area of 22,000 hectares at dam site (MM, 2004). The general characteristics of Koga Dam and irrigation scheme are summarized in Table 1.

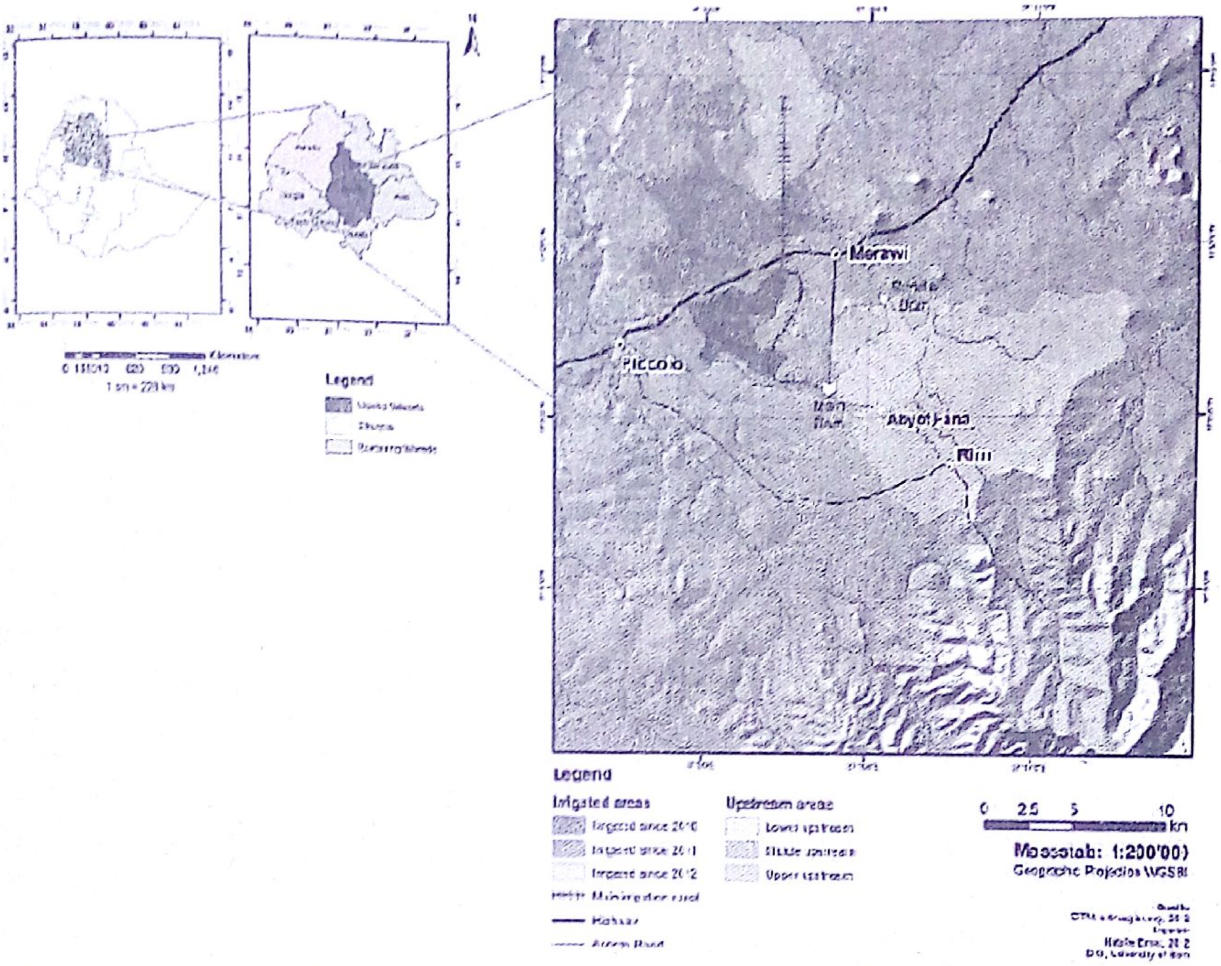

Figure 1: Koga Irrigation and Watershed Management Project, Ethiopia (Own and adopted from Ernst (2012)

Table 1: Koga irrigation scheme characteristics (MM, 2004)

Scheme characteristics	Magnitude
Catchment area	22,000 ha
Dam height	21 m
Dam crest length	1730 m
Reservoir area	1,750 m
Reservoir capacity	83.1* $10^6 m^3$
Irrigation area	7000 ha
Beneficiary family head	1400
Main canal discharge	9.1 m^3/s
Environmental release	1 m^3/s
Spillway discharge	335.4 m^3/s

2.2. Irrigation and environmental water demand

Reservoir operation model requires estimates for reservoir inflows, irrigation and environmental water demands, evaporation and conveyance losses. Expected monthly inflows into the reservoir at 90%, 80%, 70%, 60% and 50% probability of exceedence (ρ) were estimated from the distributions fitted using Cumulative Frequency Program (www.waterlog.info). Irrigation water demand was estimated using CROPWAT 8:0 for five scenarios (I, II, III, IV and V) of specified cropping patterns of maize, wheat, potato, onion and pepper (Table 2). These cropping patterns of scenario I to IV were determined using a chance constraint linear programming (CCLP) model. Scenario V is the irrigation project's design cropping pattern (MM, 2006). Environmental compensation release values are shown in Table 3.

Table 2.Cropping patterns in hectares for different scenarios

Scenarios	Maize	Wheat	Potato	Onion	Pepper	Total area
Scenario I	3290	654.3	1120	840	0	5904.3
Scenario II	3290	1260	1120	1330	0	7000
Scenario III	3558.8	1066.8	1211.5	908.6		6745.7
Scenario IV	3558.8	1363	1211.5	1438.7	0	7572
Scenario V(design)	3290	1260	1120	840	490	7000

Table 3. Monthly compensation flow (MCM) (MM, 2006)

Months	Nov	Dec	Jan	Feb	March	April	May	Total
Flows	1.56	0.80	1.07	0.97	0.80	0.65	0.80	6.65

2.3. Model development

The objective of reservoir operations planning is to minimize the annual water supply deficit function (Equation 1). This function is defined as the sum of the squares of the differences between the quantity of water released from storage and the target requirement for all intervals of the irrigation season. The target water requirements were obtained from gross irrigation water calculated for specified cropping patterns for irrigation season. The irrigation system efficiency of 48% (MM, 2006) for the conveyance and application losses was used.

Reservoir storage was determined by available storage at the beginning of every month and the expected inflows during the month. The inflow to the reservoir was treated as a stochastic state variable in the reservoir continuity equation for solving the chance constraint non linear programming (CCNLP) problem. In chance-constrained models for reservoir operation, deterministic constraints involving hydrologic parameters subjected to uncertainty are replaced by probabilistic statements (Mays and Tung, 1992).

The developed CCNLP model was solved using Excel Optimization Solver (EOS) integrated with Microsoft Excel. The information needed by EOS are target cell, changing cell and constraints and the adjustment of maximum run-time, iterations, precisions, tolerance, convergence, and defining linear or non linearity of the problem. The deficit function to be minimized (Z_t) is given by:

$$Minimize, Z_t = \sum_{t=1}^{T}(R_t - D_t) \quad (1)$$

Subject to:

(i) Reservoir storage continuity equation

Water balance of reservoir during irrigation season t is governed by chance constraint reservoir storage continuity equation.

$$S_{t+1} - S_t - P_t + R_t + ER_t + EVP_t = \rho I_t \quad (2)$$

where, S_{t+1} is storage at the end of time period t, S_t is storage at the beginning of time period t , P_t is rainfall during time period t , R_t is release volume at time period t+1, ER_t is environmental release at time period t,

R_t is release volume at time period t+1, ER_t is environmental release at time period t. EVP_t is evaporation rate at time period t (Equation 9), p represents the exceedance probability levels of 90% , 80%, 70%, 60% and 50% of reservoir inflow volume and I_t is Inflow volume during time period t. All are expressed in million cubic meters (MCM).

(ii) Storage boundary constraint

The reservoir storage in any month should not be more than the capacity of the reservoir, and should not be less than the dead storage capacity and is represented by

$$S_{min} \leq S_t \leq S_{max} \quad (3)$$

where, S_{max} is the storage capacity of the reservoir (83.1 Mm^3) and S_{min} is the dead storage volume (4.80 Mm^3).

(iii) Surface area constraint

$$A_{min} \leq S_t \leq A_{max} \quad (4)$$

where, A_{min} is minimum (2.69 Km^2) and A_{max} is maximum (19.12 Km^2) surface area constraints, corresponding to minimum and maximum storage volume boundaries, respectively.

(iv) Release constraint

Amount of water to be released (R_t) from the reservoir for irrigation purposes should meet the irrigation demands of pre-defined cropping pattern.

$$R_t \leq D_t \quad (5)$$

where, D_t is the target demand for irrigation (MCM).

(v) Over flow constraint

When the final storage in any month exceeds the capacity of the reservoir the constraint is given by:

$$Of_t = S_{t+1} - S_{max} \quad (6)$$

where, Of_t = Surplus from the reservoir during the month't'.

(iv) Canal capacity constraint

Monthly reservoir release should not be greater than maximum canal capacity.

$$R_t \leq CC_t \quad (7)$$

where, CCt is canal capacity for time interval 't'. The main canal was designed to convey 1.2 L/s/ha to 7583 ha of total potential irrigable area (MM, 2006). The upstream main canal design discharge is 9.1 m^3/s. Therefore, CCt of 24.37 $*10^6 m^3$ per month was used.

(i) Non-negativity

All the decision variables must be greater than or equal to zero.

$$R_c \geq 0, A_c \geq 0, EVP_t \geq 0, ER_t, Of_t \geq 0 \quad (8)$$

Monthly precipitation data for the Merawi meteorological station was used to estimate monthly rainfall volume on the reservoir surface area. Reservoir surface area for each month t was estimated substituting the reservoir volume in to area -capacity curve fitted using data from Table 4. The evaporation loss (EVP_t) is a nonlinear function of the reservoir surface area (A_t) at period t.

$$EVP_t = e_t * A_t \quad (9)$$

where e_t is evaporation rate (mm/day) estimated using a simplified penman equation (Linacre, 1993). Monthly reservoir volume available for irrigation from June to November (wet season) was calculated by subtracting evaporation losses, and adding inflows and rainfall on the reservoir surface using Microsoft Excel Solver. No environmental flow was deducted in this case as it is not permitted in wet season. Therefore, the reservoir volume at the end of November was used as initial storage while optimizing reservoir release using Microsoft Excel Solver.

2.4. Reservoir Performance

The reservoir system analysis model must be able to compute values of the performance measures as a function of operating policies. The purpose of performance measures is to have a mechanism to quantitatively compare, for alternative operating plans, the effectiveness of the reservoir system in meeting specified objectives. Consequently, the performance measures must be a function of the storage and release parameters which define an operating policy. In this study, reliability and vulnerability, and sum of square deficit (SSD) of output water for meeting demand were used as reservoir system performance indices.

Table 4. Koga reservoir area, volumes and stage relationship

Contour (m)	2004	2006	2008	2010	2012	2014	2016
Area (km^2)	0.19	0.98	2.92	7.14	11.84	15.83	19.99
Volume (Mm^3)	0.2	1	4.8	14.2	33.8	61.5	97.6

Reliability is the probability of success. The success interval is an interval in which the amount of water meeting demand is more than a specific threshold. The threshold can be 100% or less of demand. Reliability estimates can be computed on either a period or volumetric basis. Period reliability can be defined as the proportion of time that the reservoir is able to meet demands. Volumetric reliability (R_v) is the ratio of the volume of water supplied to the volume demanded (McMahon *et al.*, 2006) (Equation 10).

$$R_v = \frac{V_S}{V_d} \qquad (10)$$

where, V_s is the volume of water supplied and V_d is the volume of water demanded during a given period. Vulnerability measures the possible magnitude of a failure if one occurs. Maximum vulnerability is a suitable indicator of reservoir performance (Kjeldsen and Rosbjerg, 2004) (Equation 11).

$$v_{max} = \max_j \{v_j\} \qquad (11)$$

In this study, six thresholds of 100%, 90%, 80%, 70%, 60%, 50% of the irrigation demand which are equivalent to 0%, 10%, 20%, 30%, 40% and 50% deficit irrigation, respectively were used to compute volumetric reliability and vulnerability for exceedance probability of 90%, 80%, 70%, 60% and 50% of reservoir inflows. However, in this paper optimal reservoir operation at exceedance values of 80% at different thresholds of deficit was presented. Then the best scenario was selected based on minimum sum of square deviation (SSD), the highest reliability and minimum vulnerability indices. Finally, optimal reservoir operation policies (storage and release values) in the form of table were presented and their rule curves were developed

Table 5. Gross irrigation (mm) and irrigation demand (10^6m^3) for different scenarios

Irrigation demand	Dec	Jan	Feb	Mar	Apr	May	June	Total
Gross Irrigation	235.5	834.8	1453.8	1736.5	1501.9	634.5	64.85	
Scenario I	7.75	15.27	19.00	19.44	13.31	1.31		76.08
Scenario II	7.75	16.43	22.14	23.55	16.79	1.81		88.47
Scenario III	8.38	17.20	21.54	22.42	15.48	1.42		86.44
Scenario IV	8.38	17.77	23.95	25.47	18.16	1.96		95.69
Scenario V	7.75	16.43	21.61	23.43	16.97	2.69	0.32	88.88

3.2. Reservoir water supply

Expected monthly inflow into the reservoir at 90%, 80% and 70%, 60% and 50% probability of exceedance (ρ) is shown in Figure 2. The higher probability levels indicate low flows and the lower ones indicate high flows. The volume of reservoir inflow begins to increase in June and reaches its maximum in August. Then rapidly decreases to November following the decline rainfall. It is only base flow that flows into the reservoir from December to May (dry season).

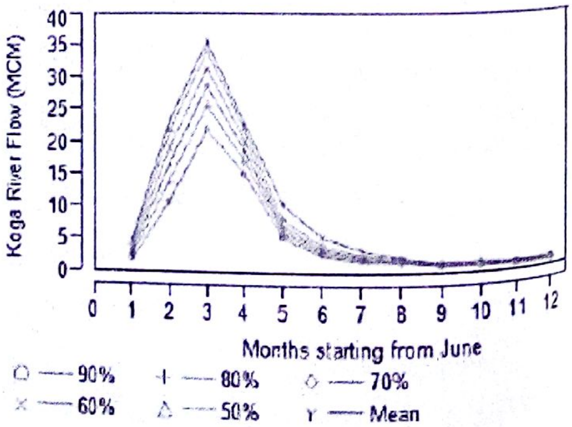

Figure 2: Koga river flow at different probability levels

According to MM (2006), the 7000 ha irrigated area is governed by the 80% reliability yield per annum from the dam. This design reservoir yield could be achieved at all exceedence probability levels of 80% and less when the reservoir is empty at the end of irrigation season (May) (Table 6). Cumulative reservoir inflow was 77.67*10^6m^3 at 80% probability of exceedance (ρ).

Table 6. Cumulative reservoir inflows (10^6m^3) when it is empty at May

ρ	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
90%	1.9	12.8	34.8	50	55.45	58.26	60.2	61.85	63.05	64.27	65.24	66.21
80%	2.52	16.61	42.37	59.53	65.62	68.79	70.99	72.84	74.15	75.49	76.57	77.67
70%	3.08	19.76	48.54	67.28	73.99	77.51	79.94	81.95	83.36	84.79	85.95	87.16
60%	3.66	22.79	54.32	74.66	82.06	85.96	88.65	90.8	92.32	93.83	95.07	96.39
50%	4.3	25.94	60.11	81.99	90.22	94.57	97.55	99.85	101.48	103.07	104.39	105.84

The reservoir storage volumes in 10^6m^3 at the end of November with carry over year storage of 4.8 10^6m^3 were 63.30, 73.60, 82.60, 82.89 and 83.1 at 90%, 80%, 70%, 60% and 50% of exceedance probability, respectively. These volumes were used as initial storage during optimizing reservoir operation. Thus, the reservoir storage for the most dry (90% dependable yield) and the average year (50% dependable yield) were 63.30 and 83.1 10^6m^3, respectively.

$$A_t = 2.68 + 0.26 * V_t - 0.002(V_t - 30.4429) \quad (12)$$

The best fitted reservoir surface area –capacity curve was shown by Equation 12. For which the determination coefficient (R^2) is 0.99.

where, A_t is reservoir area (km^2) at month t and V_t is reservoir volume (10^6m^3) at month t.

Estimated monthly evaporation rate (mm) is shown in Table 7.

Table 7. Monthly reservoir evaporation (mm)

Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
123.9	94.2	85.8	87.2	88.2	72.1	63.7	70.5	86.8	125.7	145.6	148.2

3.3. Actual reservoir operation

The actual data of reservoir stage, volume and irrigation release recorded for the year 2012/13 is shown in Table 8. No environmental flow was permitted for downstream. Before the commencement of irrigation season, a total of 1.53*10^6m^3 of the over flow water of 0.52*10^6m^3 in October and 1.02 *10^6m^3 in November was released through the main canal and utilized for land preparation. The use of over flow water for irrigation purpose was a good practice of conserving excess water in the soil reservoir. This increases the initial soil moisture content. Since only the reservoir water in the live storage was used for optimization of reservoir operation, this excess water used for land preparation was not considered during comparison of the optimized release with the actual releases. Hence, excluding this volume of water 66.16*$10^6m^3$of water from live storage was utilized for irrigation purpose from November to May first in 2013 irrigation season.

Table 8. Actual reservoir operation for the year 2012/13

Months	Stage	Volume	Release
Nov	2014.88	76.00	4.54
Dec	2014.25	66.00	12.82
Jan	2013.25	51.00	15.17
Feb	2012.00	35.00	15.64
Mar	2010.63	21.00	11.94
Apr	2010	15.5	5.33
May	2009.5	12	0.72

3.4. Optimal reservoir operating policies

Based on minimum sum of square deficit (SSD) criterion, the best reservoir operation policies selected under all scenarios at exceedance probability (ρ) of 80% with and without environmental flow permitted are shown in Table 9 and Table 10, respectively.

From the results of the reservoir operation analysis (Table 9), sum of squared deficit (SSD) was minimized to zero under all scenarios at maximum allowable deficit of 20% for scenario I, at 30% for scenario II, III and V, and at 40% for scenario IV. In this case, reservoir operation with the lowest thresholds of water deficit and SSD is scenario I. Having minimum SSD would reduce the risk and consequences of irrigation water supply shortages for farming activities in the irrigation project. Therefore, reservoir operation is the most reliable at scenario I and the least reliable at scenario IV at ρ= 80%.

If environmental flow was not permitted, SSD would be zero at 10% for scenario I, at 20% for scenario II, III and V, and at 30% for scenario IV at ρ=80% (Table 10). Based on minimum thresholds of deficit irrigation and SSD, scenario I was the most reliable, scenario II, III and V were the second most and scenario IV was the least reliable reservoir operations.

Table 9. Reservoir operation policies for different thresholds of irrigation and cropping pattern scenarios with environmental flow permitted

Parameters	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Tot release	SSD	Deficit
Release (I)		6.2	12.22	15.2	15.56	10.65	1.05		60.88	0.00	20%
Storage(I)	73.6	67.4	53.97	37.2	20.14	8.55	7.11				
Release(II)		5.42	11.50	15.50	16.48	11.75	1.27		61.92	0.00	30%
Storage(II)	73.60	68.18	55.45	38.35	20.32	7.62	6.01				
Release(III)		5.87	12.04	15.08	15.69	10.83	0.99		60.51	0.00	30%
Storage(III)	73.60	67.73	54.47	37.81	20.59	8.79	7.39				
Release(IV)		5.03	10.66	14.37	15.28	10.90	1.18		57.42	0.00	40%
Storage(IV)	73.60	68.57	56.68	40.68	23.77	11.75	9.99				
Design release (V)		5.42	11.50	15.13	16.40	11.88	1.88	0.22	62.21	0.00	30%
Design storage (V)	73.60	68.18	55.45	38.73	20.76	7.91	5.67	5.22			
Actual release	4.54	12.82	15.17	15.64	11.94	5.33	0.72		66.17		
Actual volume	76	66	51	35	21	15.5	12				

Table 10.Reservoir operation policies for different thresholds of irrigation and cropping pattern scenarios with no environmental flow permitted.

Parameters	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Tot release	SSD	% irr. deficit
Release(I)		6.97	13.74	17.1	17.5	11.98	1.18		68.47	0.00	10%
Storage(I)	80.25	73.28	59.03	41.32	23.15	10.87	9.83				
Release(II)		6.20	13.14	17.71	18.84	13.43	1.45		70.77	0.00	20%
Storage(II)	80.25	74.05	60.40	42.05	22.52	8.82	7.63				
Release(III)		6.70	13.76	17.23	17.93	12.38	1.13		69.15	0.00	20%
Storage(III)	80.25	73.55	59.28	41.43	22.82	10.16	9.21				
Release(IV)		5.87	12.44	16.76	17.83	12.72	1.37		66.98	0.00	30%
Storage (IV)	80.25	74.38	61.43	44.01	25.42	12.30	10.98				
Release(V)		6.20	13.14	17.29	18.75	13.57	2.15	0.25	71.09	0.00	20%
Storage(V)	80.25	74.05	60.40	42.48	23.02	9.16	7.25	7.49			
Actual rel	4.54	12.82	15.17	15.64	11.94	5.33	0.72		66.17		
Actual vol	76	66	51	35	21	15.5	12				

3.5. Performance measures

The performance measures of chance constraint models at exceedance probability of 80% under different irrigation deficit levels with and without environmental flow permitted are shown in Table 11 and Table 12, respectively. From Table 11, the values of the lowest sum of square deviations (SSD) and vulnerability were zero, and the maximum volumetric reliability was one under all scenarios of cropping pattern. These all were gained at irrigation deficit thresholds of 20% under scenario I, 30% under scenario II, III and V, and 40% under scenario IV when environmental flow is allowed to be released for downstream environment. Similarly, the lowest SSD and vulnerability of zero and the highest volumetric reliability of one were gained at irrigation deficit thresholds of 10% under scenario I, 20% under scenario II, III and V, and 30% under scenario IV when environmental flow is not allowed for downstream environment.

SSD of zero indicates that irrigation water demand has been met at all monthly time intervals in irrigation season. Similarly, vulnerability of zero shows the maximum irrigation water deficit among all the continuous failure or unsatisfactory periods was zero. Volumetric reliability of one implies that 100% of the irrigation demand has been met throughout irrigation season. The results of these performance measures denote that irrigation demand has been met throughout irrigation season at the stated thresholds of deficit irrigation.

Reservoir operation of scenario V was the best among scenario II and III for the following reasons. First, scenario V has best mixes of all crops with the least onion crop (which is perishable) area allocation. Hence, scenario V was with least risks of crop damage. Second, the area cultivated under scenario V was greater than that of scenario III but equal with that of scenario II. Hence, as large area cultivated, greater land holders benefitted and greater job opportunities for daily laborers.

Table 11.Performance tests of reservoir operation at ρ=80% without environmental flow

	Scenario I			Scenario II			Scenario III			Scenario IV			Design		
Deficit	SSD	R_v	V	SSD	R_v	V	SSD	R_v	V	SSD	R_v	V	SSD	R_v	V
0%	26.5	0.84	2.41	493.8	0.71	22.14	94.3	0.74	4.64	601.0	0.66	23.95	113.7	0.71	4.97
10%	4.0	0.93	0.91	45.20	0.80	3.14	35.2	0.82	2.80	91.2	0.74	4.52	47.4	0.79	3.10
20%	0.0	1.00	0.00	9.00	0.90	1.40	5.18	0.92	1.08	29.19	0.83	2.49	10.7	0.88	1.49
30%	0.0	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	2.18	0.95	0.68	0.0	1.00	0.00
40%	0.0	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.0	1.00	0.00
50%	0.0	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.0	1.00	0.00

Table 12. Performance tests of reservoir operation at ρ=80% with environmental flow

	Scenario I			Scenario II			Scenario III			Scenario IV			Design		
Deficit	SSD	R_v	V	SSD	R_v	V	SSD	R_v	V	SSD	R_v	V	SSD	R_v	V
0%	0.6	0.98	0.34	86.8	0.84	7.78	26.36	0.86	2.43	307.7	0.79	17.42	36.74	0.83	2.72
10%	0.0	1.0	0.00	5.10	0.93	1.03	2.12	0.96	0.71	24.88	0.86	2.32	6.05	0.93	1.12
20%	0.0	1.0	0.00	0.0	1.00	0.00	0.0	1.00	0.00	1.07	0.97	0.47	0.0	1.00	0.00
30%	0.0	1.0	0.00	0.0	1.00	0.00	0.00	1.00	0.00	0.0	1.00	0.00	0.0	1.00	0.00
40%	0.0	1.0	0.00	0.0	1.00	0.00	0.00	1.00	0.00	0.0	1.00	0.00	0.0	1.00	0.00
50%	0.0	1.0	0.00	0.0	1.00	0.00	0.00	1.00	0.00	0.0	1.00	0.00	0.0	1.00	0.00

3.6. Optimal operating rule curves

Optimal operating rule curves derived from the best reservoir operation policies from Table 11 and Table 12 are shown in Figure 11 and Figure 12, respectively. The curves indicate the desired storage volumes of the reservoir and release at any particular month. These curves stipulate how water is to be stored and released during the subsequent months based on the current state of the storage volume and time of the irrigation season at 80% probability of exceedance. The results dictate that the patterns of the optimal rule curves for storage versus time are similar to the actual rule curve. But the actual curve lies above the optimal curves in April and May. This implied that more water was left at the end of irrigation season. This reduces the reservoir efficiency. However the patterns of optimal release rule curves are not exactly similar with that of the actual. This was because of different starting time for reservoir release.

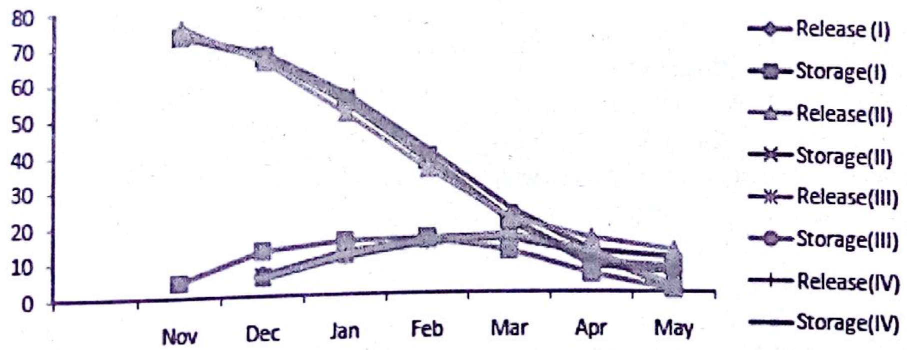

Figure 3. Operating rule curves for irrigation when environmental flow is permitted

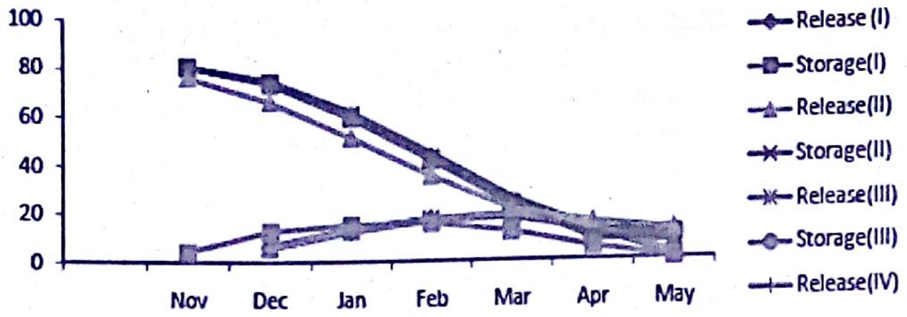

Figure 4. Operating rule curves for irrigation when environmental flow is not permitted

4. Conclusions and Recommendations

In this study, a chance constraint non linear programming optimization was applied to determine monthly operating policies for five scenarios of predetermined cropping patterns of the Koga irrigation scheme, Ethiopia using Microsoft Excel Solver. The objective function of the model was set to minimize the sum of squared deviation (SSD) from the desired targeted supply. Using optimal operating policies (storage and release values), the rule curves were developed. The developed rule curves could be used to stimulate how water is to be released during the subsequent months based on the current state of the storage volume and time of the irrigation season at exceedance probability of 80%.

From the results of the reservoir operation analysis, SSD was minimized to zero under all scenarios at maximum allowable deficit of 20% for scenario I, at 30% for scenario II, III and V, and at 40% for scenario IV if environmental flow is permitted. The lowest SSD, zero vulnerability, and the maximum volumetric reliability were gained at irrigation deficit thresholds of 20% under scenario I, 30% under scenario II, III and V, and 40% under scenario IV when environmental flow is allowed to be released for downstream environment.

Therefore, the most reliable reservoir operation was obtained at scenario II. Scenario II, III and V were the second most reliable and scenario IV was the least reliable. However, reservoir operation of scenario V was the best among scenario II and III for best mixes of all crops with least risks of crop damage and larger numbers of land holders benefitted from greater area cultivated. Therefore, the total design command area of 7000 ha, denoted by scenario V, could be irrigated at maximum thresholds of 30% deficit irrigation with 100% reliability and without any vulnerability to water shortage. Its thresholds of deficit could be reduced to 20% if environmental flow is not permitted. This threshold of deficit could be reduced if the irrigation system efficiency is improved.

It was concluded that the reservoir water would not be able to meet 100% of irrigation demand at any of the scenarios. If environmental flow is not permitted, the thresholds of deficits for all scenarios were reduced by 10% from that of environmental flow permitted.

The study also demonstrated that the simplicity and flexibility of Microsoft Excel Solver in efficiently optimizing the operation policy of an existing reservoir for varying water supply and demand conditions. The developed model could be used by operator or decision maker, given simple training, for real time reservoir operation decision making. Finally, it was recommended to study the application efficiency of furrow irrigation and conveyance efficiency of irrigation canals, and determination of optimal thresholds of deficit irrigation for major crops for water productivity maximization.

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Seasonal Streamflow Variability Analysis and Forecasting, Lake Tana Basin, Upper Blue Nile, Ethiopia

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Abstract

In this paper seasonal rainfall-runoff variability analysis is detected and streamflow is forecasted using stochastic approach for Lake Tana Sub basin of Abbay River Basin which is located at the high land areas with one rainy season within a year and having high spatial and temporal variation of rainfall and runoff. The seasonal stream flow variability analysis of the basin is done from the existing and recorded meteorological and hydrological data. The four major seasons of the year are taken for seasonality analysis (i.e. Winter (JFM), Spring (AMJ), Summer (JAS) and Autumn (OND)). The rainfall variability is analyzed using seasonality and variability measures of CV, SRRD and SRI. The rain fall variability is higher related to altitude than latitude and longitude. From the four seasons there is no significant variation and trend spatially as well as temporally. The seasonal runoff and streamflow variation is analyzed using HEC-HMS hydrological model to generate runoffs at required and selected points to detect the spatial variation. The gauged stations and catchments are easily analyzed from recorded time series streamflow data. Runoff coefficient is taken as a variability measure for both generated and recorded stream flows. The runoff coefficient ranges from 0 to 1. The range is high at dry seasons and less at wet seasons. The average runoff coefficient vale of the basin is obtained as 0.28 in which the value ranging from 0.18 to 0.36 at dry and wet seasons. The average SRC value from generated runoffs is 0.45 at which it is 0.3 at dry and 0.6 at wet seasons. Runoff coefficient is more dependent on antecedent soil wetness condition. Seasonal streamflow is forecasted using PARMA (p, q) and MPAR (p) models.

Keywords: *Lake Tana Basin, Seasonal Variability, CV, HEC-HMS, Runoff Coefficient, streamflow*

1. Introduction

1.1. Background

Globally, there is growing concern that natural and anthropogenic climate changes are intensifying the hydrological cycle, which may be expected to influence river flow regimes (Harvey et al., 2010). Since there is seasonal variation of climate it is unquestionable that there will be also seasonal variation of both meteorological and hydrological variables.

Stream flow variability is highly dependent on rainfall variability. Such variability occurs temporally as well as spatially. The temporal variability occurs at many time scales , from hourly to daily, from daily to monthly, from monthly to seasonally and from seasonal to inter-annual and beyond. The spatial variation also occurs from local to regional, from regional to country and from country to continental.

Whether it is natural or artificial reservoir, the seasonal flow variation affects its storage as well as the supply and demand. Knowing Seasonal flow variability and forecasting of hydrological variables potentially improves water management (Brown *et al.*, 2006). The seasonal variability of flow and stage (Lake surface level) are factors which play the major role on the natural flow of the rivers. Considering high flow and low flow seasons and the variabilities in the derivation of reservoir operating rules is essential for coordinating the relationship between flood prevention and benefit.

Generally Lake Tana sub-basin is characterized by enormous potential for development of irrigated agriculture, hydropower, tourism, bio-diversity and recreations. For this reason, it is one of the richest sub-basin concerning water resource (Daniel et al., 2007). Since there is seasonal variation of hydro meteorological variables, there is fluctuation of the lake level. The lake as a reservoir regulates the seasonal flow variations at the Chara Chara weir site for the purpose of proposed and constructed projects. For example the Tana Beles Transfer uses the regulated excess water from the lake.

2.2 Location and Accessibility

Lake Tana basin is situated on the north western plateau of Ethiopia at the head waters of the Abay River basin, in the Amhara administrative regional state.

Its geographical location extends from 10°57'N to 12°47'N latitude and from 36°53'E to 38°15'E longitude. The basin area is 15,321km^2 from which around 20% of it is the lake (Zewdie *et al.*, 2010). The basin is also divided to four main sub basins namely; GilgelAbay, Gumara, Ribb and Megech.

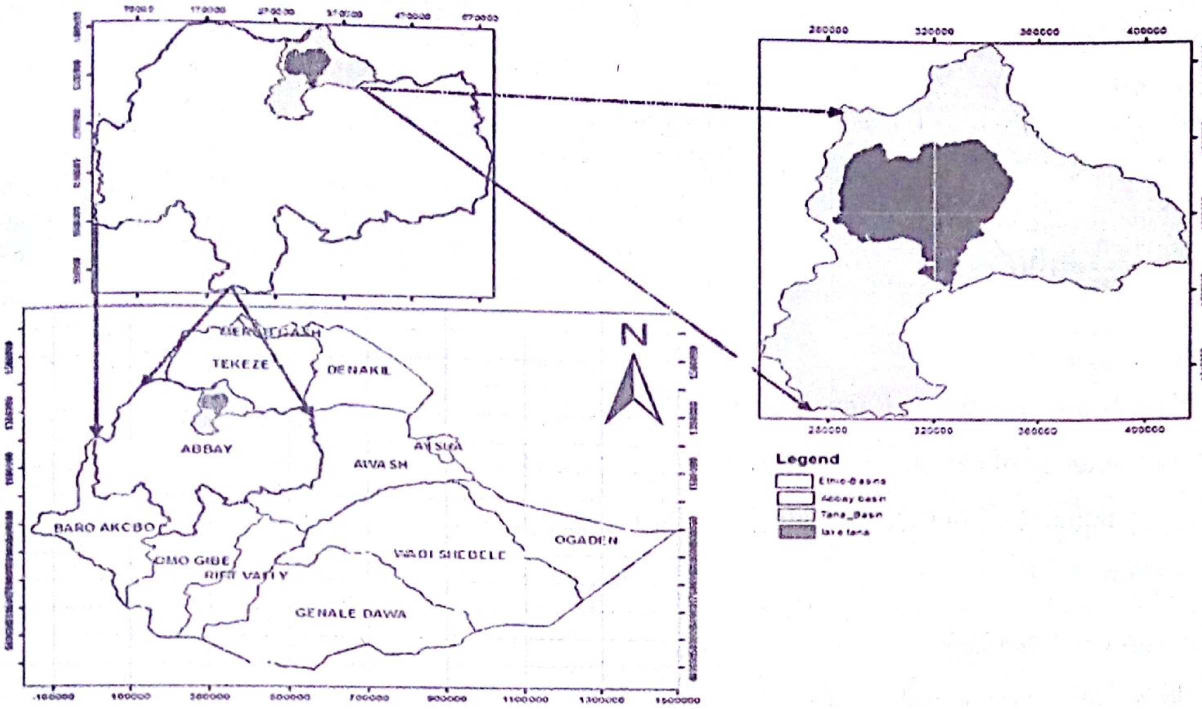

Figure 2.1: Location of Study Area

3. Objective of the Study

The general objective of the study is to analyze the seasonal spatio-temporal rainfall-runoff variability and forecast seasonal streamflow using selected stochastic hydrological models.

Specific objectives of the study include:

- To realize and detect seasonal trends of rainfall and streamflow
- To analyze spatial and temporal variation of rainfall-runoff using selected variability indices
- To select the best stochastic model for the basin and to forecast, simulate and generate future seasonal time series streamflow data
- To detect the catchment behavior and flow responses to rainfall variation
- To estimate seasonal time series parameters and analyze the spatial as well as temporal correlations within the Basin

4. Methodology and Analysis

4.1 Seasonal Rainfall variability analysis

To analyze the spatial and temporal seasonal rainfall variation, we used statistical and empirical measures. From the recorded rainfall, we have precipitation data of 12 stations. Areal precipitation is taken using thiessen polygon method for each precipitation station.

Coefficient of Variation

Coefficient of Variation is one of the statistical measures of variability which can be used for any hydrological time series variables and others. It is the ratio of standard

$$Cv_\tau = \frac{S_\tau}{\bar{y}_\tau}$$

Where

CV_τ Seasonal Coefficient of Variation

s_τ Seasonal standard deviation

$\bar{y}_\tau$ Seasonal mean

Seasonal Relative Rainy Days

It is the ratio of rainy days within the season to the total number of days in the season. It shows the variation of wet and dry days within seasons spatially as well as temporally.

$$SRRD = \frac{n}{N} * 100$$

Where

SRRD = Seasonal Relative Rainy Days in %

N = total no of days in the season and

n = number of rainy days with in the sea son

Seasonal Rainfall Intensity

It is the ratio of cumulative seasonal rainfall to that of the number of rainy days with in that season. It indicates the spatial and temporal rainfall intensity variation of different seasons.

Seasonal Runoff Coefficient (SRC)

Runoff coefficient is one measure or index to show the spatio-temporal runoff variability. This coefficient is used mostly to estimate the runoff on the data scarce places using an empirical formula of rational method.

$$SRI = \frac{CSP}{n}$$

Where

SRI = Seasonal Rainfall Intensity (mm/day)

CSP = Cumulative Seasonal Precipitation and (mm)

n = number of rainy days with in the season (day)

4.2 Seasonal flow Variability analysis

Seasonal flow variability analysis is done using Seasonal Runoff Coefficient as a measure which is simply the ratio of excess runoff to precipitation (Daniele Norbiatoet *al.*, 2009).To know the excess runoffs, the base flows are from recorded flow data for gauged stations. To see the variation on the whole basin, excess runoff is generated for selected point using HEC HMS hydrological model.

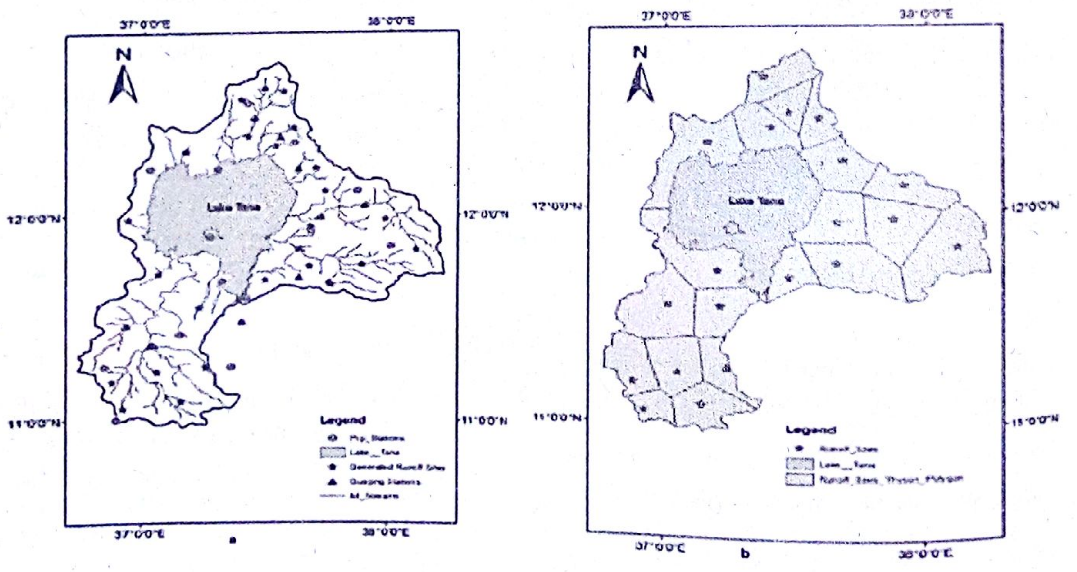

Figure 2.2: Generated excess runoff sites, Gauging stations and Precipitation stations with their Thiessen polygon (a and b respectively)

Seasonal Runoff Coefficient (SRC)

Runoff coefficient is one measure or index to show the spatio-temporal runoff variability. This coefficient is used mostly to estimate the runoff on the data scarce places using an empirical formula of rational method.

$$SRC = \frac{\Sigma Q_{sd}}{Pscp * A}$$

Where

SRC = seasonal runoff coefficient

Qsd = seasonal cumulative direct runoff

Pscp = seasonal cumulative precipitation

A = catchment area

4.3. Seasonal Flow Forecasting

In this research stochastic time series seasonal forecast models have been selected from SAMS2007 package(O. G. B. Sveinssonet *al.*, 2007). The model is used to forecast both stationary and non-stationary time series data. From the data quality results (non stationarity), models to forecast non-stationary time series data are selected. Seasonal forecast models such as Univariate PARMA (p, q) and Multivariate PAR (MPAR) are models whichare adopted to forecast seasonal time series data.

5. Results and Discussion

5.1. Seasonal Rainfall – Runoff Variability

5.1.1. Rainfall Variability

According to the country's geographical classification the seasons are classified in to four which account three months each. Thus are: Winter (January, February & March); Spring (April, May & June); Summer (July, August & September) and Autumn (October, November & December).

The variability analysis based on variability measures of CV, SRRD and SRI is resulted along altitude, longitude and latitude as spaces and the time from 1997-2005 years. As it is shown from figure5.1, there is significant coefficient of variability variation on all seasons based on CV values and their ranges. The CV value generally ranges from 0.85 to 7.76 at Summer and Winter seasons respectively. There is high variation at Autumn season which ranges from 2.35-6.22 and less variation at Summer ranging from 0.85-1.5. The rainfall coefficient of variability is relatively higher near Lake Tana.

The rainfall variation based on SRI on the altitude, Latitude and Longitude is not significant at Winter season except some events with high SRI values and the variation is significant on the rest of seasons even though the variation range is less. The SRI ranges from 0 to 50mm/day. The range is high at Winter and low at Summer seasons. There is no visible temporal trend of SRI variation.

There is significant SRRD variation at high altitudes especially above 2300m for all seasons. There is high spatial variation than that of temporal variation. There is an increasing trend of rainy days on winter season and a decreasing trend on the spring season.

As it is shown from the above figures (i.e Figure 5.2) there is high variation and increasing trend of SRRD along the altitude but not that of SRI. This indicates that the areas at high altitude get more rainy days than that of low areas and the intensity of rainfall is relatively higher at low land areas than high land areas.

As it is observed from Figures5.3, there is increasing temporal trend of SRRD on Winter and Summer seasons but a decreasing trend of on Spring and Autumn seasons. There is relatively high SRRD value at high Latitude and Longitudes. At summer season, number of rainy days are increased at low and high longitudes. There is high correlation between CV and SRRD. It is the number of rainy days that causes significant variation of CV than the rainfall intensity.

5.1.2. Runoff Variability Analysis Results

For gauged catchments the seasonal streamflow variability is easily manipulated from recorded flow data. For catchments outside gauging stations, excess runoff is generated using HEC-HMS model for selected points after the model is calibrated and validated at gauged stations. The R^2 value during the calibration period is 0.76 and is 0.68 during the validation period. Since our purpose of HEC-HMS model is to generate runoff the values are accepted.

The spatial SRC variation along the altitude, latitude and longitude is highly dependent and correlated to the SRI. As we have seen from the above figures, it is clear that all rainy days didn't give excess runoff. In other words the excess runoff is the result of infiltration excess rainfall which is the result of intensive rainfall or Antecedent Moisture Condition (AMC) of the surface. This runoff coefficient variation and distribution likely reflects the variability of the storms analyzed, mostly in terms of total precipitation, rainfall duration, rainfall intensity and antecedent wetness conditions(D. Pennaet *al.*, 2011). He finally obtained runoff coefficient ranging from 0.02-0.69 with an average value of 0.15.

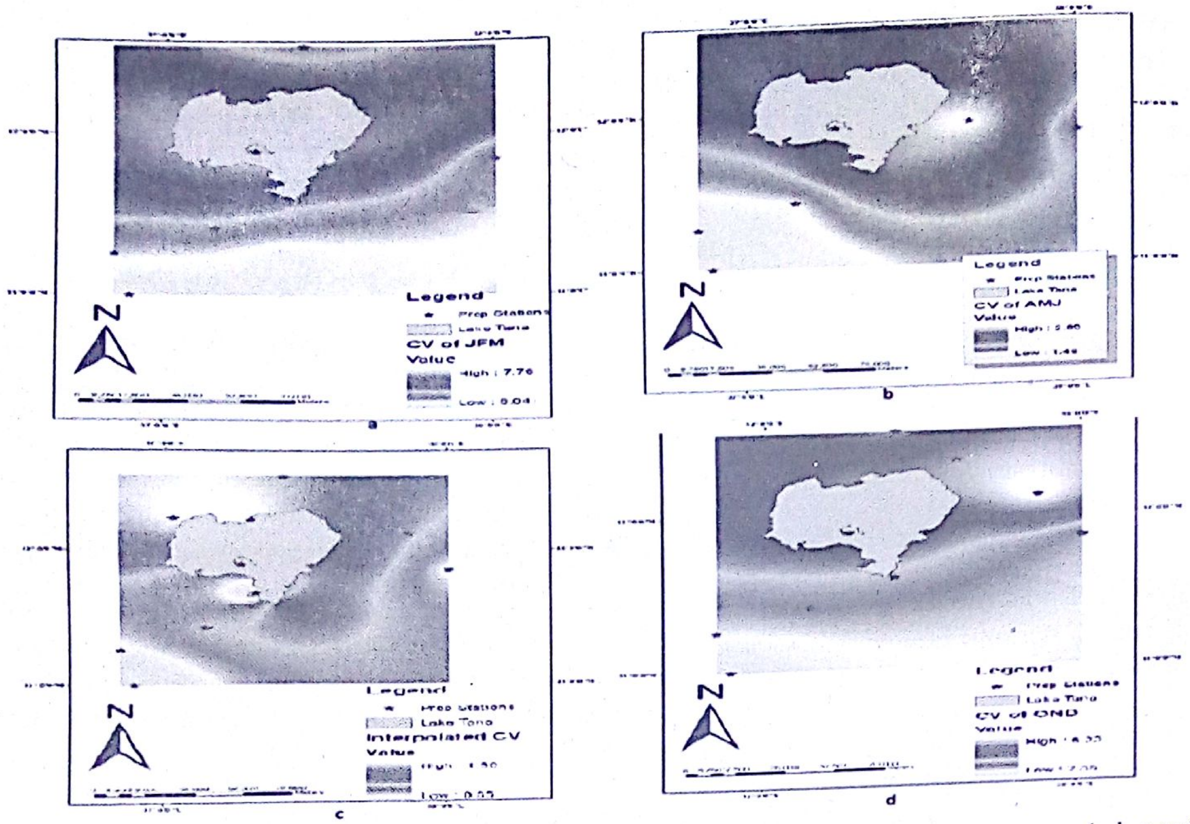

Figure 5.1: Spatial Rainfall Variability based on CV for: Winter, Spring, Summer and Autuinn seasons (a, b, c and d) respectively.

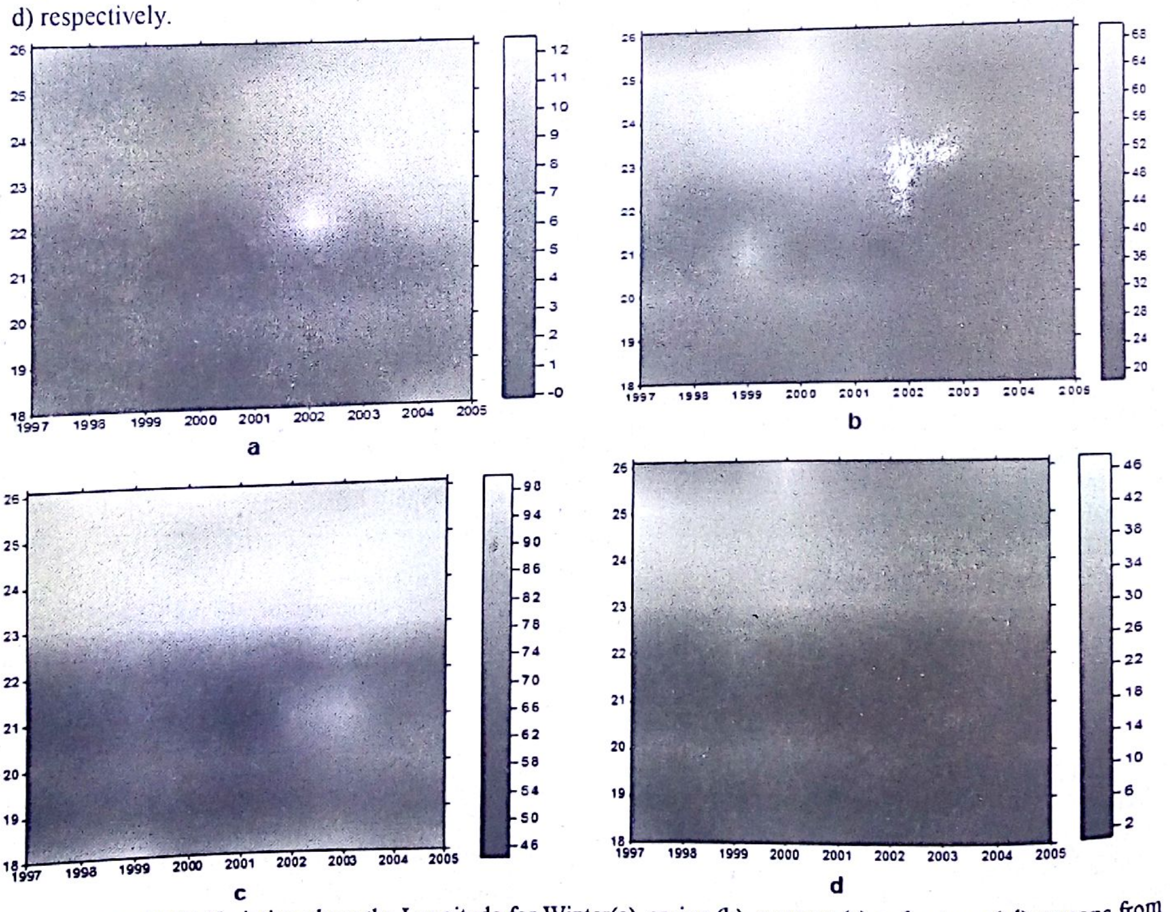

Figure 5.3: SRRD Variation along the Longitude for Winter(a), spring (b), summer (c) and autumn(d) seasons from 1997-2005.

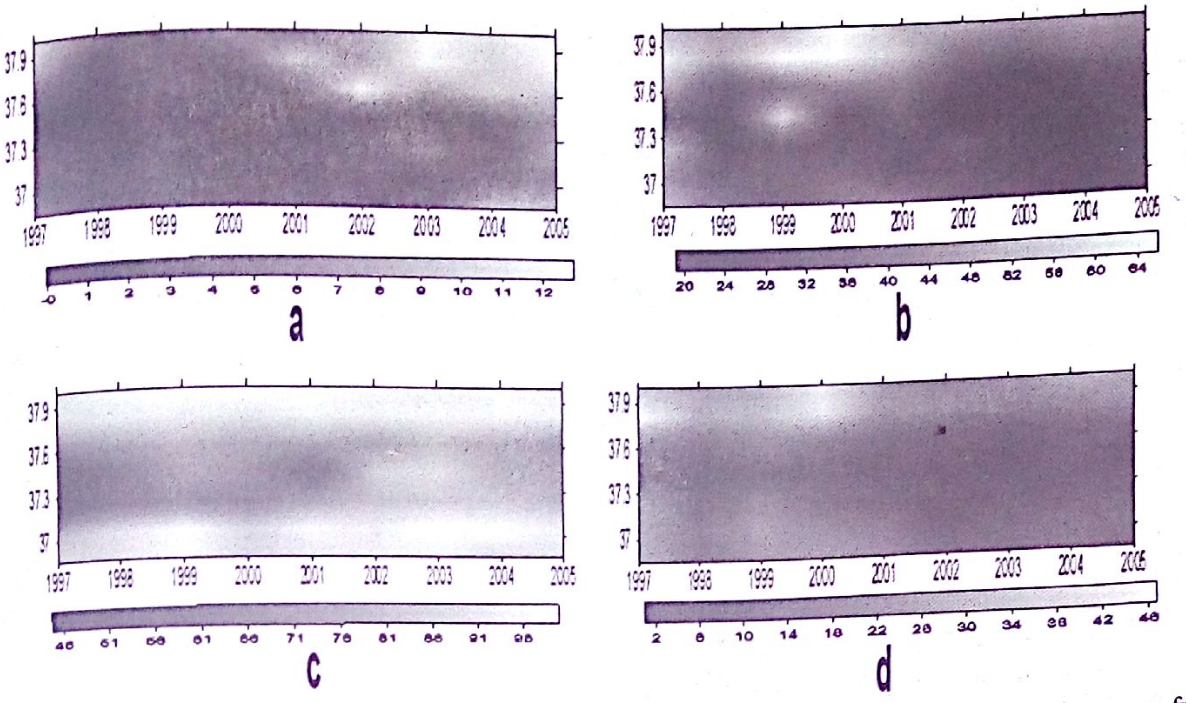

Figure 5.3: SRRD Variation along the Longitude for Winter(a) spring (b), summer (c) and autumn (d) seasons from 1997-2005.

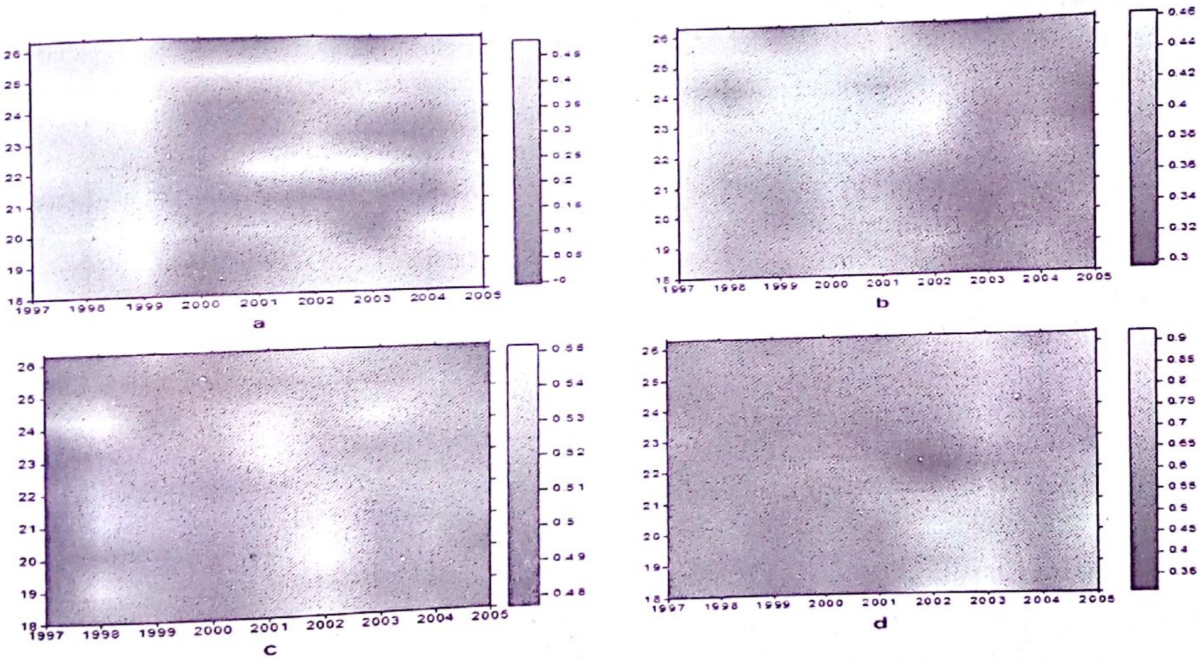

Figure 5.4: SRC Variability of selected runoff sites along the altitude from 1997-2005 for winter(a),spring (b),summer(c) and autumn seasons

From generated excess runoffs the average runoff coefficient value is 0.45 which is ranging from 0.28 at winter season and 0.64 at Autumn season.

The range of SRC variation for both gauged and ungauged sites is high at Spring and Autumn seasons and low at Summer season. But the average value is higher at Summer and Autumn seasons as a result of high runoff and erosion of the Summer season and high antecedent soil moisture condition of Autumn season from high Summer precipitation. In addition high base flow components which are considered as runoffs have significant effect for increased SRC values.

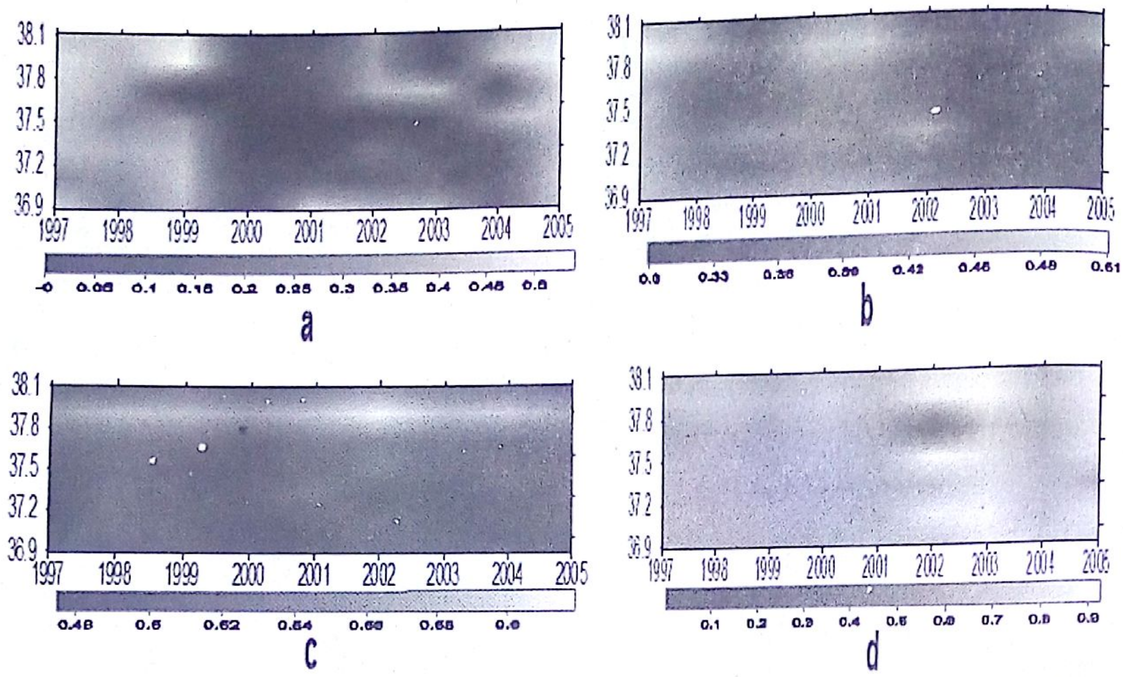

Figure 5.5: Longitudinal Runoff Variation of selected runoff sites from 1997-2005 based on SRC measure for Winter, Spring, Summer and Autumn Seasons (a, b, c and d respectively)

Even though the range is very high, the average runoff coefficient value for the basin is 0.28 from recorded historical flow data and it is 0.45 from generated excess runoffs using HEC-HMS model. From both values the average of 0.36 lies on the range of theoretical and practical values used in rational method. SRC exceeds 1 at some places and some events which indicate that there was high runoff and erosion problem at that time of specific place including its upstream.

The spatial SRC variation is relatively higher at altitudes from 2200m to2400m. Generally, the areas on south East and East of the basin have higher runoff coefficient. The range and average runoff coefficient values are consistent with those values used for different soil groups and land uses.

5.1.3. Catchment Classification

Using SRC as a classification measure, the catchments can be seasonally classified and grouped based on their seasonal runoff coefficient values. The Catchments with high SRC values implicate that these areas are severely affected by erosion and sedimentation. Whereas areas with low SRC are areas with less erosion due to good water shed management practices or due to their soil type.

From previous studies (Shimelis G. Setegn *et al.*, 2008) has identified the erosion prone areas on the catchment and the factors using SWAT hydrological model for different scenario. According to his result, the factors for erosion are: slope factor which is known to be the main driving force for the movement of surface water. Steeper and longer slopes result in high erosion rates. The second criterion is the land cover which controls the detachability and transport of soil particles and infiltration of water into the soil. The types of the soil also play a significant role for erosion depending upon their physical properties and sensitivity to erosion. As it is shown from the figures below, the runoff coefficient is high on the areas relatively higher altitudes and slope.

5.2. Seasonal Flow Forecasting

From the results of SAMS 2007 model output, PARMA (1, 2), PARMA (2, 1) and PARMA (2, 2) univariate models are better than MPAR (p) to estimate the volume. Estimation of peak flows and their timing using both PARMA (p, q) and MPAR (p) is worth except for Summer season. MPAR (p) is better than PARMA (p, q) to estimate peaks better than others for Summer season. If the volume is the criterion for streamflow prediction, PARMA (2, 0) for Winter; PARMA (2, 2) for Spring; PARMA (2, 1) for Summer and MPAR (2) for Autumn seasons can give good results than others. MPAR (p) model is better than PARMA (p, q) to estimate peak and minimum flows of summer season that gave R^2 of 0.786 and MLE of -0.055. But it is not best model to estimate timing and volume.

From the literatures it is proposed to use higher order PARMA (p, q) models to forecast seasonal flows. But from the result of this research, higher order PARMA (p, q) models have limitation to forecast all flow types. The model efficiency may also vary according to the seasonal streamflow data quality. Thus it is not possible to generalize that PARMA (p, q) and MPAR (p) models are best models for seasonal time series data except volumes and base flows.

6. Conclusion

Even though the basin is relatively getting different rainfall amounts and have also different distribution pattern, there is slight spatial and temporal variation except some events and places. There is high rainfall amount greater than 50% of annual precipitation at the summer season (25% of the year). From the results and discussions above, we can conclude that the rain fall variability is highly dependent on altitude and the lake. The coefficient of rainfall variability is highly dependent on number of rainy days weather its intensity is high or less. From the results obtained we can conclude that Lake Tana has slight effect on seasonal rainfall variation based on CV and altitude has significant impact to seasonal rainfall variation than latitude and longitudes.

Seasonal Runoff variation is more influenced by runoff intensity than rainfall duration and number of rainy days. Runoff coefficient is more influenced by rainfall intensity, antecedent moisture condition and erosion (upstream erosion and downstream sedimentation).

From the results obtained we can conclude that coefficient of variation has limitations at places of highly exposed to erosion problems in which its value is greater than 1 that indicates erosion and siltation. Runoff coefficient value should be clearly set for urban (impervious) and areas with different perviousness characteristics with erosion. From the range of runoff coefficient values, most of the areas in the basin are homogenous at summer season than other seasons. . From hydrological data quality tests, it is clearly observed that seasonal time series data are not homogeneous, stationary and independent. Minimum flows are better stationary and homogeneous than mean and maximum flows.

It is not possible to generalize that SAMS2007 model is best model or not to forecast future streamflows. For Lake Tana basin, PARMA (p, q) model is better for volume estimation which is vital for reservoir planning and management. And it is worth for peak flow estimation and timing. MPAR (p) model is also better for base flow (low flow) and summer season streamflow estimation. It is also better than PARMA to estimate peaks without considering the timing. To estimate future drought seasons and floods not considering the timings, MPAR is better. Thus decision makers and researchers can use the two models according to the purpose of future water resource.

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A Tale of Two Dams: A Comparative Hydro-political Assessment of The Great Ataturk Dam of Turkey and The Grand Renaissance Dam of Ethiopia.

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Abstract

In March 2014, Egypt accused Turkey as a source of finance for the ongoing the Grand Ethiopian Renaissance Dam Project (GERDP). But Ethiopia stressed that the financial source of the project was not any other country rather the people of Ethiopia either in the form of bond or donation. Similarly Ethiopia inclined that Ethiopia will accept any kind of support including advising from any country including Turkey. It was in this situation that this author tried to investigate and compare the hydro-political issues raised across the Euphrates-Tigris and Nile rivers river basins. These rivers were the major centers of the ancient River Valley civilization of Mesopotamian and Egyptian and also crossed many countries before their final end in the great water bodies. Since ancient times the downstream countries (Syria and Iraq for Euphrates and the Sudan and Egypt for Nile) were the major beneficiaries without any prior consent of the upper stream countries like Turkey and Ethiopia. In fact more than 90% of Euphrates-Tigris waters began from the snow-belts of the Anatolian Mountains of Turkey similarly more than 86-90% of the Nile waters originated from the Ethiopian Highlands. Although the Southeastern part of Turkey and the most part of Ethiopia faced a severe shortage of water, the colonial times agreements on water resource utilization favored the downstream that were signed in 1920s and later in 1950s without any consent and approval of the upstream countries like Turkey and Ethiopia. The legacies of such agreements became a serious bottlenecks and a bone of contention for many hydro political issues rose between the upper and lower stream countries. When the upstream countries started mega projects along these rivers the down-stream countries boldly opposed by using these unidirectional agreements. In spite of their oppositions, Turkey inaugurated the multifunctional Great Atatürk Dam in 1990 which is 43kms near the Syrian boarders and now benefited a lot out of it. Currently Ethiopia is constructing the GERDP in the northwest part and 43km near the Ethio-Sudanese boarders. Thus this paper attempts to evaluate the hydro-political issues raised upon these great dams. It also tries to suggest constructive view for the issues rose on the GERDP and recommend that Egypt should came for the cooperative framework of Nile by understanding what Syria missed a chance in the Joint Technical Committee (JTC) meetings with Turkey.

Keyword: *GERDP, Hydro-politics of the Nile, IPoE meetings, cooperation*

1. Introduction

The former Ethiopian Prime Minister, Meles Zenawi, in March 2011 declared as "No matter how poor we are … the Ethiopian people will pay any sacrifice. I have no doubt they will, with one voice, say: 'Build the Dam!'" when Ethiopia openly declared the beginning of the Grand Ethiopia Renaissance Dam Project (GERDP) in Guba, the Benishangul Gumuz Region in the Northwestern part of Ethiopia which is 43km near the Ethio-Sudanese boarders. The project is intended to produce more than 6000MW hydroelectric power for both domestic and export to the neighboring states including Sudan and Egypt with a little cost (Grand Millennium Dam 2011). This project was blindly objected by Egypt and demanded the freezing of the project, despite Ethiopia's commitments of making the project real and proposed the establishment of an International Panel of Experts (IPoE) to develop confidence on the project by the downstream countries. Based on the recommendation of IPoE Ethiopia,

the Sudan and Egypt made three consecutive meetings in Khartoum in 2013 and 2014. But the meetings bore no fruits from Egypt's rigid stands of demanding the freezing off the project.

After the third tripartite meeting held in Khartoum, Sudan, in January 2014 the Egyptian delegates embarked on a "media campaign and released distorted information regarding the deliberations and outcome" of the meetings. The Egyptian government also aired as "all options are open and still on the table to secure water."(MoWE, 2014) Furthermore in March 2014 Egypt accused Turkey as a source of finance for the ongoing the Grand Ethiopian.

Renaissance Dam project of Ethiopia. But Ethiopia stressed that the financial source of the dam was not any other country rather the people of Ethiopia either in the form of bond or donation. Similarly Ethiopia inclined that Ethiopia will accept any kind of help including advising from any country including Turkey. It was in this situation that this author tried to investigate and compare the hydro-political issues raised across the Euphrates-Tigris and Nile rivers river basins. Thus in this study I used a comparative approach for evaluating the issues in the basins and to replicate their implication on the Nile hydro political issues. Attempts were also made to compare and contrast some of the issues across the Euphrates-Tigris and the Nile river basins in order to make a sound argument on the importance of win-win approach and a round-table negotiation for the optimal, efficient and effective usage on the Nile waters among the upper and lower stream countries.

Turkey and Ethiopia: Two water-towers but 'denied to use' their resource

It is quite clear that water is one of the most important and at the same time the most scares resources in the world. The demand and availability of fresh water is inversely correlated with the fastly growing population. Even more the day-to-day activities of mankind further deteriorated its availability as well as its quality and quantity for the survival of life. This made water one of the international source of conflict among many trans-boundary river systems like Euphrates-Tigris, Nile, Indus, and others which were also the center of ancient river valley civilization of Mesopotamia, Egyptian and Indus, respectively. Since the period of antiquity the downstream places/countries had the major beneficiaries of these rivers. As the upper streams attempted to use the waters, disagreement and even conflict erupted between the upper and the lower streams. Many sources reported that since 1960s many Middle East countries involved in water-born conflicts. As a matter of fact Turkey and Ethiopia, considered the upstream countries, are the major source or water tower countries in the world but their rights of exploiting their natural resources like water was absolutely denied by the lower stream countries. To put it in other words more than 90% of the waters of the Euphrates and Tigris Rivers began from the snow-belt Anatolian Mountains of Turkey and flow downwards to the arid lands of the Middle East (by crossing the territories of Syria and Iraq) before joining the Persian Sea. Similarly 86-90% of the waters of Nile emerged from the Highlands of Ethiopia and flow down wars to Egypt after joining with the White Nile in Khartoum, the Sudan, and finally joined the Mediterranean Sea. In both cases the downward countries effectively exploited the waters of these rivers since ancient times without prior consultation of the source countries.

It's obvious that through their backward irrigation system, their water projects across the rivers immensely contributed for their economy but the Arabs used inefficient and technologically backward irrigation system and produced water thirsty crops like cotton as well as due to the arid type of climate in the region, there was and still is high evaporation and water-loss that aggravated the fresh water shortage in the region. In other words the Arabs used poor irrigation system and have not changed in the 21st century and failed to use technology based irrigation system to maximize the efficient and effective use of every-drop of this scares resource, water. Rather they pointed their fingers to others and developed deep running suspicions with their water-rich neighbor states. Moreover the Arabs are too much reluctant to became dependent up on 'water-rich states' and given up their traditional food production methods through new efficient methods. Thus region wide lack of trust created food insecurity in the whole Middle East.

On the other hand the Middle East countries also strictly opposed any kind of water development projects of the upper riparian states. In this case both Turkey and Ethiopia, being a source of waters of around 90%, suffered from the age-old opposition of the downward Arab states and faced rejection of their proposal from many financial institutions from getting loan until they decided to exploit their comparative advantages and to use their resource for their developmental endeavors until recently. It is crystal clear that both Turkey and Ethiopia had no intention of harming their neighbors rather the downstream countries demanded much more waters that led them to conflicts of interests. (Kevin Freeman,2000)

The other similarities was that in both countries the downstream need to secure their 'historic right' of using the waters since ancient times and requested the up streams to manage their land/soil as well as to control the seasonal floods that affected them. To secure their right, the downstream countries raised some of the colonial times agreement as their legal document without giving any prior attention for the upstream rights of exploiting their natural resources within their territories.

Up until 1960s both the upper and downstream countries had a harmonious relation across the issue of water is concerned as it was highly monopolized by the later. However in post-1960s Turkey and in post-1990s Ethiopia declared a new policy of exploiting water resource as the major means of development. This was a bitter-sorrow to swallow by the downstream as it threatened their 'historic right' of water-monopoly and hardly needed to listen from any other body. This slowly but surely led them to conflict of interest with their neighbors.

Water Politics and the role of Turkey

Up until 1960s, there was harmonious relation between Turkey, Syria and Iraq on the waters of Euphrates and Tigris. Later it was radically changed it was due to Turkey's plan of constructing dam. Long before it, Iraq and Syria already expanded their irrigation schemes and constructed dams and demanded more waters so that they openly opposed Turkey's plan of exploiting the waters. The situation was further deteriorated when Turkey embarked off constructing mega water projects including (the Great Atatürk Dam which is the master piece of the multi-purpose) the Güney Doğü Projesi (GAP) in the long-ignored and the most fertile region of the southeastern part of Turkey. GAP has planned to include many dams, reservoirs and huge hydropower plants as well as huge irrigation projects. The hydroelectric power plant has a total of installed power capacity of 2,400MW and generates 8,900GWh electricity annually and intended to irrigate more than 30,000sq.mils which is near to the Syrian borders (İbrahim Yuksel, 2012, Akpinar 2012).

After its completion, the project not only tripled Turkey's agricultural production as well as providing electric power for the industries but also benefited the whole Middle Eastern countries by reducing the variability of the river as well as controlled the destructive effects of seasonal flooding. For instance in the dry summer season the flow of the river ranges from less than 150-200cubic meters per second while in the winter due to smelting of snow in the Anatolia Mountains it reached to more than 5000 cubic meters per second. After the construction of the dam, the dam regulates a regular flow of water throughout the year.

However this was wrongly viewed by the downstream countries and openly accused Turkey of plotting of denying their 'historic right' as well as a means of reducing their age-old water monopoly in the region. They were also successful in convincing some financial institutions from giving loan for Turkey's water projects.

As a good neighbor, Turkey clarified the advantages of her water projects for the entire region. The project also intended to irrigate more than 6500km long pipe line irrigation scheme named as Turkey Peace Pipe Line that carry freshwater for the arable land of middle Eastern countries as far as the Persian Gulf. The Arabs not only refuted the proposal but also wrongly perceived as Turkey's secret plan of making them to be dependent upon her both politically and economically (Kevin Freeman, 2000).

The Arabs also opposed any projects of Turkey and accused that any water project would reduce the quality and quantity of the flow of the river waters. Such water reduction could lead to the drying up off the existing irrigation projects in Iraq and Syria. Furthermore both Syria and Iraq also blamed Turkey of not notifying them in advance about the planned water projects according the rule laid down by the International Law Commission (ILC). When Turkey implemented the planned projects, they were successful in convincing international financial institutions like World Bank to disapprove loan to Turkey, on the ground that under its protocol, any project devised by a state would need the approval of other riparian countries. However Turkey embarked on construction by her own and as progress made other intuitions gave loan except World Bank.

On her part Turkey argues that the dam and the water projects on the rivers was part of her right of exploiting her natural resources for development. As opposed to this both Syria and Iraq argues that Turkey is violating their 'historic right' for many thousand years and no any power has the right to take away from their hands. And, proposed to share the water based on a mathematical formula based upon their current use of the water. In other words the new mathematical method gave the lions-share of the water to them.

Even though the Middle East hydro politics shaped and reshaped by the construction of major development projects in both Turkey, Syrian and Iraq as well as a series of negotiations had been taken place as Turkey gave prior attention for the importance of negotiation and the optimal equitable use of many scares resources like water.

Turkey and the downstream countries meetings

As stated earlier, agreements over the Euphrates River was made in the colonial period between the newly emerged Turkish Republic and the French on behalf of Syria in 1923 and 1926. Turkey also signed agreement with Iraq in 1946 too. All these protocols provided a 5 framework of 'building up of flood control works on the upstream' and underlined the positive impact of storage facilities with in the territories of Turkey. Based on this the three riparian countries entered a new phase of relationship over water resources (Ayşegül 2005 and 2007; Kevin Freeman,2000).

The period of post 1960s witnessed the alarming expansion of Iraq's irrigation projects and the construction of the Haditha Dam as well as Syria's completion of the Tabaqa Dam. At this time Turkey also decided to construct a small dam, Keban Dam, on Euphrates River. The

Keban Dam was designed only for the production of Electricity and had no any feature which changed the water balance of the basin. Moreover, based on their request, it had a very positive impact upon the water storage facility of Syria and Iraq by ensuring the regulation of the variability of the flow by 70% (Kevin Freeman, 2000; Levent Aytemiz,2001). However, the downstream countries ill-conceived it as violating their 'historic right' of using water since old-days.

Due to Turkey's commitment and in order to provide the Syrian and Iraqi officials with the up-to-date information and to develop confidence on the newly constructed Keban Dam, copies of the feasibility report of the project were submitted and called them to sit in a roundtable and negotiate for the optimal usage of the water for their region-wide development endeavors. Hence the first meeting was held on 22-27 June 1964 with the participation of

Turkey and Iraqi water experts. In the meeting Turkey clarified that the filling of the dam depended up on the natural condition without affecting the natural course of the river.

However, under pressure from the donors like USAID, Turkey guaranteed to undertake all necessary measures to maintain the discharge of the river flow immediately to the

downstreams. On the other side financial institutions like World Bank were already financed a huge amount of money for the construction of dams and irrigation projects in both Syria and Iraq (Mehmet Tomanbay, 2000).

Due to the involvement of third party, like financial institutions, in the mediation process, and due to their favoritism to the downward countries and interference of the sovereign rights of the country, Turkey proposed for the establishment of a Joint Technical Committee (JTC) which would inspect each river at their sources to determine their yearly discharge. In addition JTC would determine the irrigation needs of the three countries through a field studies. The JTC also authorized by calculating the riparian's need for present and future projects to prepare a statement of main principles and procedures to reach an agreement on water rights.

The second meeting was held with Syria in Ankara in 1964. In the meeting both delegates exchanged information's on the status achieved in the development of the two Keban and Tabaqa projects. In this meeting Turkey recommended the first tripartite negotiation to be held in Baghdad and accepted. In the 1965 Baghdad meeting, the delegates exchanged technical data with regard to the Haditha (Iraq), Tabaqa (Syria) and Keban (Turkey) Dams. In this meeting Iraq proposed JTC to be a body to supervise and implement the agreement. This proposal rejected by others on condition that JTC could carry and only authorized to maintain, coordination of the present and future projects across the basin. Syria also supported Turkey stand on JTC function to study the water requirements of the irrigable lands in the basin. In time of shortage of water Syria proposal include the possibilities of diverting part of the Tigris waters to the Euphrates. Syria's proposal was strongly objected by Iraq and insisted their negotiations should focus only on Euphrates not of Tigris waters (Levent Aytemiz, 2001).

During the 1970s a series of JTC negotiations and meetings were held but no reference were made on the water rights because the opposition from the downstream countries. Even in 1973 JTC made a field trip on the three countries projects. Based on the observation, Turkey pointed out severe doubts on the accuracy of some of the figures that Iraq presented as Iraq insisted an exaggerated amount of water to ensure much water. Turkey's effort to share the water equitably finally failed in the meeting held at Thawra, Syria, in 1973. Due to the failure of series of JTC meetings, Turkey and Syria went a separate way and Turkey started the impounding of the Keban reservations by February 1974 and Syria also completed her dam and impounding started. The 1974-75 dry weather the situation escalated to crisis as Iraq accused Syria while Syria placed the blame on Ankara that led a war over water between Iraq and Syria (Ayşegül 2005 and 2007; Levent Aytemiz, 2001).

In 1974 Turkey started negotiation with World Bank to construct another dam just down from Keban, the Karakaya Dam. After a series of tripartite technical negotiations, Turkey faced difficulty in obtaining fund even though Turkey gave a guarantee of increasing the downward flow of the river. It was due to Syria's long-hand on

Similarly Ethiopia also faced similar challenge from Egypt when Ethiopia knocked the donors-door to finance some of her water projects (Levent Aytemiz,2001).

In the absence of any alternatives Turkey embarked a huge developmental project in the southeastern part of Turkey named GAP to construct through mobilization her own resources. As stated earlier GAP has a multi and far reaching benefits upon its completion. In the project the largest and the masterpiece one was the Great Atatürk Dam which was renamed on the honor of the great founding father of the Modern Turkish Republic, Mustafa Kamal Atatürk (1881-1938). The project was started in 1983 completed after seven years.

The Great Atatürk Dam and the Grand Ethiopian Renaissance Dam Project: A Tale of two dams

In 1983 Turkey initiated the construction of the Great Atatürk Dam by mobilizing her own resources. Similarly Ethiopia also embarked on constructing the huge GERDP by mobilizing her own resources through bond and donation from her own citizens since March 2011. The Great Atatürk Dam has a total storage capacity of 48.7billion cubic meters and intended to generate 2400MW. When Turkey announced its construction the downstream countries initiated to the continuation of the works of the JTC. From 1983 to 1993 JTC held more than 16 meetings including two high-profiled meetings at the ministerial levels. In those meetings JTC had given a mandate to exchange basic hydrological and metrological data and information on the entire basin for the policy makers. Based on this Turkey provided the complete information including the rules of operation of the reservoirs in her territories in order to ensure better water management in the basin. However the other countries failed to do this and after sixteen successive meetings, the JTC unable to fulfill its objectives and the talk became a deadlocked because of the unending refusal and rigid stands of the downstream countries of securing 'historic right' without giving prior attention for their neighboring state, Turkey.

Some of the Syrian claims include after constructing three dams (Tabaqa (completed in 1975), Ali Baath (completed in 1986), and Tinshirin (completed in 1999)) for irrigation, HEP and domestic water supply demanded even much more waters. Secondly Syria also claimed Euphrates and Tigris rivers as international rivers and classified as shared resources and the waters must be shared among states determined by quota or mathematical formula which is hardly accepted by Turkey. Syria also demanded the diversion of Tigris River to Euphrates in order to get more which is refuted by Iraq. Besides to this Syria also demanded the participation of the United Nations in all negotiations and requested the application of international law as soon as possible by rejecting Turkey's offer of peace-pipe plan of irrigating the region based on techno-based irrigation systems (Kevin Freeman,2000). In order to secure her water interest Syria also interfere in the internal affairs of Turkey by hosting and arming Kurdistan Workers Party (PKK) against Turkey (Levent Aytemiz,2001). In the post 1990s Syria and Turkey were involved a proxy war against water. Due to her refusal of negotiation Syria missed a chance of getting more waters as well as hydroelectric energy with a low cost from Turkey.

In spite of their opposition the construction of the Great Atatürk Dam completed in 1990. The dam completely transformed the area in to the major economic hub of Turkey even though PKK operate in the area. One of the benefits of the dam was providing a regular and stable flow of water to the downstream. It also argued that due to Turkey's geographical and topographical nature the dam reduce the water losses through evaporation. Upon the completion of the dam, Turkey temporarily halted and diverted the flow of the river for filling the great reservoir for four weeks after notifying her neighbors in November 1989.

However Syria and Iraq officially protested and called for an agreement to share the water of Euphrates. In this time all Syrian dams got a severe shortage of water and unable to produce more energy and at the end the Syrian economy severely damaged. Although Syria refused to negotiate, Turkey effectively exploited her water resources and her comparative advantages by constructing many dams and reservoirs as well as by defeating PKK. On the other side Syria is still suffering from shortage of water and poverty and even recently in civil wars.

In 1996 Turkey also started the construction of the Birecik Dam on Euphrates. The dam was intended and designed to regulate the water level of Euphrates during the generation of HEP at the Atatürk Dam. Both Syria and Iraq sent official notes to Ankara in December 1995 and January 1996, respectively, indicating their objection of the construction of the dam on the ground that the dam would affect the quality and quantity of the water flow. Despite their objection and Turkey's commitment, after the construction of the dams in Turkey both Syria and Iraq have had a regular flow of water throughout the year. They were also free from the destructive effect of seasonal flooding every year.

It's also the same in the case of Ethiopia and Egyptian relation across the Nile waters. By using the colonial agreements as well as 'historic rights' Egypt objected any water projects in Ethiopia and even delayed and successful in convincing some financial institution not to finance such projects. As Ethiopia has a policy of exploiting her waters for development as well as playing leading role in the use of renewable energy for combating climate change, Ethiopia embarked construction of small dams and finally declared the construction of GERD in March 2011 which is financed by Ethiopian government and peoples through donation and bond. This was a nightmare for Egypt and requested Ethiopia to stop and halt the project but due to the commitment of the Ethiopian government the project is now (June 2014) already 34% completed and it will be completed as per the action plans.

When Ethiopia started the construction of the GERDP, it is designed for the production of hydroelectric power and has no plan of using the waters for irrigation. But Egypt objected as it affect her age-old water monopoly as well as refused to sign the Nile Cooperation Framework Agreement which was signed by seven Nile riparian countries with a logic of win-win approach and cooperation. Instead Egypt accused Ethiopia for constructing dam. The dam has an international engineering standards and designs. To be clear the matters Ethiopia proposed the establishment of an International Panel of Experts (IPoE) represented from Egypt, Sudan and Ethiopia. The panel of experts made a field trip and came up with a document stated that there is no sever impact of the dam on the downward flow of the river. Based on the study, the panel of expert made that the GERD project was being undertaken in line of international designs, criteria and standards. It had a region wide significant benefits to all countries. As Ethiopia clearly stated, the project improved a good access of energy as well as it solved the problems of siltation in the dams in the Sudan and Egypt by controlling the problem of frequent flooding and improve a constant flow throughout the year. The dam also sharply cut sediments reached to the Aswan Dam as well as reduces evaporation and water loss in the region. Besides to this Ethiopia also constantly assured to the Sudan and Egypt GRED that it will have a region wide benefit and boldly underlined the construction of the dam will have a lot of benefit not only for the country but also across the continent Africa by linking with hydroelectric through the lowest cost. Thus Ethiopian to the initiatives and invited the two downstream countries with a good faith of cooperation to negotiate on the issue and recently the Sudan is baking the project because of its benefits while Egypt is still running around the bush. Like Syria, Egypt is missing the advantages of negotiations as Ethiopia called all including Egypt to work together for their better future.

In all the three tripartite meetings held in Khartoum, Egypt raised different concerns on the project ranging for freezing off the project to a joint administration of the project. Ethiopia made clear that it's a question of sovereignty and stressed on the importance of solving such issues through a round-table. Recently Egypt accused many in financing the dam including EU, US, Turkey and others, but Ethiopia boldly downgraded the Egyptian claims as the source of the finance is and will be the Ethiopian government and Ethiopian people only. In March 2013 Egypt accused off Turkey for financing the project after the Turkish Foreign Minister Ahmet Davutoğlu attended the 22nd African Union Summit held in Addis Ababa on 30-31 January 2014 held in Addis Ababa.

Conclusion and Recommendation

Like Turkey, Ethiopia followed a good faith of cooperation and win-win approach for the optimal utilization on the Nile waters. Ethiopia has no and will not have any plan or intention of harming the downstream countries. A good example may be after constructing the dam Ethiopia has no plan of using the water for irrigation even though there is a huge irrigable land in the area. However Egypt blindly requested Ethiopia to stop the construction of the dam. In all earlier meetings of the Nile Basin Initiatives as well as the tripartite meetings in Khartoum, Egypt raised inept and groundless claims over the Nile and refused to join to these meetings. Even in those meetings Egypt joined with the aim of agreeing not to agree. As a result, Egypt failed to sign the Cooperative Framework Agreement (CFA) in 2007 in Entebbe (Dereje, 2010) as well as the three successive meeting held in Khartoum. Like Syria Egyptians refusal might cost them in their future relation with the riparian countries.

In spite of Turkey's and Ethiopia's wide range of initiatives and equitable and optimal utilization of the water that raised from their land as well as playing a leading role in bringing the downstream countries to a round-table discussions, the downstream countries advocate an old rhetoric of 'historic right' and water monopoly even in the 21st century. These countries instead of cooperation and follow a win-win approach in the issue of trans-boundary waters they interfere and sometimes gave shelters for some terrorist organization and even arming them to destabilize the upstream states. A good example may be Syria became a safe haven for the movements of PKK until the end of 1999 when its leader arrested. In the some case Egypt also did the same ranging from releasing false and distorted information to the media to diplomatic move against Ethiopia and her water projects. If possible, Egypt might also support some anti- Ethiopian groups as she did in the past.

In all negotiation endeavors, like Syria, Egypt also gave a deaf-ear for the recommendation of the IPoE as well as Ethiopia's proposal of the region wide benefits of the project as one Egyptian professor acknowledges. Even Ethiopia also proposed the techno-based water pipe system for the efficient and effective use of every drop of waters and to reduce the high evaporation and water loss in the arid lands as well as to increase a mutual benefit with all the riparian countries. Even Ethiopia also committed to share and to reach her energy hub as far as the poor Egyptian villages. But these all Ethiopian plea fell on a deaf-ear of Egypt who demanded only the abandonment of the project while the Ethiopian government stressed the dam will never halt for a second and committed to finish by working 24 hours a day by allocating a huge amount of money as well as resources for the dam.

Thus it is possible to conclude that both the Great Atatürk and the GERD Projects have promoted region wide developmental benefits. In this game no one will lose rather all parties will be the winner unless they settled their difference by round table negotiations. In the case of Turkey, Turkey gained a lot as the dam alarmingly tripled her economic and political growth after its completion. It also changed the region drastically from a long-ignored barren land to the center of economic growth. The project not only increased the agricultural production but also provide a huge job opportunity for the local people, infrastructural development as well as recreational and fishing activities introduced in the region. Similarly GERD project intended not only to benefit the local people but also it provides electricity with a low cost for the neighboring states including the Sudan and Egypt. It also secured a regular flow of the river by controlling the seasonal variability and destructive impact of flooding.

Finally, based on the facts mentioned above it is possible to forward some recommendation including:-

- Ethiopia should complete the project as per the action plan and promote the benefit of the basin wide advantages of the dam to the International community, including the Egyptians.
- Ethiopia should promote more public relation and public diplomacy on the dam as well as strengthen more the political and economic diplomacy to change the behaviors of the International community as well as some financial institutions
- Ethiopia should mobilize more the public to get more financial, moral and technical support from the population, as it is doing now
- Ethiopia, as did it before, should urge the downstream to come to discussion and negation for mutual benefit and growth.
- Like Sudan, Egypt should accept the basin wide benefit of the project and came to the round-table agreement.
- Egypt should learn from Syria when Turkey started filling of the dam Syria's economy severely damaged due to shortage of water available for her dams as well as water
- supply for her population. Thus Egypt has to respect the positive impact of cooperation and should sign the Cooperative Framework Agreement as well as support the construction of the dam.
- As a good neighbor, Egypt should refrain from any subversive actions against Ethiopia, as she did before.
- Like the Egyptian, the Ethiopian government should give a prior attention for water security right as well as effectively exploitation of her water resources which is the only way out of reducing poverty in the country, as stated in the country's polices, strategies and directives.

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Evaluating Climate Change Impact on Water Demand of Irrigation Schemes in the Lake Tana Basin using newly developed Climate Change Scenario – RCP 4.5 and CanESM2 Global Climate Model

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Abstract

A number of irrigation schemes are either at design, construction or operational stage in the Lake Tana sub-basin. Various studies have estimated the current water demand of these schemes under stationary climate ignoring climate change. In this study, we assessed the net irrigation requirement (NIR) of these schemes for a changing climatic condition using the newly developed Representative Concentration Pathway (RCP) scenario. More specifically, we used the RCP4.5 scenario in which total radiative forcing is stabilized at 4.5 W/m2 shortly after the year 2100. The Swedish Meteorological and Hydrological Institute (SMHI) dynamically downscaled the CanESM2 Global Climate Model by using the RCA4 Regional Climate Model (RCM). This dynamically downscaled climate data was obtained from CORDEX-Africa program. Reference meteorological data for bias correction of the RCM outputs was provided by the National Meteorology Agency of Ethiopia. We retrieved proposed cropping patterns for 9 irrigation projects from design or master plan reports subject to the status of the schemes. Impact of climate change was evaluated for the short term (2011-2040), middle term (2041-2070) and long term (2071-2100). The average annual rainfall of the schemes show mixed changes with a decline in near future and an increment in the medium and far futures. A consistent increment in potential evapotranspiration is projected for the future. This has resulted in a future increase in NIR which slightly affects the inflow and storage of Lake Tana. Currently, we are expanding this work to eight GCMs outputs which are dynamically downscaled by CORDEX-Africa. We are also evaluating the overall impact on the Lake Tana water balance and assessing appropriate adaptation strategies.

Keywords: *Climate change, irrigation water requirement, RCP, Lake Tana*

1. Introduction

Nowadays, there is undeniable scientific evidence about the increasing concentration of greenhouse gases in the atmosphere and its visible impact on the global climate system. Since the industrial revolution an increase of green house gases such as CO2 and CH4 has occurred and as a result the entire global surface temperature has increased. Over the period 1880 to 2012, the globally averaged combined land and ocean surface temperature data showed a warming of 0.85
°C. This increase in temperature is reflected by the considerable rise of global averaged sea level and the average rate of ice loss from glaciers around the world (Hartmann et al., 2013). Precipitation trends are not very clear but during the last 3-6 decades precipitation changes were sources of droughts and heavy rainfall in eastern Africa (IPCC, 2014).

In Ethiopia, McSweeney (2008) stated that the mean annual temperature between 1960 and 2006 has increased by 1.3°C, at an average rate of 0.28 °C per decade while the climate change national adaptation programme of action (NAPA) of Ethiopia (NAPA, 2007) specified a higher rate of temperature increase of 0.34 °C per decade between 1951 and 2006. Projections of 18 global climate models for the country suggest an average future warming of 1.2° C and 2.2°C by 2020 and 2050 respectively (Conway and Shipper, 2011). The increase in temperature is predicted for all four seasons and in all regions of Ethiopia. The same multi-model study suggests a very small increase in average annual precipitation of 0.4% and 1% by 2020 and 2050 respectively. Projections of 19 CMIP models for the representative concentration pathway RCP 8.5 scenario show a warming of the Upper Blue Nile basin by 4 to 6°C for the time period 2006 to 2100. Also, 80% of these models agree on an increase in precipitation trends. For Lake Tana which is our study area an increase of 2-5°C was projected across 15 GCM models but a clear trend of precipitation change could not be drawn as there was no consensus between the climate models (Setegn et al., 2011).
The agricultural sector will be very much affected by climate change since this sector is very sensitive to shifts in temperature and precipitation pattern.

For developing countries, the impact of climate change has much more implication due to their reliance on the agricultural sector and limited adaptive capacity related to the existing low levels of development (Nelson, 2009). By 2020, between 75 and 250 million people in Africa are projected to be exposed to increased water stress due to climate change. In some countries, yields from rain-fed agriculture could be reduced by up to 50% which will accentuate the previously existing food security and malnutrition problems (IPCC, 2007). Therefore, for countries like Ethiopia that are trying to achieve significant economic growth, climate change is a major bottleneck. A model used in World Bank (2006) assessed the economic effect of hydrological variability in Ethiopia. It predicted that hydrological variability reduces projected rates of economic growth by 1/3 and increases projected poverty rates by 25%. Therefore, observed and predicted increasing temperature and changing precipitation trends will require implementation of adaptation measures that will manage and reduce risks on productive systems such as agriculture (IPCC, 2014).

In order to meet water demands of agricultural systems and cope with climate change we should invest in new irrigation infrastructures and improve the existing once (World Bank, 2006; Falkenmark et al., 2008; Misra, 2014). Irrigation is a good adaptation option as it increase productivity and withstand rainwater shortages (Kurukulasuriya and Rosenthal, 2003). This being said, irrigation schemes can also be affected by climate change. Because global warming will affect temperature, evopotanspiration and precipitation patterns, there will be direct impacts on water requirements (McKenney and Rosenberg, 1993). Doll (2002) predicted that two thirds of the global area equipped for irrigation in 1995 will possibly suffer from increased water requirements due to climate change. Also, Fisher et al. (2007) suggested that climate change will increase irrigation water requirement and affect socio-economic development.

The implementation of irrigation schemes requires large and long-lived (30 to 200 years) hydraulic investments (Hallegatte, 2008). And because of climate change impact on water demand these investment need to be flexible. In other words they should take into account the magnitude and direction of future climate change (Hallegatte, 2008; World Bank, 2011). In Ethiopia where climate change is one of the major concerns, projects that aim to alleviate its impact through the development of irrigation scheme are being implemented in the Lake Tana sub-basin. In the sub-basin, reservoirs that will help convert the rain fed agriculture to an irrigated agriculture are being built. Various design reports have estimated the current water demand of these schemes under stationary climate but none of them have considered a changing climate.

For Ethiopia, most scientific studies focused on climate change impact on water availability (e.g. Abdo, 2009; Setegn et al., 2011; Hanibal, 2013; Aich et al., 2014; Reynolds, 2013). However, scientific studies that assess impact of climate change on water demand are rare. In the aforementioned studies, we can notice that works on Ethiopia's context are mostly based on the General Circulation Models (GCM), which have a rather small resolution compared to Regional Climate Models (RCM). Different GCMs were used for different parts of Ethiopia but the most commonly used is the UK Had CM3 model. The SRES (IPCC, 2007) scenarios are mostly used in previous studies while very few (e.g. Aich et al., 2014) used the newly developed Representative Concentration Pathway scenarios (RCP).

In this study, we assessed the impact of climate change on the net irrigation requirement (NIR) of ongoing and planned irrigation schemes in the Lake Tana sub-basin. The climate data was obtained from an RCM simulation with unprecedented resolution for the sub-basin. One of the newly developed Representative Concentration Pathway (RCP) scenarios is also used.

2. Study area and data set

2.1 Study area

The Lake Tana basin is located in the north-west highlands of Ethiopia at an elevation of 1800 m. Lake Tana which is the main source of the Blue Nile River is the largest lake in Ethiopia with a surface area of 3156 km2. The lake is shallow and has a maximum depth of 15 m. The climate of the region is 'tropical highland monsoon' with one main rainy season between June and September. Its catchment area receives 1280 mm mean annual rainfall while the lake receives 1347mm of rainfall annually, on average. The air temperature shows large diurnal but small seasonal changes with an annual average of 20 °C. The annual mean actual evapotranspiration of the catchment area is estimated to be 773 mm (Setegn et al., 2009). Mean annual lake evaporation is 1563 mm.

Tributaries of Lake Tana constitute more than 40 rivers and streams. However, only four major rivers contribute to > 93% of the lake inflow: Gilgel Abbay, Ribb, Gumara and Megech. The only surface outflow is the Upper Blue Nile, which comprises 7% of the Blue Nile flow at the Ethio-Sudanese border (Shahin, 1988; Conway, 2000).

Rientjes et al. (2011) estimated that the the mean annual inflow to the lake is 5426 million cubic meter (MCM) and the mean annual outflow is 4508 MCM (Table 1).

Table 1: Lake Tana water balance (Rientjes et al., 2011)

Water balance components	mm yr^{-1}	MCM yr^{-1}
Lake areal rainfall	+1347	+4104
Gauged river inflow	+1254	+3821
Ungauged river inflow	+527	+1605
Lake evaporation	−1563	−4762
River outflow	−1480	−4508
Closure term	+85	+260

Over the most recent years, Lake Tana sub-basin's huge water resource potential has been recognized and government initiatives are focusing on making the region an exemplary growth corridor of the country. A hydropower development and a number of irrigation schemes planned on the main tributary rivers are at the center of the water resource development plan of the region. The design of eight irrigation schemes is completed with slightly smaller than 60,000 ha irrigated land (Fig. 1) and are expected to have a total annual water demand of greater than 600 MCM (USBR, 1964; BCEOM, 1999). The Koga irrigation project (7,000 ha) is the only one to be currently operational and is expected to serve as a model, in other words a confidence builder for upcoming irrigation projects (Reynolds, 2013). Construction of Ribb irrigation project will be completed soon while that of Megech has just been started. Fig. 2 shows the status of the irrigation schemes in the sub-basin. The North East Tana, Megech Robit and Megech Seraba projects will pump water from the Lake when the others will have reservoirs. For almost all of these projects, furrow (flooding) irrigation will be the method that is going to be used. Exceptionally for Ribb a gradual conversion to sprinkler irrigation is planned in the near future (i.e. ten years after the scheme is operational).

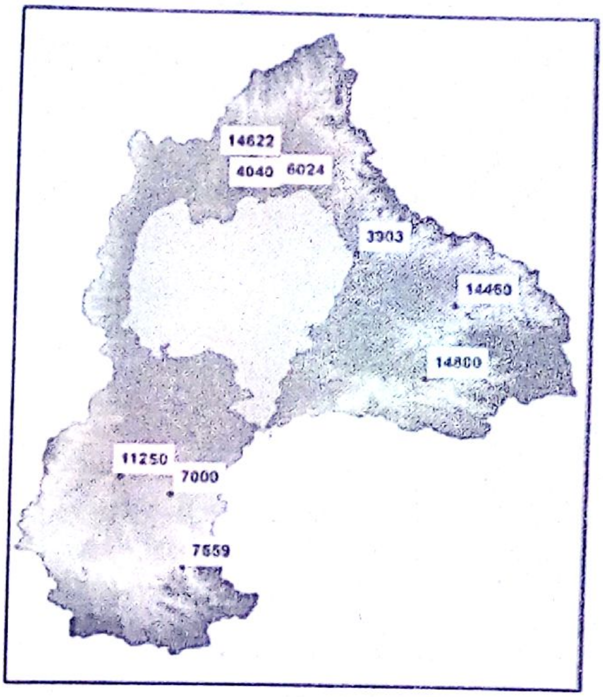

Figure 1: Lake Tana Beles schemes irrigated area

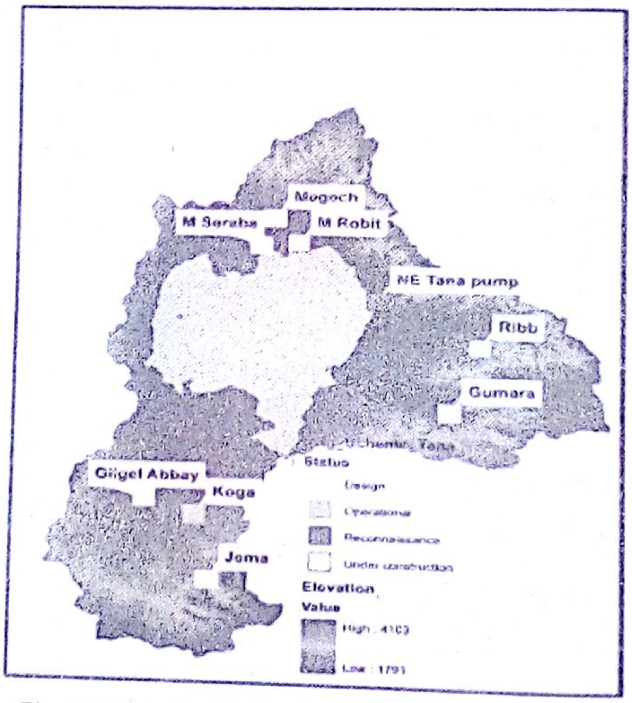

Figure 2: Lake Tana Beles schemes status

2.2 Data set

The Penman-Monteith equation is the international standard in both humid and arid environments for estimating reference evapotranspiration (ETo) (Smith, 2000). A set of climatic variables are needed to calculate ETo using the Penman-Monteith formula. The key variables that influence ETo estimation are mean daily maximum temperature (in °C), mean daily minimum temperature (in °C), mean temperature (in °C), mean wind speed (in m s-1) and mean cloud cover (in %). These data sets for the baseline and future time periods (1970 to 2100) were obtained from CORDEX-Africa which made dynamically downscaled data readily available for users.

The data used in this study came from the RCA4 Regional Climate Model (RCM) which was used to downscale the outputs of the GCM model: Canadian Center for Climate Modeling and Analysis (CCCma). In this study we used the RCP4.5, which is a medium-low scenario aiming for stabilization of the radiative forcing at 4.5 Wm-2 shortly after the year 2100 (Table 2). This target is achieved through low emission energy technologies, carbon capture and geologic storage technologies.

For bias correction of the RCM data, climate data was obtained from the National Meteorology Agency (NMA) of Ethiopia. The observation period is subject to the stations and variables with most of the collected data covering the time period between 1986 and 2005. The Quantile mapping method was used to correct the bias of rainfall while the temperature bias is corrected by shifting to adjust the mean and scaling to adjust the standard deviation.

Table 2: Characteristics of newly developed RCP scenarios

Scenario Component	RCP2.6	RCP4.5	RCP6	RCP8.5
Comparison with old scenario	No analogue	Very close to B1 by 2100, but higher emissions at mid-century	Similar to A1B by 2100, but closer to B1 at mid-century	Nearly identical A1F1
Greenhouse gas emissions	Very low	Medium-low mitigation	High mitigation	High baseline
Agricultural area	Medium for cropland and pasture	Very low for both cropland and pasture	Medium for Cropland but very low for pasture (total low)	Medium for both cropland and pasture
Air pollution	Medium-Low	Medium	Medium	Medium-high

3. Methods

Net irrigation requirements (NIR) is often estimated using the CROPWAT software. The main inputs of CROPWAT are monthly average climate data which include rainfall, reference crop evapotranspiration, crop coefficients, planting dates, growing stages, crop heights and soil type. In this study, we implemented CROPWAT in R-software so that to be able to continuously simulate NIR for 130 years (1971-2000). Proposed cropping pattern as well as crop specific data (crop coefficients, planting dates, growing stages, and crop heights) for the 9 irrigation projects was retrieved from design or feasibility reports subject to the status of the schemes (Fig.1). When the required data was not available on these reports we referred to the FAO database. Percentage of cultivated land of the irrigation schemes is shown in Figure 3 for dry season, wet season and perennial crops. Also pre-irrigation water (water allowance for land preparation) was assumed at a rate of 70 mm/ha for annual crops. The area-weighted NIR is processed for monthly and annual time scales from the year 1970 to 2100. In this study, the analysis period was divided into four: baseline (1971-2000), near future (2011-2040), midium future (2041-2070) and far future (2071-2100).

4. Results and Discussions

The average annual precipitation, ETo and NIR of the 9 irrigations schemes for the three future time periods was compared to the baseline period 1971-2000 (Table 3). The change in annual precipitation did not show a clear trend. Annual precipitation is likely to decrease by almost 2% in the near future and increase by 4.5% and 2% in the middle and future time period, respectively. A 5%, 6% and 8.5% increase in ETo are expected in the near, medium and far future periods, respectively. Also, the NIR showed a similar trend to the ETo as annual NIR is likely to increase by 4.5%, 6% and 7% in the three future time periods, respectively.

NIR will likely increase for all irrigation schemes in the future but the magnitude of the change differs from one scheme to the other (Figure 4). The change in magnitude can be attributed to the difference in cropping pattern but also to region specific climatic and geographical characteristics.

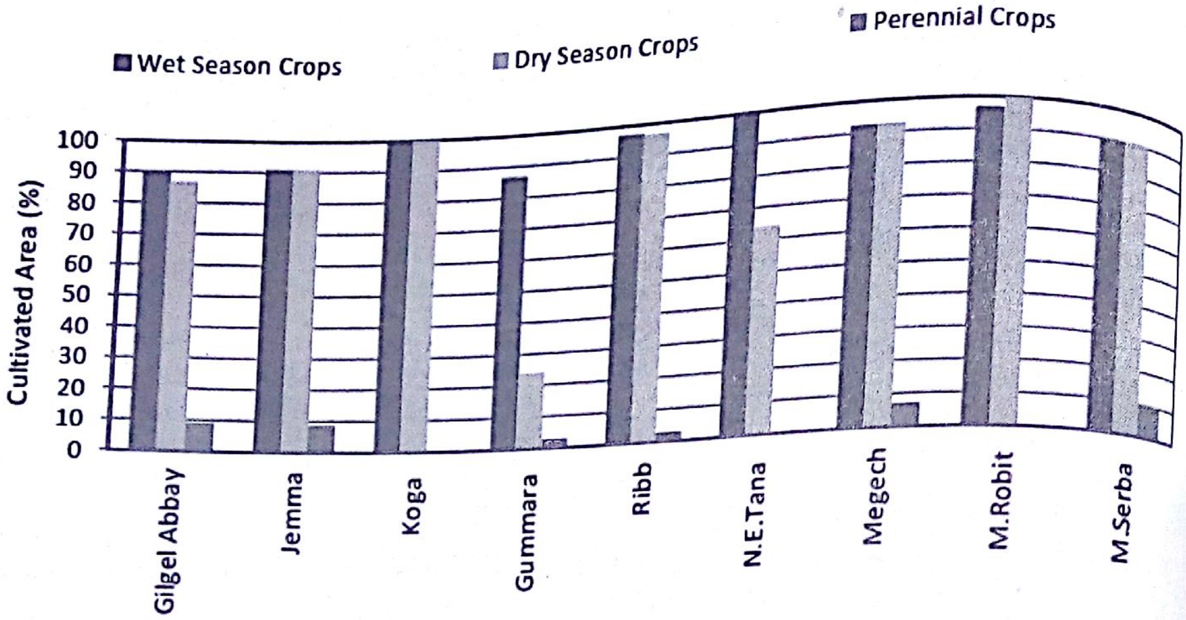

Figure 3: Proportion in % of Annual and Perennial Crops

Table 3: Change in annual precipitation, ETo and NIR for Climate Change Scenario (RCP4.5)

	Near future 2011-2040	Medium future 2041-2070	Far future 2071-2100
Change in Precipitation (%)	-1.83	4.55	2.16
Change in ETo (%)	5.15	6.32	8.57
Change in NIR (%)	4.56	5.87	7.13

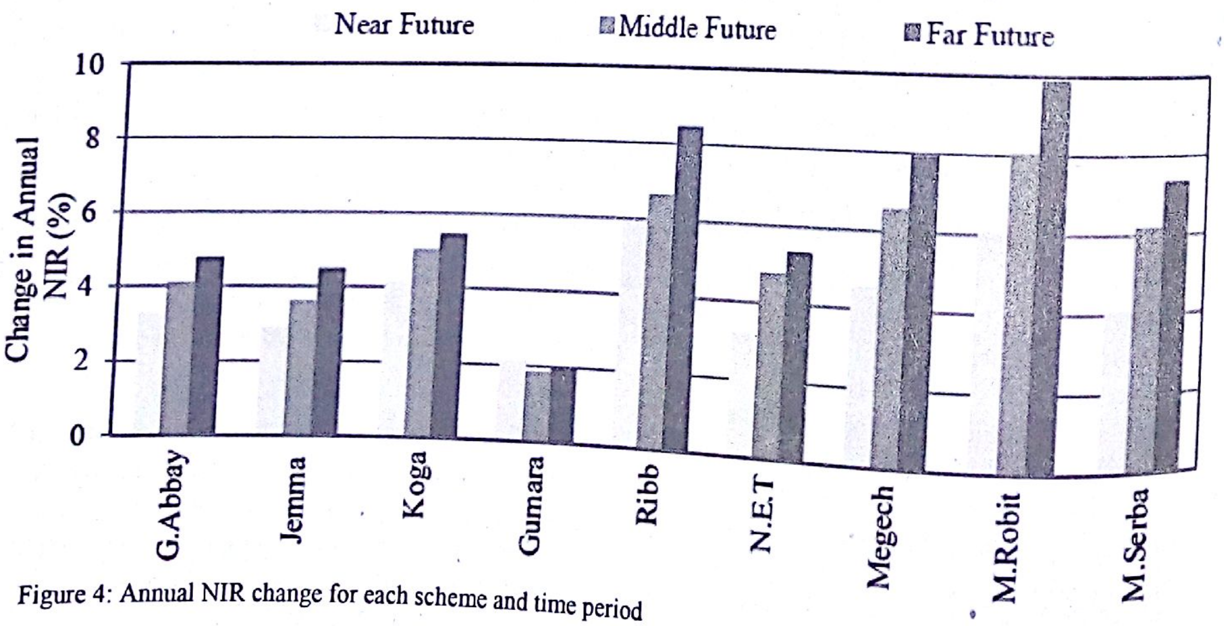

Figure 4: Annual NIR change for each scheme and time period

The maximum percent of future increase in NIR is observed for the Ribb and Megech schemes. NIR change for the Gumara scheme is exceptionally very small (an increase of only 2% by 2100). This is because the dry season crops only account for 23% of the total irrigated area of Gumara.

The annual cycle of NIR in the sub-basin is shown Figure 5. There is strong intra-annual variation in irrigation requirement which varies from <5 MMC in the peak rainy months (July and August) to nearly 90 MMC in the dry month (February). The change in monthly water season (January to May) compared to the wet season (June to December).

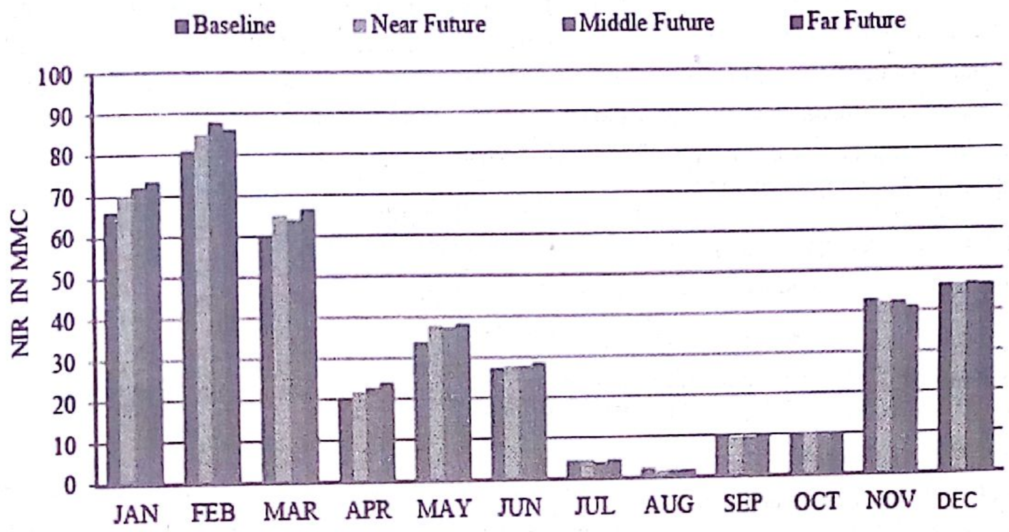

Figure 5: Monthly NIR for Climate Change Scenario (RCP 4.5)

5. Conclusions

In this study, we evaluated the impact of climate change on net irrigation requirement of the planned and ongoing irrigation schemes in Lake Tana sub-basin. The study is unprecedented for the sub-basin as it uses high resolution RCM data and the new RCP 4.5 scenario. Our results show that annual precipitation of the 9 irrigation schemes in the sub-basin will slightly decrease in the near future but will increase in the medium and far future. These results are in consensus with the 4th IPCC Report on Regional Climate which reported a likely increase in annual mean rainfall in East Africa. In the future, increased evapotranspiration will lead to higher net irrigation requirement in the sub-basin. However there exists strong intra-annual variation in NIR which peaks in February and attains its lowest in August. Ribb irrigation scheme has the largest net irrigation requirement while Gumara has the lowest requirement. This is mainly explained by size of irrigated land and cropping pattern. For an overall irrigation efficiency of 50%, the gross irrigation requirement in the sub-basin is 863 MCM per year for the baseline period which represents 14.91% of the annual average inflow of Lake Tana. However, GIR will account for 15.55%, 15.72% and 15.88 % of the lake inflow in near, medium and far future, respectively. In other terms, the impact of irrigation withdrawal on the lake inflow will increase by 1% by the end of the century. Nevertheless, a further study that does take into account additional parameters and other projects (hydro-power projects) in the basin should be carried out to assess the overall impact on the basin inflow and storage. In this study, we applied only one possible pathway of climate change which refers to total radiative forcing stabilized at 4.5 W/m2 shortly after the year 2100 through low emission energy technologies, carbon capture and geologic storage technologies. To be more conclusive, we suggest use of the RCP 2.6 and 8.5 scenarios as well as climate outputs of multiple GCM-RCM combinations.

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Deforestation and a Strategy for Rehabilitation in Beles Sub-Basin, Ethiopia

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Abstract

Being identified as one of the growth corridors of Ethiopia with untapped common pool resources, the regions' abundant natural resources are not yet adequately utilized in planned, integrated and systematic manner. In connection to this, the country has initiated and implemented large-scale development projects such as the renaissance dam of Ethiopia and the Tana-Beles sugar factory in Beles sub basin region. A study is undertaken on deforestation and its protection strategy in Beles sub basin which focuses on estimating the pattern and magnitude of deforestation and the triggering factors of deforestation. The study uses NDVI data from two periods (2001 and 2012) to analyze the rate of deforestation and the associated biodiversity loss. Key informants interview and focus group discussions were held to generate the required data. Secondary data on ecological and socio-economic issues were obtained from different GIS and Satellite images, which were downscaled using NDVI technique. The result shows that deforestation and the resulting environmental degradation were the major problems in the Beles sub basin of Ethiopia. High population pressure, agricultural land expansion, large-scale investments, uncontrolled wildfire, illegal logging, firewood and charcoal production, and forced villegalization program were found to be the main drivers of deforestation. As a result, environmental consequences such as climate change, massive deforestation in the name of investment and migration of precious animal such as lion, elephant and buffalo to Sudan were few of the overwhelming problems. This may strongly confront the food security, community livelihood and sustainable development of the study area. Therefore, continuous water, land and forest conservation activity by local communities based on the principles of collective actions and Participatory Forest Management (PFM) is recommended as vital development activities. Furthermore, frequent awareness creation on wildfire protection, modern charcoal production, EIA preparation and implementation for large scale agricultural investments, and implementation of voluntary villegalization program is suggested for long run effective use of the Beles basin natural resources.

Keywords: *deforestation, biodiversity loss, NDVI and GIS, Beles Basin, Benishangul Gumuz and Amhara Region, Ethiopia*

1. Introduction

Ethiopia is the second-largest population in Africa, with limited capacity to manage natural resources, and widespread land degradation. The country also faces many serious challenges to conserve its biodiversity and forests. With broad latitudinal and altitudinal ranges, Ethiopia encompasses an extraordinary number of ecological zones, which in turn host rare and endangered species and high rates of endemism (USID, 2008). In combination with its importance as a center of genetic and agricultural diversity, conservation of water, forest and biodiversity is an issue of global importance. Benishangul Gumuz region, which covers the majority parts of beles sub basin area is one of the richest regions in terms of vegetation coverage in the country comprising about 68, 495 ha of forest coverage. Moreover, the region possesses about 2,473, 064 ha of woodland, and 1,422,191 ha of shrub land. Yet the rate of deforestation and forest degradation is alarmingly high due to overexploitation, overgrazing, expansion of cultivation and settlements that are accompanied by excessive deforestations, invasions of alien species and pollution. According to Benishangul-Gumuz Regional Food Security Strategy Report (BGRFSSR) report, degradation of forest resources is increasing at an alarming rate due to various factors such as encroachment, forest fires, absence of secure land use policy, effects of agricultural expansion and intensive resettlement programs (BGRFSSR, 2004). Lack of equitable access to natural resources and, hence, inequitable distribution of their benefits often leads to clandestine encroachment, resource use conflict and misappropriation of these resources (Veerakumaran, 2007). In the same ways, the rich forest resources of Beles basin area in the BGR are being depleted because of several factors. These in turn, hamper the economic growth of the region.

Although there are some cases of improvements in some parts of Amhara region as the result of implementation of participatory forest management (PFM) and basin conservation activities, still massive forest degradation is threatening much of the biodiversity of the Beles basin. Consequently, from time to time, the distribution and population of many mammals and birds is dramatically declining. A study conducted in Benishangul Gumuz region indicated that large scale projects significantly and negatively affect the socio-economic and environment condition of the local people (Semeneh, 2014). As a result, the environmental consequences such as massive deforestation and migration of precious animal such as lion, elephant and buffalo to Sudan are one of the overwhelming challenges. Though ample theoretical evidence is cited on the economic, social and political causes of biodiversity loss in Tana-Beles basin, there is lack of scientific study on magnitude and pattern of deforestation in Beles basin. If it exists, the available studies are fragmented, meager or even non-existent particularly in BGR parts of the basin.

To reverse the situation, academicians in the field of natural resource economics often suggest cooperative/ collective management of forest by local people themselves, while others still recommend privatization and centralized state management. Despite the advantages and disadvantages of the aforementioned development approaches, currently, collective forest management initiatives has been under implementation through PFM strategy adopted in the regions. Hence more scientific research in this area is imperative to validate the effectiveness of such development strategies.

2. Objectives of the Study

This study will have the following interrelated three objectives.

i. Demonstrate the pattern and trends of deforestation in Beles Basin areas of Benishangul Gumuz and Amhara regions.

ii. Identify the main causes of deforestation in the in Beles Basin areas of Benishangul Gumuz and Amhara regions.

iii. Suggest policy option that can reduces deforestation and biodiversity loss in future planning.

3. Methodology

3.1. Location and Description of the Study Areas

This section will describe location of the study areas and brief research design followed in achieving the research objectives. More specifically, the location and description of BG and Amhara regions, data collection techniques, data type and method of data analysis is briefly described.

2.2. Location and description of Beles sub basin

The Beles sub basin is part of Abbay River Basin and situated within Metekel zone of Benishangul-Gumuz Regional State (BGRS) and five *woredas* of Amhara National Regional State (ANRS). The sub basin covers an area of 14,209 km2; including the catchments of a number of small rivers (totaling about 650 km2) that drain directly into the Abbay and are strictly not part of the Beles river catchment. The Beles River has two rivers: The major river is called Abate and the other is Gilgel Beles River. Apart from this, many small tributaries drained into the Beles River. To mention some of them: on the right bank of Beles River (Babzenda, Yazbil, Aysika and Gulbak) whereas on the left bank (Bunta, Rapids, Shar, Dukusi, Gorishi and Bajengi).

The highest point in the Sub basin is 2,725 m.a.s.l, at the water divide between the Tana and Beles basins. The mean elevation of the sub basin is 1,190 m.a.s.l and the Beles river joins the Abbay at an elevation of 540 m.a.s.l, near the border with Sudan. The rainfall pattern within the sub basin shows spatial and temporal variation. Despite the variation, the average annual rainfall within the sub basin is about 1,490 mm/year. From the past field data collected, land cover of the sub basin includes 56.37 percent open forest in which the cultivated land may be found, 26.3 percent closed forest and others cover the rest 17.33 percent. It can be concluded that the land cover of the sub basin is predominated by forest. Meanwhile, the Beles sub basin at both lower and upper Beles has a huge potential of irrigable land. According to Nile basin master plan document, 17,232 hector of land are estimated as suitable for irrigation.

3.3. Data Collection Technique and Dataset

As indicated above, the study is conducted in Benishangul -Gumuz and Amhara regions. These regions are selected purposively based on the huge resource endowment and thei are of deforestation as the result of manmade and natural causes. The basin area includes 12 districts (seven districts in BGR and five in Amhara) region. The study utilized both primary and secondary data.

Primary data was collection using various survey techniques. These were Key informant interview, focus group discussion, and field observations. These methods are briefly described as follows. 30 key persons participated in

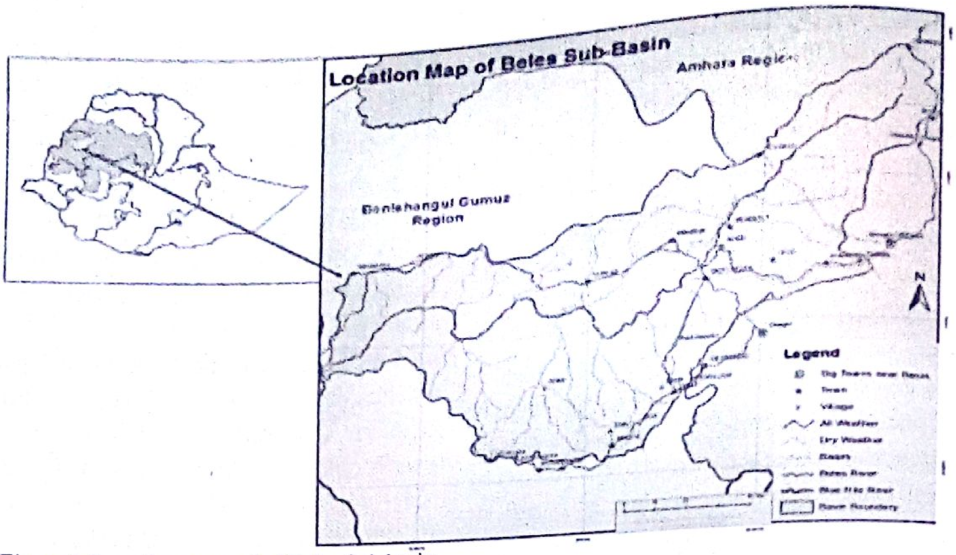

Figure4: Location map of of Beles Sub basin

the interview process that comprises the zonal bureau of agriculture heads, NRM experts, woreda environmental protection and land administration heads and experts, regional and woreda and NRM expert, representative of various institutions at *woreda* and community levels were identified and interviewed. Two step field visits across the basin area was observed and assessed with the help of photographic images. During this time, infrastructure, forest resources, landscapes and the ecosystems of the basin were visited. Specially, the degradation statuses of the forest resources such as forest cover of bamboo forest, landscape and basin woodlands and their status. Moreover, geographic information system (GIS) was used. The study also gathered secondary data from various government reports, unpublished documents, proclamations, and from government and private Medias.

3.4. Methods of Data Analysis

The Normalized Difference Vegetation Index (NDVI) was used to estimate the trend and magnitude of deforestation. NDVI is an index of plant "greenness" or photosynthetic activity used to estimate the status of deforestation. The NDVI is commonly used to assess the situation of green biomass and its inter annual changes to draw conclusions about trends in biomass development Gu et al. (2011). NDVI are based on the observation that different surfaces reflect different types of light differently. Photosynthetically active vegetation, in particular, absorbs most of the red light that hits it while reflecting much of the near infrared light. Vegetation that is dead or stressed reflects more red lights and less near infrared light. Likewise, non-vegetated surfaces have a much more even reflectance across the light spectrum. NDVI is calculated on a per-pixel basis as the normalized difference between the red and near infrared bands from an image:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where NIR is the near infrared band value for a cell and RED is the red band value for the cell.

The biophysical interpretation of NDVI is the fraction of absorbed photosynthetically active radiation. Water typically has an NDVI value less than 0, bare soils values are between 0 and 0.1 and vegetation values are over 0.1. The disadvantage of this approach is that the determination of whether vegetation degradation is climate or human induced is not indicated. This is because many factors affect NDVI values like plant photosynthetic activity, total plant cover, biomass, plant and soil moisture, and plant stress. Because of this, NDVI is correlated with many ecosystem attributes that are of interest to researchers and managers (*e.g.*, net primary productivity, canopy cover, bare ground cover). Although NDVI is affected by soil background, atmospheric scattering, and is relatively insensitive to high biomass levels, it provides sufficient stability to capture seasonal and inter-annual changes in vegetation status (Vrielinge et al, 2002). Because it is a ratio of two bands, NDVI helps compensate for differences both in illumination within an image due to slope and aspect, and differences between images due things like time of day or season when the images were acquired. Thus, vegetation indices like NDVI make it possible to compare images over time to look for ecologically significant changes. Vegetation indices like NDVI, however, are not a panacea for rangeland assessment and monitoring. The output of NDVI is a new image file/layer.

Theoretically, the values of NDVI can range from -1.0 to +1.0, but values less than zero typically do not have any ecological meaning, so the range of the index is truncated to 0.0 to +1.0. Higher values signify a larger difference between the red and near infrared and low NDVI values mean there is little difference between the red and NIR signals. This happens when there is little photosynthetic activity, or when there is just very little NIR light reflectance (*i.e.*, water reflects very little NIR light). Although NDVI is affected by soil background, atmospheric scattering, and is relatively insensitive to high biomass levels, it provides sufficient stability to capture seasonal and inter-annual changes in vegetation status (Huete et al. 2002).

3.4. Empirical study on Deforestation using NDVI Approach

Vast numbers of researches related to deforestation have been conducted using NDVI approach. For example, *Kumar et al., (2013)* applied Advanced Very High Resolution Radiometer (AVHRR) Normalized Difference Vegetation Index (NDVI) to estimate forest coverage and amount of deforestation in India. Using time resinous analysis 1981–2001 period Julien *et al.* (2009) has used NDVI to detect changes in the Iberian land cover in Valencia, Spain. Social and land-use/land-cover change data was modeled to assess drivers of smallholder deforestation in Belize. The predicted rate of total deforestation between 1989 and 2004 was found to be 30 percent.

NDVI and rainfall estimates data from the National Oceanic and Atmospheric Administration (NOAA) satellites were used to investigate the spatio-tempotal pattern of precipitation and the response of vegetation to precipitation in Ethiopia (Getahun, 2008). Land use and land cover changes that occurred from 1984 to 2009 in the Fincha'a Sugar Estate, Blue Nile Basin of western Ethiopia, were estimated using a geographic information system (GIS) and a remote sensing approach (Getahun et al., 20014). According to this study the natural forest cover declined from 17.25 percent in 1984 to 10.16 percent in 2005 and 8.70 percent in 2009. The total natural forest cleared between 1984 and 2009 amounts to 3186 hector, which was equivalent to 50 percent of the forest cover that existed in 1984. The pattern and magnitude of deforestation that occurred from 1972 to 2000 in the south central Rift Valley of Ethiopia were analyzed using similar techniques (Gessesse and J. Kleman, 2007). The results show that natural forest cover declined from 16 percent in 1972 to 2.8 percent in 2000. Their estimate indicated that total natural forest cleared between 1972 and 2000 amounted to 40,324 ha, corresponding to an annual loss of 1440 hector. Other others such as Getachew *et al.,* 2011; Yitea *et al.,* 2012; Francesco *et al.,* 2009) have used NDVI to estimate deforestation, desertification and land use land cover in various parts of Ethiopia. Hence this paper has also followed the same approach.

4. Results and Discussions

This section presents two main findings of NDVI data and secondary data collected from various sources. The first section focuses on estimation of deforestation in the study area. Then analysis on the driving forces of deforestation in Beles sub basin followed.

4.1. Land use system in Beles sub basin region

From field observation and secondary data collected from different sources, land cover of the study area was found to be 56.37 percent open forest in which the cultivated land was 26.3 percent, the remaining are closed forest 17.33 percent. The result implied that the land cover of the region is still predominated by (mainly bamboo) but in a declining sate. This figure was also cited in most past studies. For example, qualitative study conducted by Habtamu et al (2012) indicated similar finding. From my field observation and KIIs, economically important tree species such as incense tree and the lowland bamboo are highly threatened by human intervention. On the other hand, the regenerating capacities of these types of tree species are generally very low; once removed, it will be difficult to bring them back. In terms of the types of forest, grassland was found to be the dominant forest type which covers about half of the total forest while state farm are the least existed in the basin region.

However, compared to other regions, due to poor infrastructure and little population density, the rate of deforestation becomes generally low in tower parts of the basin. The evidences indicated that population density in the Guba *woreda* is quite low. In contrast, there is high forest cover compared with the highly populated areas of

Alefa and North and South Achefer in the upper parts of basin area. The indigenous types *Wanza /cordia Africans, yehager-grer/Acacia spp/, Zigba /podocarpus graciolaris/, Sholla /Ficus sycomorus/, Woira/Olea african/, Zenbaba/ palm tree, Kerer/Aningeria altissian, Kerkeha/Bamboo, Dokuma/Syzygium/*are being endangered due to charcoal making and other sources of livelihoods in the basin area, especially in the lower parts of the basin. Deforestation and the land degradation have brought losses of different types of small and big wildlife. Just to mention a few: Hart

Beast, Bead-Buck, Water-Buck, Bush-Buck, Bush-Duiker, Wild-pig, Ape, Globes, Fox, Giraffe, Wild cat, Porcupine, Crocodile, Warthog, Guinness hen, Birds, Warthog, Fish, Guinean fowls, Hyena, Lion, buffalo, and Monkey live in the in the region. Since the major parts of the basin forest resource are cover by bamboo, the following has estimated the rate of bamboo deforestation.

Table 1: Land use type and area covered by forest (MoWR, 2013)

Land Use	Area (Sq.km)	Area covered (%)
Grassland	6,028.88	49.24
Cultivation	3,571.07	29.17
Shrub land	2,320.05	18.95
Woodland	266.90	2.18
State farms	56.45	0.46

Woreda level NDVI analyses illustrate the amount total forest areas cleared in the study area. High rate of deforestation was observed in South Achefer (69.16 percent) and the least being in Mandura *woreda* 21.47 percent. In terms of total forest area cleared Dangur *woreda* was found to be very high, with the total area of 125, 400 hectors within the six years time period. The data indicates that the upper parts of the basin areas, which mainly fall in Amhara region was the most degraded area as compared to the lower parts of the basin areas. As indicated, the lower parts of the basin which covers Benishangul Gumuz region was covered with dense forest. The high rate of deforestation and land degradation could be due to the high population pressure in the upper parts of the basin areas.

3.2. Estimation of the rate Bamboo Deforestation in Beles sub basin

Table 2 represents the mean annual forest coverage and patterns for bamboo deforestation (from 2006 to 2012). Quantitative analysis of changes in bamboo forest coverage between these time periods depicted a general decline in bamboo forest coverage. However, bamboo coverage seems to improve since in the years 2011 and 2012. The decline in forest coverage was the replica of decline in the calculated values of NDVI. For the first five years the value of NDVI and the corresponding bamboo forest has sharply declined. Increase in the value of NDVI up to (0.55) in 2011 and 2012 years revealed recovery in bamboo forest coverage in the study area. The result shows that in 2006, the bamboo coverage was estimated to be 1,056,187 hector while in the year 2012 it falls to 556, 715 hector, indicating 499,472 hector decline of bamboo forest within seven years. Moreover, the data revealed high rate and low of bamboo deforestation in the year 2008.

Table 2: Estimated annual rate of deforestation in Beles sub basin (2006-2012) (Downscaled NDVI data, 2014)

Year	Forest Area (ha)	Amount deforested (ha)
2006	1,056,187	-
2007	980,080	(-)76107
2008	887,101	(-)92979
2009	420,044	(-)467057
2010	435,816	(-)15772
2011	509,051	(+) 73 635
2012	556,715	(+) 47664

4. Drivers of Deforestation and Forest Degradation

This section critically assesses the main drivers of deforestation and subsequent biodiversity loss in the basin areas. There are several causes of deforestation in beles basin area. However, in this study only few causes of deforestation are reported.

4.1. Clearance of forest for cropland expansion

Forest ecosystems often serve two contradictory roles. On the one hand, they offer essential, ecological, social and economic services and benefits. On the other hand, ecosystems are considered as reserves, hence taken as opportunities for development through other economic sectors such as agriculture and agri-investment (Mulugeta and Bekabil, 2011).

Table2:Change in forest coverage between (2006 -2012)

Woreda	Change in forest (loss)	Percentage change
Alefa	26,849.83	40.24
Bulen	39,523.53	27.22
Dangla	13,220.04	45.72
Dangur	125,349.55	49.14
Dibatie	14,966.90	34.39
Mandura	13,960.48	12.47
S.Achefer	32,816.46	69.16
Pawe	25,246.75	41.44
Jawi	47,366.41	52.81
Wombera	70,377.48	31.84
N.Achefer	12,515.54	32.24
Guba	77,278.64	67.52

Similarly, a major concern in the beles basin *woredas* today is found as the alarming deforestation of natural forests and woodlands for agricultural land expansion. In fact, from the results of field data, this variable is the most important direct driver of deforestation in the basin region. The reason for the high rate of clearance and conversion to cropland is the fact that the economy of the study area largely depend on agriculture, which accounts for 93.2% of employment for the economically active population. Furthermore, the high rate of migration from different regions of Ethiopia in search of cropland instigated high rate of conversion of forest woodlands to croplands.

The zero state basin documents of BESBO highlighted that Beles basin is blessed with different natural resources (Forest, water, aquatic, and wild animals). The area occupies attractive natural beauties and historical sites. Its rolling mountains, breath taking landscapes, agreeable climates, endemic wildlife, diverse cultural heritages, hospitable people, and artifacts could make the nation an alluring destination. As per the findings of this study, the most direct household level consequences of deforestation in the basin include reduced wild fruits, reduced wood products and reduced wildlife products. However, it is commonly argued that forest area of the basin has been declining from time to time (BESBO, 2012). In consequence, economically important trees like Etan and Mucha are highly over-utilized.

Figure 2: Etan Tree in Beles Basin Area

4.2. Unregulated forest fire

Fire is being used widely as site clearance technology in the region. Unbodtly, this has been one of the major degrading agent in the basin areas. In the area, fire is caused by several factors that include: i) wild honey hunting; ii) site clearance for shifting cultivation and cropland preparation; iii) road clearance for gum and incense tapping; defense agains wild animals, and iv) trophy hunting. As there is no or weak systematic burning and fire control mechanism, fires consum huge areas of land including unintended areas. Conseqently, fire has been consuming a huge areas of natural land every year. On average, 1 percent of ali forests were reported to be significantly affected each year by forest fires (FAO, 2011).

However, the area of forest affected by fires was severely underreported, with information missing from the study areas. According to the valuable evidence in the study site local Communities basically ignite fires deliberately in order to hunt wild animals, to harvest honey, and to collect wood. Previously, forest areas were also set fire for charcoal production. Enforcing mechanism to prevent such problem was challenging even today it is still difficult due to the difficulty of identifying who starts a fire. The main consequences of fire and the subsequent deforestation were habitat destruction and decline of water availability. As it can be seen from the following picture below people intentionally set fire in Dangur woreda affecting the ecosystem and economically important three. Specifically, the lowland bamboo is one of the highly victimized economic trees in the basin.

Figure 3: The effect of fire on in Guba and Dangur *woredas* (own field photo, 2013)

4.3. Unsustainable wood harvest for fuel and construction

Wood is the main source of energy and construction materials in BG region. However, the wood harvest for construction, fuel wood, and other sources of energy is often unregulated owing to lack of formal or informal regulatory system, hence more or less open access harvesting takes place where households or individuals harvest and use wood products and materials often extravagantly. Similar to the effect of fire, the bamboo forest is particularly the major victim of the unsustainable harvest since it is the most widely used species as a construction material.

Data obtained from BGR agricultural and rural development office revealed that a huge number of woods are being consumed by wonbera woreda. From the total 316,785 wood consumed in metekel zone as the source of energy, about 68, 353 wood is consumed by 8701 rural families and 672 urban famiiies per annum. Dibate is the second largest worked in terms of wood consumption. A total of 59,831 woods are being consumed annually which is equivalent to 239472 ha of forest land. Pawi, Dangur, Bulen and Mangura woredas consume about 56,474woods, 50,831woods, 31,974woods, and Mangura 35,664 woods respectively. Guba district is the least consumer of fuel energy. Only 2,692 rural families and 271 urban families depend on wood as the sources of fuel energy which is equivalent to 40,5396 ha of forest coverage.

4.4. Large scale investment

The government report revealed that in Benishangul-Gumuz region about 691,984 hectors of agricultural land has been transferred to the Federal land bank to undertake large scale agricultural investment. Some researchers in Ethiopia associate the situation with the so called "global land grabbing" (Dessalegn, 2011). Land grabbing is the rush for commercial land in Africa and elsewhere by private and sovereign investors for the production and export of food crops as well as bio-fuels, in which the land deals involved stand to benefit the investors at the expense of host countries and their populations.

According to Tsegaye (2013) in BGR a substantial amount of land has been transferred to domestic and foreign investors without mapping of existing land uses. Moreover, his study identifies that the land transferring process lacks genuine participation of local communities and identifies that the land transferring process lacks genuine participation of local communities and authorities. In consequence, these the dispossession and displacement of communities from their villages and destruction of the natural environment threatened the livelihoods of the local people.

A study conducted in BGR by Maru (2012) suggests that there is weak linkage, monitoring and support from federal, regional and district levels in relation to large scale agricultural investment activities. Moreover, weak capacity of domestic investors has accelerated degradation of forest resources, and threatened livelihood security of rural community. During my preliminary filed survey in the region it has been realized that different large-scale development projects have been undertaken by private investors with the view of promoting regional development. However, these large-scale development projects are perceived as a threat by the local communities and causes of investor-farmers conflict.

Table 7: Total annual wood consumption by their residence in the basin areas of BGR

Woredas	Rural Families	Urban Families	Area (ha)	Total wood
Bulen	4,165	898	287756	31,974
Dengur	6,868	1,068	865252	50,831
Dibate	9,413	886	239472	59,874
Guba	2,292	271	405396	13,615
Mandura	5,259	488	102312	35,664
Pawe	9,502	1,982	62,796	56,474
Wenbera	8,701	672	734,436	68,353
Subtotal	46,201	6,265	2,697,420	316,785

Figure 10: Environmental Effect of Large Scale Investment in Dangur Woreda (Own photo, 2013)

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In connection with rich version land and suitable for land for private and public investment, Massive large scale investment has been undertaking in the region. During the discussion with the residents of Dangur woreda large scale investors are engaged in destructing economically important tree species and transport it to Amhara region.

When the local people and *kebele* leaders request the project owners to pay attention to environmental issues, the investors often fail to do so. Secondary data and some KII revealed that50 percent of the basin's virgin land is allotted for

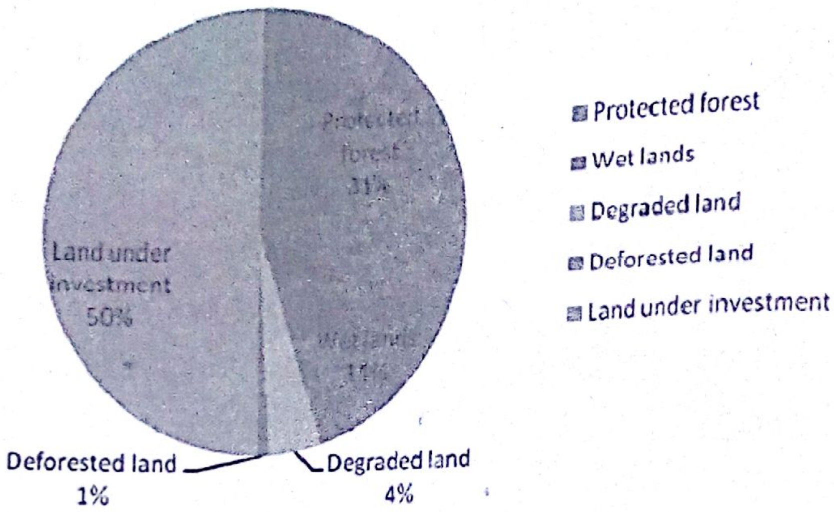

Figure 11: Land under different use types

4.5. High population growth

Population growth, although debatable, is one of the root drivers of degradation under poorer economy that heavily depends on natural resources extraction for survival. In all districts of the basin, population is growing due to the characteristic high fertility rate. One of the reasons for this is the prevalence of the practice of polygamy. In this regard, projected regional demographic parameters suggest that even more serious pressure on natural resources is yet to come (RCS, 1997). The high young population in the region as well as in the Beles basin may imply a high pressure on the future livelihood of generation. In general, as population grows, pressure on forest and other natural resources also build. Demand for cropland will increase to feed more mouths, wood demand will increase to provide more energy and shelter. In general, deforestation has risen as population figures continue their inexorable increase. These could be attributed to the cutting of trees in the forests for various uses such as firewood, timber production and clearing for agricultural purposes. These decreases could be linked to changes in climate change, and the effects of in-migration and population growth.

4.6. Weak institutions

Leftwich and Sen (2010) indicated that institutions are the formal and informal *'rules of the game'* that shape, but do not determine, human behavior in economic, social and political life. They are understood as "sets of rules that allow a plurality of persons to coordinate their behavior and to routinely solve typical problems that arise in social interaction" (Vanberg, 2001). The regional state does not have regional formal institution like forest policy and accompanying acts or legal instruments so far. In fact there is land administration policy but these do not explicitly look in to the forestry condition of the region.

The land administration policy states that land is government property, but when government could not quickly put in place regal instruments and its enforcing institutions, the resources, as usually the case, fall into the state of open access resulting over utilization of the resources.

4.7. Lacke of commitment on rehabilitation of degraded forest lands and tree plantation

Side by side with improving the management of natural forest, rehabilitation of degraded lands through soil and water conservation, tree planting, area exclosure and other relevant techniques is an important action to contribute to improved natural resources management in the region. Tree planting, except for fruit trees, is not practiced by the community in the region. So far there is little motivation from the regional government to boost their endeavour for rehabilitation and tree planting, due to the relatively large coverage of the landmass by natural vegetation. However, by planting trees on degrading lands, further pressure on the natural vegetation can significantly be reduced. Therefore, tree planting need to be considered seriously as strategy to reduce pressure on natural resources base.

Figure12: Participatory Forest Management in Amhara Region

5. Recommendation

Based on the findings of collected data and field observations controlling shifting cultivation, regulating large scale agricultural investment, promoting participatory forest management, controlling forest fire, establish national / regional protected areas, focusing on bamboo development, provision of alternative energy sources such as power saving stoves to the farmers, improving formal and informal institutions and control population growth are suggested for effective use of the basin resource.

References

Standardizing Local Engineering Capacity for Developing Sustainable MHP in Ethiopia: CFD Based Performance Simulation and Experimental Validation of Locally Made Cross Flow Hydraulic Turbine

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Abstract

Upgrading traditional watermills is techno-economically viable approach to develop Micro hydropower (MHP) plants in Ethiopia (Tadele.et.al, 2013). In this regard the large cost incurring component of the system is the electro mechanical component specifically the hydraulic turbine. Most commonly in developing countries the hydraulic turbine being used for the development of MHP plants is impulse type cross flow turbine. Similarly in Ethiopia more than 41% of energy generation cost from the material procurement share is taken by the turbine which mainly is imported from Indonesia that is capable of generating up to 60kw even though this value is 300% - 500% more than the rated output of the installed systems at their commissioning. Hence ,it become mandatory to identify the efficiency and cost compromise that is to be made between importing and manufacturing cross flow turbine for developing techno-economically viable and sustainable MHP scheme. In this study analytical design of impulse type cross flow turbine is done and the performance of this turbine is virtually predicted by ANSYS-CFX software at different operating conditions. The simulation result is validated experimentally using locally fabricated cross-flow turbine. The study result indicates the geometric configuration and efficiency of the locally fabricated cross-flow turbine is in good match with the commercially available T-12 cross-flow turbine. The simulated and experimentally obtained turbine efficiency has a percentage magnitude difference of 14.7% with the trend lines showing a best fit. Moreover, the locally fabricated cross-flow turbines will reduce the cost of energy generation by at least 15% compared to the imported ones with slight reduction in maximum efficiency from T-12 cross-flow turbines. Hence, this study result will assist key stakeholders in the energy sector of Ethiopia for making techno-economically feasible small scale hydropower development through promoting local skill and technology.

Keywords: *Micro Hydro Power, Cross flow turbine, CFD, Efficiency,*

1. Introduction

More than 90% of rural household energy demand in Ethiopia is supplied through utilization of the then ample the now scarce biomass resource. Similar to other Sub-Saharan African countries the modern energy supply in the rural areas is very limited [1]. Being called as the water tower of East Africa; Ethiopia contributes 85% of the water volume to the Nile. It has economically exploitable potential of 45GW for large scale hydropower and up to 100MW for Micro Hydropower in addition to the 600 traditional watermills with a potential to be upgraded [2].

In south western part of Ethiopia, where there is huge potential of large and small scale hydropower, the household energy demand is estimated to be 126.24kwh/day/village with the household capacity of paying $0.104/kwht for lighting service.

village with the household capacity of paying $0.104/kwht for lighting service. In this area there is large number of traditional watermills, of which 76% could be upgrade to MHP plants with an existing capacity ranging from 6kw - 26kw [3].

Many stakeholders in the energy sector are working on development of micro hydro power plants for both mechanical and electrical application in few parts of the country especially in the south-western parts. In this regard the investment cost is proven to be the major draw-back for the techno-economic feasibility and sustainability of these schemes. Depending on their level of advancement MHP schemes cost 2000 $/kW - 10,000$/kW in Ethiopia with the international value being 1000$/kW - 4000$/kW [4]. The major cost intensive component of the schemes being the electro mechanical component; the imported T-series cross flow turbine is reported to cost up to 15% of the total energy generation cost for its importation process only [3].

Figure 1: Detail View of T-series cross flow turbine

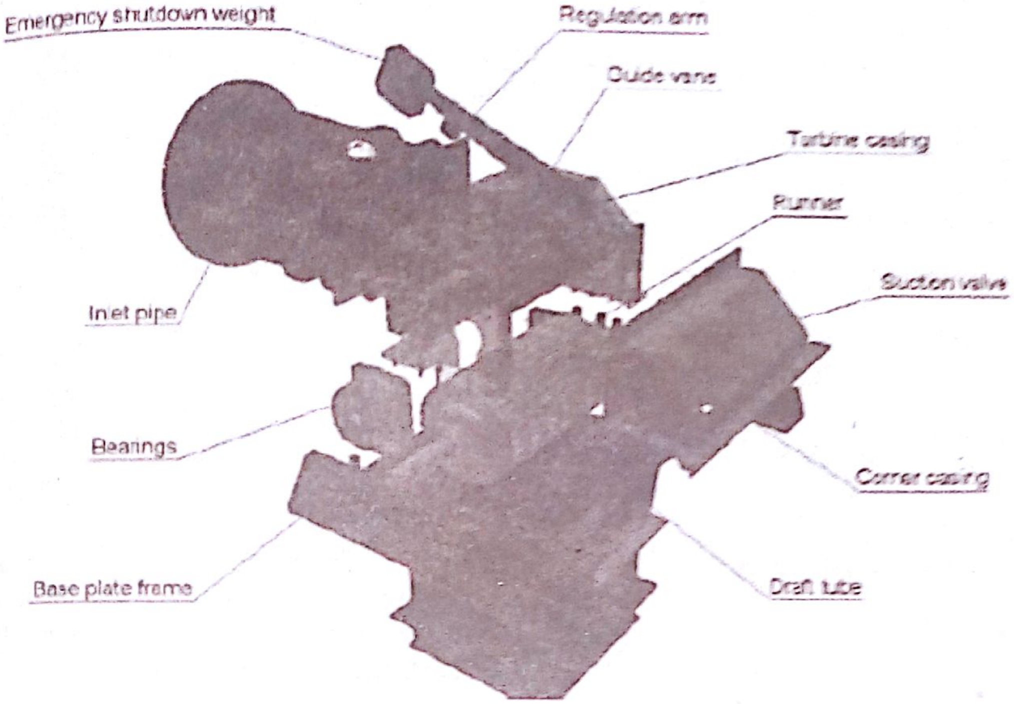

Figure 1: Detail View of T-series cross flow turbine

Cross-flow hydraulic turbine is gaining popularity in low head and small water flow rate establishments, due to its simple structure and ease of manufacturing. The cross-flow turbine is composed of two major parts as shown in figure 1, the runner and the guide vane. The runner is a circular rotor with side walls to which the blades are fixed along the periphery of the turbine and the guide vane directs water into the runner at a certain angle of attack [5]. Recently, there are few efforts being made by different organizations to locally fabricate the cross-flow turbine of different type. However the performance of these locally manufactured cross flow turbines is not well defined and standardised; hence many stakeholders are still importing this technology from abroad [3]. In this study the overall performance of locally made T-12 cross-flow turbine is simulated by using ANSYS - CFX setup and the result is validated through laboratory experimentation. In this regard different methodologies used by different scholars to simulate the performance of cross-flow hydraulic turbine [6 -10] has been reviewed and adopted for achieving the best possible result.

2. Methodology

2.1. *Analytical Design*

Physical site data for the study area was found to be 11.8m net head and 150liter/sec design discharge in south western part of Ethiopia [3]. Using these data and different engineering relations (eq.1 - 8) which are based on the velocity diagram of the turbine shown in Fig.2, the analytical design is made.

Major Equations Used In the Analysis

a) Turbine Speed (N)

$$N = 513.25 * H_n^{0.745} / \sqrt{P_t}$$

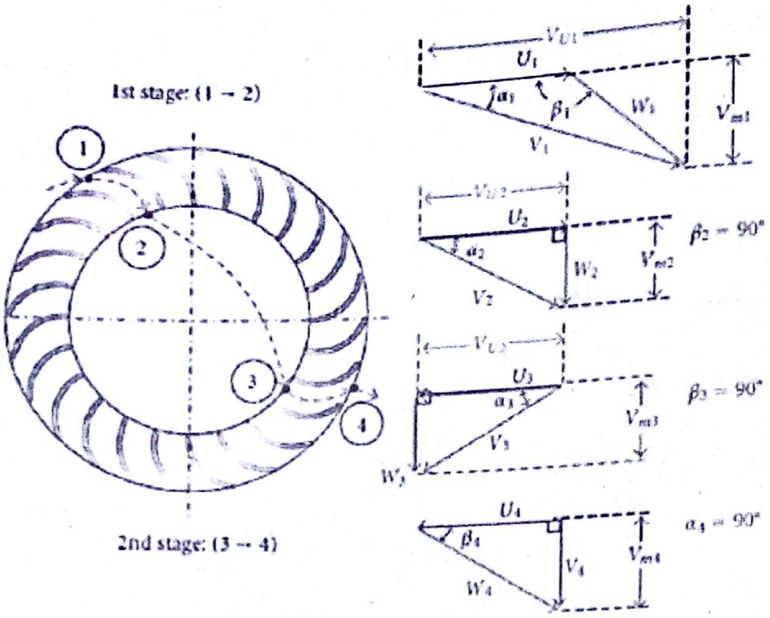

Figure 2: Theoretical velocity diagram of 2 stages of cross flow turbine

b) Runner outer diameter (D_o)

$$D_o = 40 * \sqrt{H_n}/N$$

C) Blade Spacing (t_b)

$$t_b = 0.174 * D_o$$

d) Radial rim width (a)

$$a = 0.174 * D_o$$

e) Number of runner blades

$$n = \pi * D_o / t_b$$

f) Runner length

$$L = Q * N / 50 * H_n$$

g) Water Jet Thickness

$$t_j = 0.29 * D_o$$

h) Blade curvature radius

$$r_c = 0.163 * D_o$$

The result of the analytical work is summarized in a manner that it will describe the input that is used for the virtual simulation and manufacturing of experimental turbine runner as indicated in the following table.

Table 1: Summery of the turbines geometric dimensions

Symbol	Description	Value
D_o	Wheel outer diameter	200mm
Di	Wheel inner diameter	132mm
r_c	Blade Curve. radius	33mm
L	Length of the runner	130mm
δ	Blade Central angle	74.5°
d_s	Runner shaft diameter	35mm
b_t	Thickness of the blade	2mm
n	Number of blades	20
S_o	Nozzle opening	17.4mm
t_s	Support disk thickness	3mm
C_b	Blade circumference	42.4mm

2.2. Virtual Performance Simulation

The geometry in this analysis has two domains; the water as fluid domain and the runner as immersed solid domain. The analysis is a 3D steady state, single phase and free surface flow analysis with assumption of cross flow turbine as an impulse turbine using a k-epsilon turbulence model. Three boundary conditions were used and the operating conditions that were varied to predict the performance are nozzle opening, mass flow rate (kg/s) and runner speed (RPM).

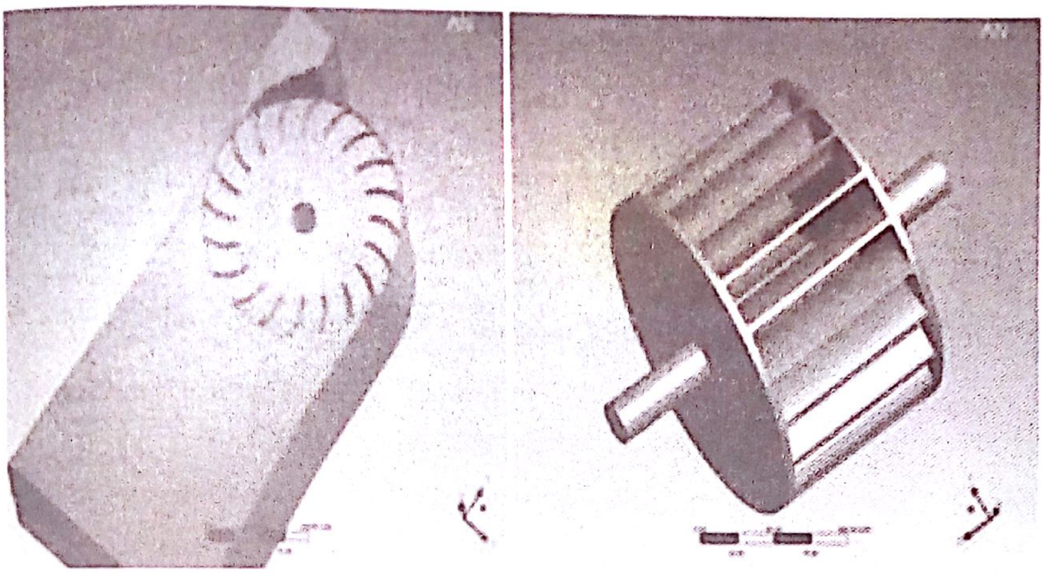

Figure 3: Separate view of the two domains of the geometry

The geometry is meshed in the triangular mesh type with mesh grid nodes of 79992.The mesh size and element size of 8×10^{-6} and 363502 respectively were used. After the completion of geometry development and meshing a range of parameters shown in the table 2 were used to perform the performance simulation on CFX-solver.

Table 2: Operating condition parameters used as in put for CFX solver

RPM	500	700	900	1100	1300
Mass flow rate	25	27	31	33	36
Nozzle Opening	½	2/3	Full		

In the CFX-setup 10^{-4} residual was set for all continuity and momentum calculations and six user points were set at different points in the turbine geometry to follow the solver for the 1000 iterations. The computational time was about 58.75hrs taking about 47minitus for each case with 75 computational cases being solved. Three Dell-780 computers with RAM size of 2 GB were used.

2.3. Experimental Validation

Experimental Setup: it includes locally fabricated cross flow turbine runner, two centrifugal pumps for water re-circulation and frequency regulators for motor control, water tanker and Infrared tachometer and Prony brake torque measurement mechanism as shown in Figure 4.

Experimental Procedure:

Flow measurement the simplest method filling bucket method is applied and the exact value of the discharge was obtained using continuity equation

$$Q = V \text{ (water volume } m^3\text{) /time (sec)}$$

Torque measurement was made using the Prony brake torque measurement method using the following relation

$$Fe = Mg - Fs.$$

$$\text{Torque } (T) = Fe * \text{Arm length}$$

Hence, from the result of equation 11 the actual shaft power that the turbine was able to produce is calculated using equation 12 by multiplying t with the measured speed of the runner.

$$\text{Shaft Power } (P_{act}) = T^{*} \omega$$

Where, $\omega = (2 * \pi / 60) * N_t$

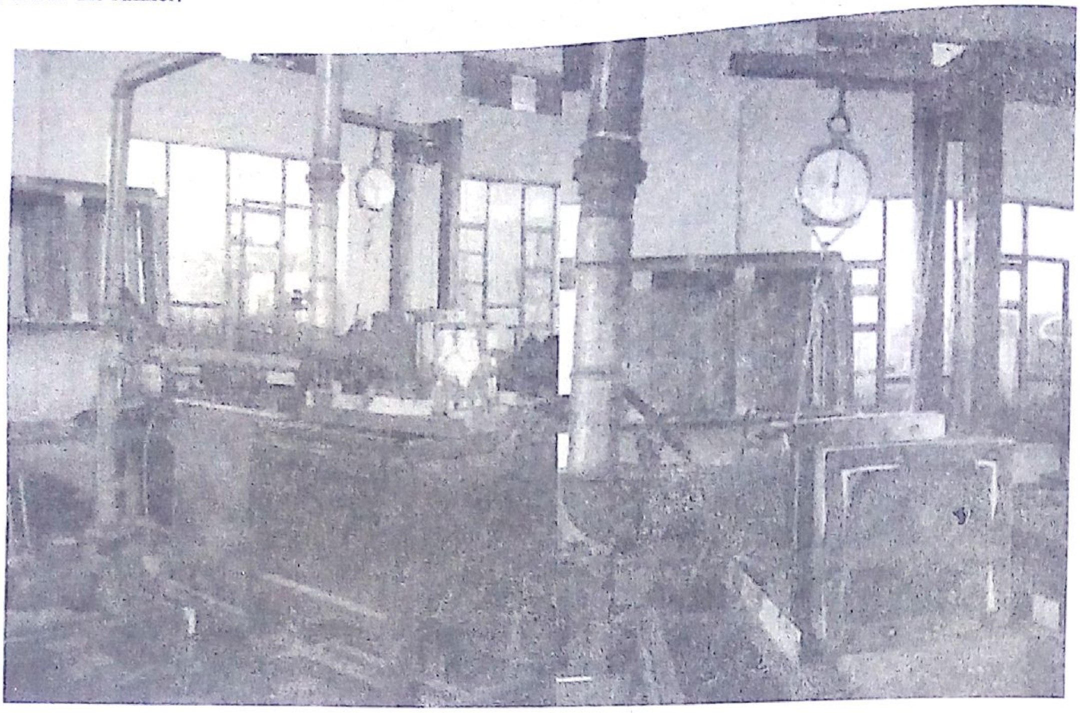

Figure 4: Partial view of the experimental setup in Jimma university mechanical engineering department

3. Result and Discussion

A turbine runner will rotate with a given RPM under the impact of mass flow rate of fluid. Hence in this analysis the primary target is to virtually investigate the efficiency with which the locally fabricated runner work in addition to checking its part load performance; as one of the advantages of cross flow turbine is it comfortable operation during part load conditions.

In this regard the numerical analysis indicated that the runner operates with an average efficiency of 72% [Fig.5]. The minimum efficiency at different part load conditions are 23%, 43.5% and 71.5% for ½ closed, 1/3 closed and fully open conditions of the guide vane respectively [Fig.5]. This in turn indicates that it is possible to generate a minimum of 172.8kwh/day energy which just enough for the intended use.

The average experimental efficiency of the runner as presented in Table 3 above is 58.02% with the minimum and the maximum being 54.7% and 61.6% respectively. Comparing this result with the company specification of 70% maximum efficiency for the imported T-12 turbine the experimental result is acceptable.

Moreover, as it is shown in Fig.6 the trained line of the efficiency curves for the virtual and experimental performance test are in a good fit. However there is a percentage magnitude difference of 14.7% between the two cases which resulted due to software over estimation of efficiency for rotating domains, the manufacturing efficiency of the experimental runner and the effectiveness of the test setup. Finally it was possible to predict and standardize the performance of locally manufactured T-12 cross flow turbine through virtual and physical experimentation and any T-12 cross flow turbine that can perform up to 58% experimental efficiency is fit for developing techno-economically feasible MHP from upgrading of watermills in Ethiopia.

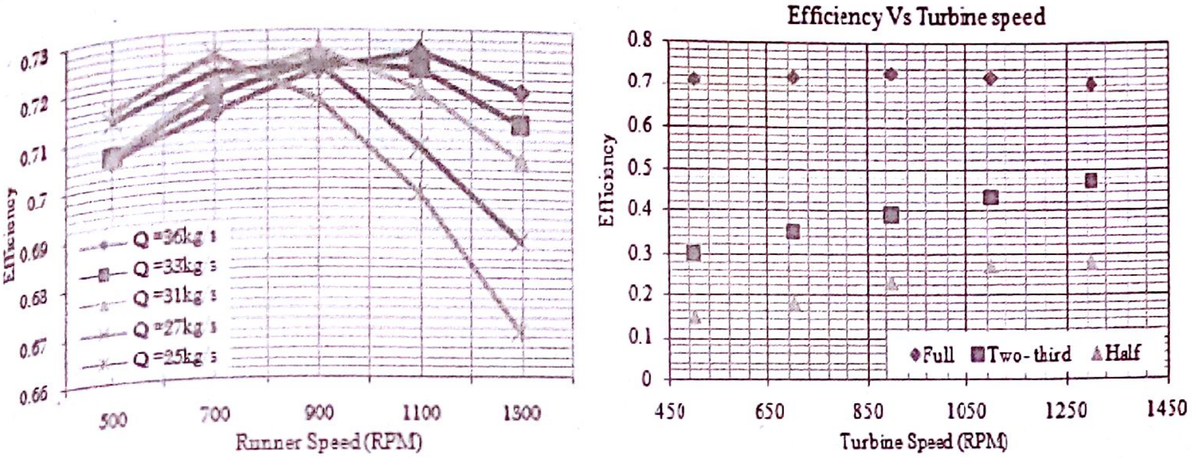

Figure 5: Efficiency of the runner at different mass flow rate and part load

Table 3: Parameters Measured and Calculated During Experimentation

RPM	Torque	Actual Power	Theoretical Power	Efficiency (Experiment)	Efficiency (Simulated)	% difference in Efficiency
362	3.3354	134	245	54.7	70.9	16.3
412	3.3354	149	262	56.9	71.6	14.7
472	3.3354	164	276	59.4	74.3	14.9
511	3.3354	178	289	61.6	75.3	13.7
562	3.3354	187	325	57.5	71.7	14.1

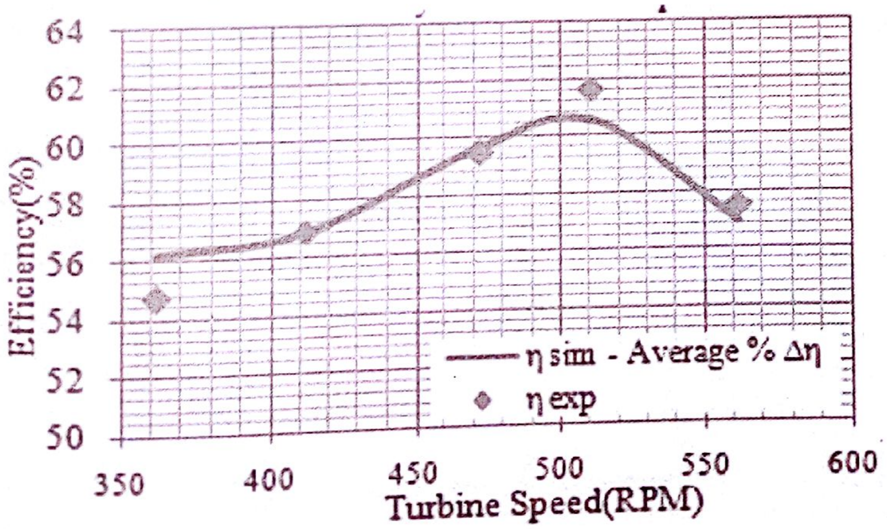

Figure 6: Efficiency difference between the virtual and experimental tests of the runner

4. Conclusions

Small scale hydropower development is the main focus for future work of different stakeholders in SSA countries working in the water resource and energy development sector. For instance, World Bank energy and environment strategy indicates its future development activity in Africa will be on small scale hydropower [**]. In this study it was possible to virtually simulate and experimentally validated the performance of locally made cross flow turbine which could be used for small scale hydropower development in Ethiopia. Therefore, it is evident that MHP scheme developed using locally fabricated cross-flow turbine; with maximum efficiency of 61.5% which resulted in reduction of energy generation cost by more than15%; is techno-economically feasible and replicable.

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Water Delivery Performance at Metahara Large-Scale Gravity Irrigation Scheme, Ethiopia

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Abstract

Distribution of water and its delivery and the flow hydrodynamics in manually operated gravity irrigation schemes are often complex. The nature of the hydrodynamics and its impacts on water delivery is generally not clearly understood by operators and system managers. Metahara Large-scale Scheme in Ethiopia, with a gross gravity-irrigated area of 11,500 ha for sugarcane, is an example of such a scheme. This paper assesses total water supply and demand for the whole Metahara scheme and evaluates the water delivery performance to lateral and sub-lateral offtakes. Adequacy, efficiency, equity and dependability were used as indicators based on measured flows at 15 offtakes along a canal of 10 km long. Results indicate that the average annual irrigation supply is in excess of demand by 24%, accounting for about 37 Mm^3 (million cubic metres) of unintended water diversion. With increasing completion for water in the basin, both for irrigation and other sectors, this volume of water if could be saved, would have irrigated about 1,400 ha of land. Water delivery at tertiary levels in was adequate in terms of quantity. There were also insignificant water losses at tertiary levels. Excessive water diversion to the scheme mainly lost as seepage and drainage to poor quality groundwater and brackish swamps whose water cannot be reused. We found that in addition to claims of water shortage, the major problem of water management in the scheme is lack of a sound operation rule that can respond to the system hydrodynamics. This in turn made the delivery to be inequitable. Optimal water diversion and delivery not only saves water but also reduces the danger of waterlogging, which has already become a serious problem in Metahara Large-scale Scheme.

Keywords: *Metahara Large-Scale Scheme; gravity irrigation; water delivery; performance analysis, performance indicators.*

1. Introduction

Operation of large-scale gravity irrigation systems is one of the major challenges to irrigation managers and operators in least developed countries. The complex hydrodynamic behaviour of the conveyance and distribution systems in these schemes is generally not clearly understood both by gate operators and system managers (Kumar *et al.*, 2002). Manually-operated large scale irrigation schemes require operational skills and expertise that could cope with the complex nature of the hydrodynamics that lacks in many schemes in least developed nations. The consequences of inadequate operation of control structures and the resulting distorted hydrodynamics is inequitable water delivery and loss of significant quantity of water as tail runoff particularly in systems where return flows are not easily recoverable. Better understanding of the hydraulic behaviour of conveyance and distribution systems and control structures would assist the operation of irrigation schemes for optimal water distribution and gaining significant saving on off-demand water losses. Khan and Ghumman (2008) state that better knowledge of the complex hydraulics of large-scale irrigation schemes would help significant gain on water saving.

The objective of this study is to evaluate the water delivery performance in Metahara Sugar Estate Irrigation Scheme in Ethiopia at lateral and sub-lateral levels. The paper also gives an insight on the total water diversion versus actual field demand. There has been no initiative of irrigation performance assessment in this scheme in the past. This research is therefore a useful start for improving irrigation water management, water use and distribution within the scheme. Metahara Sugar Estate Irrigation Scheme is located in the central-east semi-arid region of Ethiopia where there is scarcity of surface water resources. The scheme has a net sugarcane irrigated area of more than 11,500 ha with exclusively manually operated flow control systems. However, this study focussed on the part of the system which irrigates 8,000 ha of land, called the Main System. The other part of the system is called Abadir, irrigating about 3,500 ha of land. Continuous monitoring of the flow measurement and control structures is missing in the system and it is blamed for excessive diversion and wastage of irrigation water.

On the downstream of Metahara Sugar Estate Irrigation Scheme, there are cascades of irrigation schemes being supplied from Awash River, and suffering water shortage particularly during low flows. Currently, there is a vast expansion of irrigated agriculture in the Awash Basin, and there is a need for putting forward more effective operation rules for water management within the scheme in order to save water and contribute to basin-wide effective water utilization.

2. Materials and Methods

2.1. Description of the study area

Metahara Sugar Estate Irrigation Scheme

Metahara Sugar Estate Irrigation Scheme is one of the large-scale gravity irrigation schemes in Ethiopia. It was commissioned in 1968, and currently it is a public scheme exclusively growing sugarcane in an area of about 11,500 ha. The system has two parts called Main system and Abadir with separate intake structures. The main system and Abadir have command areas of 8,000 ha and 3,500 ha respectively. The field irrigation method is furrow and water is conveyed and distributed in an extensive network of open channels. It is a gravity irrigation system and its operation is totally manual. The canal system consists of main canal, branch canals, secondary canals, lateral canals and sub-laterals (tertiary canals). The layout of the irrigation system is shown in Figure 1.

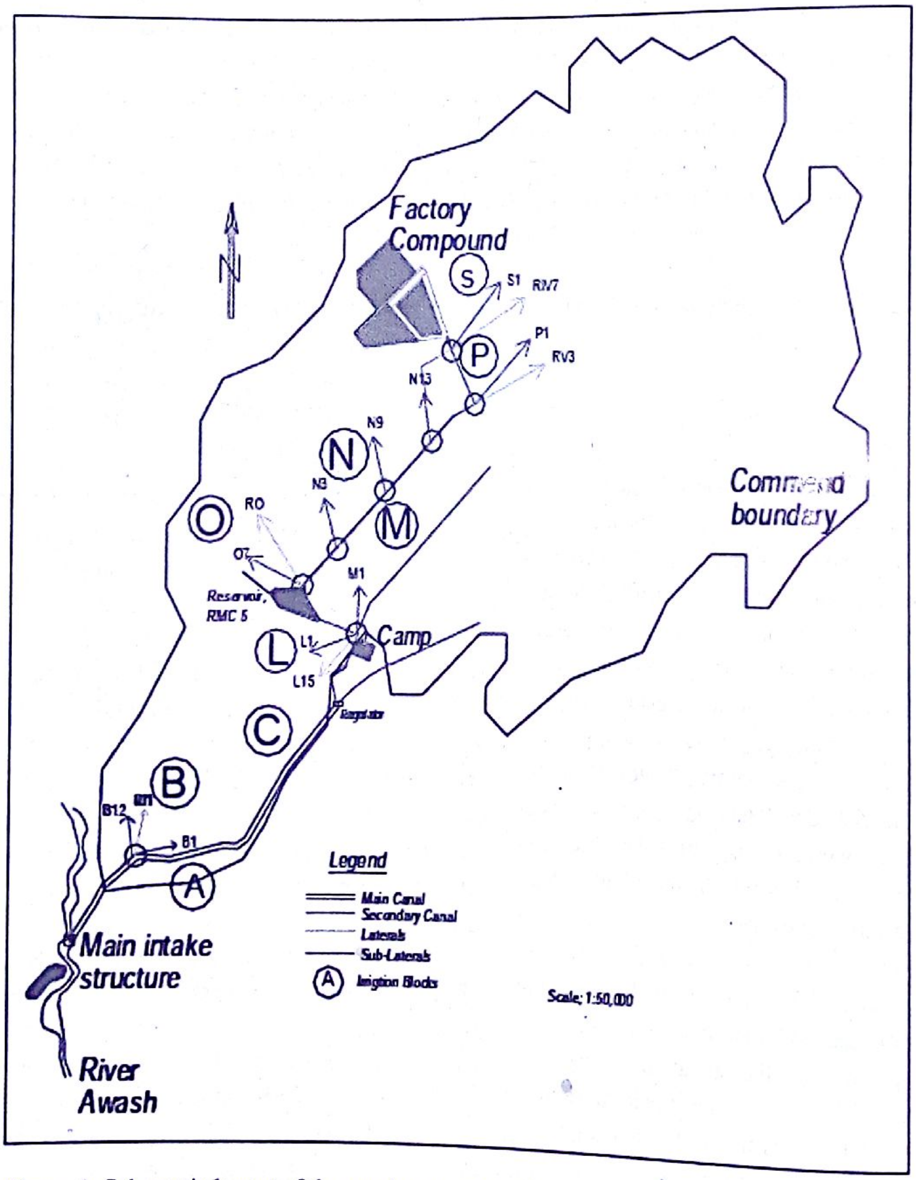

Figure 1. Schematic layout of the canal system considered and its offtakes

Climatic data

Climatic data are among basic data required for water and irrigation related research. In this specific research, climate data were required for estimation of evapotranspiration and hence scheme water and irrigation demand determination. The sugar estate has its own weather station where daily records of data of rainfall, temperature, wind speed, relative humidity and sunshine hours data are available for over 40 years. In this research, monthly values of these data are required as shown in Table I.

Table I. Average monthly climatic data at Metahara Sugar Estate Irrigation Scheme

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Rainfall, mm	9.5	30.2	50.2	51.6	29.2	26.0	117.9	118.7	42.4	23.3	3.1	7.4	-
Min. temp. ^{0}C	14.8	16.0	18.4	19.1	19.1	21.3	20.3	19.8	19.1	16.2	14.1	13.8	17.7
Max. temp. ^{0}C	30.8	32.0	33.7	34.2	35.6	36.4	33.1	32.4	33.8	33	31.7	30.3	33.1
RH, %	62	60	59	59	55	50	58	61	58	57	61	62	59
Wind, m/s	2.4	2.6	2.4	2.2	2.2	3.6	3.9	3.0	2.0	1.8	2.1	2.3	2.6
Sunshine, hrs	9.0	8.8	8.0	8.0	8.6	8.0	7.3	7.1	8.4	8.8	9.2	9.3	8.4

Scheme water and irrigation demand/supply assessment

Monthly and annual total water and irrigation demand of the scheme was assessed using the existing cropping pattern, crop data and climatic data. Irrigation requirement is that part of the water requirement which has to be satisfied by irrigation. The growing period of sugarcane is normally one year and planting generally takes place between December and March. FAO CROPWAT software was used to determine the total water and irrigation requirements. For estimating the irrigation supply, a record of daily irrigation flow (supply) is being taken by the estate with the help of a stage measurement in the head reach of the main canal at the immediate downstream of the main diversion. A stage-discharge relation at this location yielded the average daily and hence monthly irrigation supplies for 5 years (from 2006-2010).

Calibration of flow measurement and control structures

One of the major reasons for inefficiency and poor water delivery performance at Metahara Sugar Estate Irrigation Scheme is mis-calibration of structures and poor irrigation water measurement. There are large numbers of flow measurement structures all over the scheme; particularly at offtake points. Most of these measurement structures were provided with fixed vertical graduations either for water levels or discharge measurements. In case water levels are measured, these are related to discharges with stage-discharge (Q-H) relations for the structures. However, at many of these measuring structures, the measuring graduations are either removed or provide wrong measurements due to lack of maintenance and wear out. Sedimentation and change of canal geometry are the main causes for inaccurate flow measurements. As a result, the flows assumed by gate operators significantly deviate from the actual flows through the structures; which caused excesses in some parts and shortages in other parts of the scheme. The flow characteristics of flow control and measuring structures at offtakes along the main canal of about 10 km long were monitored by current-metering at various discharges passing. These measurements enabled determination of the deviation of the actual flows from the assumed ones and hence recalibration of structures.

Flow measurement (current metering)

Flow measurement is central to water delivery performance evaluation and improvement in irrigation systems. It enables determination of delivery performance indicators, which basically are based on required flows (Q_R) and actual water delivered (Q_D). The average actual flows at different offtakes of lateral/sub-lateral canals along the canal system of 10 km considered were determined for three consecutive months during which the river flow is minimum (January, February, March) for the years 2012 and 2013 using current meters. These flow measurements were made on daily basis from which the average monthly flows were determined.

The required (design) flow in each offtake was based on the area it irrigates; it is 200 l/s for sub-laterals and depends on the number of tertiary units fed for lateral canals.

Water delivery performance indicators

The internal performance of irrigation water delivery systems could be assessed with indicators depicting the state of performance. Internal performance indicators are used in this case to assess internal processes; i.e. the inputs, which are resources used and the outputs, which are the services provided. Clemmens (2006) states that these indicators are useful tools for understanding the internal operational processes that affect the water distribution and delivery; and hence assist to find ways that could enhance the water delivery. The purpose of these indicators is to evaluate whether the system delivers water at the required rate at the right place and to assess whether the water delivery service is healthy. Adequacy indicator (P_A) (delivery performance ratio), efficiency indicator (P_F), equity indicator (P_E) and dependability indicator (P_D) were the main indicators of internal water delivery performance used in this study. In this study, these indicators were determined for each offtake as well as for a group of head, middle and tail offakes. For instance, Unal*et al.* (2004) employed these indicators to assess the performance of water delivery system at tertiary canal level in the Menemen irrigation system, Turkey. Kazbekov*et al.* (2009) and Tariq *et al.*(2004) also applied indicators based daily monitored flows at offtakes to evaluate performance of water user associations and as a diagnostic tool to operation gravity canal system.

The following is a brief explanation of the aforementioned indicators.

Adequacy indicator (P_A)

Adequacy is a measure of the ability of a system to reach targeted deliveries in terms of quantity (Renault and Wahaj, 2005). For a single point (offtake), it is the ratio of delivered (Q_D) to required (Q_R) delivery in terms of flow rate or volume. Adequacy can however be determined for an irrigation system as whole or for sub-systems. In this case, it is aggregated for a service area R averaged over a period of consideration T. Under this study, adequacy was calculated for lateral/sub-lateral offtakes along the main canal for three consecutive months. In order to assess any variation is adequacy levels, it was determined for head, middle and tail offtakes.

It is given as (Molden and Gates, 1990a):

$$P_A = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R p_A\right)$$

Where P_A is adequacy indicator over an area R and time period T, and p_A is an adequacy at a point for a specific time.

Efficiency indicator (P_F)

Efficiency refers to the water conservation property of the irrigation system, i.e., its ability to minimize water losses due to oversupply. The ratio of required/delivered flows (Q_R/Q_R) indicates the offtake efficiency (Renault and Wahaj, 2005). The required and delivered flows could be in flow rates or volume of water over a certain period of time. Efficiency was determined for head, middle and tail reach offtakes in order to distinguish any variation and to justify the reasons for so. It is given as:

$$P_F = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R p_F\right)$$

Where P_F is efficiency indicator over an area R and time period T and p_F is efficiency indicator at a point for a specific time.

Equity indicator (P_E)

Equity refers to fairness of water deliveries and reflects the way the irrigation service is spatially distributed. The coefficient of variation (CV) of the ratio of delivered to required flows (Q_D/Q_R) over a region R and for time period T indicates the fairness of the water distribution over a region and is called equity indicator (Molden and Gates, 1990b). Equity indicator (P_E), as per the above definition is given as:

$$P_E = \frac{1}{T}\sum_T CV_R\left(\frac{Q_D}{Q_R}\right)$$

Where P_E is equity indicator over an area R for a period of T, and CV_R is spatial coefficient of variation of the ratio Q_D/Q_R over a region R.

Dependability indicator (P_D)

Dependability is an indicator for the degree to which water delivery conforms to the prior expectations of users.

It implies the achievement of temporal uniformity of the relative water delivery over a region R:

$$P_D = \frac{1}{R}\sum_{R} CV_T\left(\frac{Q_D}{Q_R}\right)$$

Where P_D is dependability indicator over a time period T for a region R, and CV_T is the temporal coefficient of variation of the ratio Q_D/Q_R over time T.

3. Results and Discussions

Monthly and annual water and irrigation demand

As stated, monthly and annual water demand for the scheme was determined using FAO CROPWAT Version 8 software. Daily records of meteorological data required for determination of evapotranspiration were available at the scheme. However, in this research average monthly values of the data were sufficient and used. For crop water requirement, the planting dates were staggered over four months from January to April. Each planted area covers a quarter (2,000 ha) of the whole irrigated area of the main system (8,000 ha); and the water demand was determined for each cropped area separately, whose sum gives the annual water requirement. Annual water demand of the whole main scheme is given in Table II. Monthly irrigation demand was determined as the net difference between monthly water demand and effective rainfall as shown in Table III.

Table II. Annual water demand for MetaharaSugare Estate Irrigation Scheme

Cropping category	Planting date	Annual water demand , mm	Cropped area, ha	Water demand volume, Mm^3
Sugarcane 1	1-Jan	2,380	2,000	47.6
Sugarcane 2	1-Feb	2,370	2,000	47.4
Sugarcane 3	1-Mar	2,360	2,000	47.2
Sugarcane 4	1-Apr	2,330	2,000	46.6
Total annual demand, Mm^3				188.8

Table III. Monthly and annual irrigation demand for Metahara Sugar Estate Irrigation Scheme

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
ER, mm/month	9.4	28.7	46.2	47.3	27.8	24.9	95.7	96.2	39.5	22.4	3.1	7.3	449
NIR, mm/day	4.4	3.9	4	4.5	6.2	8	5	4.2	5.8	5.9	5.8	4.9	
NIR, mm/month	136	110	123	134	193	241	157	132	174	182	175	152	1,910
Irr. req., l/s/h	0.51	0.45	0.46	0.52	0.72	0.93	0.59	0.49	0.67	0.68	0.68	0.57	
Irrigated area, ha	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	
Q, m^3/s	4.1	3.6	3.7	4.1	5.8	7.4	4.7	3.9	5.4	5.4	5.4	4.5	
Demand vol., Mm^3	10.5	8.8	9.8	10.7	15.4	19.3	12.6	10.6	13.9	14.6	14.0	12.2	152

Monthly and annual total irrigation supply

Records of daily and hence monthly irrigation supplies are being taken by the Estate with a stage-discharge relation established at the head reach of the main canal. Annual values of irrigation supplies for 5 years (2006 to 2010) calculated as a sum of daily, and hence monthly supplies from the Q-H relation and percent excess/shortage are shown in Table IV.

It can be noticed that on average the annual irrigation supply exceeds demand by 24%, and this means 37 Mm^3 of excess water diversion annually. While there is shortage in significant parts of the scheme, excess diversion apparently means wastage in the conveyance, storage and distribution systems. The main rainy season in the area extends from June to September; however, the rainfall is still very low to meet the water requirement. While there is excess diversion at intake during all the other months of the year, August and September are months with field demands exceeding diversion. The river flow during these months is sufficiently high; however the managers assume that the rainfall would meet the demand while it would not.

Monthly average irrigation water supply (diversion) in comparison with field demand along with percent excess/shortage is shown in Figure 2.

Table IV. Annual irrigation supplies and excesses for 5 consecutive years

Year	2006	2007	2008	2009	2010	Avg.
Supply vol., Mm^3	194	178	199	187	189	190
Demand vol., Mm^3	152					
Excess, %	28	17	31	23	24	24
Vol. excess, Mm^3	42.4	24.3	47.2	35.3	37.2	37.0

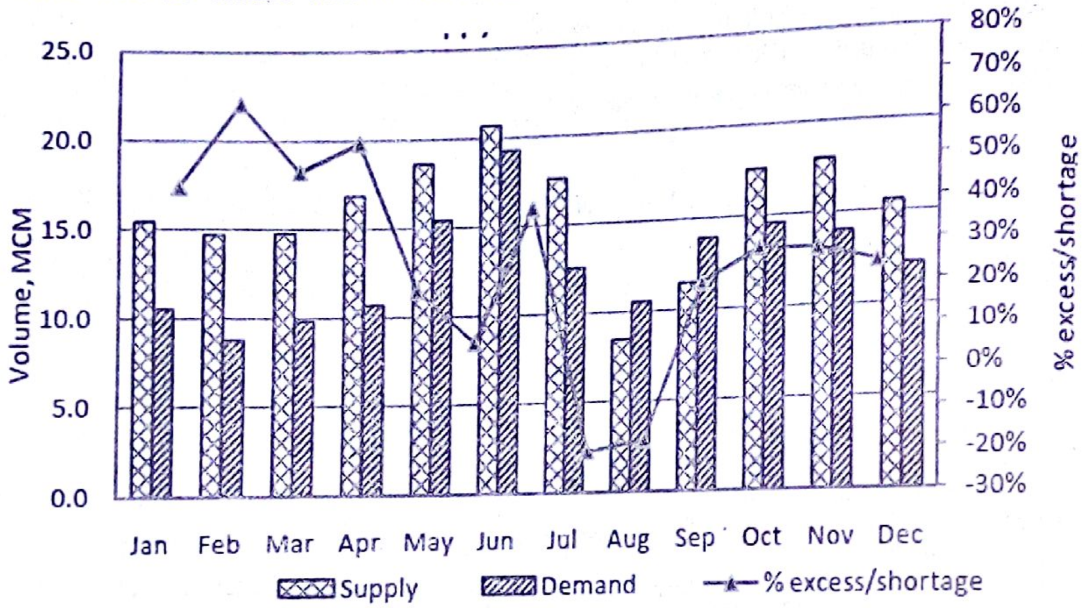

Figure 2. Monthly irrigation water supply versus demand at Metahara Sugar Estate Irrigation Scheme

Water delivery equity performance at scheme level

At MetaharaSugar Estate Irrigation Scheme, misunderstanding the hydraulic characteristics, and hence misoperation of flow control and measurement structures are found to play a significant role for non-optimal water distribution within a scheme. There is practically no monitoring mechanism that verifies the accuracy of flow measuring structures at offtakes. In this research, current-metering and stage-discharge relations were employed to calibrate these structures. Offtake flow measurements were then used to evaluate the water delivery performance under the existing operational scenario adopted by gate operators. The flow control structures at tertiary offtakes are either Romijn weirs or sluice gates; while those at secondary offtakes are sluice gates. It was found out that there are significant variations between the actual flows through the structures and the flows assumed by operators. While the actual flows at some offtakes were in excess of the intended flows, at others they were in short. So, continuous monitoring and calibration of control structures was found to be critical for improving the operation and enhancing the water delivery performance.

The non-uniformity of water distribution in the scheme was visible both spatially and temporally. To have a first insight on the degree of non-uniformity of water distribution within the scheme in general, spatial equity levels of water deliveries of offtakes were determined for the scheme as whole. For this, 10 tertiary (sub-lateral) offtakes were randomly considered from the head, middle and tail reaches all over the scheme. Actual daily flows were monitored over a period of 6months (January-June, 2011) at these offtakes (Table V), which were then compared to the intended flow of 200 l/s for each.

Spatial coefficient of variation (CV) was used as an indicator of spatial equity of delivery in the scheme as a whole. For instance, (Tariq *et al.*, 2004) applied CV to evaluate the level of variability of irrigation supplies at offtakes along a minor. For tertiary offtakes, a target CV of 10% is assumed practically acceptable in systems with good water management. Nevertheless, we obtained a CV of 32% in this case, which is much more than the target. Apparently, this gives an insight that the water distribution among tertiary offtakes over the whole scheme is remarkably non-equitable. It is evident from Table V that the measured average flows at 8 offtakes are in short of the intended flows. However, there has been significant amount of excess irrigation water diversion at the source unlike shortages at offtakes. Apparently, the diverted excess water accounts for operational drainage losses within and at the tail-ends of the distribution systems.

Table V. Measured average flows and deviations at selected tertiary offtakes

Offtake	1	2	3	4	5	6	7	8	9	10
Measured average Q (over 6 months), l/s	159	189	109	200	124	69	141	222	101	169
Deviation, l/s	-41	-11	-91	0	-76	-131	-59	22	-99	-31
% deviation	-20.5	-5.5	-45.5	0	-38	-65.5	-29.5	11	-49.5	-15.5

Hydrodynamic characteristics of the canal system selected

The irrigation network considered in this study consists of part of a main canal and secondary canal, from which lateral and sub-lateral (tertiary) canals offtake. Of the total length of 10 km, the first 5 km is the main canal of the system, while the remaining 5 km is part of a secondary canal. Of a total of 15 offtakes considered, the first 6 are in the head reach, next 5 in the middle reach and last 4 in the tail reach. There is a night storage reservoir in the system at a distance of 6 km from the main river intake. Offtakes from O7 downstream are supplied from this reservoir. There is a gated underflow water leFvel regulator at oftakes, except for B12, B1, RI1 and N8. The design of the system is based on 9 hours of irrigation per day (6AM - 3PM), with constant offtake flows. However, with extensive field observations and measurements, we found out that the design criteria are not followed in the day to day management of the irrigation system. Offtakes are operated twice a day (for opening and closing), which caused large fluctuations in water levels and discharges during a day. This has in turn caused inefficient water use and non-uniform water distribution in the scheme. Table VIshows some of the features of the offtakes in the system considered.

The flow in the system during night hours is minimal. When opened early in the morning, the system responds slowly to assume design conditions. As such, the flows at offtakes increase gradually and on average tops design discharges 3 to 4 hours after opening. There occurs significant excess flow for 2 to 3 hours on average and starts to decline once again with depletion of water in the system and storage reservoirs. During excess flows, irrigators could not have effective control on the water, causing significant field and off-farm losses. While as high as 200% excess flows were observed during a day, as low as only 40% of the design discharges were also observed in the monitoring process. Lag-time and the unsteady state situation of the flow control system are the major causes of these fluctuations. Particularly, the first two offtakes in the middle reach are located just at the outlet of a reservoir; and hence an insignificant lag-time. However, the flow starts to decline significantly 1-2 hours after opening. The hydrodynamic situations have distinct effects on the offtakes at the head, middle and tail reaches of the system in general (Figure 2).

Evaluation of the water delivery performance

The water delivery performance of the system was evaluated based on flows monitored at each offtake. Four indicators of water delivery performance were considered; namely, adequacy, efficiency, equity and dependability were considered. The intended flow of sub-lateral canals is 200 l/s, while that of laterals is variable based on the number of tertiary offtakes it supplies. For each offtake, the monthly average actual delivered flows for a period of 3 months (January, February, March) were determined from daily flow measurements by current-metering for the years 2012 and 2013 (Table VII).

Table VI. Features of offtakes in the three reaches of the system

Location	Head reach						Middle reach					Tail reach			
Offtake name	B12	B1	RI1	L15	L1	M1	O7	RO	N4	N8	N13	P1	PT	RIV7	S1
Q_R (m^3/s)	0.2	0.2	0.8	0.6	0.2	0.2	0.2	1.0	0.2	0.2	0.2	0.2	0.8	0.8	0.2
Type	S	S	S	L	S	S	S	L	S	S	S	S	L	L	S
Flow type	U	U	U	U	U	O	O	U	O	O	O	O	O	U	O
WL regulator	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Operational lag time (h)	1h	1h	1h	4h	4h	4h	0h	0h	1h	2h	3h	4h	4h	4h	4h
Perturbation level	M	M	M	M	M	M	C	C	A	A	A	M	M	M	M

S= Sub lateral, U= Under flow, M= Minor, A= Average L= Lateral, O= Over flow, C= Considerable

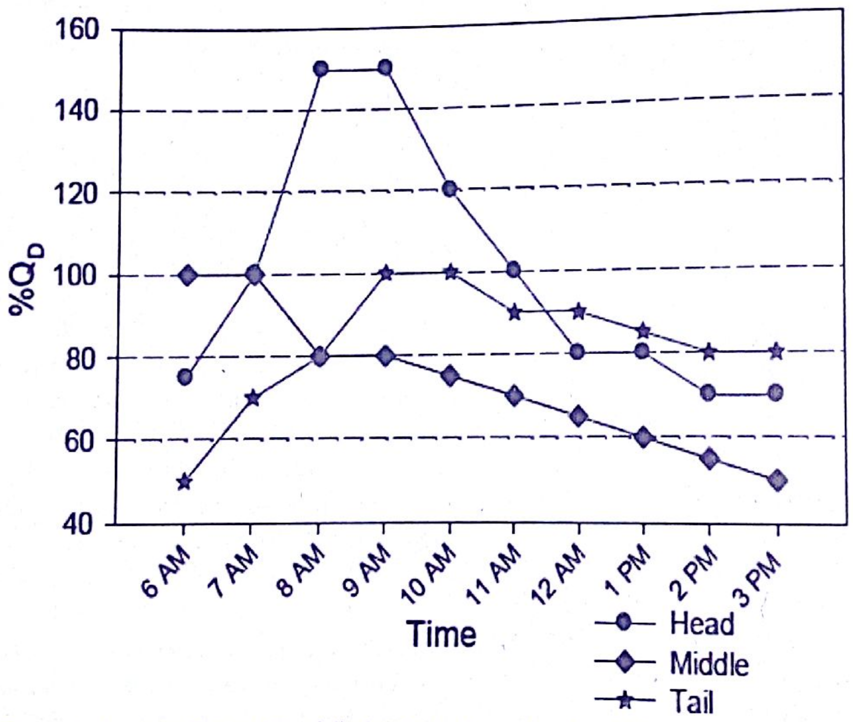

Figure 2: Average fluctuation of discharges in time at head, middle and tail offtakes

We considered part of the main canal and part of a secondary canal with a combined length of 10 km. Recently,with the expansion of new irrigation schemes irrigation in the Awash Basin, there have been an increasing need for saving water in existing schemes, of which Metahara Sugar Estate Irrigation Scheme is one. To this end, the Awash River Basin Authority is working to achieve a more effective and integrated water resources management in the basin. Metahara Sugar Estate Irrigation Schemewas blamed for diverting excess water and causing serious shortage on the downstream. On the other hand, there have been claims of water shortage at Metahara Sugar Estate Irrigation Scheme itself. However, the analysis on water diversion-demand confirmed that excess diversion amounts to about 24%.

TableVII. Measured actual delivered flows (Q_D) at lateral and sub-lateral offtakes

Year	Location	Head reach						Middle reach					Tail reach			
		Delivered flows, Q_D (m^3/s)														
	Lat/Sub-lat.	B12 (Q_R=0. 2 m^3/s)	B1 (Q_R=0. 2 m^3/s)	RI1 (Q_R=0. 8 m^3/s)	L15-L27 (Q_R=0. 6 m^3/s)	L1 (Q_R=0. 2 m^3/s)	M1 (Q_R=0. 2 m^3/s)	O7 (Q_R=0. 2 m^3/s)	RO (Q_R=1. 0 m3/s)	N4 SMC6 (Q_R=0. 2 m^3/s)	N8 SMC7 (Q_R=0. 2 m^3/s)	N13 SMC8 (Q_R=0. 2 m_3/s)	P1 (Q_R=0. 2 m_3/s)	PT (Q_R=0. 6 m_3/s)	RIV7 (Q_R=0. 8 m_3/s)	S1 (Q_R=0. 2 m_3/s)
2012	Jan	0.21	0.28	0.80	0.74	0.20	0.19	0.16	0.77	0.22	0.15	0.22	0.20	0.64	0.76	0.19
	Feb	0.15	0.16	0.73	0.40	0.20	0.16	0.06	0.65	0.08	0.12	0.12	0.17	0.56	0.84	0.23
	Mar	0.17	0.14	0.70	0.48	0.22	0.13	0.08	0.57	0.16	0.14	0.21	0.15	0.67	0.74	0.23
2013	Jan	0.18	0.28	0.69	0.72	0.31	0.20	0.22	0.81	0.20	0.17	0.18	0.19	0.63	1.04	0.19
	Feb	0.19	0.20	0.60	0.50	0.25	0.17	0.23	0.85	0.17	0.14	0.17	0.22	0.66	0.92	0.22
	Mar	0.25	0.19	0.64	0.60	0.19	0.20	0.25	0.83	0.19	0.16	0.20	0.20	0.68	0.96	0.24

But where is the excess water diverted lost; in the conveyance and distribution or in the field? For this, both spatial and temporal levels of delivery performance need to be evaluated at the offtakes. The results of performance evaluation are in the following sections.

Temporal performance indicators

Temporal values of performance indicators were evaluated for adequacy, efficiency and dependability. The indicators were assessed for each offtake and reach-wise (head, middle, tail) for the years 2012 and 2013 (Figure 3). The temporal indicators show that the level of adequacy of water delivery is generally adequate at the head and tail reach offtakes, both for 2012 and 2013. However, values show that the delivery got inferior at middle offtakes, which could be explained by the following two factors. First, there is inadequate operation of the night storage reservoir, which causes significant temporal fluctuations in water stage in the offtaking canal (Figure 4). Second, all the sub-lateral offtakes in the middle reach except one lateral, have overflow structures, while the water level regulators are underflow. Hence, the offtakes are hyper-proportional. This means that any change in the flow or water level in the parent canal generates relatively larger changes in flow of the offtakes.

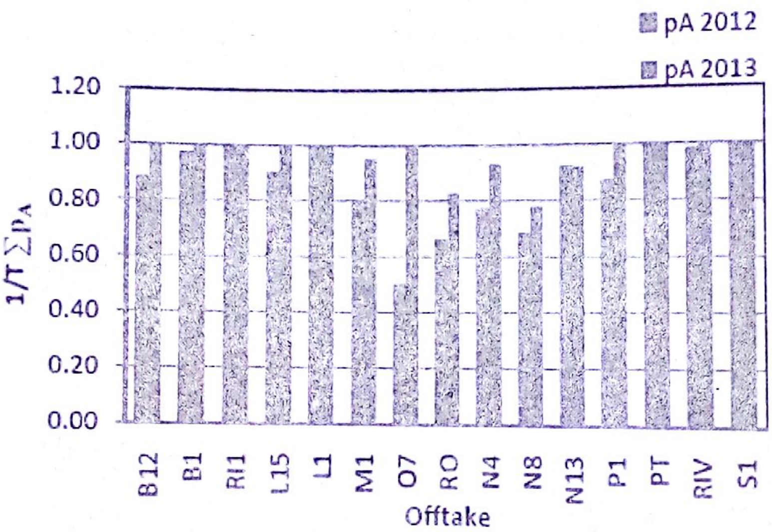

Figure 3: Average temporal point adequacy, p_A

Figure 4: Low stage in a parent canal behind an offtake in the middle reach

The temporal average efficiency indicator for each offtake is shown in Figure 5, in which the level of performance ranges from 'fair' to 'good'. Reach-wise, efficiency levels are nearly unity in each offtake in the middle reach, showing that there is no excess water downstream of these offtakes. Efficiency values in general indicate water losses in the system at lateral and sub-lateral (tertiary) levels are very little, and hence the excess diversion is lost in the main system, into drainage within the system, and at the downstream end.

The temporal coefficient of variation of water delivery, which indicates the dependability of supply are for the years 2012 and 2013 are shown in Figure 6. It is evident that for both years, the supply was more predictable for the tail reach offtakes than head and middle. Though the dependability is particularly very poor in 2013 at 5 offtakes in the head and middle reaches, the monthly fluctuation in delivery at offtakes is acceptable.

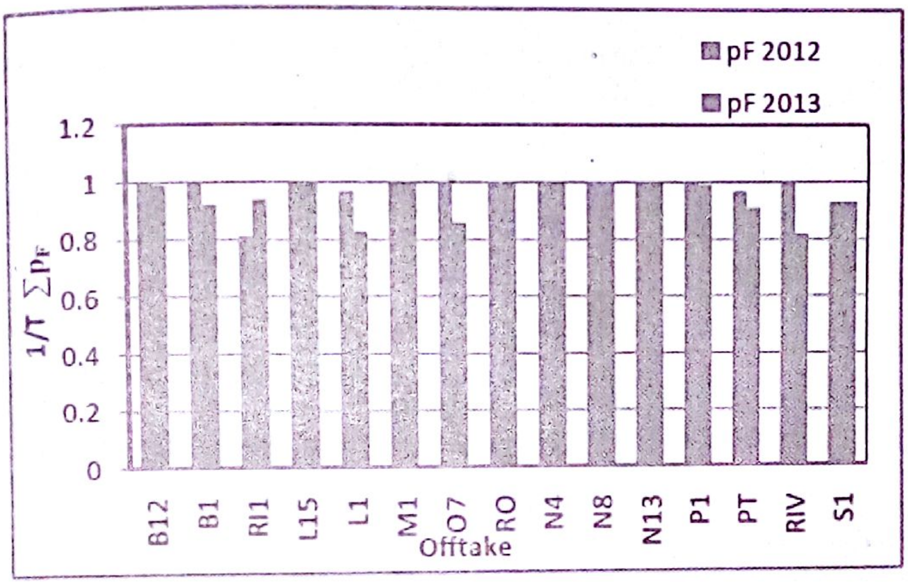

Figure 5: Average temporal point efficiency, p_F

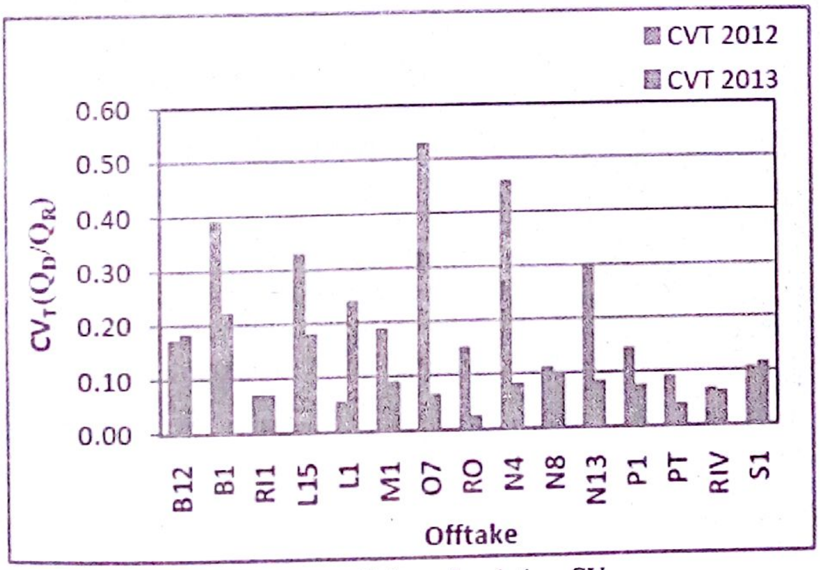

Figure 6. Average temporal coefficient of variation, CV_T

Spatial performance indicators

These are spatially-averaged values of indicators of water delivery performance of all offtakes for different periods of time. Spatial values of indicators were evaluated for adequacy, efficiency and equity for three months of the years 2012 and 2013 (Figure 7). January, February and March are the driest months in the area with minimum flow in the Awash River. Adequacy levels are superior for each month in 2013 and there is insignificant monthly variation. However, February and March are months with lower adequacy; still the monthly fluctuation of adequacy acceptable as per the standard. On the other hand monthly averaged efficiency indicators of nearly unity (Figure 8) depict that offtakes deliver nearly the water required. This also means that there is no significant water loss in the offtakes at lateral and sub-lateral levels.

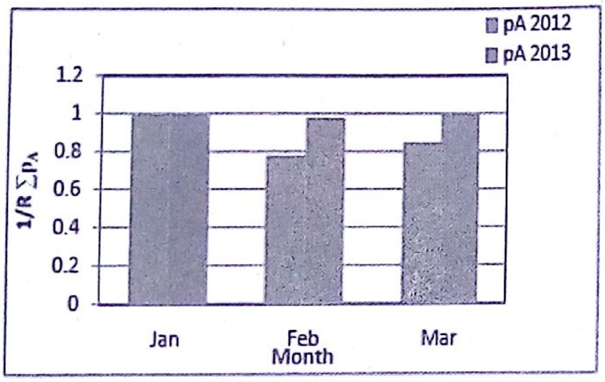

Figure 7: Average spatial adequacy, p_A

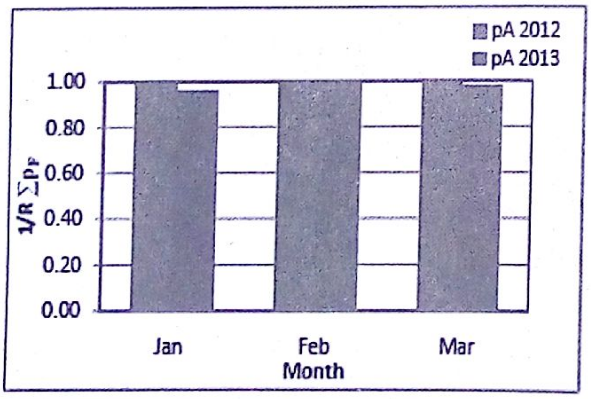

Figure 8: Average spatial efficiency, p_A

The spatial coefficient of variation of water delivery (Figure 9) shows the degree of spatial equity of water delivery to all offtakes in time. The equity levels were 'fair' for each month in 2013; while it got 'poor' for February and March in 2012. It is evident that there is a significant fluctuation in equity levels from year to year for the same month.

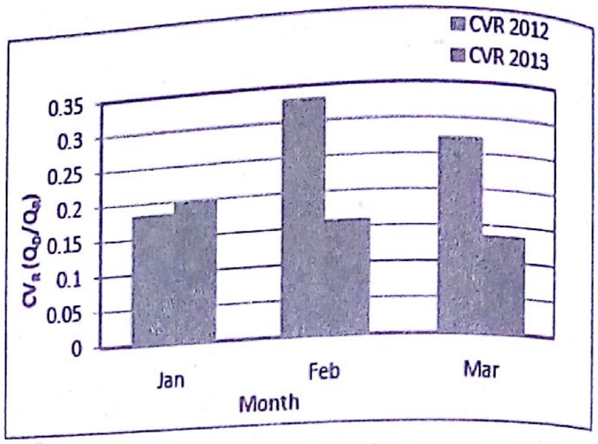

Figure 9.Average spatial coefficient of variation, CV_R

Reach averaged and overall performance indicators

In addition to spatial and temporal indicators of water delivery, reach-aggregated indicators enable to understand the water delivery performance better. Average indicators of adequacy and efficiency in each reach are given in Figures 10 and 11. P_A for 2013 within each reach was 'good'; while for 2012, P_A got 'poor' for the middle reach. In both years, P_A value was inferior in the middle reach. P_F values in each reach were greater than 0.90, implying that deliveries closely match demands.

Overall performance values depict the performance of the whole system averaged over space and time. It indicates the average water delivery performance of 15 offtakes over a period of three months for 2012 and 2013 (Table VIII). Adequacy (P_A) values indicate that the water delivery was 'fair' and 'good' for the years 2012 and 2013 respectively. Efficiency (P_F) implies that delivery in each reach is 'good' as per the delivery standard (Molden and Gates, 1990a). There are claims of water shortage during low flow in Awash River by the irrigation system managers of Metahara Sugar Estate Irrigation Scheme. However, unlike their claims, the water delivery in terms of quantity to offtakes at sub-lateral and lateral levels is quite adequate on average. The average overall equity (P_E) of delivery is 'fair' in each year. The average dependability (P_D) is 'fair' and 'good' for years 2012 and 2013, indicating satisfactory reliability of supply.

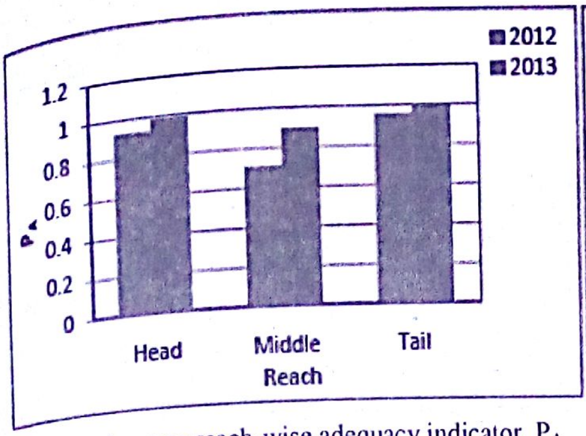

Figure 10: Average reach-wise adequacy indicator, P_A

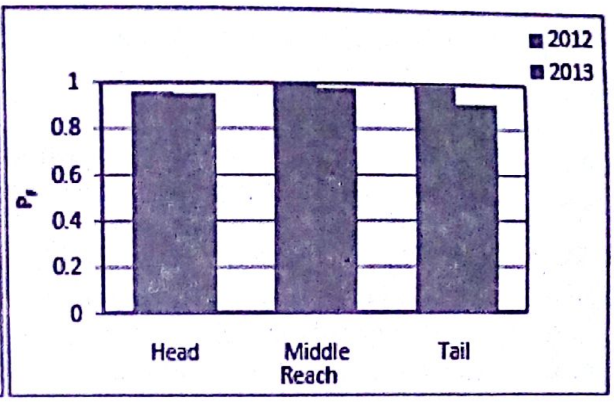

Figure 11: Average reach-wise efficiency indicator, P_F

Table VIII. Average overall values of water delivery performance indicators

Year	PA	Level	PF	Level	PE	Level	PD	Level
2012	0.87	Fair	0.98	Good	21	Fair	20	Fair
2013	0.96	Good	0.94	Good	14	Fair	10	Good

4. Conclusions

The existing operation rules for water diversion at the main intake of Matahara Large-scale Irrigation Scheme is based on discharges of 9 to 10 m^3/s for irrigation hours of the day (9 hours) and of 5 to 6 m^3/s for the remaining 15 off-irrigation hours. During the rainy months of August and September, it is operated under diversion rates of 3 to 4 m^3/s. However, this operation rules are not adequate and is not sound in that demand and supply are poorly matched. The diversionsare below demand in August and September, during which the supply is cut-off for canal maintenance, hence causing minor water stresses. However, Metahara Large-scale Irrigation Scheme is located in a semi-arid region and irrigation is required the whole year. On the other hand, water diversions during 10 months are in excess of demands, accounting for about 24% annual surplus. Significant part of the scheme and the surrounding is dominated by poorly drained heavy soils with a high risk of shallow groundwater tables. Located in the Rift Valley region, the area is also highly vulnerable to salinization. Excess drainage water from the scheme is less recovered back for downstream use, because: (i) percolates and causes significant rise of saline groundwater within the scheme, posing problems of salinity and waterlogging; (ii) resulted in significant swamps and contributed to rising water levels of lakes in the vicinity with poor water quality. Competition for water in the basin for irrigation and other sectors is currently rising with significant increase in water withdrawals. Surplus water diverted to the scheme, if could be saved, could have irrigated as much as 1,400 ha of land on the downstream.

The average water delivery performance to offtakesat tertiary level is in general satisfactory in terms of adequacy and efficiency, and implies little percolation losses at field levels. However, the operation of offtakes was found not to be adequate in terms of overall equity. Inequity is directly related to limited knowledge of canal managers and operators on the complex hydrodynamic characteristics of the canals, night storage reservoir and flow control structures.

Reach wise evaluation showed that offtake water delivery adequacy was unsatisfactory at middle offtakes as a result of inappropriate operation of night storage reservoir and the hyper-proportional nature of offtakes. More than 90% of unintended diversion to the scheme was lost as seepage in the conveyance and distribution (main and off-farm system), into leakage and drainage within the system and at the system tail end. Flow monitoring at offtakes has confirmed that the proportions of the losses at field levels are less than 10%. The major water losses are: main and off-farm seepage (25%), drainage and operation within the scheme (20%) and tail loss (45%), which all do not reach the field. An operation plan for water diversion the main intake, the reservoir and offtakes, which is field demand-responsive, based on continuous flow monitoring at offtakes instead of operators' presumptions and with continuous calibration of control structures is will be required. To this end, further study on the hydrodynamic analysis and specific operation plans for structures is required.

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Numerical Groundwater Flow Modeling of the Meki River Catchment, Central Ethiopia

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Abstract

A three dimensional steady-state finite difference groundwater flow model is used to quantify the groundwater fluxes and analyze the subsurface hydrodynamics in the Meki river catchment by giving emphasis to the well field that supplies water to the community. The area is characterized by Quaternary volcanic covered with lacustrine, alluvial, talus, and pyroclastic deposits. The model is calibrated using head observations from 95 wells. The simulation is made in a one layer unconfined aquifer with spatially variable recharge and hydraulic conductivities under well-defined boundary conditions. The calibrated model is used to forecast groundwater flow pattern, the interaction of groundwater and surface water, and evaluate the behavior of the groundwater system under possible future utilization scenarios. A sensitivity analysis conducted indicates that the model is more sensitive to decrease in recharge and increase in hydraulic conductivity but less sensitive to increment or decrement of pumpage. The simulation result indicates that the groundwater flows from western escarpment to east directions finally join Lake Ziway. Lakes and rivers play important role in recharging the aquifer. Simulations made under different possible future utilization scenarios including increase in pumping rate results in substantial regional groundwater level decline, which will lead to the drying of springs, and shallow hand dug wells. It has also implications of reversal of flow from contaminated rivers in to productive aquifers close to main river courses; decrease in recharge caused more inflow from Lakes as well as increase stream flow but decrease drains, and disappearance of Lake Tuffa results in increased recharge and groundwater outflow through springs. The sensitivity and scenario analysis provided important information on the data gaps and the specific sites to be selected for monitoring that may be of great help for transient model development. This study has laid the foundation for developing detailed predictive groundwater model, which can be readily used for groundwater management practices.

Keywords- Central Ethiopian, Meki, Modeling, Modflow, Volcanic aquifer, groundwater management

1. Introduction

Numerical groundwater flow models are important tools in hydrogeological studies in different parts of the world. Groundwater models have played an increasingly important role in the evaluation of alternative approaches to groundwater development and management. In recent times groundwater simulation models have received attention in Ethiopia for hydrogeological system analysis [1]. However, due to limitations in pertinent data it has been difficult to develop robust three-dimensional transient models that can be used as groundwater management tool.

Meki river catchment has an abundance surface and groundwater resources; however, due to climatic change, industrialization, high population growth, the amount of water available is decreasing and its quality is degrading. In a country like Ethiopia, where rain fed agriculture is the main source of economy and ensures the wellbeing of many people, water resources are essential.

Nevertheless, if the water resources are not utilized properly in an integrated planning manner, its sustainability and its support to food security to the country will become endanger. Therefore proper planning of water resources development as well as utilization is very essential.

Groundwater plays significant role in the region and presently used for almost all town and village water supply of the sub basin. The integral approach considers both surface and sub-surface water as the major resource of the region. It is observed that there are a lot of boreholes, shallow wells, dug wells, wind pumps and springs over the region which serve as community water supply.

Several conventional investigations have been carried out in the area over the last two decades. The most important groundwater resource assessment has been carried out by [2]. General hydrology and hydrogeology of Ziway–Shalla basin and numerical groundwater flow modeling of the central main Ethiopian rift lake basin have also been addressed [3]-[4].These studies provided initial conceptual view of the quaternary volcanic aquifer systems, hydraulic parameters and the movement and occurrence of groundwater.

Groundwater is pumped by different industries, institutions. Often groundwater abstractions are carried out without the basic understanding of the groundwater recharge, lateral and vertical extent of aquifers and the available groundwater reserve. One important issue to be addressed is the mechanism of groundwater flow, occurrence and assessing the response of the system to different abstraction and recharge rates. In this regard groundwater flow models play important role. This work tries to describe the movement and occurrence of groundwater using steady-state groundwater model. Model simulation is made under different stress scenarios (variable pumping rates) with distributed model input parameters such as recharge and hydraulic conductivity.

Site description

The Meki river catchment is located in the central main Ethiopian rift valley. The total surface area of the catchment is 2318.58 km^2. It is bounded between 7^{0}51' to 8^{0}27' N latitude and 38^{0}15' to 38^{0}51' E longitude (Fig. 1). The high plateaux of the Gurage highlands such as Zebidar Mountain of the area range (3611 m.a.s.l) forming the main recharge area. The lowest elevation is to the rift floor around Lake Ziway close to the Meki River (1636 m.a.s.l). The western escarpment or highlands of Gurage Mountain comprises highly welded ignimbrites, tuff, rhyolite and trachyte without visible large faults. The upper weathered rock and soils are permeable; however, the underlying volcanic sequences are massive. Butajira-Pediment, Kuntane-Inseno-Kela-Plain, Tora-Koshe-Dugda-Ridge and North Eastern area is characterized by ignimbrite, fracturing and weathering grade. The study area consists of recent basalts and highly fractured ignimbrites; and scoria cones along the major fault east of Butajira. Ziway-Plain covers large area around the Lake Ziway. The lithological groups found in this area are ignimbrites overlain by lacustrine sediments such as: clay, diatomite, shale beds and reworked pumice. Major perennial rivers start from the western escarpment and drain to the east. The main ones are the weja, Irinzaf and Meki rivers draining to the Ziway Lake.

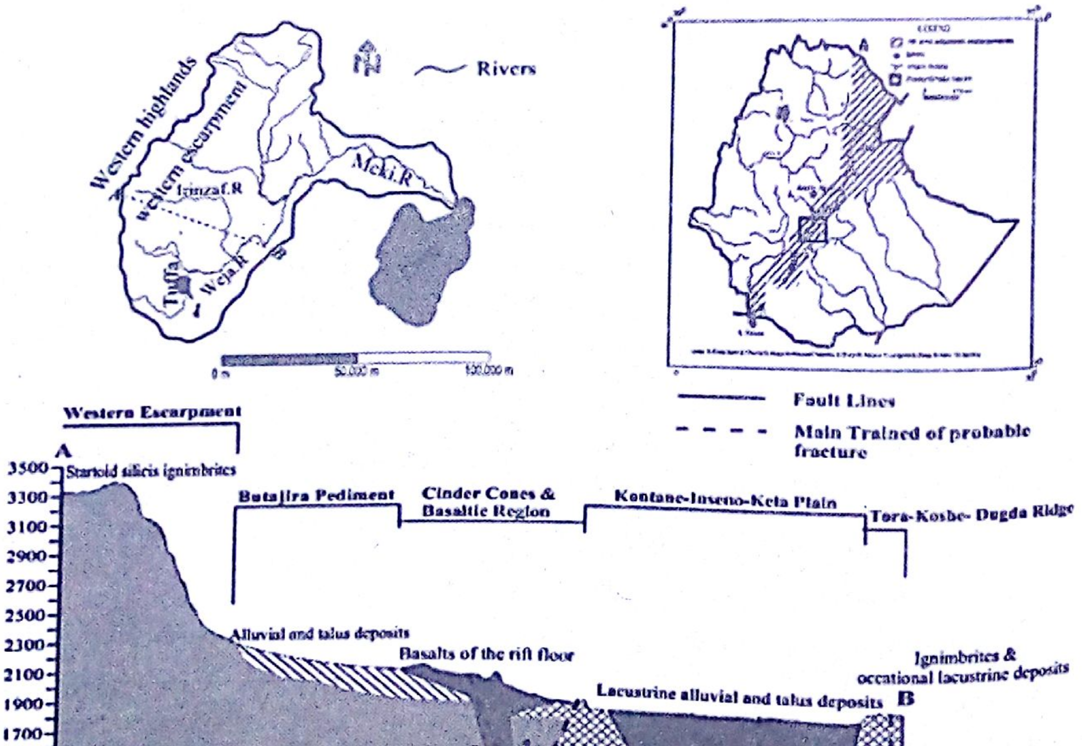

Figure 1: Location map of Meki river catchment with A-B schematic section

The Climate consists of three ecological zones: humid to dry humid, dry sub-humid or semi-arid and semiarid or arid lands [5]. Accordingly, highland areas and west of Butajira is categorized under humid to dry sub-humid land. The areas east of Butajira around Lake Abaya are dry sub-humid lands. The rest of the area which is around the lake is in semiarid or arid zone. Rainfall and temperature in the area show strong altitudinal variations. The average annual rainfall varies spatially and ranges from around 715 mm/year in the rift floor to more than 1100 mm/year at extreme highland areas. The average annual prevailing mean temperature ranges from about 110C in the highlands to around 26 0C in the rift.

2. Methodology

The study focuses more on groundwater flow system analysis, rather than developing a well calibrated model that can readily be used as a management tool. Because the available data does not allow us to establish a robust three -dimensional transient flow model. However, the model developed in this study lays the foundation for attaining versatile transient three-dimensional flow models that can play important role for sustainable groundwater management including assessment of contaminant transport.

The catchment was modelled using the widely used United States Geological Survey groundwater flow model called MODFLOW, under steady-state conditions. MODFLOW is a modular three-dimensional finite difference groundwater flow code [6], which simulates saturated porous media under steady-state and transient conditions. Groundwater flow models have been used to solve practical problems in a wide variety of hydrogeological environments in different parts of the world [7]-[8]-[9]. The steady-state groundwater flow is simulated based on the following governing differential equation under two-dimensional aerial view [10].

$$\frac{\partial}{\partial x}(T_x \frac{\partial h}{\partial x}) + (\frac{\partial}{\partial y} T_y \frac{\partial h}{\partial y}) \pm R = 0$$

Where, h is hydraulic head and R is a sink/source term. T_x and T_y represent the principal components of the transmissivity tensor in the x and y directions respectively.

Well logs and pumping test data were collected mainly from previous studies [11] to develop the conceptual hydrogeological model. The pumping tests were made by different organizations using different methods to estimate the aquifer parameters. Both constant discharge and recovery tests were carried out, with very few step-drawdown tests. The most important methods applied include [12]-[13]. In a few cases [14] method has been applied. The duration of the constant discharge tests range from 24 to 72 hours, and for recovery tests it ranges from 2 to 12 hours. The estimated transmissivity and hydraulic conductivity values obtained are quite similar to [3].

The groundwater recharge was taken from previous studies [11] estimated using a soil-water balance model and chloride mass balance approach. The recharge estimation processes accounted all pertinent hydrometerological data, soil types, slope and land use aspects. Static groundwater levels were recorded from 95 wells for calibration. Water levels were measured in limited wells periodically since the year 2000. A systematic hydrogeological field survey of stream courses was made to determine the inputs for the river package such as riverbed hydraulic conductance, thickness of riverbed sediments, length and width of rivers at different reaches. The river bed hydraulic conductance was adapted from similar areas in the Ethiopian rift system [3]. The discharge data of the Meki River (MoWR, 2010) was used to check the aquifer-river relations locally.

Groundwater modeling often involves large geospatial data sets. A Geographic Information System (GIS) provides an integrated platform to manage, analyze, and display spatial data. It also greatly facilitates modeling efforts in data compilation, calibration and presentation. Furthermore, it can be used to generate information for decision making through spatial overlay and processing of model simulation results. GIS has also been used to develop the digital elevation model (DEM) of the catchment which in turn helped to define the top of the aquifer. The DEM was derived from the Shuttle Radar Topography Mission (SRTM) satellite data at a resolution of 90 by 90 meters, which was later converted to the resolution of the model grid. For this study one of the most widely used windows-based GIS software ArcGIS, surfer 10, global mapper 12 and 3D master is used.

Model calibration

Calibration checks that the simulation is reproducing field measured heads and flows [10]. It involves adjustment and refinement of parameter structure and values to provide the best match between measured and simulated hydraulic heads and flows. Steady-state calibration was made using static water level observations of 95 wells.

In the course of calibration adjustments on aquifer thickness, hydraulic conductivity and recharge were made within reasonable ranges based on field hydrogeological observations and pumping test data.

Calibration can be achieved in two ways; forward and inverse problem solutions. In an inverse solution method one determines values for a given parameter structure and hydrologic stress using a mathematical technique, such as nonlinear regression from information about head distribution [10]. This technique is sometimes called parameter estimation and it finds the set of parameter values that minimize the difference between simulated and measured quantities such as hydraulic heads and flows. The forward problem calibrates parameters, such as hydraulic conductivity and hydrologic stresses, are specified and the model calculates the head distribution.

In this study, the forward solution is used by a conventional trial and error method in which model parameters were adjusted manually within reasonable limits of the existing data and field hydrogeological observations to achieve the best fit. The effectiveness of calibration is evaluated by comparing measured heads with simulated heads for all observation wells used. Two calibration criteria were used; visual matching of simulated contours to those of observed contours was set and matching simulated hydraulic heads at 90 % of the points to within 5 m of the observed hydraulic heads. The model was assumed calibrated when the fit between observed and calibrated heads was within this criteria and simulated groundwater contours (Fig. 2). The correlation coefficient is the found to be 0.996.

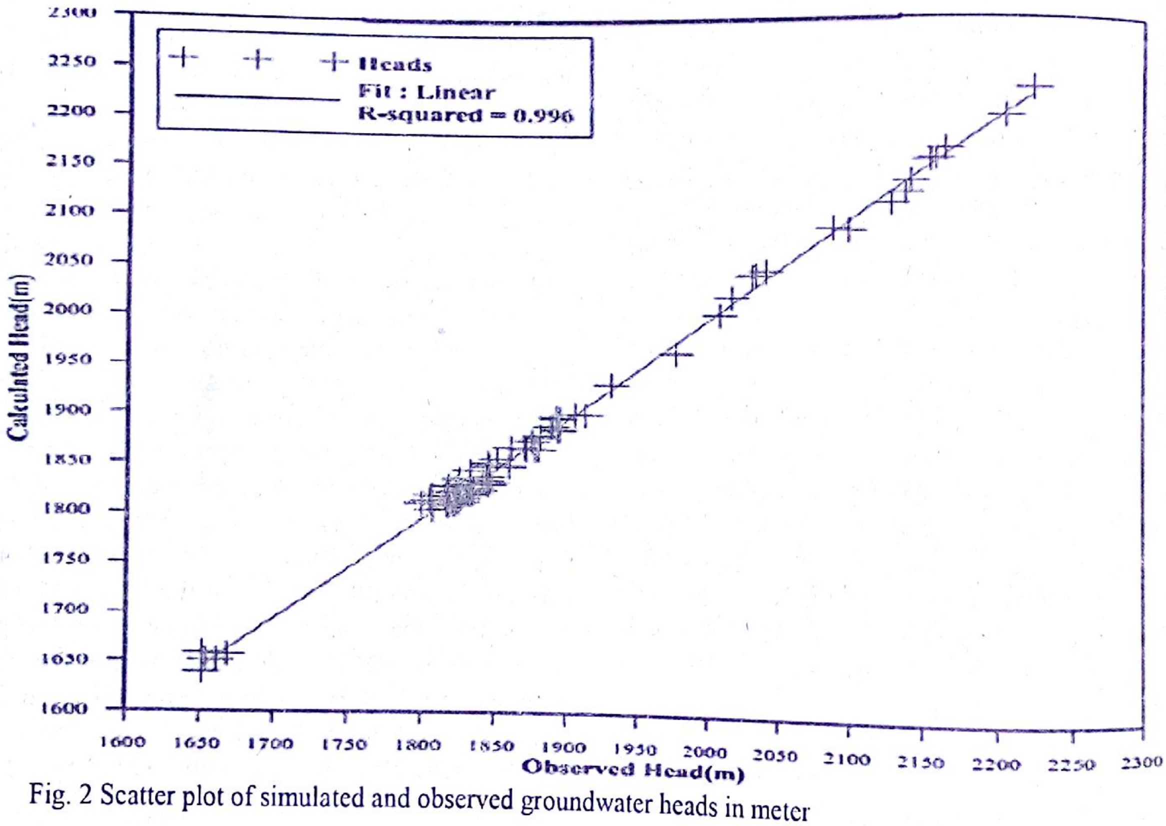

Fig. 2 Scatter plot of simulated and observed groundwater heads in meter

5. Results and Discussions

The steady-state model provided valuable information on the groundwater balance, the response of the catchment to different stresses, the groundwater-surface water interactions and flow patterns. It has also shown the specific areas to be monitored and additional data gathered in the course of future detailed transient model development.

5.1 Groundwater balance and the role of surface waters

Groundwater balance refers to the quantification of the inflow and outflow from part or the entire model domain. In a steady-state model simulation, inflows into and outflows from aquifers should be quantified. In this case groundwater inflow includes aerial recharge from precipitation and fluxes from rivers and lakes. An outflow includes the base flow of rivers, well withdrawals and spring discharge.

Table 1: Groundwater balance and effect of each scenario

Scenarios	Water balance components	Inflow (m^3/day)	Outflow (m^3/day)	Difference (m^3/day)	Change with respect to the calibrated Value (%)
Calibrated value	Constant head	98868	262635		
	Wells	-	22570		
	Drains	-	1158		
	River leakage	151919	664285		
	Recharge	699698	-		
Scenario 1 (Increasing pumping by 50%)	Constant head	99203	261798	837	0
	Wells	-	33855	-11285	-50
	Drains	-	1139	19	2
	River leakage	153109	655381	8904	1
	Recharge	699698	-	-	-
Scenario 2 (Decreased recharge by 25%)	Constant head	106989	240549	-22086	-8
	Wells	-	22570	0	0
	Drains	-	855	-303	-26
	River leakage	173487	541396	-122889	-18
	Recharge	524960	-	-	-
Scenario 3 (Disappearance of Lake Tuffa)	Constant head	20586	166359	-96276	-37
	Wells	-	22570	0	0
	Drains	-	1250	92	8
	River leakage	150298	683849	19564	3
	Recharge	702979	-	-	-

Table1 summarizes the steady-state groundwater balance of the entire model domain. The simulation was made under three different scenarios; with the aquifer system response to increased pumpage by 50% (scenario 1), decreased recharge by 25% (scenario 2), and complete disappearance of Lake Tuffa (scenario 3).The rationale of selecting the different scenarios is to assess the changes in the various water balance components under variable recharge rates. Changes in climatic conditions from time to time affect groundwater resources as a result of changing recharge rates. Recent studies clearly show large water resources variability and environmental changes in Ethiopia dominantly governed by climatic changes [15]. The study made by the United Nations Food and Agricultural Organization (FAO) in East African countries shows wide variability of rainfall in the region over the last half a century [16].

5.2 Groundwater flow pattern

The model estimated groundwater head distribution reasonably agrees with the regional groundwater contour map reconstructed from limited wellhead measurements. Unfortunately parametric data in the west, northwest and southwest is scarce, making comparison difficult in these areas. The simulated head distribution shows the groundwater flow from western escarpment to east directions finally join Lake Ziway. The groundwater level is generally flat to gentle slope except at Tora-Koshe-Dugda-Ridge and the Cinder Cone areas. In these areas the groundwater contour shows steep slope probably due to the nature of the rocks or the fault systems separating these zones. The groundwater has a slope of 0.1% at Ziway-Plain; Tora-Koshe-Dugda ridge has 1.4%, Kuntane Inseno-Kela-Plain 0.3% and Cinder-Cone and Basaltic areas have 3.7%.The groundwater level drops from 2000 m.a.s.l in Butajira-Crescent to 1800 m.a.s.l in Kuntane-Inseno area.

5.3 Sensitivity analysis

Sensitivity analysis was made to understand the uncertainty in the calibrated model caused by limitation in the estimates of aquifer parameters and stresses. Groundwater models are sensitive to different model input parameters and parameters for which the model is most sensitive; small changes in those parameters will result in large differences in simulated heads or fluxes.

The response of the calibrated numerical model to changes in model parameters like hydraulic conductivity and recharge was examined. During simulation, the effect of one parameter was being tested, the other parameters were kept to the steady-state calibrated value and each parameter was changed uniformly over the whole model domain. The magnitude of changes in heads or fluxes from the calibrated solution was used as a measure of the sensitivity of the model to that particular parameter.

In the model, simulated water levels were more sensitive to the decrease in the recharge values, mainly away from 40 percent. But it is more sensitive to the increase of hydraulic conductivity values, especially above 30 percent. Compared to recharge and hydraulic conductivity the model is less sensitive to the decrease or increase of pumpage. Model runs have been made by changing the hydraulic conductivity and recharge by the specified percent and the respective mean absolute error head changes in percent from the calibrated value are shown in Figure 3.

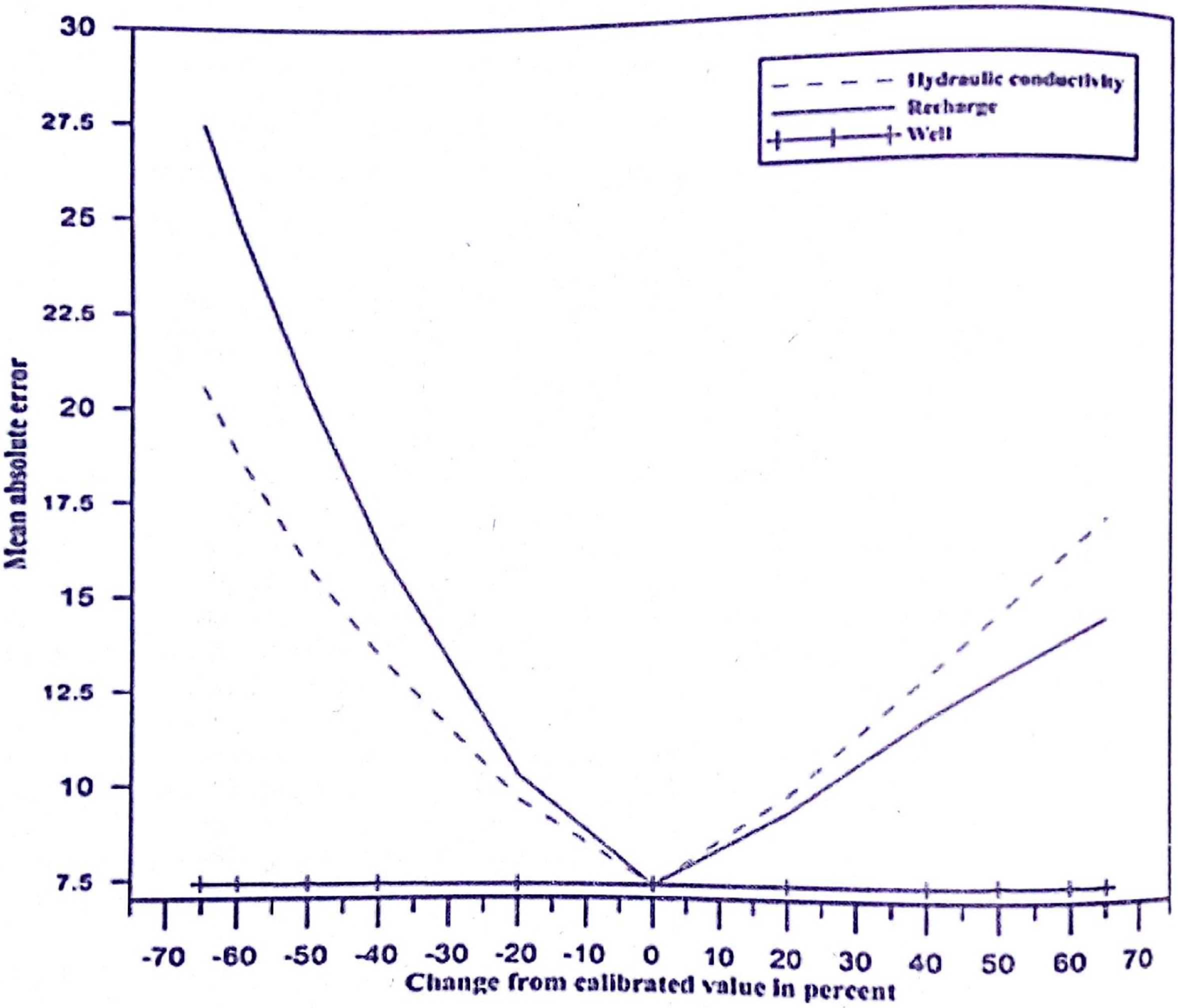

Figure 4: Sensitivity analysis result

6. Conclusion and Recommendations

6.1. Conclusions

Both the conventional field hydrogeological evidences and model simulations indicate that groundwater converges towards southeast (Lake Ziway). The comparison made between the groundwater and topographic contours and the model sensitivity analysis indicate the dominance of topographically-driven flow system under water table conditions, although limited lithological differences and large faults form local discrete flows in fractured and weathered zones. A shallow flow system mainly controlled by steep topography and sharp hydraulic contrast between geologic units is observed in the western escarpment or Gurage mountainous areas in the foot hills where a number of small and intermediate discharges springs emerge.

6.2. Limitations and Recommendations

At this stage the model has provided valuable hydrogeological information of the catchment. However, the steady-state model may not be readily used for detailed groundwater management purposes owing to data limitations on hydraulic conductivity, wellheads and aquifer thickness information in some areas of the catchment. The overall accuracy of the results depends on how these input parameters are quantified and temporal variations are treated under transient conditions.

The results obtained here should not be interpreted as a perfect simulation, rather as system response projections within a fairly realistic model input parameters. Hence, the results should be interpreted and applied by considering all the limitations and drawbacks associated with the data gaps. The authors believe that this study has laid the foundation for future detailed predictive transient model development. However, achieving a well-calibrated transient groundwater flow model requires filling the data gaps and collecting multi-temporal data at higher resolution. In this regard the following recommendations can be forwarded.

Great effort is needed to develop a 3D dimensional conceptual hydrogeological model. The well lithologic logs in some areas show different volcanic layers representing different hydraulic characteristics. These issues have to be seen in a detailed manner in the future. The big data gaps on the hydraulic conductivity have to be filled by collecting more pumping test data. The pumping test data will also provide data for transient simulation such as specific yield, storage coefficient, etc. A fair estimate has been done on the groundwater recharge, although more refinements can be made in the future, according to the ever changing land use and expansion of the city with in the catchment which reduces the groundwater recharge. It is also essential to determine distributed multi-temporal recharge for transient models by accounting, all influencing hydro-climatic factors. Very little is known about the aquifer layers below the depth of 250 meters. It is essential to study this system by drilling test wells and using proper geophysical methods.

Acknowledgements

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Solar Water Pumping as Sustainable Option for Rural Water Supply System- A Case Study in Dolo Odo Woreda of Somali Region

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Abstract

Solar radiation potential as energy alternative for sustainable water pumping with respect to commonly used diesel driven pump systems and electric powered options for water supply in rural community of Somali region is the main focus of this study. Technical details such as design governing factors, water source, cost, affordability, willingness to pay, institutional setup, and environmental benefits of the system have been assessed in depth based on the relevant data gathered. Ease of maintenance and operation is an important aspect of the study compared with the existing diesel powered systems that require escalating fuel cost. Initial cost, operation and mantenance cost, photovoltaic panel wattage and power available, community attitude and acceptance are also investiagted according to the local context based on primary data gathered. Solar potential studies and NASA data are used to estimate the radiation potential and energy generation of the study area. Life cycle cost comparison for different energy source driven pumps has been assessed by applying Hybrid Optimization Model for Electric Renewables (HOMER) in order to identify economic feasibility of the systems. Statistical equations and SPSS software are also used to analyze qualitative and quantitative data. As a result the solar potential and relative advantage with regard to sustainability of photovoltaic solar pumps in rural water supply system is investigated against its diesel/petrol counterpart while favoring green energy technology.

The result of the study shows that hydraulic load and solar potential of the area are governng factors in order to design solar PV water pumping system. The hydraulic load and number of panels required to pump water has linear relationship. When the hydraulic load increases the number of panels required for lifting of water increases. With respect to cost, affordability, willingness to pay, and environmental view, PV systems are advantageous over diesel driven systems. The study used life cycle cost analysis method for cost comparsion. As result, PV driven systems are economical than diesel driven systems considering all cost components within the specified life span. Though the investment cost of PV pumping is higher, thier operation and maintenance cost is aforadble than diesel driven system. In addtion, operation and maintenance of diesel generators is not only expensive but also extensive than PV system and some times require a senior technician during failure. This particular study also show that, diesel driven generator can produce 5,000-7,000kg of CO_2 per annum for 1000-3000m^4/d of hydraulic load, which can be avoided by replacing the system with PV systems. Hence, PV driven system is more sustinable option than diesel counterpart.

1. Introduction

Water pumps, powered by photovoltaic (PV) panels, are being used frequently to pump water for domestic usage, to irrigate crops and landscape, to cattle, and provide potable water. The advantage of using solar energy for pumping the water is that major quantities of water are required during day time when the sun is on top of our head, and during this time the PV panels produce maximum energy and hence the water quantity. These solar pumps can be installed anywhere no matter it is a valley, remotely located farms, forest, or locations which are difficult to reach and are not connected to national electric grid. The utilization of solar water pump in developing countries is providing a workable solution to meet water needs of the people. At the same time, one can also save the environment by avoiding or minimizing the burning of fossil fuel for energy generation. The solar water-pumping technology is commercially available, has-proven record of reliability, require minimal skilled manpower once in operation, operation and maintenance cost is also very minimal, and affordable.

Study Area Description

Dolo Odo woreda located in the Liben Zone of Somali Region of Ethiopia. The woreda is situated in the angle formed by the confluence of the Ganale Dorya River with the Dawa River and is bordered to the northwest by Filtu, on the northeast by Afder Zone, on the southeast by Somalia, and on the south by Kenya. Bekol Mayo, Dolo and Suftu are the towns found in the woreda. The altitude of the woreda ranges from 200 to 1000 meters above sea level.

Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), this woreda has a total population of 111,511, of which 60,778 are men and 50,733 women. While 37,404 (33.54%) are urban inhabitants and 33,869 (30.37%) are pastoralists. 95.69% of the populations were Muslims. According to 2007 Ethiopian census the population is estimate to be 130,077 with annual growth rate of 2.6% per year. There are 5 refugee camps housing a total of 185,628 individuals (43,568 HHs) from Somalia, located in Dolo Odo.

According to 2007 Population and Housing Census data of Ethiopia, 88.6% of housing units in the woreda collect water from unprotected sources while only 5.7% housing units obtain water from protected sources. The remaining 5.7% of housing units are supplied water by tap inside the house and compound.

2. Objective of the study

The present study is aimed at investigating the economical, technical, institutional, social and environmental viability of solar water pumps with respect to diesel systems of water supply systems.

The sepcific objectives of the study were:

- To assess appropriate solar voltaic panel size to meet a given pump discharge and head using solar potential of the study area
- To study the cost of solar pumps with respect to fuel driven generator system pumps for water supply at different hydraulic load scenarios.
- To assess affordability, willingness to pay for the service, operation & maintenance, and environmental considerations of the system

3. Methodology

3.1. Data sources and collection methods

For primary data acquisition questionnaire/household survey method was employed to collect information from selected water users. Technical information was collected from NGO working on solar water pumping and up-to-date information on fuel and lubricant cost is also taken at Dolo and Addis Ababa. In addition, solar PV pumping components available in the country market and their cost is gathered for from different suppliers and sellers in Addis Ababa.

Ministry of water, irrigation & energy, Intermon Oxfam, Dolo Odo Woreda water office, Dolo meteorological center, Ethiopian Petroleum Enterprise were consulted to collect secondary data on background of the study area, water supply coverage, water, wind and solar resources of the country, region, and in some circumstance of the study area.

In addition, site visit was done at the study area where there are operational and maintenance criticalities and in Taramesa kebele of Shebidino woreda of Sidama zone.

The visit in Taramesa kebele was targeted in order to acquire better information about working solar PV water supply system in view of benefits and operational drawbacks. The scheme is under operation and implemented by the project called community managed renewable energy project for rural Ethiopia in 2010 and operational till now.

3.2. Sampling technique

In order to assess the affordability, willingness to pay, and operational issues related to the community, household survey was conducted among 120 households in 5 kebeles of the study woreda. From each kebele around 20 to 30 households contacted to conduct questionnaire data collection. The low number of the household survey is attributed due to the limitation to reach because of disperse settlement of the dwellers. In addition, the movement of household heads with their cattle and to their ploughing fields near river sides is other reality to fail access to some households. The questionnaires are prepared in English and therefore translation to Somali language is done with the help of local expertise.

Sampling technique used for conducting household survey is purposive sampling. The sampling technique is selected based on the settlement realities at the study area. The kebeles considered for survey are the in between 5 to 50 km away from the Dolo town. The remote kebele from the town for this study is Kole which is 50 km and the closet one has a distance about 5 km.

The survey is also considered the settlement along the two rivers and that is why two kebele namely Kilimasenge and Helewoyni are from Genale site and two kebeles namely Bardale and Holomoge are from Dawa site.

3.3. Analysis of Data

Governing design factors of PV driven systems for the purpose of water supply are defined in order to quantify design parameters for three different cases assumed for this particular study. The design parameters are quantified for analysis based on data from secondary sources.

For cost analysis, the present-day initial cost of equipments and fuel together with estimates of operational and maintenance costs are entered to Hybrid Optimization Model for Electric Renewables (HOMER) and the output is checked for different comparisons between Solar and diesel driven water pumping. HOMER software uses life cycle cost (LCC) method for analysis of different cases. The net present cost (or life-cycle cost) of a component is the present value of all the costs of installing and operating that component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER calculates the net present cost of each component of the system, and of the system as a whole.

Data collected using key informant interview, physical observation, and secondary sources were used to triangulate the household survey and enabled to know the potential resource and technical criticalities of the study area. Besides, information obtained as secondary data are used to reinforce the analysis results obtained from primary data collection.

4. Results and Discussions

PV system design consideration

The main factors for deigning solar PV driven pumping are hydraulic load, solar potential of the area under investigation, and solar PV technology. Each factor consists of different parameters that have to be defined properly for better design.

Hydraulic load

Hydraulic load, expressed in m^4/d, is the product of total dynamic pumping head and daily water demand of the community under consideration.

The size and cost of solar PV module depends up on the amount of water required per day. Solar water pumping systems work only some hours in a day time whereas water demand is the sum of requirements in 24 hours of a day. Water demand in summer is higher where the solar energy generation is higher is one of the advantages of this system. Daily water (liter/day or m^3/day) is decided based on rate of water demand and population.

As agro-pastoralist area, household water demand of the study area includes the domestic water demand and livestock consumption as elaborated in table 2. In addition, average number of family size, livestock size and rate of water demand in a household is presented in table 1 (livestock information is based on the household survey conducted).

Table 1 Human and livestock water demand per household per day of the study area ((Somali Region Water Sector Review 2009/10- based on ILRI, 1986)

User	Average size per household	Daily demand (lit/d)	Total demand per household (lit/d)
Human	6.2	20	124
Camel	0.74	36	26.64
Donkey	0.62	40	24.8
Goat	10.4	5	52
Cattle	3.49	40	139.6
Sheep	2.39	5	11.95
Total			379

Every rural household of the study area needs 379 liters of water per day in average for domestic use and livestock consumption.

Total dynamic head (meters) signifies the effective pressure at which pump must operate. Primarily, it consists of total vertical lift and frictional losses.

Total vertical lift is the sum of drawdown, standing water level, and elevation. Drawdown is the height by which ground water level drops due to pumping. Standing water level is the depth below the ground surface to ground water level when the drawdown is zero. Elevation is the height difference between the ground and the height at which water is discharged.

Frictional loss (equivalent meters) is the pressure required to overcome friction in pipes from water pump to the point of water discharge. Factors affect frictional losses are: size of pipe, flow rate, type of fittings number of bends, etc.

To select appropriate pump for a given hydraulic load, there are pump performance curves that are provided by manufacturers.

Surface water resource in the study area

The study area shares the regional reality with regard to water scarcity though it is endowed with big perennial rivers, Genale and Dawa. Settlement pattern of majority of kebeles in the Dolo Odo woreda is situated close to either Genale or Dawa rivers. The Dawa and Ganale Rivers transect the southern part of Somali region and form the Juba

River after their confluence at the Somalian border.

Hydrogeology of the study area

The area is covered by gypsiferous alluvial sediments underlain by shally limestone intercalated with gypsum. According to the geological map of Ethiopia, this unit is mapped as Uarandab Series. The presence of gypsum is responsible for the bad quality of groundwater. According to hydrogeological investigation by SHACC Consulting (2011) in Rama and Bour Amino kebeles and Suftu town, the geology of the area consists of thin alluvial sediments, underlain by alternation of shale, marl and gypsum of the Uarandab Series. As result of this formation, the ground water got bad quality i.e. saline and not fit human consumption. The only chance of obtaining fresh water is close to the river so to take of river infiltration into the groundwater causing salt to be diluted. The maximum depth investigated by SHACC consulting is 50m at Rama kebele close to the bank of Dawa kebele.

Solar potential of the area

The solar potential of at Dolaw center of Somalia, only 2.5 km away from the study wereda capital Dolo, has got 5kWh/m^2 to 6.78 kWh/m^2 of daily solar radiation in horizontal surface. Let's take the average value for design which is equal to 5.76kWh/m^2.

To generate more energy, the PV module should face north to south at an angle equals to the latitude of the location which ranges between 3°55′ to 4°50′ N (google earth). When placing PV module angle equals to latitude angle the daily solar radiation will increase from 5.76kWh/m^2/d to 5.78kWk/m^2/d. Internet source, simulated by HOMER, for latitude at which 4° 08′ N and longitude at which 42° E display the daily solar radiation of 5.92kWh/m^2/d. To be more conservative, it is the lower figure which is equal to 5.78kW/m^2/d is used for this specific study.

Solar PV technologies

The technology of solar energy predominantly focuses on improving the efficiency of PV cell. The higher the efficiency will result on the higher generation of energy per square meter. Mono-crystalline and multi-crystalline silicon cells are widely used and available in the local market. The efficiency of mono-crystalline silicon PV cell is slightly higher than multi-crystalline cells.

Whenever there is need to change DC to AC solar PV pump, it is necessary to search for the type inverter with higher possible efficiency. This is useful to maximize the energy converted to AC form.

For the case of operation and cost effectiveness of water supply schemes, it is not necessary to use batteries to back -up the energy. Rather it is essential to design reservoir or tank to balance low supply condition.

In the section below three different cases are particularized in order to analyze the relation between hydraulic head, power output from the solar PV panel and PV panel numbers required. Furthermore, the cases are essential for cost analysis in comparison with diesel driven generator set applications.

Since some studies state that (Omer, 2001) the solar PV driven system are more feasible for the power less than 5kW, it is essential to investigate the feasibility in view of lifecycle cost for less than 5kW power and greater than 5kW power.

Argaw et.al (2001) recommended that AC pumps are ideal for hydraulic load equivalent to 1500m^4/d. Therefore, this study investigates three different cases of hydraulic load, one less than 1500m^4/d and the other two greater than 1500m^4/d.

Additionally, this study contemplates two prominent cases: power generation less than 5kW (i.e. at 3kW and 4.7kW) and power generation greater than 5kW (i.e. third case with 7.45kW power).

Assumption

The study assumes the cost of pump for both PV and diesel driven system is equal.

For hydraulic load 1200, 1895 and 3010m^4/d, table 2 summarizes the power generated and number of panels required to obtain the energy needed.

Finally, relationship between hydraulic head and number of solar PV panel for the area under investigation is presented in the figure 1 as shown.

Monthly solar radiation, deferrable load, monthly average temperature, annual interest rate, project life time, investment and replacement cost, operation and maintenance cost, life time of the component are the major data inputs of PV system to run HOMER model.

Instead of solar radiation and temperature data, fuel type and cost, and emissions factor are the inputs of generator system. As result, the outputs obtained through simulation of the model include monthly electric and net present cost.

Table 2: Summary of the three cases

	Case 1	Case 2	Case 3
Head assumed	60	50	50
HH	54	100	160
Amount of water required (m^3/d)	20	37.9	60.2
Hydraulic load (m^4/d)	1,200	1,895	3,010
Hydraulic energy (Watt-hr/d)	3,270	5,163.88	8210.56
Power (watt)	565.74	893.40	1420.51
Power in watt after losses	2,983	4,710.65	7,489
Required number of panels	23	36	57

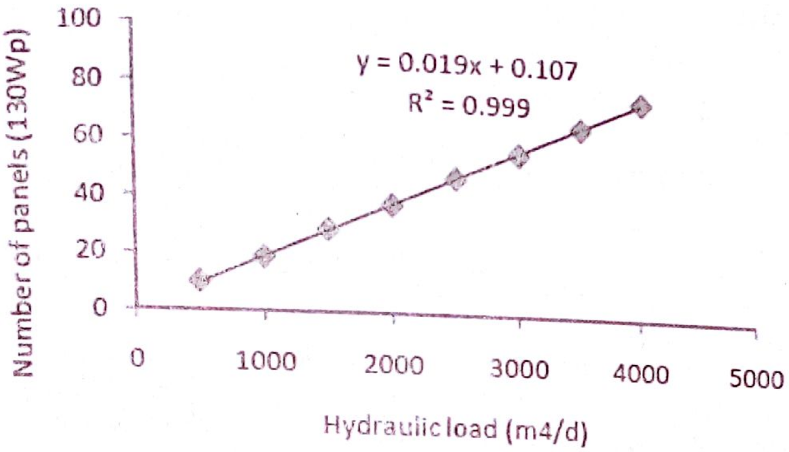

Figure 1: Number of PV panel required as a function of hydraulic load

Cost Analysis

The study targets to define different types of costs that need to be estimated and the cost comparison between diesel driven and solar PV pumping system using HOMER model on the basis of lifecycle cost analysis. The U.S. National Renewable Energy Laboratory (NREL) has developed a sophisticated simulation program, namely Homer model, and optimizes the most economic energy choices per specific project inputs.

In this study, HOMER (Hybrid Optimization Model for Electric Renewables) is used to model choices for a pumping system that is designed to pump 1200, 1895, and 3010m4/d of hydraulic load. It compares three different cases accordingly their hydraulic load needed;

Case 1: A solar array of 3kW against a 6.5 kW diesel generator (i.e. for 1200m^4/d of hydraulic load)

Case 2 : A solar array of 4.7kW against a 9 kW diesel generator (i.e. for 1895m^4/d of hydraulic load)

Case 3: A solar array of 7.45 kW against a 15 kW diesel generator (i.e. for 3010m^4/d of hydraulic load)

Fuel cost

Cost of diesel is an important component of life cycle cost analysis of generator driven pumping system. Cost of petroleum products was three folded between 2006/07 and 2011/12 according to the retail price in Addis Ababa (Ethiopian petroleum enterprise, 2013).

HOMER model uses fuel curve defined by the manufacturer which is based on the generator type and power generation. Lister Petter and Daylife generators used for the cost analysis of three cases. For instance, case 2 used 9 kW Lister Petter generator with fuel consumption of 2.7 and 3.6 liters/hr for 75% and 100% load respectively.

The net present cost of 20years of project life for 3kW generator is 25,260USD and its equivalent 6.5kW generator is 37, 307USD. Therefore, the PV pumping system is economical than diesel driven generator pumping for this case.

The total cost is also estimated for pumping systems having a hydraulic load of 1,000 and 3,000m4/d. The breakeven points are approximately 2.7 and 6.7 years respectively as shown in Figures 2 and 3. Whenthe hydraulic load increases the year to breakeven point increases which means at lower and medium range of power generation for water pumping PV system is economical than diesel driven generator system

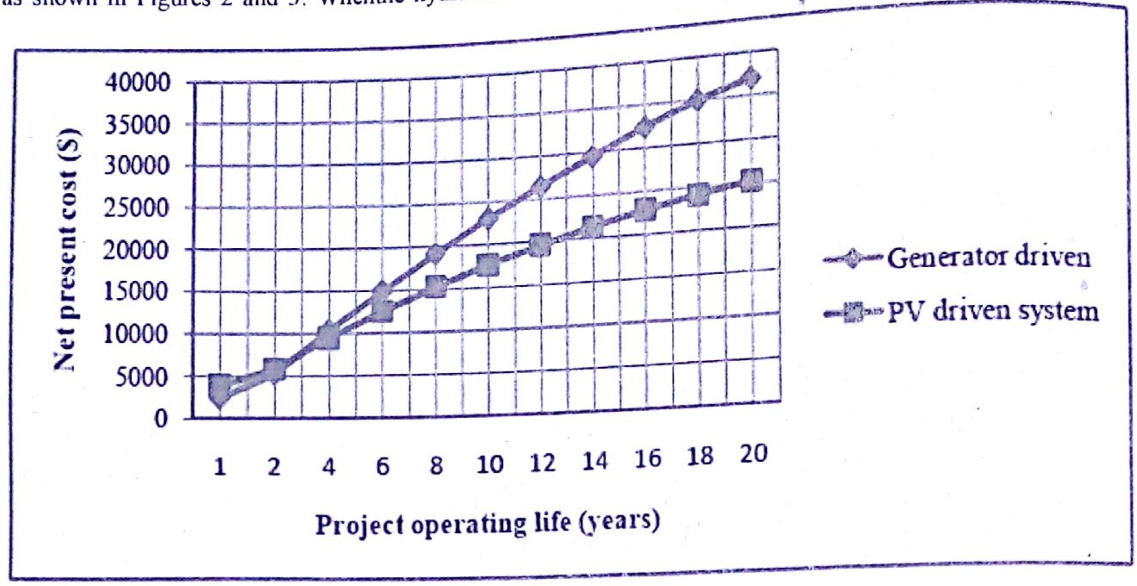

Figure 2: Breakeven graph for 1,000m[4]/d hydraulic load of PV and diesel driven pumping systems

The net present cost of 20years of project life for 7.45kW generator is 62,772USD and its equivalent 15kW generator is 77, 020USD. Therefore, the PV pumping system is economical than diesel driven generator pumping for this case. For case 3, the system becomes economical starting from 6.7 years, after breakeven point as shown in Figure 3.

It is the initial cost of PV system which is huge amount that contribute a fear among different water scheme implementing organization for the ignorance of solar driven system of water supply. However, the study results show that PV systems of water pumping is economical than diesel driven generator set based on life cycle cost analysis for the three cases under investigation.

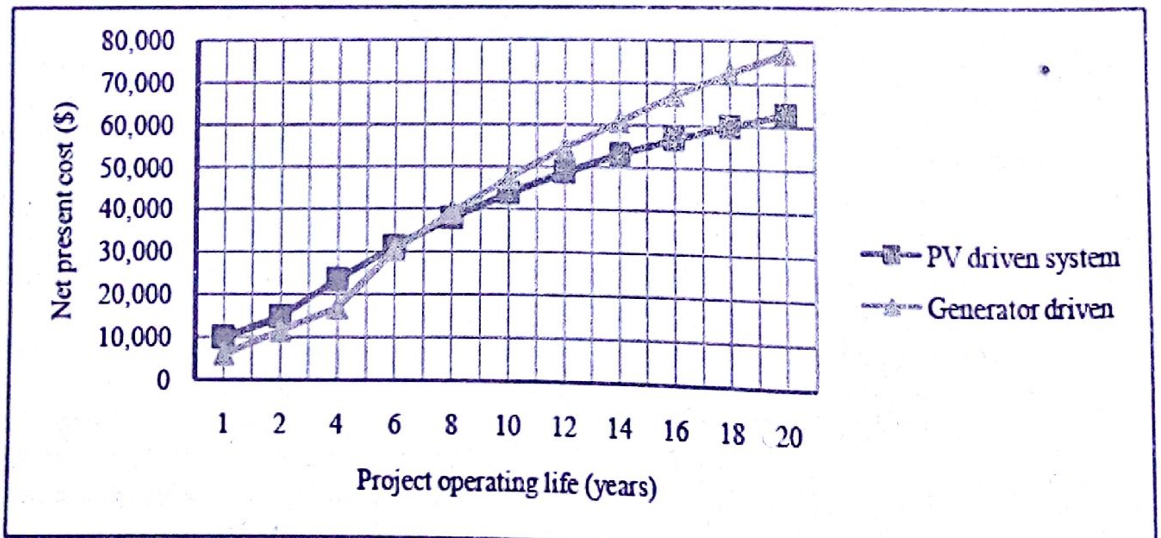

Figure 3: Breakeven graph for 3,000m[4]/d hydraulic load of PV and diesel driven pumping systems

Figure4 elaborates the life cycle cost difference between diesel driven and PV system of water pumping at different hydraulic load. When the hydraulic load is equals to 3,010m^4/d, the third case, still the PV system of water pumping is economical than diesel driven pumping system except the increment of breakeven point, the point at which the PV system and diesel system obtain the same value and afterwards the PV system is economical over diesel one, i.e., approximately from 3 years to 7 years.

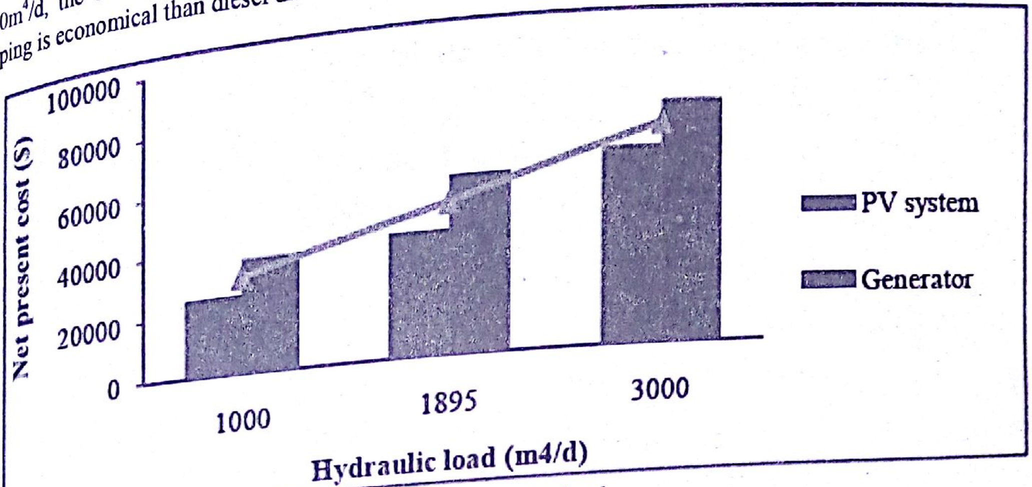

Figure 4: Life cycle costing as a function of the hydraulic load

Affordability and willingness to pay

Affordability of the PV system

Affordability is defined as the ability to pay. Most communities do have resources and hence the ability to pay (at least something) for maintenance; however, the way in which those resources are managed will influence the ability of communities to access resources when needed.

Affordability of rural water supply systems should mainly focus on the operation and maintenance of schemes according to water resource management policy of the country. Under the policy, the water supply and sanitation sector able to insure that rural tariff settings are based on the objective of recovering operation and maintenance costs. Hence the PV system water pumping is the cheaper system than diesel driven generator set sytetems in view of operation and maintenance if the initial cost is covered by government and community or NGO and community or combination of the three.

The initial or capital cost of PV water pumping system considers cost of equipment, mounting, installation and transportaion cost. Cost of equipment includes cost of panles requried and inverter and other electrical components such as electric cables etc.

Daily cost of household to satisfy their water demand = 379lit/HH/day * 0.1Birr/20lit = 1.895Birr/HH/day which is equivalent to 56.85Birr/HH/month.

The cost is affordable if and only if the household uses waters livestock from others sources such as rivers in their vicinity. Household water demand excluding livestock consumption as discussed in 3.1.1 is 124 l/HH/day.

Daily cost of household for domestic consumption excluding livestock demand is:

= 124lit/HH/day * 0.1Birr/20lit = 0.62Birr/HH/day or

= 18.6Birr/HH/month

Willingness to pay

Willingness to pay (WTP) is not necessarily directly linked to poverty but potentially has far greater impact on service sustainability. There are various definitions of willingness to pay but the one used most widely states that 'WTP is the maximum amount that an individual states they are willing to pay for a good or service' (DFID Demand Assessment Seminar, December, 1997).

Measuring willingness to pay

There are three ways of estimating WTP (Harvey et.al, 2004):

- Observing prices that people pay for goods in various markets (e.g. water vending, buying from neighbours, paying local taxes).
- Observing individual expenditures of money, time, labour etc. to obtain goods or to avoid their loss. This method might involve an assessment of coping strategies and involve observations, focus group discussions and even household surveys.

Plastic jerry can with 20 liter capacity is a major means of water collection in rural areas of the woreda under study. In addition to visual observation, household survey shows that 98% of households use this kind of water collection materials. 95% of households store water by the same material, jerry-cans.

Water collecting groups discussion result shows that the minimum price for 20 liter jerry-can ranges from 20 cents to 1 birr depending upon the proximity of the source to the users. According to the survey, 75% of households travel more than 1.5 km distance to collect water for their domestic use; however, the remaining 25% travel 0.5 to 1.5km to collect water from either unprotected or protected sources.

Asking directly the households about their willingness to pay showed that 26.7% are willing to pay 10-20birr/month, if the service is delivered at their vicinity. 41.7% of the households are willing to pay more than 20birr/month for the service. The remaining fraction of households showed their interest to pay 5-10birr/month.

Environmental benefits of solar driven water pumping system

Apart from the noise generated by diesel generators different gases are produced and create environmental impact through "greenhouse effect" to contribute global warming. Different pollutants such as carbon dioxide (CO_2), Carbon monoxide (CO), Nitrogen oxides (NO_x), Sulfur dioxide (SO_2), unburned hydrocarbons, and particulate matter are emitted to the environment due to use of diesel driven generators.

PV driven systems do not produce any "greenhouse gases" as result the energy produced is clean to the environment. Emission of gases will be there during manufacturing and installation of the system.

Emission factors of different gases from diesel

The values shown below are derived from *Climate Registry Default Emission Factors, 2013*. The figures presented show case of Canada and United states where there is a measurement of different emissions from different sources.

1. Canadian Default Factors for Calculating CO_2 Emissions from Combustion of Diesel is:CO_2 Emission Factor (Per Unit Mass or Volume) = 2689.63 g CO_2 / L
2. Canadian Default Factors for Calculating CH_4 and N_2O Emissions from Combustion of Diesel is:
   CH_4 Emission Factor (Per Unit Mass or Volume) = 0.133 g CH_4 / L
   N_2O Emission Factor (Per Unit Mass or Volume) = 0.4 g N_2O / L
3. U.S. Default Factors for Calculating CO_2 Emissions from heavy gas oil is:
   CO_2 Emission Factor (Per Unit Mass or Volume) = 11.09 kg CO_2 / gallon = 2929.67 g CO_2 / L
4. Some construction equipment
   CH_4 Emission Factor (Per Unit Mass or Volume) = 0.58 g CH_4 / gallon = 0.153 g C_H4 / L N_2O Emission Factor (Per Unit Mass or Volume) = 0.26 g N_2O / gallon = 0.069 g N_2O / L
5. HOMER default values
   CO_2 Emission Factor (Per Unit Mass or Volume) = 2630 g CO_2 / L
   CO Emission Factor (Per Unit Mass or Volume) = 6.5 g CO / L

In general more than 99% of fuel carbon destination is CO_2. CO_2 is the second next to water vapor to contribute to "greenhouse effect". Disasters throughout the world related to flooding and desertification are due to greenhouse gases.

The "greenhouse effect" often gets a bad rap because of its association with global warming, but the truth is we couldn't live without it. Without it, scientists estimate that the average temperature on Earth would be colder by approximately 30 degrees Celsius (54 degrees Fahrenheit), far too cold to sustain our current ecosystem. The problems begin when human activities distort and accelerate the natural process by creating *more* greenhouse gases in the atmosphere than are necessary to warm the planet to an ideal temperature.

For this study, the amount of carbon di oxide generated from case 1, 6.5kW generator, and case 3, 9kW generator, is about 5,252 kg/yr and 7,041kg/yr respectively. So, use of solar driven pumping system will reduce considerably the risk of environmental pollution.

4. Conclusions

PV driven pumping system needs higher investment cost at initial phase than diesel driven systems. As result, people opt for the motorized diesel systems only in view of the initial cost. However, it is very crucial to compare the two counterparts on the basis of their life cycle cost without neglecting environmental component cost. Ever increasing fuel cost and declining PV systems cost per wattage is another driving force that solar driven systems are a major energy sources of future world.

Solar driven water pumping system is more economical in comparison to diesel driven system at small to medium ranges of power generation.

Now a day, environmental pollution is a concern over the globe. Diesel driven systems pollute air, land, and water bodies in such a way that spill of oil products after or during lubrication, emission of unwanted gases, and generation of particulate matter which are hazardous and cause greenhouse effect to our environment. Hence, dissemination and use of renewable energy resources like solar is a medication to cope up with the challenge since the contribution of pollutant from these technologies is negligible. With respect to noise pollution to the environment, solar PV technology is silent and does not create any noise to the environment and therefore advantageous than diesel driven motorized water pumping scheme.

Hydraulic load and solar potential of the area under the study are decisive factors to design solar PV water pumping systems. Hydraulic load consists of two important parameters, total dynamic pumping head and daily water demand. Total dynamic head is dependent upon the situation of source, topography, and pipe material characteristic, length, and number of bends and junctions while water demand is contingent upon per capita consumption and number of users. Solar potential of the study area can be optimized by selecting appropriate technologies available such as PV module and PV tracking technologies.

The major problem of water sources in the study area is salinity as a result of geological formations. The geology of the area consists of alluvial sediments, underlain by either alternation shale or gypsum of the Uarandab Series. The only chance of obtaining fresh water is close to the river so as to take of river infiltration into the groundwater causing salt to be diluted. So, it is advantageous for the solar driven pumps to lift more water since the total head of pumping is not as high as bore holes or wells.

The other merit of use of solar energy for water pumping is that solar energy increases when water demand increases. It is quite clear that people and livestock consume more water during hot seasons than they consume during cold seasons. This could be balanced by pumping more water as result of increased solar energy generation.

For small to medium water pumping requirements, PV driven water pumping system is more sustainable option in terms of economic, environmental, and equity than diesel driven water pumping system.

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Evaluation of Different Furrow Irrigation Methods For Maize Production In Kobo Girrana Valley, Ethiopia

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Abstract

The lack of irrigation water management techniques are a serious obstacles for the expansion of irrigation infrastructures in Kobo Girana valley. A new irrigation method for maize production was designed and tested for yield and water use efficiency (WUE). A field experiment was conducted in area of kobo valley and the experiment was carried out for 2 consecutive years (2011 and 2012). Irrigation water was applied to furrows using siphon from furrow head ditch lined with geo-membrane plastic, inflow rate of 0.17l/sec. Totally nine treatments were arranged in factorial RCBD design from three furrow type (alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI)) and three irrigation amounts (40, 30 and 20 mm). The frequency of irrigation was fixed at 7 days interval. It was observed that most of yield and yield parameters were significant different. Both irrigation water levels and furrow types showed an interaction effects on almost all parameters except biomass yield which not showed significant interaction effects. Maximum grain yield 3.32 t.ha^{-1} was observed in the treatment combination of CFI-40mm and lowest water productivity of 0.64kg.m^{-3}. However, 3.17 t.ha^{-1} optimum grain yield and 1.23 kg.m^{-3} water productivity was recorded due to AFI and 40mm depth of application. Compared to other methods alternate furrow irrigation technique could increase water productivity for scarce water resource utilizations. Alternate furrow irrigation could save 50% of water and reduces the labor required to carry out the irrigation compare to conventional type. Labor savings and improved flexibility in farm irrigation management are also expected to be achieved using AFI.

Keywords: *Crop water requirement, water use efficiency, irrigation method and alternate furrow*

1. Introduction

Efficient water use has become an important issue in recent years because the lack of available water resources in some areas is increasingly becoming a serious problem. Agronomic measures such as varying tillage practices, mulching and anti-transparent can reduce the demand for irrigation water and improve irrigation water use efficiency (IWUE). Development of novel water saving irrigation techniques represents another option for increase water use efficiency. During the last two decades, water–saving irrigation techniques such as deficit irrigation (DI) and partial root zone drying (PRD) or alternative irrigation (AI) have been developed and tested for field crops and fruit trees. Most recently, these irrigation techniques are being tested also in vegetable crops such as tomatoes (Zegbe-Domínguez, 2003).

Ideally, WUE should be improved by reduced leaf transpiration. Stomata control the door of plant gas exchange and transpiration water loss. Recent investigations have shown that stomata may directly respond to the availability of water in the soil such that they may reduce their opening according to the amount of water available in the soil. The advantage of such regulation is that plant may delay the onset of an injurious leaf water deficit and enhance its chance of survival under unpredictable rainfall conditions. More recent evidence has shown that such a feed forward stomatal regulation process works through a chemical signal. The increased concentration of abscises acid (ABA), in the xylem flow soil can produce large amount of ABA while the rest of the root system in wet soil may function normally to keep the plant hydrated (zhang and and devise 1987). The result of such a response is that the plant may have a reduced stomatal opening in the absence of a visible leaf water deficit.

Fischbach and Mulliner (1972) reported that alternate furrow irrigation in cash crops offer and opportunity for reduced water use and increased WUE. Alternate furrow irrigation was practiced for a number of crops such as potato, tomato, soybean and corn to conserve water. AFI can avert severe leaf water deficit, which develops in the shoots when irrigation is drastically reduced. It is well known that leaf growth and shoot elongation are inhibited when shoot water deficit develops and turgor is reduced as a result (Bradford and Hsiao, 1982).

The hypothesis behind irrigating alternate furrows is that:

1. In alternate furrow irrigation less surface water is wetted and less evaporation from the surface occurs.
2. More lateral roots are stimulated and a chemical signal is produced in drying roots to reduce the shoot water loss.
3. Amount of water needed (i.e. irrigation water use), time and labor requirement for irrigation is decreased.
4. Water use efficiency (WUE) will be nearly doubled by using this method.

But there were not yet any researches in the region specifically in the study area regarding different furrow irrigation methods for better yield of maize while utilizing water resources efficiently. Thus, this study was initiated to evaluate efficiencies of different alternate furrow irrigation and amount of water on water productivity and yield of maize.

2. Material and Methodology Used

2.1. Description of Study Area

The experiment was conducted in Kobo irrigation research station which is located at about 50 kilometres from Woldia town to the North-East direction in Kobo Woreda, on main road from Addiss Abeba to Mekele and situated at 12.08^0 N (latitude), at 39.28^0 E longitudes and at an altitude of 1470 m mean above sea level. The 15 years mean annual rainfall is about 630 mm and average daily reference evapo-transpiration rate of 5.94 mm. The soil type in the experimental site is silty clay loam with average FC and PWP of 17.57% and 12.3% on volume basis accordingly. The site is characterized by average infiltration rate of 8 mm/hr and pH value of 7.8.

2.2. Experimental Methodology Used

The design of the experiment was Factorial-RCBD with three replications. Totally nine treatments were composed from three furrow methods; Alternate furrow irrigation (AFI), Fixed furrow irrigation (FFI) & conventional furrow irrigation (CFI) and three Irrigation amounts; 20, 30, and 40 mm. Irrigation application depth was determined through using CROPWAT version 8 soft ware program. The experiment was conducted for two consecutive years of 2011 and 2012. AFI means that one of the two neighboring furrows was alternately irrigated during consecutive watering. FFI means that irrigation was fixed to one of the two neighboring furrows while CFI was the conventional way where every furrow was irrigated during each watering.

Table 1: Seasonal irrigation water requirements of each treatment

Treatments	Furrow type	Application Depth (mm)	Seasonal Irrigation Water Requirement (mm)
1	CFI	40	560
2	CFI	30	420
3	CFI	20	280
4	FFI	40	280
5	FFI	30	210
6	FFI	20	140
7	AFI	40	286
8	AFI	30	210
9	AFI	20	140

Maize (zea maize) of variety *'katumani'* was planted in experimental plot size of 3 m x 6 m and spacing between plants and rows were 30 cm and 75 cm consequently. In the experimental seasons maize planted at 1st week of February and harvested on mid of May with the length of growing period 90-100days. The frequency of irrigation was fixed as 7 days interval, hence all plots irrigated 14 times throughout the growing season. Irrigation water was applied to furrows using siphon from furrow head ditch lined with geo-membrane plastic, inflow rate of 0.17l/sec. Prior to planting all plots was irrigated with equal amount of water up to the field capacity to initiate germination. Agronomic parameters grain yield, dry biomass yield, plant height and water productivity was recorded. Finally the collected data subjected to Genstat 13th Edition for analysis.

3. Results and Discussions

From ANNOVA Table 2, it was observed that most of yield and yield parameters showed significant difference ($\alpha<0.01$). Both irrigation water levels and furrow types had a significant interaction effects on measured agronomic parameters except for dry biomass yield.

In all furrow irrigation methods the grain yield produced showed an increasing trend when the amount of water added increased. Similarly Seghatoleslami et al. (2005) reported water stress reduced seed yield in foxtail millet. In alternative furrow irrigation the plant height was increased with increased the amount of water added in both years. Even though treatment combination of CFI-40mm gave maximum grain yield 3.316 t.ha^{-1}, optimum grain yield 3.17 t.ha^{-1} obtained due to AFI-40mm. Additionally alternate furrow gave the highest plant height but didn't showed a significant difference in each irrigation level. To take advantage of this type of plant response, Kang et al. (1997) suggested that irrigation might be designed so that part of the root system is exposed to drying soil while the rest is in wet soil. Such a design could lead to reduced stomatal opening without leaf water deficit. Fixed furrow irrigation, fixed some furrows for irrigation, while adjacent furrows were not irrigated for the whole season. These techniques are a trade-off: a lower yield.

Table 2: ANNOVA

Source of variation	Degree of freedom	Mean Square: Grain yield (ton/ha)	Biomass (ton/ha)	Plant height (cm)	Water productivity (kg/m^3)
Replication	2	0.02363	38.37	5.54	0.00387
Year	1	0.00104	28.16	56.63	0.000017
Rep/year	2	0.0083	36.29	105.16	0.001677
Irrigation level	2	7.94147**	39.15**	880.06**	0.014136*
Types of furrow	2	4.35283**	16.81**	330.76*	1.405746**
Irrigation Level/furrow	4	0.2958**	41.49	146.68*	0.025753**
Errors	40	0.01147	38.23	41.27	0.002172

Table 3: Effects of furrow type and irrigation level on agronomic parameters and water productivity

Furrow type With Irrigation levels	Plant height (cm)	Grain yield (t.ha^{-1})	Water productivity (kgm^{-3})
AFI-20	186.4a	1.496f	1.1635c
AFI-30	181.1ab	2.395c	1.2901a
AFI-40	179.1ab	3.174b	1.2348b
CFI-20	172.9bc	1.849e	0.7195g
CFI-30	172.9bc	2.503c	0.6743gh
CFI-40	169.5c	3.316a	0.6449h
FFI-20	168.7c	1.218g	0.9475d
FFI-30	167.9cd	1.59f	0.8564e
FFI-40	160.3d	2.058d	0.8005f
CV (%)	7.7	8.9	5.0
LSD(0.05)	7.496**	2232.3*	0.05439**
Mean	173.19	2.18	0.93

Compare to other irrigation methods alternate irrigation with different irrigation depths gave the highest water productivity. Water productivity of 1.23kg.m^{-3} was obtained due to alternate furrow irrigation with 40mm irrigation water application. Low irrigation levels also significantly reduced the total dry biomass yield. Conventional irrigation method produced maximum dry biomass yield.

Compared to conventional watering or watering fixed parts of the root system alternate irrigation reduced water consumption by 50% with a total biomass reduction of 10% and increment of 9% consequently. The two years data showed that if the AFI method was used, less irrigation could maintain optimum grain yield as that of conventional irrigation with high irrigation amount. Finally the conclusion is that the AFI system can substantially save water. Generally results show that alternative drying of part of the root system is better than the drying of fixed part of the root zone. Alternate furrow irrigation usually requires a maximum amount of irrigation due to large wetted fronts. However, this is dependent on the soil infiltration characteristic and the amount of lateral soil-water movement.

Table 4: Mean effects of furrow types and irrigation levels on dry biomass yield

Water levels	Dry biomass yield (t.ha^{-1})	Furrow types	Dry biomass yield (t.ha^{-1})
100%	8.14a	CCF	7.94a
75%	6.94b	AFI	7.16b
50%	6.55c	FFI	6.53c
CV	10.0	CV	10.0
Lsd	0.5036	Lsd	0.5036

4. Conclusions and Recommendations

- In the case of kobo Girrana valley soil and environmental characteristics might be highly affecting the method of application. Hence AFI may be a useful practice to reduce the time taken to irrigate the whole farm systems; using full supply of CROPWAT generated application depth of 40mm (100%).
- The result showed that alternative drying of part of the root system is better than the drying of fixed part of the root zone.
- Alternate furrow irrigation can save 50% of water and reduces the labor required to carry out the irrigation compare to conventional type. Labor savings and improved flexibility in farm irrigation management are also expected to be achieved using AFI.
- Crop water use efficiency will be increased by using AFI which may result in substantial benefits under limited water conditions.

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