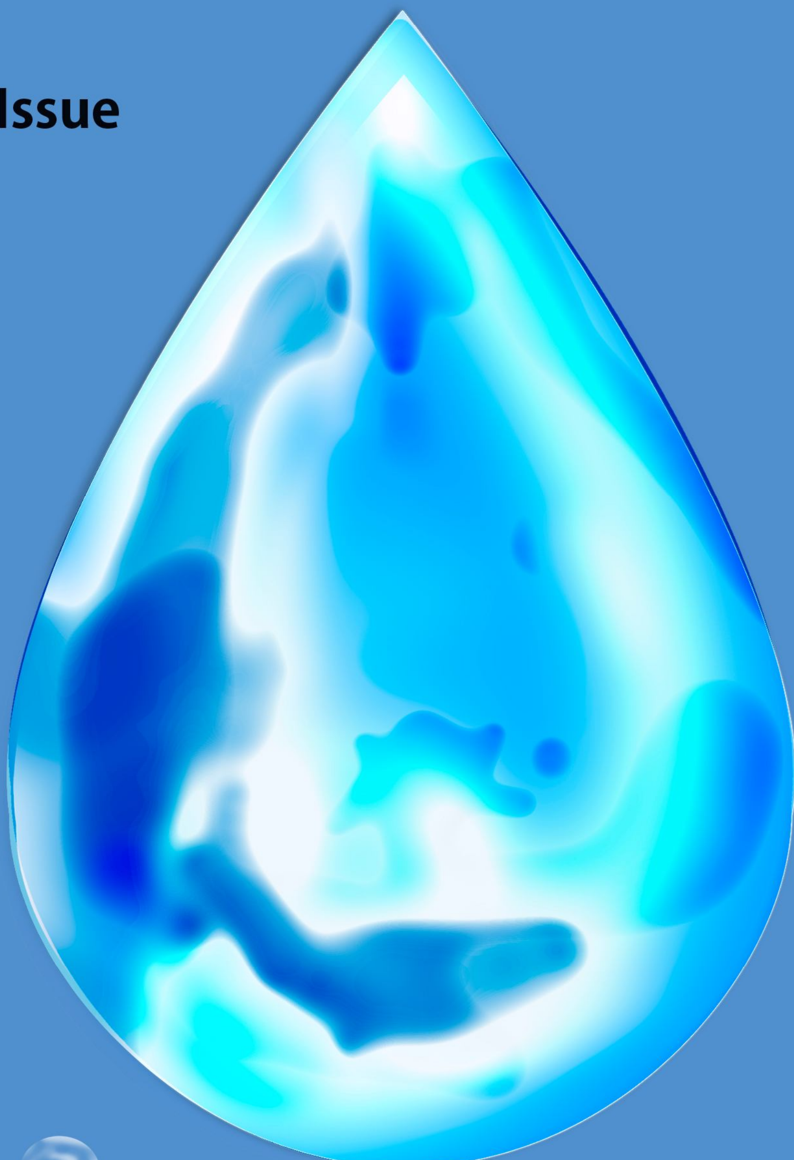
Water

Ethiopian Journal of Water Science and Technology

Special Issue

International Water Management Institute



Proceeding of the 12th Symposium on Sustainable Water Resources Development Held at Arba Minch University from June 26-27, 2012 Arba Minch

Water

Ethiopian Journal of Water Science and Technology

Special Issue

Proceeding of the 12th Symposium on
Sustainable Water Resources Development
Held at Arba Minch University
from June 26-27, 2012

Tel.: 0468810453/ 0468814970/ 0916831052

Content	**Pages**

Foreword

Ethiopia has huge physical water resources potential. However, due to different constraints, its contribution to socio-economic development of the country has been low. Since few years the country is aggressively designing and implementing many programs and projects that are used to harness, develop and utilize the water resources for the national development purposes. While developing and utilizing the resources, issues of sustainable development and management of these resources requires attention. Arba Minch University organizes symposia on Sustainable Water Resources Development since the last twelve years.

The objective of the symposium is to create a platform where professionals, researchers, practitioners and decision-makers come together and share ideas, communicate research results, good practices and innovations in that can enhance sustainable water resources development. This year the symposium marks the 12^{th} cycle in the series. The organizing committee has received more than 50 papers in different thematic areas announced in call for papers. After review process, about 20 pares have been selected for oral presentation and 10 papers for poster presentation. This proceeding contains the full contents of presented papers. I believe the research results presented in these papers can be useful references for the readers. On behalf of the organizing committee and myself I thank all contributors to this Symposium.

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

Welcome Address

Dr. Feleke Woldeyes, President of Arba Minch University

Your Excellency Ato Kebede Gerba, State Minister of Water and Energy
Distinguished guests,
Ladies and Gentlemen:

First and for most, I say you all welcome to this **12thSymposium on "Sustainable Water Resources Development"** which AMU is hosting.

Water is one of the most important resources on earth; and it is the most essential element to human life- next to air (oxygen). We all know that the living cell is largely composed of water ($\geq$75 %); and the universal solvent is essential to the functioning of every single cell and organ system in an organism's body. Moreover, as scientific theory holds, life itself emerged in the ocean. Besides its use for routine household uses such as drinking, washing, cleaning; water has always fascinated Man. The first civilizations of man started near rivers, and the vast expanse of seas and oceans has long been our major sources of food and means of travel.

Though water covers about two thirds of the total surface of the earth, there are various problems connected with the abundance of water and which, of course, are far from being resolved. All over the world, water is getting sparser and some countries are continuously looking for new sources of drinking water. The industry requires a large amount of water for the manufacturing processes, as so does agriculture. The rapidly increasing human population needs water for domestic purposes and to generate energy.

According to sources, agriculture alone consumes 70% of our fresh water resources while industry and power generation use some 22%. Nevertheless, only about 8% is used for human consumption and in human health. Some 1.5 billion people do not have access to wholesome water; some 50% of the world's population does not have adequate water purification systems; and more than 30 million people die every year from diseases linked to polluted water (cholera, malaria, hepatitis). Ethiopia is among those countries that are endowed with very rich water resources but not utilized the resource efficiently both in the agricultural and industrial sector. We also know that clean water supply to households at a very low level.

This all reminds us that there is a need to vigorously work in the area so as to develop the water sector. Occasions like the present gathering which gives scholars opportunity to come together and share ideas and conduct academic discussion is believed to contribute towards that end. I therefore believe that we will gain a lot from each other and generate ideas the will help in better utilization of the water resources of the country.

I would also like to extend my sincere appreciation to paper presenters and participants who showed interest to participate in the symposium and travelled hundreds of kilometers to join us here. In addition, let me take this opportunity to express my gratitude to the International Water Management Institute, University Partnership, and Horn Africa Regional Environmental Center and Network for co-organizing the symposium.

Wishing you all to have a pleasant time during your stay here in Arab Minch, I once again say welcome to Arba Minch and AMU.

Thank You

Opening Speech

H.E. Ato Kebede Gerba
State Minster, Ministry of Water and Energy

Dear Workshop participants,
Ladies and Gentlemen,

It gives me great pleasure to be here today and open this important symposium. I am aware that the symposium of this kind on Sustainable Water resources Development has been organized by Arba Minch University for more than one decade and this is the 12^{th} in series.

Fresh water is one of the most important elements that sustain life on earth. However, this important resource is becoming scarce in many parts of the world. Not only physical scarcity of water that constrains the availability of water but also the deterioration of water quality. Scarcity and quality of water poses serious threats to socio-economic development and ecosystem functions. Fortunately Ethiopia has immense physical water resources potentials. However, the erratic nature of its availability and other capacity limitations has been hindering the country to utilize this resource for its socio-economic development.

As agriculture is the dominant economic sector of the country and reliable water supply is essential for sustained agricultural development, there is strong link between agriculture and water. Not only food security but also good quality water supply and sanitation safeguard the health of the citizen. This is why the Government of Ethiopia has been giving due emphasis to water centered projects.

In this era, during which long year effects of socio-economic activities of human beings have resulted in serious environmental degradation and global climate change, the issues of sustainability became of priority concern. The word “sustainability” emphasizes on management and utilization of available water resources without compromising the ability of the next generation to do the same. One of the general water resources management police objectives of Ethiopia is for instance: conserving, protecting and enhancing water resources on sustainable basis. This shows that the issues of sustainable management of water resources is given due attention in all level of our policies and water resources development programs.

The Government of Ethiopia, in its plan of climate resilient Green Economy, promotes and tries to implement projects that enhance economic development of the country in an environmental friendly way. As well know many water resources development projects have been implemented and several others are underway throughout the country.

Ladies and Gentlemen,

Implementation of physical infrastructures without due attention to sustainable management cannot guaranty the achievement of the project objectives. These efforts need to be supported by scientific methods and approaches. The contribution of research and extension to the water sector development has been low which calls for attention. The few researches which have been conducted are fragmented and the results have not reached the users.

Our Ministry highly encourages and welcomes researchers, professionals and practitioners to involve in innovations and technology transfers related to efficient utilization and management of our water resources.

Forums like this symposium could be an effective media for exchange of research results and good practices in the water sector. I appreciate Arba Minch University and the organizing committee for creating and sustaining this kind of forum.

I am informed that several research papers, covering various areas of water sector, are selected for oral and poster presentation during these two days workshop.

I wish you fruitful deliberations and hereby declare that the workshop is officially open.

Thank You!

Economic impact of small scale irrigation schemes: evidence from Ethiopian Rift Valley Basins

Adugna Eneyew[1] and Ermias Alemu[2]
[1]Jimma University, [2]Arba Minch University

Abstract

Research has repeatedly shown that irrigation is the key to wealth creation and sustained poverty reduction. But, how much it contributed to household welfare has been received little attention. This paper thus assessed the economic impact of irrigation use beyond the direct impacts. It was evident from this research that use of irrigation has improved household income,by 26.5%, consumption and poverty reduction. In spite of this, the enhanced benefit that could have been gained from irrigation use was constrained due to unsatisfactory performance of the investigated schemes and badly functioning marketing systems. Thus, enhancing the capacity of water user associations, facilitation of post harvest technologies and creation of market linkage are the necessary steps to improve irrigation impacts.

Key words: *Binary logit, FGT, poverty, irrigation, Rift Valley, Ethiopia*

Introduction

Agriculture is the main stay of Ethiopian economy (50% GDP, 80% employment etc). The agricultural sector has to meet the food demand of growing population. But, it is underdeveloped due to dependence on rain availability, which is scarce and erratic by nature. Moreover, 60% of the land is arid and semiarid which receives low level of rainfall. Ethiopia is one of the poor countries of the world despite the promising economic growth for the last seven years. It has been documented that low farm production and productivity resulting from use of backward technology and other productivity-enhancing modern inputs are the major reasons for rampant poverty and food insecurity in rural Ethiopia. To overcome this problem the Government has given priority for irrigation development in the agricultural sector (MoFED, 2006).

Poverty reduction is also the priority of Ethiopian rural development strategy (FDRE, 2003, MoFED, 2012). Any solution to reduce rural poverty must focus on increasing the production and productivity of smallholder agriculture and speed up the process of structural transformation. As a vital resource in agriculture, irrigation water contributes to many productive and livelihood activities. A large majority of studies conclude that irrigation reduces poverty (Hussen, 2004). Thus, small scale is given priority in the food security program & the government is committed to enhance the development of SSI structures. In Ethiopia, the national development plan is based on a strategy called 'Agricultural Development-Led Industrialization', and aims at boosting agricultural productivity and improving the rural standard of living, which in turn will increase the demand for goods and services and further lead to industrial development. Central to achieving the agricultural policy objective is the promotion of irrigated agriculture and integrated water resource management (Mekuria, 2003; World Bank, 2006).

It is often argued that even though irrigation and other modern inputs are used to enhance production, this may not entail the intended result if farm households don't have access to markets for their produce. Research has shown that many of the small-scale irrigation projects have been operating below the required economic efficiency (Mekuria, 2003). There are only a few available studies that measure the total impact on an irrigation system. Some studies have focused only on the direct impacts. Therefore; the objective of this study is to assess the socio-economic impact of small scale irrigation schemes in the Rift valley basins.

Methodology

Sampling, data source and collection

The study employed a 'with' and 'without' approach. Once schemes were selected purposively based on performance; in the second stage, each selected scheme was purposively divided into three strata as head, middle and tail sections. Finally, sample populations classified into two groups: irrigators and non-irrigators and 313 households were selected. Quantitative data on household resource endowments, demographic and social indicators were collected through structured interview. Qualitative data on the relative economic performances of the sample schemes, water use and management, and constraints were gathered from key informants, and community representatives through transect walk, and focus group discussions at each scheme.

Data analysis

The descriptive analysis is based on means and standard deviations computed from the data. Independent sample t test and chi square tests were used to test the difference between irrigation users and non users.

The poverty line is measured based on Cost of Basic Needs (CBNs) derived from the lowest income quartile. This analysis of profitability of an enterprise, in this case irrigation farming was as follows:

Net Profit (Net Income) = Total Revenue (TR) - Total Cost (TC)

Total Cost (TC) = Total Variable Cost (TVC) + Total Fixed Cost (TFC)

Foster, Greer and Thorbecke (1984) have suggested a useful general index for poverty measures.

Their class of poverty indices takes the following form:

$$P = \frac{1}{N}\sum_{i=1}^{q}\left[\left(Z_p - Y_i\right)/Z_p\right]^{\alpha} \qquad (1)$$

where Zp denotes the poverty line, Yi the expenditure or income of the i-th poor household (or individual), N the total number of households and q the number of households whose expenditures or incomes are below the poverty line.

This index is based on measuring the gap between the poverty line and the expenditure or income of the poor as a fraction of the poverty line [Zp - Yi]/Zp, raising it to a power α and then summing over all poor units. Thus, if α=0, index P α becomes: P_0 = q/N, which has been referred to as the head-count index; if α is 1, poverty gap index and if α is 2 poverty severity index.

Econometric model

A logistic regression model was used to analyze the impact of small scale irrigation schemes on household poverty status. Similar studies have used binary logit model in irrigation impact analysis (Farah, et al 2001; Getaneh, 2011, and Oni et al, 2011). In this analysis, the independent variable is binary (1 if the household is classified as poor and 0 if the household is classified as non poor). Following Gujarati (2003), the probability that the i^{th} household is poor is given by:

$$Pi = E(Y = 1/Xi) = 1 \Big/ 1 + e^{-(\beta_0 + \beta_i \chi_i)} \qquad (2)$$

For ease of exposition, the probability that a given household is poor is expressed as:

$$\rho_i = \frac{1}{1 + e^{-(Z_i)}} \qquad (3)$$

Probability for not food insecure is 1-P_i

Thus, $$\frac{P_i}{1 - p_i} = \frac{1 + e^{zi}}{e^{-zi}} \qquad (4)$$

is the ratio of the probability that a household was poor to

$$L_i = \ln\left[\frac{P_i}{1 - P_i}\right] = Z_i = \beta_o + \beta_1\chi_1 + \beta_2\chi_2 + ... + \beta_n\chi_n \qquad (5)$$

the probability of that it was non poor.

The natural log of equation (4) is

$$Z_i = \beta_o + \beta_1\chi_1 + \beta_2\chi_2 + ... + \beta_n\chi_n \qquad (6)$$

Where

Pi= is a probability of being poor ranges from 0 to 1

Zi = is a function of n explanatory variables (x) which is also expressed as

β_o *is an* int *ercept*

$\beta_1, \beta_2, ...\beta_n$ *are the slopes of the equation*

L_i = is log of the odds ratio, which is not only linear in Xi but also linear in the parameters.

X_i = is vector of relevant independent variable

If the disturbance term (Ui) is introduced, the logit model becomes

$$Z_i = \beta_0 + \beta_1\chi_1 + \beta_2\chi_2 + ...\beta_n\chi_n + \cup_i \qquad (7)$$

3. Results and discussion

This section presents results of the study and discusses the results by giving due emphasis on the intended research objectives.

Socio-economic profile of respondents

Based on gender stratified proportional sampling the proportion of women beneficiaries was 19.3 %. This implies that women's access to irrigation is by far below that of men. The age compositions of respondents indicate that the minimum and maximum age limits are 15 and 82 respectively with mean age of 40. With respect to access to irrigation age composition does not show significant variations. Approximately 37 percent of respondents had zero years of schooling. There were (37.8% and 36.3% respectively for irrigation users and non users) with no schooling at all.

This means that 37% of the sample is functionally illiterate. According to the study, the average household size of the total sample households in was 6.6 persons, with 1 and 13 being the minimum and the maximum household sizes respectively. When we compare the average household sizes between irrigation users and non users, households that use irrigation have slightly larger household size and dependency ratio than households that do not use irrigation.

Community perspectives on the impact of irrigation

According to the focus group discussion, almost all irrigation users have improved their wellbeing as a result of irrigation. The major source of their success is realization of income improvement. Many of them have constructed a house, educate their children, and become food self sufficient either through own production or purchasing from market, or started investment.

Among others petty trading; establishing grain mill, buying vehicle (Isuzu) for transport facility. In spite of this fact, focus group discussants disclosed that from 100 beneficiaries only around households 25% were highly successful.

The rest majority were unsuccessful due to absence of capital and limited potential. This indicated that majority of the users are not gaining the intended benefit for one or another reasons. The majority of households reported that there is no change in their food security after irrigation establishment, where as about 45% households ensured that introduction of irrigation in the area has increased their food security level. Those households response from irrigation users reason out that they shifted to cash crops growing than cereals which reduced their staple crops production and food supply is replaced by money supply.

Irrigation increased production

Comparative yield analysis by crop type couldn't be done because of lack of uniformity in the use of inputs. However, gross yield for major crops by access to irrigation was presented in the. As expected, irrigation use has significantly contributed towards achieving household's goal of increased production. Descriptive data analysis of major cereals and horticultural crops in Figure 1 showed that mean crop yield per household for teffe, maize, green pepper, potato, tomato, red onion, cabbage and barely is highest for irrigation users than non users. This evidence has ensured that irrigation use is a guarantee for increased food supply and ensured food security. Some crops like tomato, onion, pepper and modern cabbage are only grown by those households with access to irrigation. This is also an indication of that irrigation use increases cropping diversification and intensity.

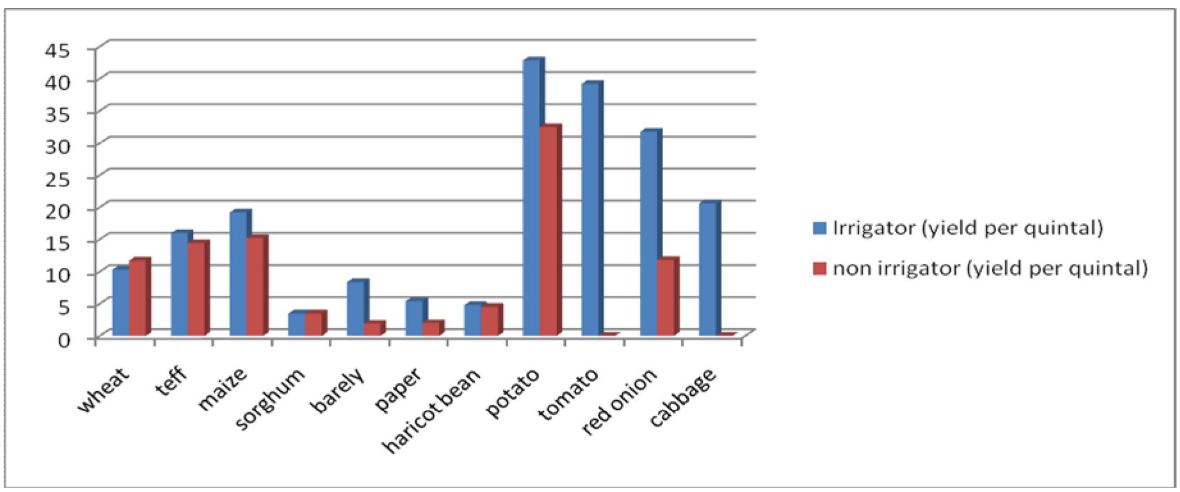


Figure 1: Mean crop yield per quintal per household

Irrigation enhanced employment opportunities

The relative success of an irrigation project in poverty alleviation and the upliftment of rural poor largely depend upon the magnitude of multiplier impacts generated by the project. Most smallholder activities all draw from the same family labor sources, supplement for certain operations by neighbor help and casual wage labor. The development of the irrigation schemes has created job opportunities for the nearby farmers besides to the irrigation users in the traditionally slack dry times. The data used for labour cost calculation was only for hired labour; it did not include family labour. Accordingly, comparison of the labour cost per ha across by irrigation use indicated that irrigation increased the cost of hired labor by 52%; while schemes showed that Argeda has the highest followed by Gedemso, whereas Bedene has the lowest labour cost per hectare.

The main reason for high value in Argeda and Gedemso schemes accounted to expensive unit labour cost and shortage of labour supply in the area; whereas the probable reason for smallest value for Bedene Yealem Tena may attribute cheap labour cost in the area.

Irrigation increased income

Irrigation beneficiaries earned an annual mean income of 10161.5 Birr per household, which is 26.5 % higher than the non users. Irrigation use has a positive impact on households earning from crop, and livestock. The value of off farm income earning was higher for non users although it does not show significant variation. This finding is similar to the findings of Getaneh (2011) which states Small-scale irrigation has a negative impact on non-farm incomes. Income share by category indicate that 76% and 70.5% of total incomes for users and non users respectively come from crop, while the rest from livestock and off farm sources. Income earned from crop indicates that non irrigators earned only 67.8% of irrigators. Income earning by access to irrigation exhibits statistical difference for the total income and crop income earned (Table 1). The data exhibit that remunerative off farm income sources like cart and trade were the results of irrigated agriculture where as inferior livelihood activities like fire wood and charcoal selling, and causal work were dominated by non irrigators.

Table 1: Income earned by access to irrigation

	Irrigation use						
Income source	User		% share	Non user		% share	
	Mean	SD		Mean	SD		t/p
Livestock	1451.6	2826.6	13.5	1070.2	2150.3	13.7	1.324 /0.179
Crop	8138.5	6012.1	76.0	5520.9	3879.3	70.5	4.635/0.000***
Off farm	1125.2	2549.6	10.5	1234.7	2239.9	15.8	-0.0.4/0.689
Total income	10161.5	5612.7	100	7606.0	4280.6	100	4.562 /0.000***

***, significant at less than 1% probability level

Table 2: Asset endowments by access to irrigation

Assets owned	Irrigation use	Mean	SD	t/p
Total value of asset	User	2060.16	6510.74	2.500/0.013**
	Non user	597.58	3450.67	
Total size of plots	User	1.50	1.00	3.84/0.000***
	Non user	1.12	0.76	
Total livestock unit	User	5.45	3.80	2.008/0.046**
	Non user	4.55	3.88	

Irrigation improved asset endowments

Irrigation allows a greater area of land to be used for crops and asset ownership increases with access to irrigation. The value of asset owned by irrigators is more than three times higher than non irrigators. Access to irrigation increases mean land ownership by 0.38 hectare and it enhance livestock ownership by a factor of 0.91 TLU (Table 2).

Irrigation improved household consumption

In order to measure the impact of irrigation on household welfare expenditure pattern was used as a proxy indicator. This usually refers to the ability of the household to produce/purchase a basket of goods containing the minimum quantity of calories and non-food commodities. The average consumption expenditure per AE per annum for irrigators is more than twofold of non irrigators. Similarly the value of home consumption, food and non food expenditures are significantly higher than that of non users.

For instance non irrigators consumption from own production is only about 51 % of that of irrigation beneficiaries. This indicates that irrigation access improves food security through home consumption by increasing the frequency of production. It also enhances the capacity to access food through purchase by 50.7%. Thus there is a positive correlation between nutritional status& irrigation access. It has also a positive impact on non food consumption. The non food consumption value of non users was 60.8% of that of irrigators. Thus, this study could argue that irrigation access improves overall welfare of rural households through improved food access, non food consumption and asset accumulation.

Irrigation ensures profitability of farm business

The financial performance of irrigation use will tell profitability of utilizing irrigation over rain fed only farm. The data showed the existence of variation in production cost, gross crop income and net farm income between irrigation users and non users. There is substantial increment in production cost and income for irrigation users significantly at less than 5% probability levels. The result of the study showed that irrigation farming is a profitable venture. Farmers realized average net revenue (profit) of 1784.3 ETB from irrigation farming; while that of non irrigators was 1011.8. It is more than two folds.

Irrigation impact on poverty reduction

Poverty status by access to irrigation

Most empirical work on poverty measurement is based on incomes or consumption expenditures, and poverty is defined as a situation where a household's or a person's income or consumption level falls below some minimum level necessary to meet basic needs(Ravallion, 1994).. Accordingly, the poverty line was 1016.49 birr per AE per year. Of the 313 sample households 30.4 percent of them are poor 89.7 percent of the users and 52.3 percent of non users are found to be non poor and 47.6 percent of non users and 10.3 percent of the users are poor. This confirms that irrigation development is a key for poverty reduction goal.

Head Count Index is commonly used method of estimating the incidence of poverty. The study showed that 48% and 10% of the non user and user households respectively were living below the locally determined poverty line on the head count basis. The corresponding poverty gap by irrigation use was 0.042 & 0.17 for user and non user respectively; whereas poverty severity index was 0.02 & 0.09 for user and non user (Table 3). Thus poverty is more severe and widespread among non irrigators than irrigators. Poverty indices for head count across schemes showed that 39%, 37%, 35% and 12% population were living below the poverty line respectively for Argeda, Ebala, Bedene Yealemetena and Gedemso schemes. The corresponding poverty gap & severity index showed poverty is high and severe in Argeda and lowest in Gedemso schemes; implying that more resource is required to bring the poor households out of poverty in Argeda.

Determinants of poverty

The regression classification table revealed that binary logistic model managed to predict 82.6 percent of the responses correctly. Apart from percent correct predictions, the model Chi-Square statistic for Hosmer and Lemeshow Test have been run to evaluate the performance of the model. Accordingly, the Chi-Square value was found to be 5.025 and the overall model was found non-significant at 0.755 levels stating that the model adequately fits the data.

Table 3: Poverty incidence and severity

Irrigation use	Head count index (α=0)	Poverty gap (α =1)	Squared poverty gap (α =2)
User	0.10	0.042	0.02
Non user	0.48	0.17	0.09
Argeda	0.39	0.45	0.26
Gedemso	0.12	0.28	0.09
Ebala	0.37	0.31	0.14
Bedene	0.35	0.37	0.20
Overall	0.30	0.36	0.19

Measures of goodness of fit of the logit model include the log pseudo-likelihood and Wald $\chi 2$ statistics, which show that the models are all significantly different from the null or intercept-only model (Table 4).

Determinants of poverty

The regression classification table revealed that binary logistic model managed to predict 82.6 percent of the responses correctly (Table 4). Apart from percent correct predictions, the model Chi-Square statistic for Hosmer and Lemeshow Test have been run to evaluate the performance of the model.

Accordingly, the Chi-Square value was found to be 5.025 and the overall model was found non-significant at 0.755 levels stating that the model adequately fits the data. Measures of goodness of fit of the logit model include the log pseudo-likelihood and Wald $\chi 2$ statistics, which show that the models are all significantly different from the null or intercept-only model (Table 4).

Table 4. Binomial logit model result for determinants of poverty

	B	S.E.	Wald	Sig.	Exp(B)
irrgfar(1)	-0.572	0.289	3.900	0.048**	0.565
agehead	0.045	0.014	9.845	0.002***	1.046
hhsize	0.521	0.095	29.847	0.000***	1.683
depratio	0.267	0.140	3.636	0.057*	1.306
farmsiz	-0.859	0.230	13.967	0.000***	0.424
tlu	-0.153	0.063	5.893	0.015**	0.858
eduhead	0.098	0.048	4.185	0.041**	1.103
dismark	-0.017	0.038	0.201	0.654	0.983
Constant	-3.993	0.812	24.157	0.000***	0.018
Pearson X^2	5.109***				
-2 Log likelihood	308.208				
Sample size	313				

Interpretation of significant variables

The estimated coefficient for dummy variable irrigation use (irrgfar) with the odds of being poor over non-poor was negatively correlated and significant. This means the probability of being poor decreases by a factor of 0.565 for those households with access to irrigation keeping other factors constant. This suggests that the probability of being poor decreases if one has access to irrigation. Among demographic factors, age of household head (agehead) was found to be related with the probability of poverty positively and significantly, hence old age is the cause of poverty. Households with larger household size (hhsize) are more likely to be poorer than those with smaller size; a unit increase in household size increased the probability of being poor by 1.683. This finding is consistent with that of (Dawit, et al, 2009; Ayalneh and Korf, 2009). Similarly, dependency ratio (depratio) was found to positively and significantly affect the probability of being poor by a factor of 1.3. This ratio allows one to measure the burden weighing on members of the labor force within the household. It's also in agreement with findings of (Gyekye and Akinboade, 2001), which sated poverty is more likely to be associated with large households with a high dependency ratio. As expected ownership of land and livestock showed strong negative effects on the probability of households to be poor. A unit increase in landholding and livestock holding size increased the probability of a household being non-poor by 0.4 and 0.8 respectively. This finding is similar to that of Dawit etal, (2009) and Ayalneh and Korf, (2009). Contrary to expectation education of head (eduhead) was found to influence poverty positively and significantly at ($P<0.05$). This means the probability of those household heads with higher years of education achievement to fall in poverty increases by a factor of 1.10 than the counterparts. It seems illogical, but the possible reason is that the educational attainment of sample household heads was below the primary level and it did not allowed them to generate income as a result of their education. Thus, unlike some findings of (Ayalneh and Korf, 2009), educational level of household heads was not found to have a negative effect on poverty.

4. Conclusion and recommendations

Conclusion

The economic impact was seen in terms of productivity growth, increased income, enhanced employment opportunity, increased asset endowment and poverty reduction. It also indicated that irrigation use would enhance farm profit. Thus, it's pertinent to conclude from this study that irrigation development helps to increase household income and reduces the incidence of poverty at the household level. However, the economic performances of irrigation systems in the study areas were constrained by imperfect market structure, lack of post harvest storage facilities, poor scheme administration and financial shortages.

Recommendations

Reorganizing cooperatives unions, capacitating water users associations by giving training and finance is a necessary step to improve irrigation performance. Agricultural extension should be improved and include market information and business training. Specifically; market value chain development and facilitation of postharvest technologies would be valuable.

5. References

Ayalneh Bogale and B. Korf, 2009. Analysis of poverty and its covariates among smallholder farmers in the eastern Hararghe highlands of Ethiopia: Con tributed Paper prepared for presentation at the International Association of Agricultural Econo mists Conference, Beijing, China, August 16-22

Dawit Alemu, Woldeamlak Bewket, Gete Zelekec , Yemis rach Assefad and Peter trutmann, 2009. Extent and determinants of household poverty in rural Ethiopia: a study of six villages, Muse project, http://muse.jhu.edu.

Farah, K.O. D.M. Nyariki,* A.A. Noor, R.K. Ngugi1 and N.K. Musimba 2001. The Socio-economic and Ecological Impacts of Small-scale Irrigation Schemes on Pastoralists and Drylands in Northern Kenya J. Soc. Sci., 7 (4): 267-274 (2001).

FDRE, 2003. The new coalition for food security in Ethiopia food security programme volume I. Addis Ababa

Getaneh Kebede Ayele, 2011. The impact of selected small -scale irrigation schemes on household income and the likelihood of poverty in the Lake Tana basin of Ethiopia A Project Paper Presented to the Faculty of the Graduate School of Cornell University in Partial Fulfillment of the Requirements for the Degree of Master of Professional Studies.

Gujarati, 2003. Basic Econometrics, fourth edition. McGrew-Hill, Inc. New York.

Gyekye A. B and O.A, Akinboade, 2001. Analysis of poverty in the northern province of south africa: implications for empowerment policy. Paper was presented at the 75th Anniversary Conference of the Economic Society of South Africa at Glenburg Lodge, Johannesburg on 13 September 2001.

Hussain, Intizar, 2004. Assessing Impacts of Irrigation on Poverty: Approaches, Methods, Case Studies and Lessons1 International Water Management Institute (IWMI)

Mekuria Tafesse, 2003. Small-scale irrigation for food security in sub-Saharan Africa Report and recommendations of a CTA study visit Ethiopia, 20–29 January 2003CTA Working Document Number 8031

MoFED, 2006. Ministry of Finance and Economic Development Ethiopia: Building on Progress. A Plan for Accelerated and Sustained Development to End Poverty 2005/6 –2009/10. Addis Ababa, Ethiopia.

MoFED, 2012. Progress towards eradicating poverty: an interim report on poverty analysis study (2010/11), march 2012, Addis Ababa.

Oni, S. A., Maliwichi, L. L. and Obadire, O. S., 2011. Assessing the contribution of smallholder irrigation to household food security, in comparison to dryland farming in Vhembe district of Limpopo province, South Africa; African Journal of Agricultural Research Vol. 6(10), pp. 2188-2197

World Bank, 2006. Ethiopia: Managing Water Resources to Maximize Sustainable Growth. A World Bank Water Resources Assistance Strategy for Ethiopia. Washington DC.

Flood Mapping and Modeling of Ribb River on Fogera Floodplain

Zelalem Abera[1] and Dr. Dereje Hailu[2],
[1]Arba Minch University and [2]Addis Ababa University

Abstract

The research involves the integration of Hydraulic Engineering Center for Hydrologic Modeling System and HEC-River Analysis System with Geographic Information Systems (GIS) to develop a regional model for floodplain mapping and representation. It tries to describe the flood extent and depth in the area for different flow conditions derived from the historical flow data of the Ribb River. The hydrologic model is calibrated using HEC-HMS for hourly time series data for return periods of 2, 10, 50 and 100 years. One dimensional hydraulic model HEC-RAS with HEC-GeoRAS interface in co-ordination with ArcGIS was applied for the analysis. Triangulated Irregular Network (TIN) was prepared from shape file

Introduction

The need to study the cause and effect of flooding has begun since flooding has become a problem to society when people and their valuables become affected. Historically many solutions have been proposed to mitigate the effects of flooding but knowledge on the actual cause effect relation is lacking. With the advent of digital computers, much emphasis has been on simulating and modeling of flood events and related characteristics and such is the main concern of this paper. The challenge here is to develop a reliable flood model to simulate flood events for Ribb catchment.

Open water flood forecasts are typically based on a two-step process in which a hydrological model is first used to route the flood and determine expected flow hydrographs at the site of interest. The peak flow from this flood routing analysis is then typically input into a steady flow hydraulic model, such as the HEC-RAS model, to determine the corresponding flood levels that would be expected along river reaches extending through populated areas along the flood plain.

In hydraulic flood modeling, availability of data in the required spatial and temporal resolution is vital. Topographic data is one of such data used as input in hydraulic flood modeling. Digital Elevation Model (DEM) and/or its derivative Triangular Irregular Network (TIN) is major source of topographic data for representing floodplain and river topography. For such availability of basic data sources, a high resolution DEM is a prerequisite.

Statement of the problem

Frequent occurrence of sever flood in and around the area, Minimum or less concern of government for the issue and lack of any flood modeling tools before in the area are the reasons that necessitates for the conduction of this paper.

Research Objectives

The objective of this study of this research was map the flood along the stretch of Fogera floodplain and Ribb River that are having different flow conditions.

Study Area

The location map of the study area is presented in Figure 1. The catchment is located between $10^{0}43'$ and $11^{0}53'$ N Latitude and $37^{0}47'$ Longitude. It has an area extension of 1540km^2. This catchment is drained by the Ribb River which originates from Guna Mountain and finally joins Lake Tana in the vicinity where the River causes flooding. The downstream part of the catchment is part of the wide flat floodplain (Fogera floodplain) with a total area of 490km^2.

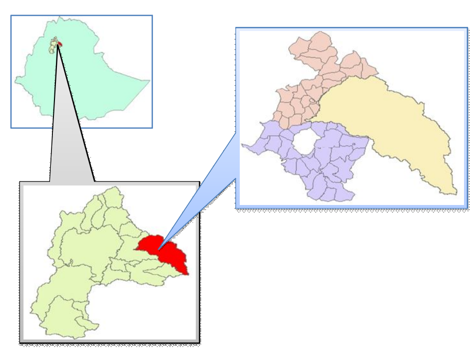


Figure 1: Location of the study area

Materials and Methods

Materials

The materials used are during the study are: GPS, Topographic map, Arial photographs, measuring rods etc.

Method/Methodology

Development of DTM

The key data element that GeoRAS uses to develop the input data is terrain data, commonly referred to as a Triangular Irregular Network (TIN) (Figure 2). It is generated from: GPS surveyed data collected along the two river banks, the spot heights of the flood plains taken from the surveyed data, River bed cross section elevation data.

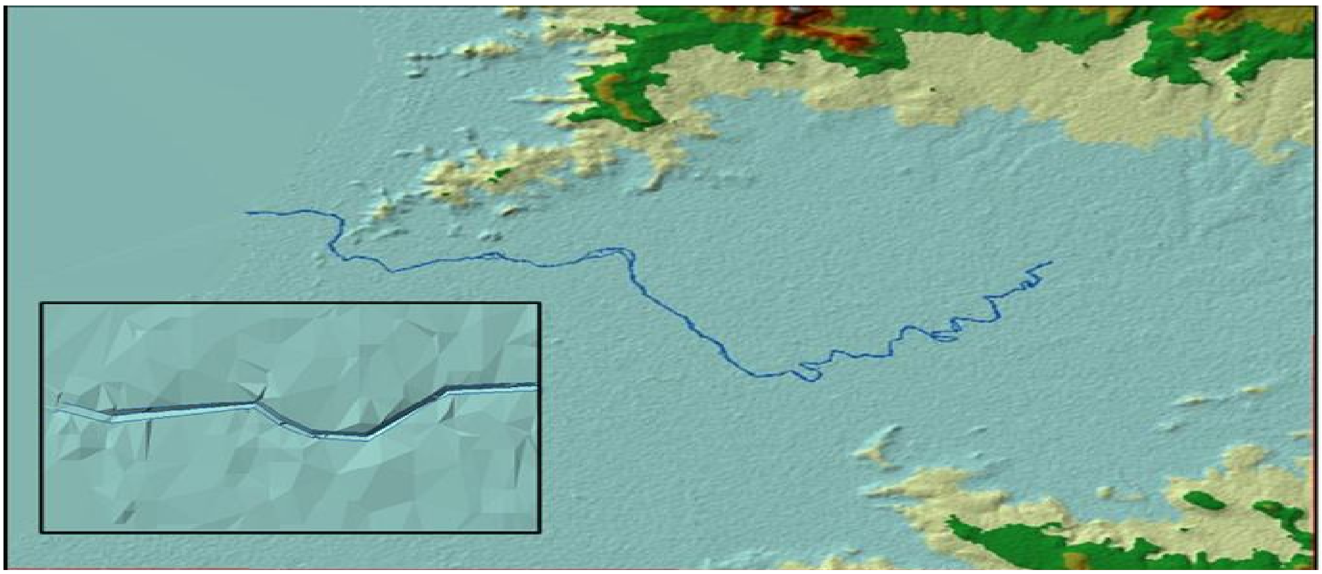


Figure 2: TIN of the floodplain and the River

Terrain Processing using Arc Hydro and HEC-GeoHMS

Using HEC-GeoHMS that operates on DEM30 sub-basin was delineated and a number of hydrologic units were prepared. HEC-HMS supports these hydrologic inputs as starting parameters for hydrologic modeling. In this paper it is intended to derive parameters like: Curve Number, Basin Lag, and Time of concentration and Loss.

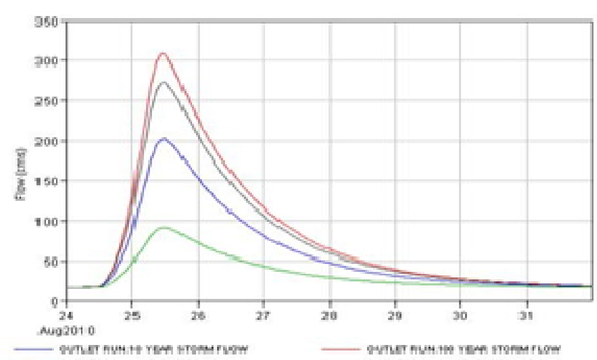


Figure 3: Flow hydrograph for return periods of 2, 10, 50 and 100 year

Results and Discussions

Hydrologic Model result

The hydrologic model (HEC-HMS) was calibrated for the return periods of 2, 10, 50 and 100 years. Accordingly the results are as indicated in Figure 3.

Flood Map

Flood map for the study area is found by the result from hydrologic modelling (HRC-HMS) and Geometric data processed by an integration of HEC-RAS and ArcGIS.

According to the result of the model the following floodm map was developed for the study area (Figure 4).

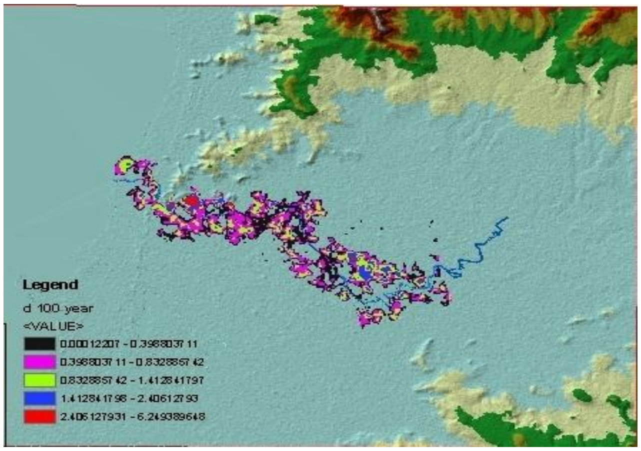


Figure 4: Flood map of the study area by 100 year flood

Flooding on Libo Kemkem Woreda

Flooding disasters are distributed among different kebele's of Libo Kemkem and Fogera woreda. Most portion of Libo Kemkem suffers high inundation. Kab, Bambiko Tsion and Teza Amba are the villages with high portion of the flood depth and area where as Genda Wuha takes little one (Figure 5).

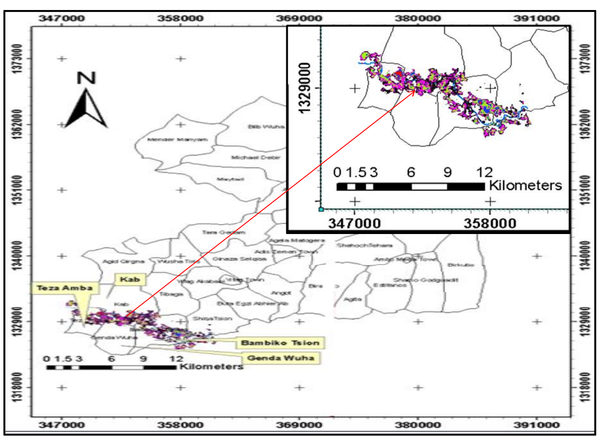


Figure 5: Flood extent in Libokemkem woreda

Flooding on Fogera Woreda

Unlike to the Libo Kemkem, Fogera Woreda has less risk and vulnerability problems. This is due to the diversion of the Ribb River from Fogera Woreda to the Libo Kemkem by using dyke. The dyke at the intersection avoids the overflow from the new diverted channel to the old channel.

The flooding has also a series effect on Fogera woreda. Even though the Libo Kemkem shares highest proportion, Abua Kokit kebel of the Fogera woreda is highly influenced.

Flood Vulnerability Analysis

Most of the areas around the flood plain are cultivated land with less proportion of agro-pastoral, marsh and pastoral. 88-90% of the flood inundated areas are covered by agricultural land. The remaining 10-12% is covered by agro-pastoral near inlet to Lake Tana.

Most cultivated land of Kab, Teza Amba, Genda Amba, Bambiko Tsion and Abua Kokit are vulnerable by the flood although with varying degree. The first three taking highest proportion of vulnerability.

Finally the paper tries to compare the result with the result developed by the ENTRO which is conducted by an American institution called River side (Figure 6). There, ENTRO means Eastern Nile Tropical Regional Organization- a regional organization run by Nile Basin Initiative.

Conclusions and Recommendations

Conclusion

- The automated floodplain mapping and analysis using GIS provide more efficient, effective and standardized results and saves time and resources.
- Topographic analysis using GIS and field survey data has a greater efficiency to represent terrain nature exactly. The higher the DEM resolution and enough topographic data, the more accurate the flood map is.
- Hydrologic data are central to flood plain analysis. Availability of hourly time series data increases the model reliability.
- Risk map of the study area shows the area under agriculture is highly affected by even the 2-year flood which becomes higher by 100-year storm flood.
- The assessment of the flood area indicates that a large percentage (more than 88 %) of vulnerable area lies in flood plain area i.e. agricultural land followed by agro-pastoral and river comprising 10.6% and 1.36% respectively.

Recommendations

This study was conducted under major constraint of limited data availability. Therefore, the following recommendations are made for the further studies in the future.

- ***Topographical Data*:** For modeling flows in overbanks, topographic data should be of high resolution and available enough so that the topography of the floodplains could be properly represented.
- ***Flow data*:** The major hydrologic parameter, flow data of long time duration is necessary for the calibration and validation of hydrologic model.

- ***Use of new technology to generate TIN*:** TINs obtained using new technologies such as LIDAR (Light Detection and Ranging), which improves the quality of the digital terrain representations is better if used for further study.
- ***Up-to-date DEM*** should be adapted for high accuracy in representation of the study area.
- Since the river morphology of Ribb is changing with time, ***frequent conduction of the channel*** during research work is essential.

Acknowledgement

I am indebted to Dr. Dereje Hailu, Lecturer and researcher at Addis Ababa Institute of Technology (AAiT) for his continuous guidance, advice and expedience. His constructive comments, untiring help, guidance and practical suggestions inspired me to accomplish this work successfully. I remember Dr. Semu Ayalew for his support in material and guidance.

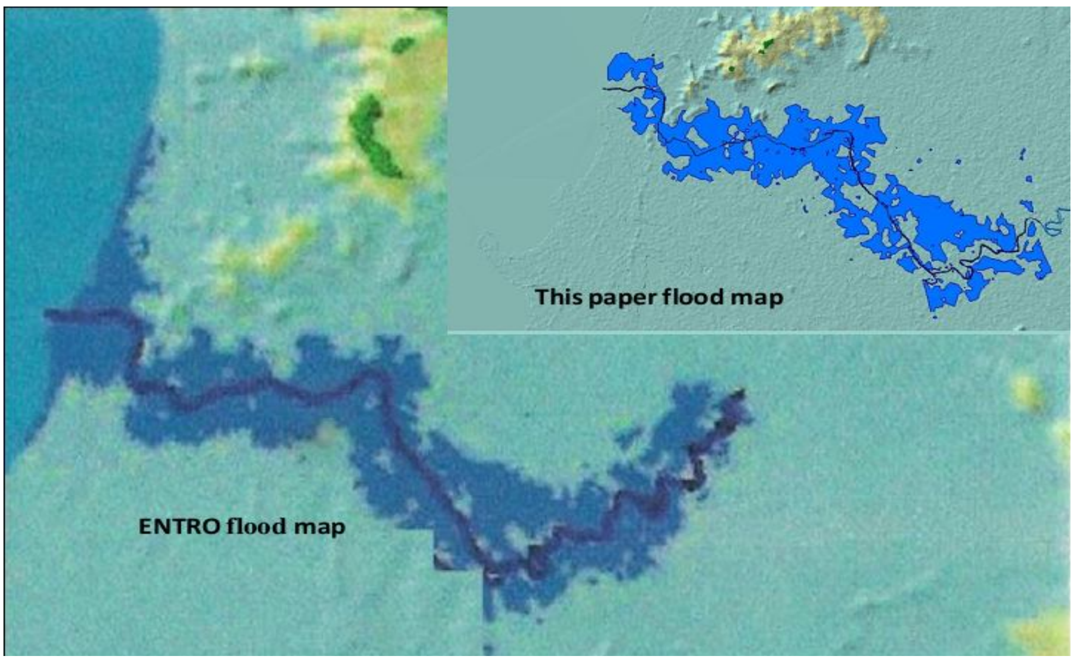


Figure 6: Result comparison of ENTRO and this research paper

References

Assefa, K.A., Andel, S.V. and Jonoski, A., 2008, Flood Forecasting and Early Warning in Lake Tana Sub-basin, Upper Blue Nile, Ethiopia. Water Mill Working Paper series, no. 16.

Dhondia, J.F. and Stelling, G.S, 2002, *application of one dimensional-two dimensional integrated hydrologic model for flood simulation and damage assessment*. Proceeding of the Fifth International Conference on Hydroinformatics, Cardiff, 1:265-276.

Dutta D., Herath S., Musiake K., 2000. *Flood inundation simulation in a river basin using a physically based distributed hydrologic mode*,. Hydrological Processes 14 (3), 497 –519.

Dyhouse, G., Benn J.R. and Jenifer Hatchet, P.E., 2003, *Flood Plain Modelling Using HEC-RAS*. US Army Corps of Engineers.

Haile, A.T. and Reintijs, T.H.M., 2005, *Effects of LIDAR DEM Resolution in Flood Modeling: A Model Sensitivity Study for the city of Tegucigalpa, Honduras*. MG Vosselman and C.Brenner (Editor), 3:168-173.

HEC-GeoRAS: An extension for support of HEC-RAS using Arcview User's Manual, Version 3.0, U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis, California, April 2000.

MoWR. (1999). Ministry of Water Resource . *Runoff estimation of Ethiopia river basins.*

Nash, J. E. (1970). *River flow forecasting through conceptual models, part one. A*

Comparison of ANN and SWAT in the Estimation of Sediment Yield in case of Mille Watershed, Afar, Ethiopia

Zerihun Yimer[1], Dr. Bogale Gebremariam[2]

[1]Department of Hydraulics Engineering, University of Samara, Samara, P.box 132, Ethiopia, zerihunyimer@gmail.com

[2] Department Of Hydraulics Engineering, University of Arbaminch, Arbaminch, P.box 21, Ethiopia, gmariam@gmail.com

Abstract

The construction of dam is one of the most important practices for the development and management of water resources. The design and management of dam life and capacity has requires studies related to the hydrology of the watershed like sediment inflow to the reservoir and sedimentation of the inflow sediment. Tendaho dam is located in the lower part of the Awash Basin and a drainage area of about 62,088 km^2. Mille River is one of the major contributors of Awash River in the lower awash part. Studies show that Mille River is a major contributor of sediment to the dam. The objective of the study were focused on the estimation of sediment yield from Mille watershed to Tendaho dam by using feed forward MLP neural network and SWAT model. Monthly estimation of sediment yield by SWAT model was superior to the daily time step estimation whereas in the ANN model estimation daily basis estimation was better than the monthly basis estimation. In the daily estimation antecedent average areal rainfall (two day previous, t-2, and one day previous, t-1), stream flow (at t-2 and t-1) and previous time step sediment yield (t-1) considered in the ANN model were increased the performance of the model. The annual average estimated sediment yield in the baseline time of the study (1996-2008) is 13.57 t/ha which was underestimated by both models. ANN model underestimated by 7.1% (i.e. 12.61 t/ha) and SWAT model underestimated by 16.3 % (i.e. 11.36 t/ha) from the observed sediment yield. Even though the average annual sediment yield estimated by ANN model was less error than SWAT model, ANN model was highly underestimated the peak flow time sediment yield of the watershed than SWAT model. ANN model was more accurately estimate low and medium sediment flow of the watershed than SWAT model. If the sediment yield of the Mille watershed will continue in this manner it will be dangerous to the Tendaho dam life with respect to its storage capacity and stability of the structure.

Key words: *MLP, ANN, SWAT, Estimation, Sediment yield, Mille River, Awash Basin*

1. Introduction

The construction of dam is one of the most important practices for the development and management of water resources. The design and management of dams requires intensive study related to the hydrology of the watershed like sediment inflow and sedimentation of the inflow sediment. But this sediment inflow to the reservoir is mainly depend on sediment yield (i.e. the portion of the eroded material that transported through the stream network to some point of interest such as reservoir) of the upstream watershed [1].

Sediment yield may fluctuate greatly because of natural or man-induced accidents. Collecting sediment flow data over a decade and periodic reservoir survey information are some resource demanding methods for estimating sediment yield rate at a catchment level [2]. Others have also cautioned that long term sediment monitoring of suspended sediment loads does not necessarily give better results [3]. Some workers have suggested that an excellent sediment-rating curve could be constructed from detailed sediment flow data of short period of sampling programs [4]. According to [5], estimation of sediment load is required in practical studies for the planning, design, operation and maintenance of water resources structures. The sediment transportation monitoring requires a good sample technique which is very lengthy and costly [6]. Therefore, it is important to develop a model that can estimate the suspended sediment yield from a basin.

For this study there was two different types of models have been used. *SWAT model:* It is physically based, spatially distributed and belongs to the public domain and the model has been tested in different tropical watershed [7], [8] and reported to be capable to well explaining watershed hydrological processes like the study by [9] upper Awash River Basin and [10] lower awash sub basin can be cited as examples, which additionally justify the possible use of this model in the study area.

ANN model: In the hydrological forecasting context, recent experiments have reported that artificial neural network (ANN) may offer a promising alternative for suspended sediment estimation [11] and the modeling of non-linear system behavior like sediment yield is well modeled by ANN [12] and based on this literature ANN model was selected to test the applicability of the model in the Mille watershed.

Even though there has been watershed management in the Awash Basin, one of critical water resource development constraint is soil erosion and reservoir sedimentation [13]. There are evidences of steady rise in soil erosion in some parts of the Awash River basin that endangered reservoirs and caused doubts about the viability of existing and future schemes. Like the other reservoirs constructed in the Awash River basin, Tendaho dam is also in risk of sedimentation and one of the major source of sediment to this dam is Mille River [14].

2. Objective of the study

The general objective of this study was to estimate the amount of sediment that come from mille sub-watershed into Tendaho reservoir per year.

The specific objectives of the study are:

- To estimate the amount of sediment yield of the Mille River into Tendaho dam by using ANN
- To estimate the amount of sediment yield of the Mille River into Tendaho dam by using SWAT model
- To compare ANN model result and SWAT model result of the Mille River sediment yield

3. Methodology

Description of the study area

Awash Basin is located between latitudes 7°53’N and 12° N and longitudes of 37°57’E and 43°25’E (Fig. 1). It covers a total land area of 110,000 km² of which only 64,000 km² of the basin drain to the awash main river or its tributaries. Mille River is one of the main tributaries to the Awash River at the lower valley of the basin [13]. Mille River is in the western side of the Awash River and start in the Ethiopian highlands west of Sulula in Tehuledere Wereda of the Amhara region and flowing to north and then curving to east to its confluence with the Awash at latitude 11°25′N and longitude of 40°58′E. The Mille watershed comprises parts of the Semien and Debub Wollo zones and special Oromiya zone of the Amhara region as well as Administrative zone one of the Afar region (Fig.1). It covers about 5543.4 km^2 areas and the main river length up to the confluence point to the Awash River is about 230km.Near the downstream of the confluence of the main River of Awash and Mille River there is Tendaho dam. It has a drainage area of 62,088 km^2 and was constructed for the purpose of irrigating nearly 60,000 ha sugarcane plantation with 1860Mm^3 storage capacity. The reservoir area is located between latitudes of 11°20’N and 11° 41’N and longitudes of 40°54’ E and 40°59’E; between Logia and Mille town of the Afar region [14].

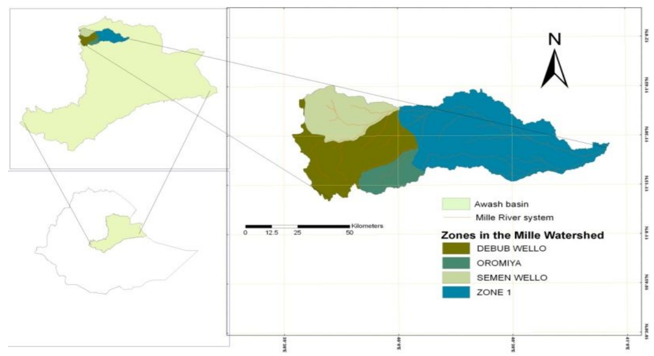


Figure 1: Location map of Mille sub-watershed

Data used

The necessary data that was collected and used for this study can be classified into spatial and time series data. Spatial data used are DEM, land use/cover and soil map of the study area. The time series data are Meteorological and hydrological data.

SWAT setup and input of the model

We delineated the watershed using a 90mx90 m resolution DEM. After watershed delineation, the watershed was partitioned in to hydrologic response units (HRU), which are unique soil and land use combinations within in the watershed to be modeled. In this study, multiple HRU with 20 % land use, 10 % soil and 20 % slope threshold in each HRU from the sub-basin were adopted. For modeling surface runoff and sediment yield we used the SCS curve number method [15] and modified universal soil loss equation respectively. In order to identify the most important or sensitive model parameters before calibration, model sensitivity analysis was carried out using a built-in SWAT sensitivity analysis tool. We used the manual calibration procedure and the model was calibrated and validated using flow and suspended sediment data measured at Mille gauging station of the watershed.

The recommended values of $R^2 > 0.6$, NSE > 0.5 and PBIAS < ±15 for flow case and $R^2 > 0.6$, NSE > 0.5 and PBIAS < ±20 for sediment yield case was used to evaluate the performance.

ANN model input and set up

ANN is black-box model that only develop the relation between input and output variables (data-driven) without the modeling of the physical processes. However, it must be realized that the data that are employed in developing black-box models contain important information about the physical processes being modeled and this information gets embedded or captured inside the model [16]. Neural network is characterized by its architecture, training, or learning algorithm and activation function [17]. For this study one type of feed forward architecture of the neuro solution, multi-linear perceptron was used. The transfer function was determined by trial and error from logistic sigmoid and hyperbolic tangent sigmoid type. The training or learning algorithm was also determined by trial and error from conjugate gradient and LM. The input of the model was normalized average areal rainfall, stream flow and sediment yield of the watershed generated by Mille gauge sediment rating curve from 1996 up to 2008.

Evaluation of Model Performance

There are a large number of performance criteria used by different researchers to quantitatively measure the accuracy, efficiency and reliability of their models. It is difficult to select one criterion as a benchmark standard and some criteria are only applied to certain specific problems. Coefficient of determination (R^2), Nash Sutcliffe efficiency (NSE) and Percent bias (PBIAS) [18] were selected performance measures for this study.
Where: S_{obs} is the Observed sediment data; S_{sim} is the simulated sediment data with the respected time.

$$R^2 = \left[\frac{\sum_{i=0}^{n} \left(S_{sim} - \bar{S}_{sim} \right)\left(S_{obs} - \bar{S}_{obs} \right)^2}{\sum_{i=0}^{n} \left(S_{obs} - \bar{S}_{obs} \right)^2 \sum_{i=0}^{n} \left(S_{sim} - \bar{S}_{sim} \right)^2} \right] \quad (1)$$

$$NSE = \left[\frac{\sum_{i=0}^{n} \left(S_{sim} - S_{sim} \right)^2}{\sum_{i=0}^{n} \left(S_{obs} - \bar{S}_{obs} \right)^2} \right] \quad (2)$$

$$PBIAS = \left[\frac{\sum_{i=0}^{n} \left(S_{sim} - S_{sim} \right)}{\sum_{i=0}^{n} \left(S_{obs} \right)} \right] \times 100 \quad (3)$$

4. Results and Discussions

A. SWAT model

Sensitivity Analysis

From the SWAT parameters the first nine parameters showed a relatively high sensitivity for flow in the watershed (Table1) and also for sediment flow the sensitive parameters in the watershed includes USLE support practice factor (USLE_ P), linear factor for channel sediment routing (SPCON), USLE cover or management factor (USLE_C) and exponential factor for channel sediment routing (SPEXP) were found very high to high sensitive to sediment flow (Table1).

Calibration and Validation

Before calibration proceeds, the performance of the model was evaluated from the initial simulation with model default parameter values. The monthly simulations were resulted R^2, NSE and PBIAS of 0.44, 0.40, and 17% respectively. The result shows the performance indicator was below the acceptable limits. So that, the model flow parameters were required adjustment and this adjustment was based on the sensitivity analysis result. The initial/default and finally calibrated values of flow and sediment yield parameters were shown in Table 2.

After each simulation, the model goodness-of-fit was evaluated and the selected model performance after adjusting all the above parameters were satisfied both in monthly and daily time step. Likewise, in the validation period the R^2, NSE and PBIAS indicate in the acceptance limit in monthly time step whereas the R^2 value in the daily basis estimation was below the acceptance limit (Table 3).

Like flow calibration and validation, sediment yield parameters was also adjusted based on the sensitive parameters, and the monthly simulations were satisfied the objective functions whereas in the daily time step the estimation of sediment yield by the model were below the acceptance limit of the SWAT developers recommendation (Table 3).

Table1: Result of sensitive analysis of flow and sediment parameters in mille watershed

Flow sensitivity				Sediment sensitivity			
Rank	Parameter	mean sensitivity	sensitivity	rank	parameter	mean sensitivity	sensitivity
1	CN2	1.63	Very high	1	USLE_P	2.78	Very high
2	ALPHA_BF(days)	0.597	high	2	SPCON	0.975	high
3	GWQMN(mm)	0.508	high	3	USLE_C	0.502	high
4	ESCO	0.359	high	4	SPEXP	0.102	high
5	REVAPMN	0.216	high	5	CH_COV	0	negligible
6	SOL_Z(mm)	0.206	high				
7	SOL_AWC(mm /mm)	0.197	high				
8	SOL_K(mm/hr)	0.127	medium				
9	GW_REVAP	0.06	medium				
10	SURLAG	0.007	small				

Table 2: The initial/default and final calibrated values of flow and sediment yield parameters

Flow				Sediment			
Parameter	Range	Default	Adjusted	parameters	range	initial	Adjusted
CN2	±25%	*	+17%	USLE_P	0-1	1	0.85
ALPHA_BF	0-1	0.048	0.0803	SPCON	0.0001-0.01	0.0001	0.008
GWQMN	0-5000	0	1900	USLE_C for agricultural land	0.001-0.5	0.03	0.39
ESCO	0-1	0.95	0.64	USLE_C for forest	0.001-0.5	0.003	0.35
REVAPMN	0-500	0.0	230	USLE_C for range grasses	0.001-0.5	0.03	0.01
SOL_Z	±25%	**	-10%	USLE_C for range brush	0.001-0.5	0.05	0.2
SOL_AWC	±25%	**	+19%	USLE_C for wet land non forested	0.001-0.5	0.3	0.1
SOL_K	±25%	**	+11.5%	SPEXP	1-2	1	1.33
GW_REVAP	0.02-0.2	0.02	0.1				

*

* indicates SWAT default parameter values for each land use and soil type in the HRU.
** indicates the initial parameter values from the appended soil data base values of the watershed soil.

Table3: Calibration and validation statistics of simulated and gauged flow and sediment

	Time step of simulation	Calibration (1997-2002)			Validation(2004-2008)		
		PBIAS	R^2	NSE	PBIAS	R^2	NSE
Flow	Daily	13.1	0.62	0.55	-8.8	0.57	0.54
Sediment		69.4	0.55	0.41	58.3	0.42	0.35
Flow	Monthly	1.2	0.88	0.84	-12.7	0.81	0.80
Sediment		14	0.82	0.8	16.2	0.79	0.75

Table 4: Calibration and validation period simulated and gauged flow and sediment

Simulation period	mean annual stream flow (m^3/s)		Annual mean sediment yield (ton/ha)	
	Observed	Simulated	Observed	Simulated
Calibration (1997-2002)	10.53	10.41	16.33	14.35
Validation(2004-2008)	6.07	6.84	8.61	7.37

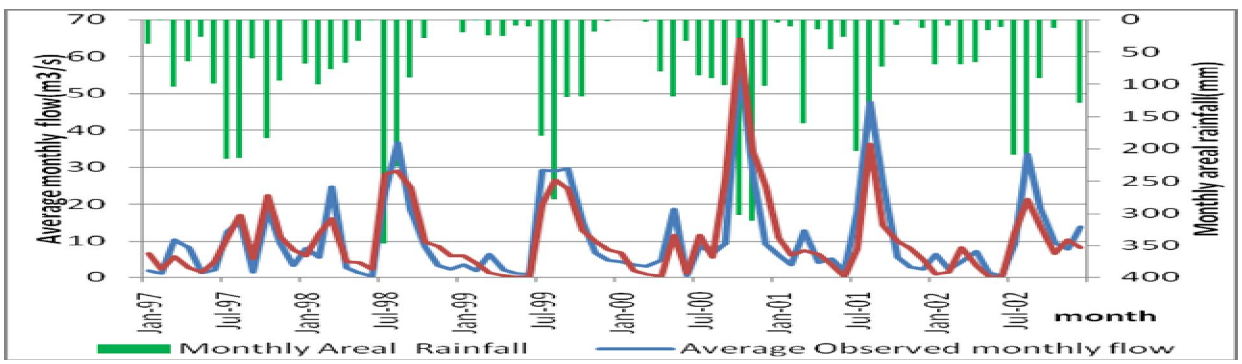


Figure 2: Observed and simulated monthly flow hydrograph of calibration period (1997-2002)

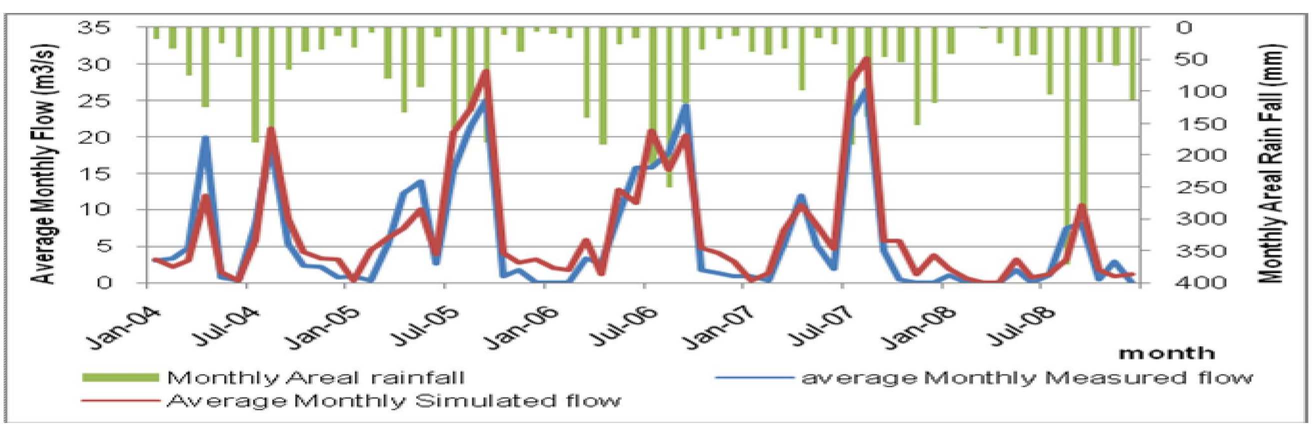


Fig.ure 3: Observed and simulated monthly flow hydrograph of validation period (2004-2008)

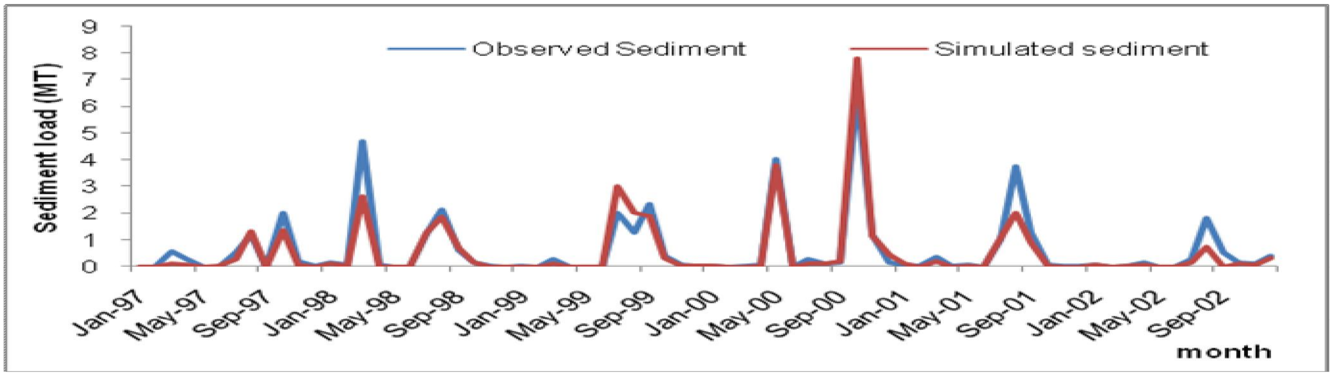


Figure 4: Observed and simulated monthly sediment yield in the calibration period (1997-2002)

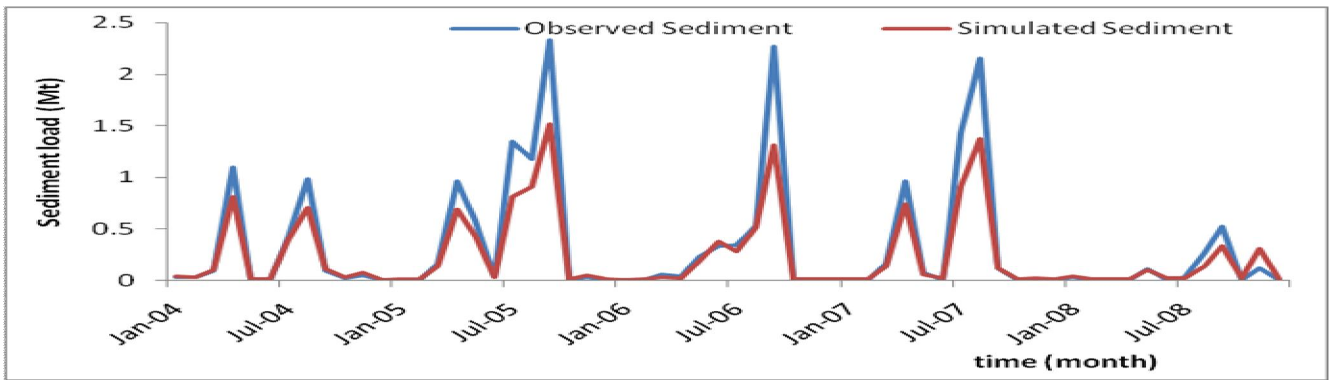


Fig.ure 5: Observed and simulated monthly sediment yield in the validation period (2004-2008)

B. ANN Model

In monthly time step estimation with different combination of transfer function and learning rule the model cannot estimate the observed sediment yield of the watershed (Table 5). This is due to the model property that is data intensiveness. But in the daily base estimation the LM training algorithm with hyperbolic tangent transfer function has more satisfactory than the conjugate gradient with hyperbolic tangent transfer function. Combination 7 (in Table 7) has resulted best from the other combinations of input.

Table 5: Simulated and observed monthly sediment yield in the training and testing period

	Mean annual sediment yield(ton)		**Annual mean sediment yield(t/ha)**	
Simulation period	Observed	Simulated	Observed	Simulated
Training time	6,899,631.7	3,332,847.6	15.4	7.46
Testing time	3,594,347.8	1,891,339.5	8.05	4.23

Table 6: Training, cross-validation and testing statistics of simulated daily sediment yield by using conjugate gradient training algorithm for each combination of inputs

Com.	Epoch size	hidden layer	PE	Training			Cross-validation			Testing		
				PBIAS	R^2	NSE	PBIAS	R^2	NSE	PBIAS	R^2	NSE
1	1200	2	5, 3	13.44	0.61	0.46	19.51	0.61	0.44	73.2	0.44	0.39
2	1000	1	11	22.81	0.60	0.55	29.32	0.59	0.50	49.9	0.49	0.42
3	700	1	16	13.44	0.71	0.54	32.1	0.54	0.42	36.4	0.49	0.43
4	1000	1	13	18.00	0.71	0.56	2 3.1	0.54	0.40	36.1	0.48	0.43
5	2000	2	7,3	21.44	0.57	0.51	23.1	0.51	0.50	49.1	0.50	0.32
6	300	1	8	31.2	0.59	0.50	30.2	0.48	0.48	45.1	0.48	0.37
7	1500	1	13	25	0.74	0.61	27.1	0.52	0.50	29.91	0.47	0.42
8	1100	1	8	31	0.79	0.57	45.3	0.51	0.34	38.5	0.46	0.29

Table 7: Training, cross-validation and testing statistics of simulated daily sediment yield by using LM training algorithm for each combination of the inputs

Com.	Epoch size	No, of hidden layer	PE	Training			Cross-validation			Testing		
				PBIAS	R^2	NSE	PBIAS	R^2	NSE	PBIAS	R^2	NSE
1	1200	1	9	13.44	0.91	0.76	12.51	0.65	0.52	23.2	0.56	0.44
2	200	2	3,1	14.4	0.82	0.57	19.2	0.66	0.53	25.9	0.56	0.46
3	800	1	11	18.4	0.87	0.59	32.1	0.56	0.52	31.1	0.54	0.51
4	1000	1	10	11.4	0.91	0.61	15.5	0.59	0.55	23.4	0.42	0.39
5	2000	1	14	7.9	0.90	0.72	10.8	0.75	0.57	21.5	0.51	0.50
6	1200	1	12	6.7	0.92	0.57	12.54	0.58	0.52	15.45	0.53	0.50
7	**1000**	**1**	**10**	**4.77**	**0.96**	**0.92**	**15.8**	**0.94**	**0.92**	**15.11**	**0.91**	**0.89**
8	1200	1	16	7.95	0.91	0.90	21.4	0.79	0.54	28.7	0.74	0.53

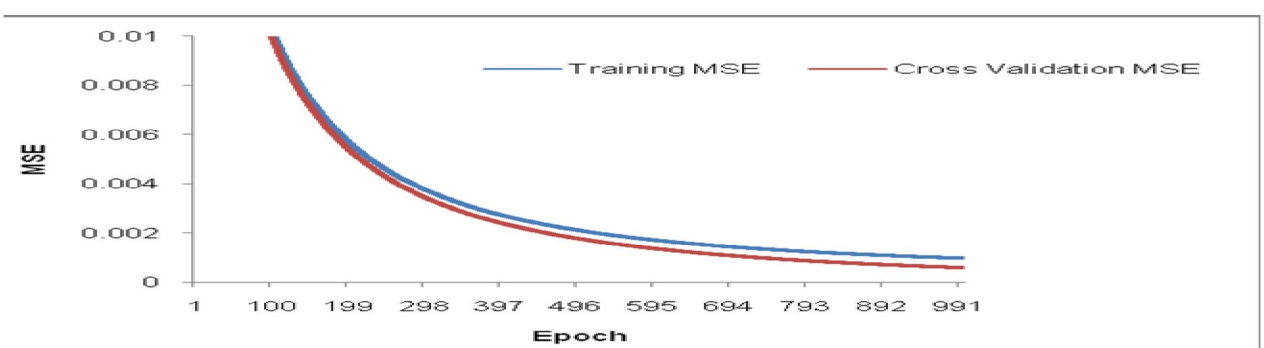


Figure 6: Mean square error versus epoch size graph of the training and cross-validation

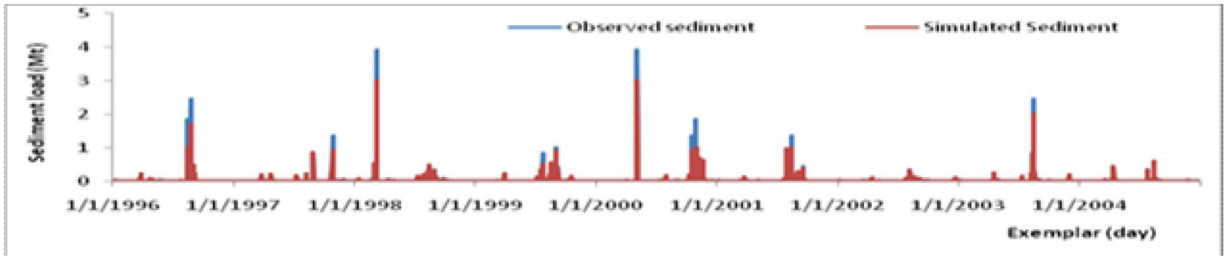


Figure 7: Observed and simulated daily sediment yield in the training period of the model

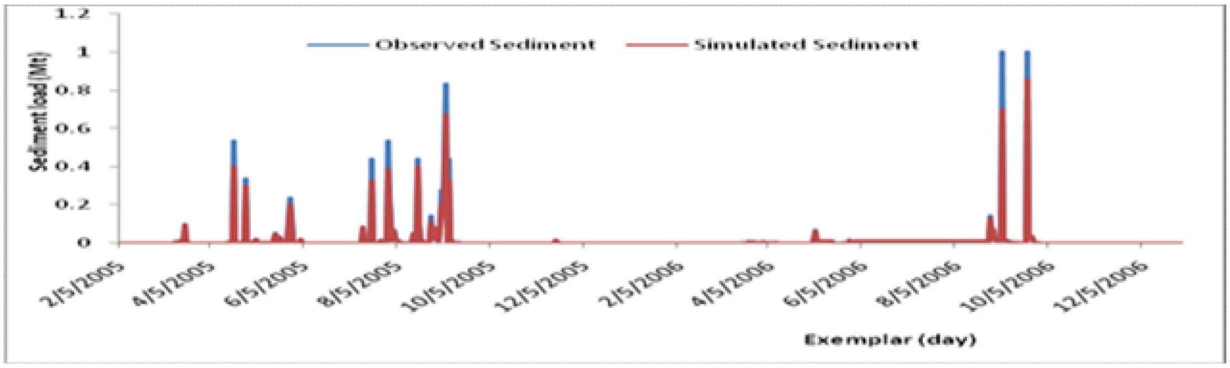


Fig.ure 8: Observed and simulated daily sediment yield in the cross-validation period

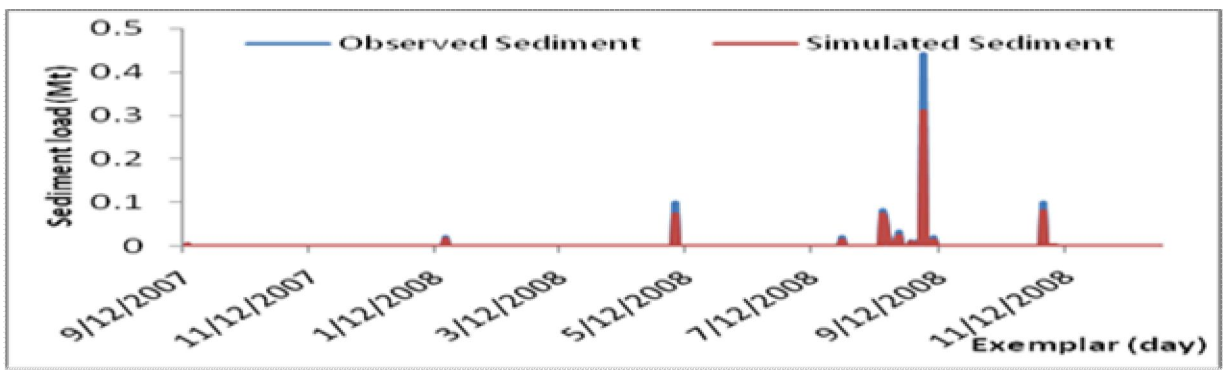


Figure 9: Observed and simulated daily sediment yield in the testing period

5.Conclusions and Recommendations

Conclusion

The 13 years (1996-2008) result showed that the simulated annual average suspended sediment yield by SWAT model was 11.36t/ha and by ANN model 12.61t/ha. The comparison of the two model results showed that SWAT model underestimated the sediment yield in the total 13 years (1996-2008) simulation by 16.3% and ANN model also underestimated by 7.1%. The SWAT model simulation error was higher due to the inclusion of the two years warm up period (1996 and 2003) of the modeling time in the comparison.

Recommendation

Most of the parameters had to adjust on a basin wide basis during calibration time in the SWAT model. Consequently, errors that may be 'averaged out' on larger basins would be quite apparent on small basins because input data and parameters have been set on large scale. In this case it is recommended more accurately calibrate the small sub-basins (specially the wetland portion) within the system separately in order to accurately capture the processes on a small scale. ANN model is very young in the field of sediment estimation, In future study, the use of this model in other watersheds of the country to verify the acceptance of this model in the countries at large and also testing of other types of network architecture (like feedback network) is recommended.

Model prediction output depends on the quality of input data. The constraints in conducting this research work was lack of well representative meteorological stations in and around the watershed, lack of continuous measured suspended sediment data. Hence, responsible bodies should give due attention to minimize this problems for well managed water resources application.
The sediment yield of the mille watershed will continue in this manner it will dangerous to the Tendaho dam life with respect of their storage capacity and stability of the structure. So the responsible bodies must take action in the sediment minimization techniques.

6. References

[1]Morris, G. L., & Fan, Jiahua (2009). *Reservoir Sedimentation Handbook, Design and management of dams, reservoirs and watersheds for sustainable use,* McGraw-Hill, New York.

[2]Silva,R.M.,Santos,C.A.G.&Silva,L.P.(2007).*Evaluation of soil loss in Guaraira basin by GIS and remote sensing based model.* J. Urban Environ. Engng, 1(2), 44-52

[3]Summer, W.,Klaghofer, E.,Abi-zeid,I.,&Villeneuve,J.P. (1992). *Critical reflections on long term sediment monitoring programmes demonstrated on the Austrian Danube*. Erosion and sediment Transport Monitoring Programmes in River Basins. Proceedings of the Oslo symposium, August 1992,IAHS Publ. No.210,pp.255-262.

[4]Ndomba, P.M., & Birhanu, B.Z. (2008). *Problems and prospects of SWAT model applications in Nilotic catchments: a review*. Nile Basin Water Engng. Scientific Magazine, 1, 41–52.

[5]Altunkaynak A. (2009).*Sediment load prediction by genetic algorithms*. Advances in Engineering Software, 40(9), 928-934.

[6]Pavanelli D. and Palgliarani A. (2002). *Monitoring water flow, turbidity and suspended sediment load, from an Apennine catchment basin, Italy*. Biosystems Engineering, 83(4), 463-468.

[7]Tadele Kassa, & Forch Gerd (2007). *Impact of Land use/ Land Cover change on stream flow: A case study of Hare watershed, Ethiopia*. FWU Water Resources Publications,06, ISSN No. 1613-1045, pp 80-84

[8]Mulungu, D.M.M. & Munishi, S.E. (2007).*Simiyu river catchment parameterization using SWAT model*. J. Physics and Chemistry of the Earth, 32, 15-18 & 1032 – 1039.

[9]Dilnesaw Alamirew. (2006). *Modeling of Hydrology and Soil Erosion of Upper Awash River Basin*. PhD Thesis, University of Bonn.

[10]Yidenkachew, A. (2008*). Flood Frequency Analysis in Lower Awash Sub basin*. Master's thesis, Addis Ababa University.

[11]Kisi, O.(2005). *Suspended sediment estimation using neuro-fuzzy and neural network approaches*. Hydrol Sci., 50(4), 683–696.

[12]Coulibaly, P., F. Anctil and B. Bobee (2000). *Daily reservoir inflow forecasting using artificial neural networks with stopped training approach*. Journal of Hydrology, 230(3-4), 244-257.

[13]Hal crow, Sir William & Partners (1989),*Master Plan for the Development of Surface Water Resources in the Awash Basin, Climate and Hydrology, Final report*,Vo.4, Annex A

[14]Water Works Design & Supervision Enterprise in association (WWDSE) with Water and Power Consultancy Services (WPCS, India). (2005). *Hydrology of Tendaho Dam, Final Design Report*. Addis Abeba, Ethiopia.

[15]Soil Conservation Service.(1972).*Section 4:Hydrology*. In National Engineering Handbook.SCS.

[16]Lange, N. T.(1999).*New mathematical approaches in hydrological modeling-an application of artificial neural networks*. Phys.& Chem. Of the Earth, 24(1&2), 31 –35

[17]Bekele, F.G. (2007). *Integrated modeling System for multi- objective management of ecosystem services in a watershed*. University of Carbondale, United States.

[18]Gupta, H. V., S. Sorooshian, and P. O. Yapo. (1999). *Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. J. Hydrologic Eng.* 4(2), 135-143.

Irrigation water pricing System and Land productivity in Awash River Basin: *Analysis of the Nexus*

Mengistu Abate (MA)[1,] Mekonen Ayana (PhD.) [2],
[1]Wollo University, P.o.Box: 1345/ 0911963278; [2]Arba Minch University, P.o.Box: 21/ phone: 0916831052

Abstract
Agriculture is considered as wasteful user of precious water. Water pricing has been used widely to encourage efficient use of water. Awash River Basin is the only basin in Ethiopia in which water pricing is practiced. The purpose of this study was to evaluate the effects of the pricing system on scheme level performance of irrigated agriculture in the basin. Relevant secondary data such as names of the clients, area irrigated, water consumed, and fees collected per year for the last five years have been collected from the office of Awash Basin authority.
Theoretical water requirements were calculated using CROPWATT model, and using meteorological data collected from the relevant stations. Crop yields and other relevant information have been collected from respective farms. A total of 18 cotton, 6 sugarcane and 3 onion farms were surveyed. Both productivity and water supply indicators have been used to evaluate the performances of the schemes. The results indicate that both land and water productivities are relatively low. Irrigation efficiency in more than 60% of the 135 cases is less than 35%. The values of all water supply indicators (relative irrigation supply, relative water supply, water delivery ratio) showed that water application is in excess of the requirement. Water service charges collected is only 0.2 – 1.8% of the total farm revenue, including maintenance cost. The total charges ranges from 1.4 – 4.7% of the total farm revenue. Not only the low rate of water charges but also inability of proper controlling and measuring of water distribution are among the causes why the system is not encouraging users to enhance performances.

Key words: water pricing, awash basin, irrigation performance, water productivity

1. Introduction

Irrigation highly contributes to world's food production. Of the 1,500 million hectares of global cropland only 17% is irrigated, but accounts 40% of the world food production (FAO, 2002). However, agriculture is a major user of water in the world with about 70% annual fresh-water withdrawal, (FAO, 2007). On the other hand, irrigated agriculture is facing rising strain to release water for other uses through improving its water productivity due to growing water scarcity.

This inclusive trend is also reflected in the Ethiopian context, mainly in Awash-intensively utilized river basin of the country. The competition for water among different users will definitely increase in ABA, due to its multifaceted topography and suitability for multipurpose development projects, and the basin is under increasing development. It hosts the oldest Koka dam and d/t irrigation schemes in the dam-Wonji Shoa, and Metahara, two of the oldest sugar estates in the country, are found in the immediate downstream vicinity of Koka dam. The Awash Basin Authority (ABA) -legally established in 2000- manages the basin including its water. Any significant water diversion from the river for irrigation purpose requires the approval of the authority.

The general practices of ABA in water management, the relations of water management services and land productivity, and associated problems in Awash Basin have not been studied. Thus, this paper is designed to address these and other related issues.

2. Objective of the study

The general objective of the research is to evaluate the relation of water pricing systems in the Awash River Basin land productivity

The specific objectives are:

- to asses the general practices of current water pricing system in the basin
- to analyze the productivity of irrigated land in terms of money and crop production per unit area, and to compare them with the total costs

3. Materials and Methods

Description of the study area

Awash River basin is part of the Great Rift Valley in Ethiopia ranging from 8.5^0N to 12^0N. It covers a total area of 112,000km^2 of which 64,000km^2 comprises the western catchment, which drains to the main river or its tributaries.

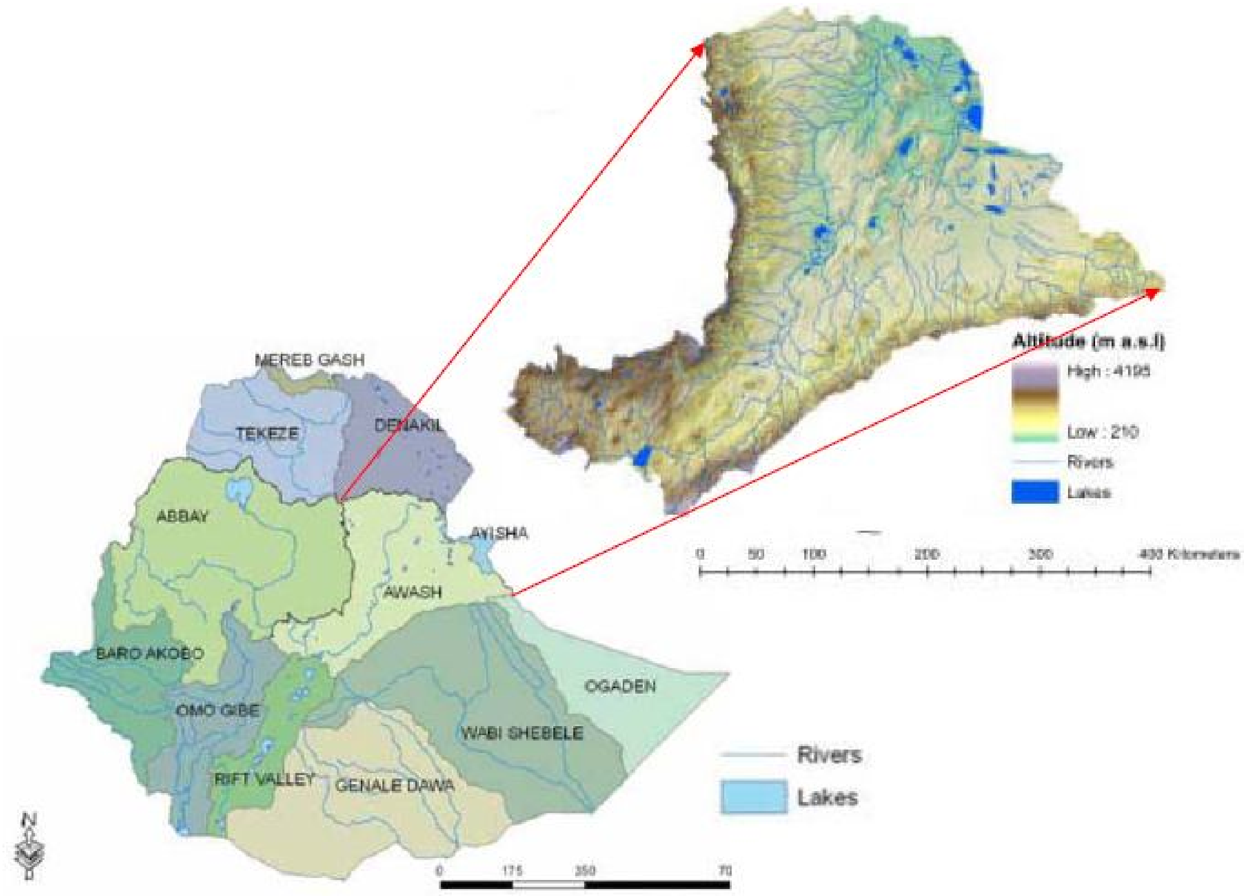


Figure 3.1: Location of Awash River Basin and its topography

The Awash River originates from Central West part of Ethiopia, flowing 1200 Km long, and provides a number of benefits to Ethiopia; one of the most intensively utilized river basins in the country , it originates and remains entirely in the country. The river basin has a lowest elevation of 210 m and a highest elevation of 4195 m (Figure 3.1). The total mean annual flow of the river Awash is estimated to be 4900 million cubic meters.

The estimated irrigation potential is about 134,121 hectares of which about 30,556 ha are for small-scale, 24,500 ha for medium-scale and 79,065 ha for large-scale development (Awulachew et al., 2007)

Methods of data collection and analysis

Primary data

Primary data were generated using structured questionnaires and interviews. Representative respondents were systematically selected from all legally registered irrigation water users with the following considerations:

- Data availability- a scheme that has the data over at least 5 consecutive years (from 2005/6-2009/10 production years)
- Management type – samples were to be drawn from private, community, state farms
- Scale – samples were tdrawn from small, medium and large scale irrigation schemes
- Cropping type – major crops cultivated in the basin were to be included in sampling
- Water diversion methods – samples from major diversion methods in use such as gravity and pumps were to be included

Considering the above mentioned selection criteria, 29 irrigation water users were selected from middle and upper Awash River Basin. Generally, about 20 small scale (command area less then 200ha), 5 medium (200-3000ha) and 4 large scale (more than 3000ha) irrigation schemes were included in the assessment. These selected irrigation schemes are distributed around Amibara, Merti, Metehara and Wonji areas for cotton, onion, and sugarcane production respectively.

Secondary data

Relevant information was reviewed from different documents such as the Ethiopian water resources management policy, water sector strategy, water sector program and different water resources management related proclamations and regulations. These documents were collected from ministry of water resources and energy (MoWRE) and Awash Basin Authority to find out whether there exists legal ground for irrigation water pricing or not. Detailed discussions were held with officials and experts from ministry of water resources and mines and Awash Basin Authority about irrigation water pricing experiences and its impacts. Scheme specific data such as area cultivated, amount of water diverted to each scheme each year, water fees collected, service charge and operation and maintenance cost for primary irrigation canals of each legal water user in the basin for the last five consecutive production years (2005/06-2009/10) were collected from Awash basin authority. Climate data, and annual market price of irrigated crops were other collected data

Methods of data analysis

The quantitative and qualitative data collected from the primary sources were analyzed using qualitative methods and descriptive statistics. Statistical Package for Social Sciences (SPSS) software was used for the analysis of quantitative data to estimate the response of irrigation water users to irrigation water pricing, impacts of irrigation water pricing and irrigation water users' willingness to pay for irrigation water. Data collected from key informant interviews, discussions and observations were qualitatively assessed to state the current irrigation water pricing system, its objectives and its practical application in Awash Basin. Finally, outputs of the statistical analysis were presented using tabulation, cross-tabulation, means, frequencies and percentages.

Measurements of performance indicators

Irrigation performance indictors considered in this study are mainly: 1) economic indicators, i.e. land and water productivity, 2) water management indicators, i.e. relative water and irrigation supply. The description of these indicators and methods of their measurement are given in the following sections.

Land productivity

Land productivity denotes the ratio of farm output, i.e., marketable yield or its economic return to cultivated (irrigated) area. Land productivity or the crop production rate was calculated for all sampled irrigation schemes over the last 5 successive production years. Land productivity was expressed in terms of:

- Harvested crop yield per unit of irrigated area (Quintals/ha)
- Gross economic return per unit of irrigated area (Birr/ha)

Water productivity (WP)

Water productivity can be expressed in terms of physical water productivity, i.e. the ratio of agricultural output to the amount of water consumed and economic water productivity which means the value derived per unit of water used (Molden et al., 2010). In a broad sense, WP refers to the benefits derived from a use of water and at the same time the efficiency with which a unit of water has been used.

WP was measured in terms of:

- Harvested crop yield per unit of water diverted or supplied (Quintals/m^3)
- Gross economic return per unit of water diverted or supplied (Birr/m^3).

The first and the second indicators are also called physical and economic water productivity, respectively.

4.Results and Discussion s

General Practice

ABA controls any significant water diversion from Awash River for irrigation purposes-schemes irrigation systems in the basin up to the primary canal respective individual irrigators control secondary, tertiary and on-farm canals. In Ethiopia, Only ABA operates with the concept of river basin management. It collects water fees on volumetric basis with an objective of covering all expenses of the authority at a rate of 3birr per 1000m3

The two parties sign a contract of agreement each year to issue clients' irrigation water use permit. The permit specifies its expiration date, the amount of water required by each client, means of water abstraction, method (s) for measurement of abstracted water, area to be irrigated, and irrigation period. The authority prepares water request format for legal irrigators diverting water from each primary off take structure at the start of irrigation seasons. Individual irrigators submit their irrigation water demand request to the authority on a weekly basis. The Wonji sugar estate & ABA have agreed on a lump sum annual consumption of around 90 million meter cubic of water, unlike other large estates. in common and water fees are collected based on their annual cultivated area.

According to the finding, Irrigation user households pay four different types of payments for their irrigation use.

- **water distribution services:** charged 78.18 Birr per hectare per year
- **water fee**: 3 birr/1000m3
- **gate operator Salary**: for users abstracting water with gravity nearly 6 Birr per hectare per year
- **Maintenance costs:** variable

The major problems of the current irrigation water pricing system according to the study results are

- Absence of restrictions on upstream users about the maximum abstraction of irrigation water.
- No clear rules and regulations limiting the amount of water being extracted in periods of peak irrigation demand.this may force downstream irrigation users suffer from water shortage during low flow and high irrigation water demand periods. Ex. at Amibara area (middle Awash) in April and May.
- Lack of considering Irrigation scales in collecting fees of water-has similar charges for irrigators of 2 ha. to more than 10000 hectares, i.e., 3 Birr/1000m3
- Presence of many illegal irrigators who abstract water with no permit from ABA-pay neither for services nor for the cost of water. That means many users don't pay their charge are rates on time.

Current Practices of ABA

The irrigation potential of Awash River basin is about 134,121ha.Already operational irrigation schemes in the basin are about 47,469ha. Average number of farms registered annually by ABA and irrigation area developed is 66 and 38,157 ha respectively-more than 80% of the area irrigated in the basin is registered by ABA to pay for water(Table 4.1).

Table 4.1 Number of clients, area developed annually, amount of water used and total costs of water

Year	No of clients	Area developed (ha)	Water used (MCM)	Total cost of water service (Birr)
2006	56	37,572	844.06	3,861,730
2007	74	41,688	911.75	4,427,283
2008	76	41,427	821.53	3,961,898
2009	59	32,006	722.50	3,339,218
2010	63	38,091	795.80	3,868,557
Mean	66	38,157	819.13	3,891,737

Land productivity performances

Land productivity in this study is measured in terms of yield per unit area (tons/ha), or monetary value of the produce (Birr/ha)

i. Land Productivity in yields

The values of land productivity in terms of yield per hectare for cotton, sugarcane and onion from 2006-2010 varied from year to year, and between farms within the year. The five years consecutive observation of cotton productivity in eighteen farms in the middle awash showed that yields varied 1.2 to 3.6 tons/ha, as shown in table 4.2.1. Pereira et al. (2009) have reported from central Asia under similar climate that the average productivity of cotton under full irrigation was about 3.7 tons/ha.

Table 4.2: Cotton productivity of eighteen farms (tons/ha

year	2006	2007	2008	2009	2010	Mean
Mean	2.5	2.7	2.6	2.4	2.3	2.5
Minimum	1.3	1.6	1.5	1.3	1.2	1.6
Maximum	3.5	3.6	3.2	3.3	3.5	3.2
St. Deviation	0.6	0.5	0.6	0.6	0.6	0.5

The values of land productivity in terms of yield per hectare for cotton, sugarcane and onion from 2006-2010 varied; from year to year, and between farms within the year. The five years consecutive observation of cotton productivity in eighteen farms in the middle awash showed that yields varied 1.2 to 3.6 tons/ha, as indicated in Table 4.2.

Sugarcane productivity of 6 farms in five years ranged from a minimum of 117 tons/ha to a maximum of 213 tons/ha. the average productivity ranged from 173 – 183 tons/ha

ii. Water productivity

The lowest amount of water has not resulted to lowest production. However, the highest water application has result the lowest yield. In general terms, there is no clear decreasing or increasing trend observed especially in the ranges of low to middle water application, as shown in the figure below.

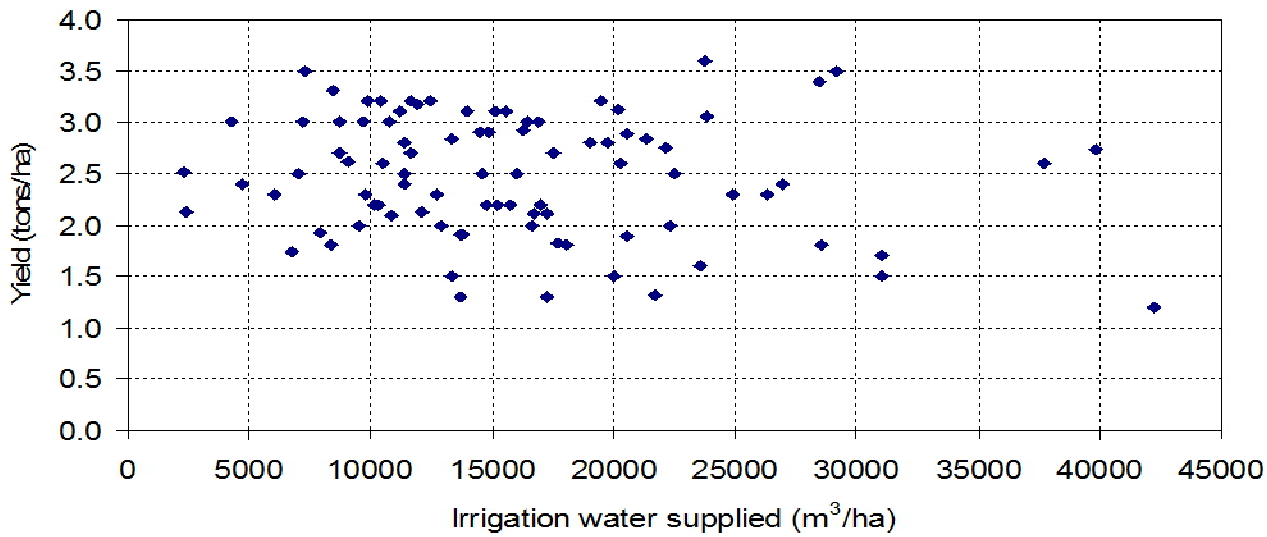


Figure 4.1: Relationships between irrigation water supplied to different cotton farms per season and yields in tons/ha.

Figure 4.2 shows the irrigation efficiencies of 27 farms operated over 5 years. According to the research output , 60% of the total samples considered (n=135) are working at an irrigation efficiency of less than 35%.

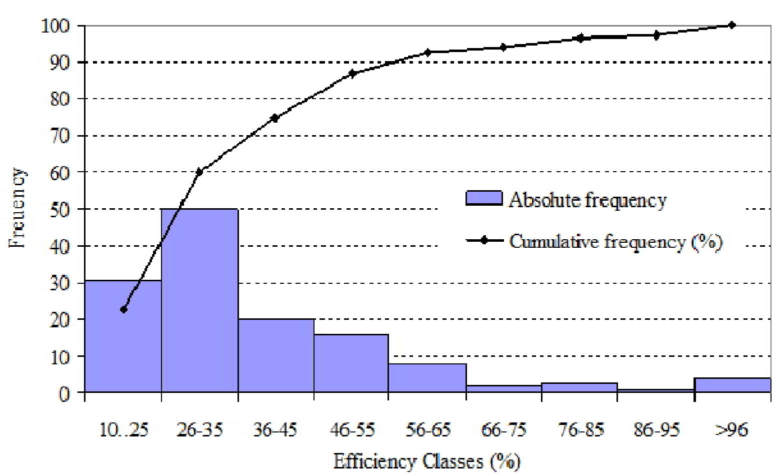


Figure 4.2: Absolute and cumulative frequency of irrigation efficiency in Upper and middle Awash basin (total number of farms 27 * 5 years data, n = 135, average efficiency = 40%)

4. Conclusion and Recommendations

Conclusion

ABA being the first organization to practice water pricing practices in Ethiopia hints vitality of giving values to natural resources like water.some of the problems in water pricing system include

- Lack of restrictions on maximum abstraction of upstream irrigation water in periods of different irrigation demand
- non consideration o f users' Irrigation water using scales in charging water fees (2 ha. to more than 10000 hectares is 3 Birr/1000m3)
- presence of illegal irrigators who abstract water with no permit from ABA and with no payment
- Users' negligence to timely pay their water fees
- Irrigation efficiency is found to be low
- This shows that the level of water price could not encourage to improve efficiency

Recommendations

- ABA along with the concerned stakeholders need to develop a rational water allocation systems to satisfy the needs of irrigators
- There should be a pricing system that influences irrigator's water demand.
- Reasonable level of water price need to be determined based on willingness to pay of water users.
- Extension communication should be harshly done to create and develop the awareness of illegal users in valuing water and pay their necessary payments, those legal users to pay timely.

5. References

Abu-Zeid M. 2001. Water Pricing in Irrigated Agriculture. Water Resources Development, (17) 4, 527–538

Clemmens A.J. and Molden D.J. 2007. Water uses and productivity of irrigation systems. Irrigation sci ence, 25, 247–261

Boss M. 1997. Performance indicators for irrigation and drainage. Irrigation and drainage systems. 2, 119-137.

FAO 2002. Crops and drops. Making the best use of water for agriculture. Rome

FAO, 2004. Water charging in irrigated agriculture. FAO Water Report 28. Rome

FNG (Federal Negari Gazeta) (2000). Ethiopian water re sources management proclamation. Proclamation Number 197/2000. Addis Ababa.

FNG (Federal Negari Gazeta) (2005). Ethiopian water re sources management regulations. Council of min istries regulation No. 115/2005. Addis Ababa.

FNG (Federal Negari Gazeta) (2008). Awash basin high council and Authority establishment regulation. Council of ministries regulation No. 156/2008. Addis Ababa.

Girma T. and Fantaw A. (2005): The nature and properties of salt affected soils in Middle Awash. http://www.cgiar.org/assessment/Research_Project/irrigation_management_Ethiopia.htm

Go'mez-Limo'n J.A. and Riesgo L. 2004. Irrigation water pricing: differential impacts on irrigated farms. Agricultural economics 31, 47-66.

World Bank. 1997. Water Pricing Experiences. An Inter national Perspective. Washington D.C.

Kumar S., Imtiyaz M., Kumar A., Singh R. 2007. Response of onion (Allium cepa L.) to different levels of irrigation. Agricultural water management. 89, 161-166.

Molden D., , Sakthivadivel R., Perry C.J., and de Fraiture C. 1998. Indicators for Comparing Performance of Irrigated Agricultural Systems. IWMI Research Report No. 20, Colombo Sri Lanka

Molden D., Oweis Th., Steduto P., Bindraban, Hanjra M.A., Kijne J. 2010. Improving agricultural water productivity. Between optimism and caution. Agricultural water management. 97, 528-535

Pereira L.S., Paredes P., Cholpankulov E.D., Inchenkova O.P., Teodoro P.R. 2009. Irrigation scheduling strategies for cotton to cope with water scarcity in the Fergana Valley, Central Asia. Agri cultural water management. 96, 723-735.

Perry C., Steduto P., Allen R.G. and Burt C.M. 2009. In creasing productivity in irrigated agriculture: Ag ronomic constraints and hydrological realities. Agricultural water management. 96, 1517-1524.

Ruijsa A, Zimmermanna A., van den Bergb M. 2008. De mand and distributional effects of water pricing policies. Ecological economics. 66, 506-516.

Yang H., Zhang X., Zehnder A.J.B. 2003. Water scarcity, pricing mechanism and institutional reform in northern China irrigated agriculture. Agricultural Water Management 61, 143–161

Tilahun H. 2010. Best irrigation water management prac tices. Paper presented on a workshop on agricul tural water and salt affected soil management. 8th July 2010. Addis Ababa. Unpublished.

Yield and Water Use Efficiency of Furrow Irrigated Potato under Regulated Deficit Irrigation, Atsbi-Womberta, North Ethiopia

Mulubrehan Kifle[1] and T.G.Gebretsadkan[1]

[1]Tigray agricultural Research institute, P.O.Box 492, Mekelle, Ethiopia

Abstract

The pressure on availability of water in Tigray regional state is likely to increase as the requirement for food production in couple with rapidly growing of the population is at increasing rate. Hence, improving water productivity using regulated deficit irrigation is important to reduce the water consumption while minimizing adverse effects on the crop yield. The experimental site is located in the eastern zone of Tigray regional state, Atsibi Womberta wereda. The aim of this study was to determine the yield and water use efficiency of potato under deficit irrigation practice. The effect of water deficit or water stress on crop yield and water use efficiencies were evaluated. Gasa potato variety was grown under eight (T_1-T_8) irrigation treatments. The treatments were replicated three times under completely randomized blocks experimental design. Water was applied to every furrow using watering can with fixed interval and variable depth irrigation scheduling technique was selected. Yield of potato was significantly ($p<0.05$) affected by water stress (deficit irrigation). The highest yield was found in T1 (18770 Kg/ha) which was not subjected to water stress (full water requirement) whereas minimum yield of potato was obtained under the fully stressed treatment T8 (7037 Kg/ha). There was no significant different between the yield of T1 (18770 Kg/ha) and T6 (14440 Kg/ha) which was 25% deficit throughout the growing season. According to the result obtained, stressed at the middle stage was affected more the yield of potato as compared to other treatments. This showed that stressing the crop at flowering/middle stage is sensitive to deficit irrigation. Giving 65% of crop water requirement throughout the growing season is better than stressing the crop only at the middle stage. The second sensitive period for water stress is the late crop stage. Crop water use efficiency was no significant different. Though it was no significantly different, T6 (2.86 kg/m^3) and T4 (1.60 kg/m^3) had the highest and the lowest water use efficiency respectively. This elaborated that applying 75% of crop water requirement has better water use efficiency than optimal or ''no stress'' irrigation. It can be conclude that using deficit irrigation is a good water management technique to save irrigation water without reducing the yield of potato. For dry land areas with water scarce, farmers are recommended to use water efficiently with deficit way and increase their irrigable land.

***Key words**: Deficit irrigation, Atsbi-wenberta, Potato*

1. Introduction

The history of agriculture in Tigray, North Ethiopia is the history of subsistence. Agriculture in this region is dependent on unreliable rainfall. The pattern of rainfall had been low, torrential and erratic. As a result, repeated crop failure is common experience in the region. In fact, farmers are not passive victims of drought. The Tigray farmers use a wide range of indigenous irrigation practices to overcome the problem of drought and to supplement rainfed agriculture. Moreover, the Government of Ethiopia is currently focused on water centered development with special attention to water harvesting and small scale irrigation schemes (Awlachew *et al.* 2006). In this issue Weldeab (2006), reported that surface irrigation like river diversion, spring development and pond systems, is a common practice used in the region to irrigate plots. BoARD (2011) indicated that 125, 000 ha of land are irrigated using traditional methods and make up 38% percent of the estimated irrigable land of 324,286 ha in the region. However, the pressure on availability of water is likely to increase as the requirement for food production and industrial use in couple with rapidly growing of the population is at increasing rate. Subsequently, improper on-farm irrigation management practices in the region lead to erosion, poor water distribution, non-uniform crop growth, water logging, salinity, all of which decrease the yield per unit of land area and per unit of water applied (Eyasu, 2005). The conventional furrow irrigation practiced by farmers is known to be less efficient particularly where there is shortage of irrigation water. Field application efficiency in most traditional irrigation schemes is still very low, typically less than 50% and often as low as 30% (FAO, 1997, FAO, 1995). Similarly water productivity of the traditional irrigation system is smaller compared to the well managed alternative methods of applications (Mintesinot, 2002 and Horst *et al.*, 2007).

In the context of improving water productivity, there is a growing interest in regulated deficit irrigation, an irrigation practice whereby water supply is reduced below maximum levels and yield stress is allowed with minimal effects on yield (Payero et al., 2006; Zhang et al., 2004 and Aujla et al., 2005).

Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains by maximizing yield per unit of water as well as by increasing of cultivable frequency or irrigable area (Bekelle and Tilahun, 2007). For a given crop farmers are inclined to use water efficiently, and water efficient crop selection also helps in getting optimum returns. Several literatures (e.g Webber H.A, et al and Kadayifci et al., 2005) shows that regulated deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield. This method is applicable by exposing the crops to a certain level of water stress during particular or the whole growing stages.

Hence, this study aims at (i) determining the yield and water use efficiency of potato under deficit irrigation practices. Second, identify crop growth stages during which the crop can withstand water stress with limited effect on yield (iii) determining optimum irrigation schedule and crop requirement of potato for Tigray agro-climatological.

2. Materials and Methods

Site description, experimental design and crop varieties

The experimental site is located in the eastern zone of Tigray regional state, Atsibi Wenberta wereda. It is located 65 km northeast of the capital of Tigray Regional State, Mekelle. The experiment soil type was sandy loam. Agro-ecologically, the woreda is classified as *Dega*. Altitude in the area ranges from 918 to 3,069 m and 75% of the woreda is in upper highlands (2600masl or above) and only 25% is found in midlands (between 1500 and 2600 m asl and below 1500 m asl), (IPMS, 2005). Annual rainfall in the study area is 620 mm per year.

The experimental design consists of completely randomized blocks with three replications. Within each block, eight irrigation regimes (Table 1) were randomly distributed. Furrow irrigation method was used for applying water; and each treatment has 3x3 m plot size. Adjacent treatment units were planted 1 m apart from each other to make sure border effect is negligible. The required crop water was calculated using CROPWAT computer programme (Allen et al., 1998).

The Guasa variety potato was selected for the study and it was planted with 30 cm between plant and 75 cm raw spacing. This crop variety was selected for its good adaptability and most usable in the study area. The growing season of the crop was mainly divided into four major growth periods: initial, development, middle and late stages based.

Table 1: Treatment setting for field experiment

Treatment	Crop growth stage				Description
	Initial	Dev.	middle	late	
T1	1	1	1	1	All normal watering
T2	0	1	1	1	Stress during initial stage
T3	1	0	1	1	Stress during Development stage
T4	1	1	0	1	Stress during middle stage
T5	1	1	1	0	Stress during late stage
T6	25%	25%	25%	25%	25% deficit throughout the growing season
T7	35%	35%	35%	35%	35% deficit throughout the growing season
T8	50%	50%	50%	50%	50% deficit throughout the growing season

Where:

1 indicates Normal watering - watering 100% of ETc (net irrigation)
0 indicates stressed watering - watering 25% of ETc (net irrigation)
25% Deficit was watering 75% of ETc (net irrigation)
50% Deficit was watering 50% of ETc (net irrigation)
35% Deficit was watering 65% of ETc (net irrigation)

Data collection and analysis

Soil samples from the study area were collected from 45 cm depth to characterize the soil in terms of physical characteristics such as textural class (soil texture), EC, pH, organic matter, initial soil moisture content, and the average bulk density. The above mentioned soil parameters were analyzed at in the soil laboratory of Mekelle Agricultural research center as indicated in Table 2. The experimental site had field capacity (FC) 35.8% and permanent welting point (PWP) 18.2% with the average total available water (TAW) 17.6% in volume percentage.

Meteorological data's (minimum and maximum temperature, relative humidity, and wind speed and daily sunshine hours) from the study area were collected to determine reference crop evapotranspiration (ET_0) and was calculated using Modified FAO Penman-Monteith method (Allen *et al.*, 1998). There was no rainfall during the growing season.

Table 2: Soil physical and chemical properties for the experimental site

Soil depth (cm)	Type of analysis										
	Bulk density	EC (ds/m)	pH	Sand %	Silt %	Clay %	Text.	Organic matter	FC Vol. %	PWP Vol. %	TAW Vol.%
0 – 15	1.15	0.85	7.10	31	39	30	CL	0.64	37.2	19.4	17.8
15 – 30	1.21	0.81	7.40	27	39	34	CL	0.66	36.7	18.8	17.9
30 – 45	1.24	0.77	7.55	45	35	20	L	0.47	33.5	16.4	17.1
Average	1.20	0.81	7.35	34	38	28	CL	0.6	35.8	18.2	17.6

Determination of crop water and irrigation requirement

Crop water requirement of potato over the growing season was determined from the reference evapotranspiration and crop coefficient as indicated in Equation 1 (Allen *et al*., 1998). 90% of application efficiency was considered as can method of water application was used. Finally, irrigation scheduling of the crop was computed using FAO CROPWAT program by considering soil type with fixed interval and variable depth (refill to field capacity).

$$ET_c = K_c * ET_o \qquad (1)$$

Where:

K_cET_c = crop evapotranspiration (mm/day),

Kc = crop coefficient (dimensionless), and

ET_o = reference crop evapotranspiration (mm/day)

As indicated in section 2.2, the amount of rainfall received during the experiment was zero and hence net irrigation requirement was taken to be equal to ETc.

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

$$WUE = \frac{Y}{ETa} \qquad (2)$$

Where:

WUE is water use efficiency, Y is the crop yield (kg/ha) and ETa, is the actual evapotranspiration (mm).

Crop evapotranspiration was predicted initially, to use in irrigation scheduling, with the FAO Penman–Monteith equation using weather data collected at the experimental site and crop coefficients for standard and stress conditions (Allen et al., 1998). Pre-irrigation was applied to every furrow in each plot, at 4 days before seeding. The purpose of pre-irrigation was to bring the soil in root zone to field capacity and to create a good seed bed.

Crop agronomy and management

Vigorous seeds were planted to all experimental plots with a spacing of 30 and 75 cm between plants and rows, respectively. 195 kg/ha of DAP was applied at the planting time and 160 kg/ha of urea at the time of planting as well as a month after sowing was applied. All agronomic practices such as cultivation and weeding were done three times during the growing season.

Statistical analysis

Analysis was performed on yield and water use efficiency of potato using MSTATC statistical software. The data of the experiment was analyzed in randomized complete block design (RCBD), and the mean difference was estimated using the least significant difference (LSD) comparison.

3. Results and Discussions

Crop water requirements and irrigation scheduling of potato

Crop water requirements were calculated by multiplying the reference evapotranspiration values with the potato crop coefficients (0.5, 1.05 and 0.75) initial, middle and late stages respectively given by Allen et al. (1998). The Amount of irrigation water required at 10 days interval, number of irrigation events is summarized in Table3. Fixed interval (every ten days) and variable depth (refill to field capacity) irrigation scheduling technique was selected. Optimal or ''no stress'' irrigation was calculated using the FAO CROPWAT program as the net amount of irrigation required to refill the soil moisture deficit (SMD) with weekly application of irrigation water. The depth

Table 3: Irrigation water requirement of potato in 10 days interval (mm)

	Treatments							
Date	T1	T2	T3	T4	T5	T6	T7	T8
4-Jan	25.6	6.4	25.6	25.6	25.6	19.2	16.6	12.8
14-Jan	26.7	6.7	26.7	26.7	26.7	20.0	17.4	13.4
24-Jan	29.5	7.4	29.5	29.5	29.5	22.2	19.2	14.8
3-Feb	41.6	41.6	10.4	41.6	41.6	31.2	27.0	20.8
13-Feb	55.1	55.1	13.8	55.1	55.1	41.3	35.8	27.5
23-Feb	66.7	66.7	16.7	66.7	66.7	50.0	43.3	33.3
5-Mar	68.3	68.3	17.1	68.3	68.3	51.3	44.4	34.2
15-Mar	68.2	68.2	68.2	17.1	68.2	51.2	44.3	34.1
25-Mar	67.7	67.7	67.7	16.9	67.7	50.7	44.0	33.8
4-Apr	66.7	66.7	66.7	16.7	66.7	50.0	43.3	33.3
14-Apr	61.2	61.2	61.2	61.2	15.3	45.9	39.8	30.6
24-Apr	52.3	52.3	52.3	52.3	13.1	39.3	34.0	26.2
4-May	43.7	43.7	43.7	43.7	10.9	32.8	28.4	21.8
Total	**673.3**	**611.9**	**499.6**	**521.4**	**555.4**	**505.0**	**437.6**	**336.7**

Yield and water use efficiency of potato

The result in Table 4 indicated that yield of potato was significantly ($p<0.05$) affected by water stress (deficit irrigation). The highest yield was found in T1 (18770 Kg/ha) which was not subjected to water stress (full water requirement) whereas minimum yield of potato was obtained under the fully stressed treatment T8 (7037 Kg/ha). There was no significant different between the yield of T1 (18770 Kg/ha) and T6 (14440 Kg/ha) which was 25% deficit throughout the growing season. According to the result obtained, stressed at the middle stage was affected more the yield of potato as compared to other treatments. This showed that stressing the crop at flowering/middle stage is sensitive to deficit irrigation. Giving 65% of crop water requirement throughout the growing season is better than stressing the crop only at the middle stage. The second sensitive period for water stress is the late crop stage. This is inline with the result obtained by Bekele and Tilahun (2007). On the other hand, ANOVA in Table 3 showed that crop water use efficiency was no significantly affected. Even though it was no significant different, T6 (2.86 kg/m^3) and T4 (1.60 kg/m^3) had the highest and the lowest water use efficiency respectively. This result elaborated that applying 75% of crop water requirement throughout the growing season has better water use efficiency than applying optimal irrigation with (100%) crop water requirement.

Table 4: Yield and water use efficiency of potato

Treatment	Yield (kg/ha)	WUE (kg/m^3)
T1	18770[a]	2.79
T2	11110[bc]	1.81
T3	13520[abc]	2.71
T4	8333[bc]	1.60
T5	10430[bc]	1.88
T6	14440[ab]	2.86
T7	10060[bc]	2.30
T8	7037[c]	2.09
SEm$\pm$	1365.2	0.3036
LSD (0.05)	2.14479	ns
CV (%)	20.19%	23.32%

As indicated in Table 5, T1 had the highest and T8 the lowest yield. From the treatments highest amount of water was saved in T8 (50%) and 9% of water was saved in T2 since T1 is taken as control (crop water requirement base). The amount of water saved in T6 was 25% which is higher than the five treatments (T1, T2, T3, T4 and T5). When the treatments compared in terms of yield reduction, T6 had (23%) yield reduction which is the least and T8 (63%) the highest yield reduction since T1 is considered as control. The results of relative WUE is presented in Table 5 with the highest value for T6 (1.03) and with lowest in T2 (0.65). As presented in Table 6, T1 obtained the highest (18780kg/ha) ranked as first and T8 obtained the lowest (7037) kg/ha) yield ranked as the least. When the treatments ranked in terms of water use efficiency, T6 and T4 had the first and the least.

Table 5: The amount of water saved and rank on water use efficiency

Treatments	Irrigation (m3/ha)	Yield (kg/ha)	WUE (kg/m3)	Water saved (%)	Yield Reduction (%)	Relative WUE
T1	673.3	18770	2.79	0	0	1.00
T2	611.9	11110	1.81	9	41	0.65
T3	499.6	13520	2.71	26	28	0.97
T4	521.4	8333	1.6	23	56	0.57
T5	555.4	10430	1.88	18	44	0.67
T6	505	14440	2.86	**25**	**23**	1.03
T7	437.6	10060	2.3	35	46	0.82
T8	336.7	7037	2.09	50	63	0.75

Table 6: Ranking of yield and water use efficiency of potato

Treatments	Yield per replication RI	RII	RIII	Yield (kg/ha)	WUE (kg/m3)	Rank on Yield	Rank on WUE
T1	17407	16296	22592	18770[a]	2.79	1	2
T2	9629	10370	13333	11110[bc]	1.81	4	7
T3	10925	14629	15000	13520[abc]	2.71	3	3
T4	7037	7037	10925	8333[bc]	1.6	7	8
T5	11481	9444	10370	10430[bc]	1.88	5	6
T6	8148	18148	17037	14440[ab]	2.86	2	1
T7	10185	8888	11111	10060[bc]	2.3	6	4
T8	4814	4629	11666	7037[c]	2.09	8	5

4. Conclusions

An experiment was carried out to understand the regulated deficit irrigation, an irrigation practice whereby water supply is reduced below maximum levels and yield stress is allowed with minimal effects on yield. The experimental design of this study was completely randomized blocks with three replications. Within each block eight irrigation regimes were randomly distributed. The result shows stressed at the middle stage can affect the yield more as compared to other treatments. This showed that stressing the crop at flowering/middle stage is sensitive to deficit irrigation. Giving 65% of crop water requirement throughout the growing season is better than stressing the crop only at the middle stage. The study clearly shows, applying 75% of crop water requirement has better water use efficiency than optimal or ‘‘no stress’’ irrigation. It can be conclude that using deficit irrigation is a good water management technique to save irrigation water without reducing the yield of crops. For dry land areas with water scarce, farmers are recommended to use water efficiently with deficit way and increase their irrigable land.

References

Abdullah, K, Tuylua, G, Yusuf, U, Cakmak, B, 2005. Crop water use of onion (Allium cepa L.) in Turkey, Agricultural water management (72), 59-62.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration Guidelines for Computing Crop Water Requirements.
Irrigation and Drainage Paper No. 56. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Aujla, H.S. Thind, G.S. Buttar, 2005.Cotton yield and water use efficiency at various levels of water and N through drip irrigation under two methods of planting. Agricultural water management (71), 169-172.

Awlachew, S.B., Menker, M., Abesha, D., Atnafe, T., Wondimkun, Y. (Eds.). 2006. Best Practices and Technologies for Small Scale Agricultural Water Management in Ethiopia. Proceeding of a MoARD/ MoWR/USAID/IWMI symposium and exhibition held at Ghion Hotel, Addis Ababa, Ethiopia 7-9 March, 2006.

Bekele ,S and Tilahun, K., 2007,.Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia (89), 148-152.

BoARD, 2011. Agricultural and rural development annual report, Tigray, Ethiopia.

Doorenbos, J. and W.O. Pruitt. 1977. Crop water require ments. FAO Irrig. and Drain. Paper 24. FAO, Rome.

FAO (Food and Agriculture Organization), 1997. Guidelines for predicting crop water requirement: Irrigation and Drainage paper no. 24, FAO, Rome.

Horst, M.G., S.S. Shamutalov, J.M.Goncalves, and L.L.Pereira, 2007. Assessing impacts of surge flow irrigation on water saving and productivity of cotton. Agricultural Water Management 87 (2007) 115-127.

IPMS (Improving Productivity and Marketing Success), 2005. Atsbi Wonberta District Pilot, Learning Site Diagosis and Program Design.

Jose´ O. Payero, Steven R. Melvin, Suat Irmak, David Tarkalson (2006). Yield response of corn to deficit irrigation in a semiarid climate.Agricultural water management (8 4) 1 0 1 – 1 1 2.

Mintesinot Behailu, 2002. Assessment and optimization of traditional vertisol irrigation in northern Ethiopia: a case study at Gumselasa microdam using maize as an indicator crop. PhD Dissertation, Ghent University, Gent, Belgium, 202p.

Oweis, T. and H. Zhang, 1998. Water-use efficiency: index for optimizing supplemental irrigation of wheat in water scarce areas. Zeitchrift Bewaesserungswirtschaft 33 (2). 321-336.

Webber, H, Madramootoo, C, Bourgault, M. Horst , G. Stulina c, 2006. Smith Water use efficiency of common bean and green gram grown using alternate furrow and deficit irrigation. Agricultural water management (82), 259-258

Woldeab Teshome, 2006. Irrigation Practices, State Intervention and Farmer’s Life-Worlds in Drought -Prone Tigray. Colombo, Srilanka: International Water Management Institute. 190pp.

Zhang, H., Pala, M., Oweis, T., Harris, H., 2000. Water use and water use efficiency of chickpea and lentil in a Mediterranean environment. Aust. J. Agric. Res. 51, 295–305.

Eyasu Yazew, 2005. Development and management of irrigated lands in Tigray, Ethiopia. PhD Thesis. UNESCO-IHE Institute for Water Education, D elft Netherlands.

Hydrology Study of Upper Awash Basin to Evaluate the Groundwater Recharge, Ethiopia

Tibebe B. Tigabu
Department of Water Resources and Environmental Engineering, University of Gondar, P.O. Box 196,
email: tibebghw@gmail.com

Abstract

Ethiopia is implementing a policy which is agricultural development lead industrialization and considers the potential water resources as an entry point for any development interventions. Based on this, the country has defined a number of development corners of intensified agricultural practices. Among the others, the Upper Awash Basin is the potential area for agricultural practices. With this context the research paper addressed the hydrology study of the area for the purpose of ground water potential assessment. In areas like Upper Awash Basin in which surface water resources are scarce, groundwater is the primary option for both domestic and agricultural water demand. Therefore, the research objective was to conduct hydrological study mainly evaluation of the major water balance components in the study area. As availability of hydrogeological data were limited for groundwater balance analysis, important data like annual and monthly

1. Introduction

General

Ethiopia is categorized under least developed countries. As a result of this the government of the country has developed long-term strategic plan to alleviate the multidimensional problems. The policy is Agricultural Development lead Industrialization and in this regard water is considered to be the entry point for whatsoever development strategy is designed.

Therefore, this hydrological study is focusing in the Amhara National Regional State in which Upper Awash Basin is found for irrigation development. The major task of the hydrological study is to estimate the water balance components which are useful to evaluate the recharge, to analyze the surface and groundwater conditions at each of the major sub basin and in the entire basin of Awash, at Amhara Region.The entire Awash River Basin Surface Water Resources Development Master Plan was conducted by the Ethiopian Valley Development Studies Authority (HALCROW, 1989).Molla D. (2000), studied the hydrology, hydrogeology and hydrochemistry of the lake system Haiq-Ardibo. Messifn (2001), also studied the hydrogeology of the Upper and middle Borkena River Catchment. Nigussie (2005), studied the water resources potential of Beresa catchment. Although, the above studies were conducted in the area, detail hydrological and meteorological analyses were lacked so that, this study addressed detail analysis of the major water balances components with regard to groundwater.

According to HALCROW (1989),the agroclimatic zones of Awash Basin were classified into five different zones based on location, altitude, climate, topography, agricultural development, inhabitants, administrative boundaries, etc. and altitude is the major determinant factor. This five classification of agro climatological zone are outlined: as **Uplands;** all lands in the basin above 1,500m, with annual rainfall above 800mm and mean daily temperature below 20^{o}c, **Upper Valley;** the area of the basin between Koka reservoir and Awash Station which lies between 1,500m and 1,000m with mean annual rainfall between 600 and 800mm, **Middle Valley;** that area of the basin between Awash Station and Milie which lies between 1000m and 500m and mean annual rainfall generally ranges from 600mm to 200mm, **Lower Plain;** these are the delatic alluvial plains in the Tendaho, Asayita, Dit Bahri area and terminal lake environs. The area lies between 500 and 200m altitude with a mean annual rainfall of less than 200mm and **Eastern Catchment;** as this zone effectively forms a closed sub-basin within the Awash basin it is appropriate to distinguish it from the other areas.

Objectives of the Study

The objective of the study in this project area is to estimate the water balance components, which are useful to evaluate the recharge and see surface and groundwater situation at each of the major sub basin and in the entire Upper Basin of Awash in Amhara Region.

2. Methodology and Materials

The materials used and the Methodologies are as follows:

- Spatial data sources like land use land cover, soil map and SRTM-DEM of 30m resolution of the study area were collected from the Federal Ministry of Water Resources The collected spatial data of the study areas were assessed, analyzed and used for the water balance evaluation of each catchment in the study.

- Analysis and interpretation of hydro-meteorological data, data consistency, and trend detection for climatic data were performed.

- The available time series point rainfall data at each rainfall recording stations were averaged and interpolated to areal rainfall using thiessen polygon. Outlier detection of rainfall and stream flow data was done using Grubbs and Beck (1972) test and the rainfall data consistency was checked using double mass curve.

- The FAO Penman Monthieth Method was used in the evaluation of Potential Evapotranspiration at stations, which have all meteorological elements, and Yilma S. (2002) regional potential Evapotranspiration estimation method was used at areas that lack important meteorological elements.

- Thornwaite and Mattern Soil Moisture Water Balance Method was used to estimate groundwater recharge at each catchment.

- In hydrological analysis the available river discharges are separated into base flow and surface runoff using Automated Base Flow Separation Technique.

Study area description

Location and Accessibility

The study area, i.e. Upper Awash valley is found at the western margin of the main Ethiopian Rift and encompasses part of North Wollo, South Wollo, North Shewa Zones and Oromia special Zone. The total area covered in this study is 16724.50 square killo meter. This includes part of Upper Awash River Basin that encompasses 14 sub basins. The geographic boundaries are confined between 502400 to 685746m E and 936569 to 1333400m N (Figure 1). The study area is accessed by all weather roads like Addis Ababa-Debire Birhan-Dessie-Woldia road, and each sub basin in the study area is accessible by dry weather roads. Generally, the study area has no significant accessibility problem.

Physiography and Drainage

Physiography

The study area is comprised of grabens, which are results of post Precambrian tectonic activity. Since the eastern and western part of the study area is mountainous, physiographically it can be divided in to mountainous and valley filled low-lying areas.

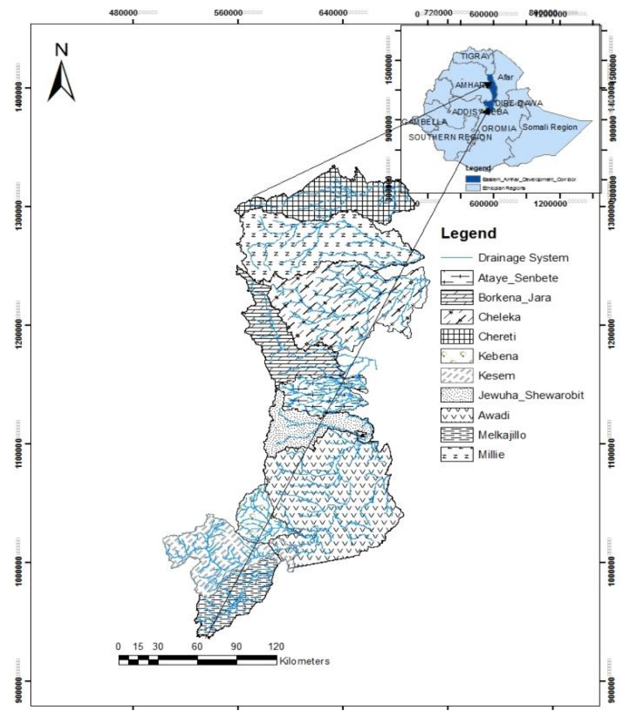


Figure 1: Location map of the study area

The minimum slope in study area is zero percent in some places of Borkena, Melkajilo and Upper Millie Catchments and the maximum slope is 89.5% at Sembete Catchment. The minimum elevation in the study area is 843.7m and the maximum elevation is 3784.45m. The western highlands generally consist of elevated plateaus, but the eastern highlands are rugged. The low-lying areas have flat to undulating topography with some volcanic ridges that separate the sub-basins.

Soil

Soil units of the study area control the hydrology of a catchment through the variation in water holding and transmission capacities. Hence, various soil types in the area have been indicated which are most important to considered and apply the soils hydrological variables over the hydrological analysis of the area. Halcrow (1989) and FAO studies on the soils, land uses and resources of the Awash basin and the whole Ethiopia are used to determine soil types in the study area. There is digital soil and land use map of the study area. The spatial input data were used for groundwater recharge estimation in the Soil Moisture Water Balance model. The textural soil classification as clay, clay loam, silt, silt loam, fine sand and fine sandy loam are important with their corresponding vegetation cover. These are important to determine the available water capacity of the root zone. The major soil units found in the study area are Haplic Xerosols, Euthric Cambisols, Calcaric Flubisols and Vertic Cambisols.

Land Use Land Cover

Land use land cover of the area is one of the important input data source in the hydrological study. The area is dominated by cultivated land of rain fed; cereals land cover system of lightly stocked. Grass land, moderately stocked, unstock, and shrub land, and forest of plantation and natural system of open (20-50%) crown cover and montane coniferous, and open woodland (20-50%) tree cover are also land use land cover units in the study area.

Climate

The spatial variation and temporal variation of rainfall in Ethiopia is strongly controlled by the inter-annual movement of the position of the Inter tropical Convergent Zone (ITCZ) (Tenalem Ayenew and Tamiru Alemayehu,2001). During its movement to the north and south of equator, the ITCZ passes over Ethiopia twice a year and this migration causes the onset and withdrawal of winds from north and south. Similarly the spatial and temporal variation of the project area is influenced by ITCZ. The ITCZ represented a low pressure area of convergence between Tropical Easterlies and Equatorial Westerlies along which wave distributions take place. The big summer rain in the project occurs when the ITCZ is found north of Ethiopia. During this period the project area is under the influence of Equatorial Westerlies from South Atlantic Ocean and southerly wind from Indian Ocean.

Furthermore climate of the study area ranges from warm temperate to cool when it is classified based on altitude. The altitude of the study area ranges from 843 to 3784 meters above mean sea level. Therefore; cool (Kur), cool temperate (Dega), temperate (WeinaDega) and warm temperate (kola) are the climatic classification of the area. The eastern portion of the study area is dominated by lowland i.e. warm temperate and western and south western part of the study area is dominated by highlands and the climate is from cool to cool temperate.

3. Results and Discussions

Monthly meteorological data including rainfall, maximum and minimum temperatures, relative humidity, wind speed and sunshine duration are collected from the National Meteorological Services Agency of Combolcha branch and from different previous reports.. There are a number of meteorological stations in the project area, although data in the stations are with many missing values. In contrast; stations having wind speed and relative humidity data don’t adequately cover the project area. .

Rainfall

The Awash Basin exhibits quite distinct areal patterns of rainfall of the seasonality of rainfall (HALCROW, 1989). Comparison of monthly rainfall at various stations which differ in the amount of rainfall they receive can be done using rainfall coefficient concept. Rainfall coefficient is defined as the mean monthly rainfall divided by 1/12 of the annual mean rainfall. A ‘’rainy’’ month was defined as one with a rainfall coefficient exceeding 0.6, the rainfall coefficient (Gamachu, 1977).

Rainfall coefficient (C) = Pm/(Pannual/12),
Where,
Pm = Rainfall of month ‘m’,
Pannual = annual rainfall.

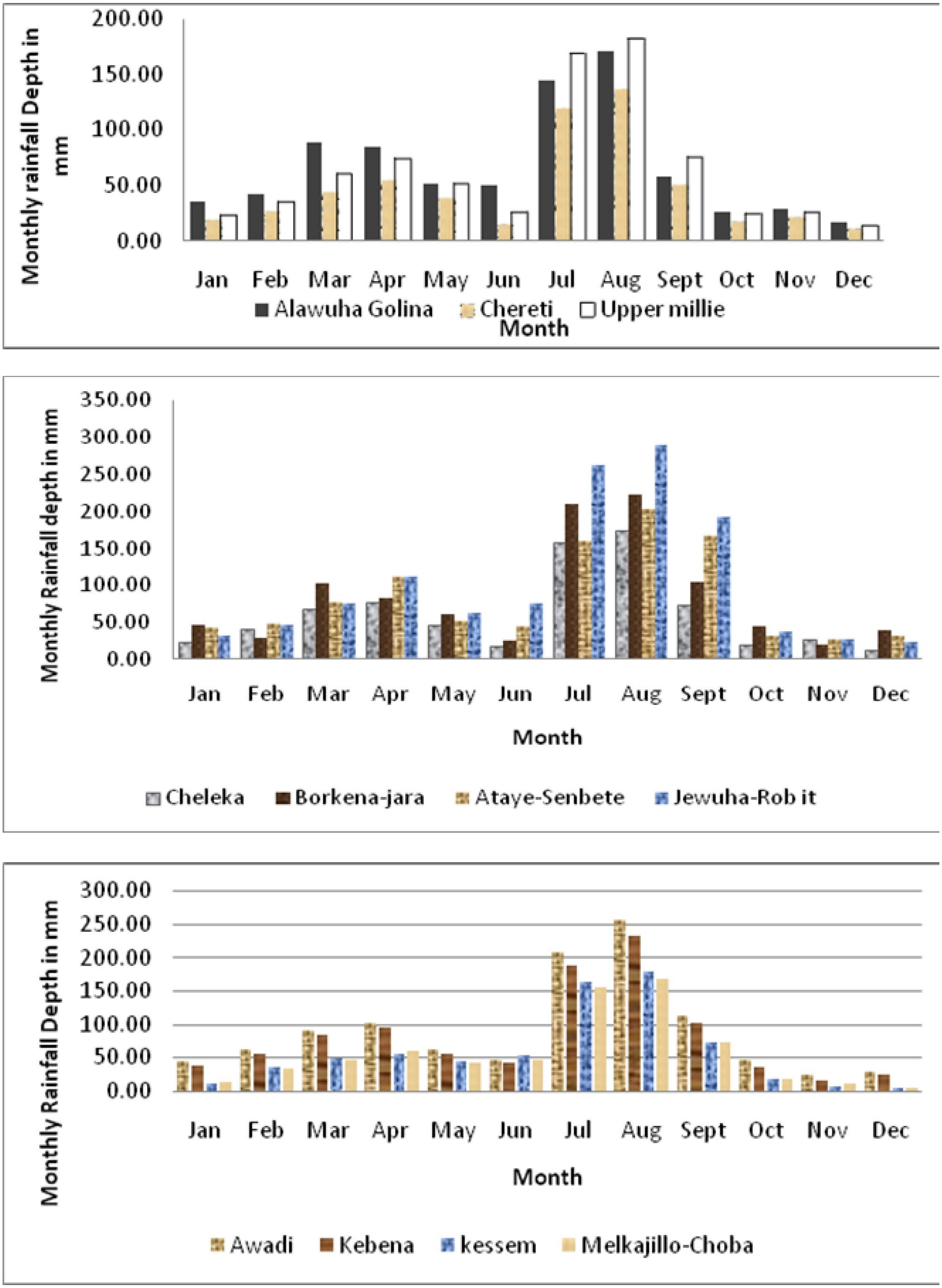


Figure 2: Monthly Areal rainfall depths in mm of sub Catchments in the study area

The quality and consistency of the available rainfall records were checked using methods of double mass curve. The long term mean monthly rainfall of each stations were used to estimate the areal rainfall of the catchments in the study area. Based on the mean monthly rainfall distribution pattern, the project area experiences a nearly bimodal (two peak) rainfall distribution. Two rainy seasons has been experienced.

The main rainy season often extends from end of June through end of September and the small rainy season from end of February to middle of May, the rest of the months are generally dry. The bimodal nature of rainfall distribution in the study area is clearly depicted in the charts (figure 2). The rainfall coefficient of each catchment was calculated and the result showed that in all the catchment the rainy months are July, August, September, April, March, June and May. The months January, February, October, November and December are dry months. Catchments Chereti, Kessem, and Melkajilo have rainfall coefficient greater than 3 either in July or August, therefore; high proportion of the rainfall is received in these two months in the aforementioned catchments. In the other catchments the rainfall coefficients of July, August, April and September are in between 1 and 3 so that, the rainfall is moderate.

Temperature

There is a considerable variation in temperature in the study area (figure 3). In November, mean minimum monthly temperate of 3.2 °C is observed at Debre Birhan, and in June mean maximum monthly temperature of 34.6 °C is observed at Abayatir. Previous studies have indicated that temperature is closely related to altitude (FAO, 1965) as cited in (HALCROW, 1989).

Relative Humidity

The relative humidity (RH) expresses the degree of saturation of the air as a ratio of the actual (ea) to the saturation (e°(T) vapor pressure at the same temperature (T). In the study area the minimum Relative humidity is 35.6% observed in June at Chefa Robit station and the maximum is observed at Enewary in August of 85.5 %.

Sunshine Duration

It is the actual duration of sunshine. In the absence of any clouds, the actual duration of sunshine is equal to the daylight hours (n = N) and the ratio is one, while on cloudy days n and consequently the ratio may be zero. The Awash Basin experiences 2700 hours of sunshine annually, ranging from 2400 hours at Combolcha to 3100 hours at Wonji (HALCROW, 1989). The monthly variation closely follows the rainfall pattern as would be expected with more sunshine hours in the dry months than in the wet months. Larger variations occur on a monthly basis in the highland areas as compared to the lowland areas. In the study area; the maximum sunshine hour is observed at Wogeltena station with 9.86 hours in November and the minimum duration is observed is 4.1 hours in the month of August at Debre Birhan station.

Wind Speed

The process of vapor removal depends to a large extent on wind and air turbulence which transfers large quantities of air over the evaporating surface. As wind speed at a given location varies with time, it is necessary to express it as an average over a given time interval. In the study area, the long term average monthly maximum wind speed is observed at Chefa Robit station in April which is 3.0m/s) while the minimum is observed at Shewa Robit station in the month of January, February, August and September with value of 0.1m/sec. In general the average wind speed is maximum in the dry months and minimum in rainy months. In Debre Birhan the average wind speed is greater than 2m/s for the months of January, February, March, April, May, June, November and December but less than 2m/s in the months, July, August, September and October (Table 15). To the contrary the wind speed is maximum in the months of June, July and August which are in the range of [1, 1.3 m/s] but less than 1m/s in Bati station.

Evapotranspiration

The combination of two separate processes, whereby water is lost on the one hand from the soil surface by evaporation, and on the other hand from the crop by transpiration is referred to as evapotranspiration (ET). Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes.

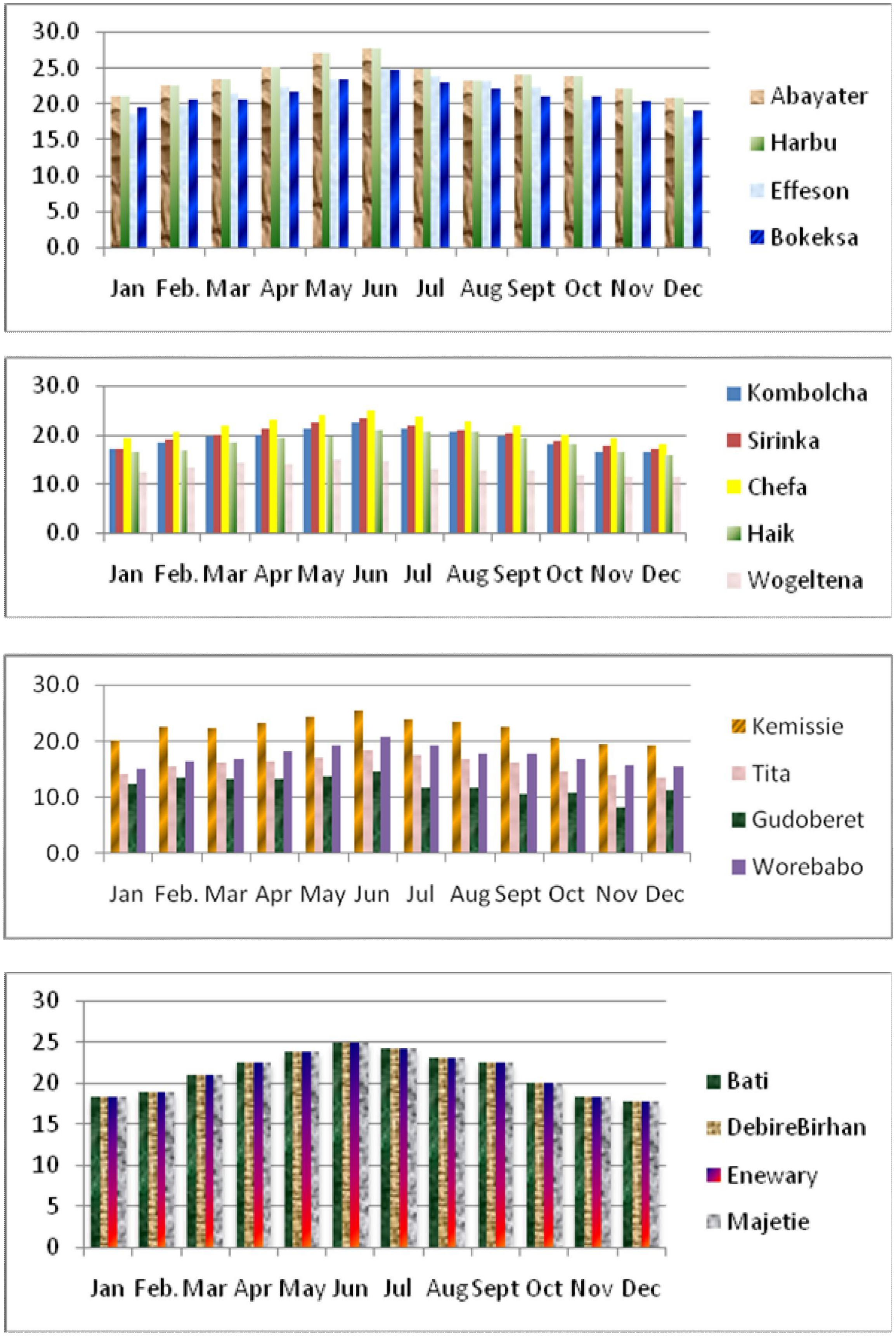


Figure 3: Mean Monthly temperature of Key Stations in the study area

Potential Evapotranspiration

A large number of more or less empirical methods have been developed over the last 50 years by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables. Among the many methods the FAO Penman-Monteith method was used in this study. The equation used to estimate ETo in the study area is displayed below.

$$ETo = 0.408*\Delta*\left((Rn-G)+\gamma*\frac{\left(\frac{900}{T+273}*U2\,(es-ea)\right)}{(\Delta+\gamma*(1+0.34*u2))}\right) \quad (1)$$

Where:

ETo	reference evapotranspiration (mm/day),
Rn	Net radiation at the crop surface (MJm
G	soil heat flux density (MJm-2 day-1)
T	Mean daily temperature at 2m height (°C)
U2	wind speed at 2m height (ms-1)
Es	saturation vapours pressure (kPa),
Ea	actual vapour pressure (kPa),
Es-Ea	saturation vapour pressure deficit (kPa)
Δ:	slope vapour pressure curve (kPa °C)
γ	Psynchrometric constant (kPa

This method was used in PET estimation for first class meteorological stations that include Bati, DebireBirhan, Eneway, Kombolcha, Sirinka, ChefaRobit, Kobo, Wogeltena, Majete, and ShewaRobit. The parameters in the FAO Penman-Monteith equation above, like soil heat flux density (G), saturation vapours pressure (Es), actual vapour pressure (Ea) and net radiation (Rn) were estimated in the spread sheet using the available data at each stations; in this case latitude, altitude, maximum and minimum temperature were used.

In the study area the maximum total monthly potential evapotranspiration estimated using the FAO Penman-Monteith method is 129.3mm at Bati station (in case of Chelka Catchment) in the month of June. Therefore; PET values calculated using the FAO Penman Monthieth Method are used in the water balance evaluation as the method is universally accepted and considers important local meteorological elements. Generally high amount of PET loss is observed in the months of May and June. The spatial variation of evaporation is generally related to altitude of the place. That is evaporation is observed to increase with decrease in elevation whereas rainfall in general increases as altitude increases.

Actual Evapotranspiration

Actual evapotranspiration (AET) - the evapotranspiration from a vegetal cover under natural or given conditions of supply of moisture, or the actual amount of vapor which might be transferred to the atmosphere, depends also on the availability of water to meet the atmospheric demand (Tenalem Ayenew and Tamiru Alemayehu, 2001).It is also one of the variables that should be considered in water balance evaluation of the catchment. The most popular method of computing actual evapotranspiration is through the calculation of potential evapotranspiration. The relationship can be expressed as:

$$AET = PET * f\left(\frac{AW}{AWC}\right) \quad (2)$$

where:

AET	actual evapotranspiration
PET	potential evapotranspiration
f	some function of the term inside the parenthesis,
AW	the available soil moisture = (soil moisture con tent-permanent wilting point)*rooting depth of vegetation (cm),
AWC	the available water capacity of soil= (field capacity- permanent wilting point)*depth of vegetation (cm).

During the months when the rainfall exceeds the potential evapotranspiration, the actual evapotranspiration will be set equal to the potential evapotranspiration.

As described in Shaw (1994), Penman (1950) introduced the concept of 'root constant' that defines the amount of soil moisture (mm depth) that can be extracted from a soil without difficulty by given vegetation.

Hydrological Data Analysis

Data Availability and Quality

Hydrological data of 8 gauging stations, relevant for the study have been collected from ministry of Water Resources. Millie near .PassoMillie, Shewa-Robi, Jewuha near .Jewuha, Ataye, Jara, Borkena near, Kombolicha, are the hydrometric stations in the study area. Although the above hydrometric stations are available in the area, the data availability and quality are not reliable due to non continuity and missing of historical records.

The flow data obtained from the above gauging station were used in the estimation process of water balance components at each sub-basin after proper correction and filling of missed data took place

The missed river flow data in the study area are filled by correlating each other. Flow data of rivers were analyzed for their correlation to fill the missed gaps and correlation. The river flow correlation of each gauged rivers area displayed in table 3 below. The available river flow records were used for estimation of annual and monthly water balance of the study area. For rivers found in the study area without historical records generation of flow from gauged river were taken place. Among the catchments considered in this study Chereti, Cheleka, Sembete, Awadi, Kebena, and Melkajillo, rivers have not historical records as there is no any gauging station in the catchments. Therefore; flow data were generated for the un-gauged catchments from the gauged catchments by considering the catchment geomorphologic parameters like catchment area, basin slope, basin elevation, shape factor, and shape length. The equations used in stream flow data generation for un-gauged catchments using the above geomorphic parameters and area ratio method are displayed below. The geomorphologic parameters of the catchments are shown in Table 1.

$$\text{Flow (ungauged)} = \text{Area (ungauged)/Area(Gauged)} * \text{Flow(gauged)}^n$$

where, n depends on the area ratio between the two catchments, it will be one if this ratio ranges between 0.8 to 1.2 (TIGABU, 2010)

$\text{Flow}_{\text{(ungaged)}} = [(A_{ug} \text{ x } S_{ug} \text{x } E_{ug} \text{x } F_{ug})/(A_g \text{ x } S_g \text{x } E_g \text{x } F_g)] \text{x Flow}_{\text{gaged)}}$ Metaferia Consulting Engineers. (2008).

Where,

Ug	ungauged and
g	gauged for the sub-basins
A	area;
S	slope;
E	elevation and
F	shape Factor.

Table 1. Geomorphologic Parameters of Catchments in the study area

Name of Catchment	Area in Sq. km	Shape length (km)	Average Elevation (m)	Average Slope (%)	Min Slope (%)	Max. Slope (%)
Chereti	376.3	156.9	1603	12.9	0.004	69.9
Upper Millie	265.7	113.3	2200	14.8	0	64.4
Cheleka	1572.5	308.1	1537	13.86	0.0052	67.84
Borkena Kombolcha	284.2	153.7	2356	13.7	0.005	65.1
Borkena nr Swamp	1698.7	406.4	2030	14.2	0	75.3
Jara	252.6	111.5	1924	15.6	0.006	66.3
Ataye	132.5	86.8	1854.7	17.03	0.013	64.2
Sembete	117.6	70.1	1712	13.6	0.003	89.5
Jewuha	485.1	168.0	1845.2	17.1	0.007	69.1
Shewa Rob it	277.5	111.3	1877	15.6	0.011	76.4
Awadi	720.1	195.8	1729	15.5	0.008	77.3
Kebena	1285.9	313.6	1285.9	17	0.012	76.4
Kesem	2845.9	503.3	2139	12.4	0.001	76.8
Melkajilo	2045.2	376.3	1456	5.3	0	66.3

Base Flow Separation

The flow data available in the study area which includes Alawuha, Upper Millie at Passo Millie, and Borkena near Swamp area, Borkena, near Combolcha, Jara, Ataye, Jewuha, and Showarobit, and Kesseme at Arerti, were separated into base flow and surface runoff components. The base flows for each of the river flow data were separated using Automated Base Flow Separation Analysis which uses daily flow values. This was done to get the surface runoff component of the hydrograph of each river as surface runoff component is one of the input variables for WATBL model.

Recharge Estimate Using Soil Moisture Water Balance Program

Determination of groundwater recharges in semi arid and arid climate are neither straightforward nor easy. Main sources of groundwater recharge are rainfall, surface water bodies (ephemeral/ seasonal rivers, lakes, reservoirs) and irrigation losses. Recharge estimation based on water balance is extremely difficult as the quantity to be estimated is small magnitude as compared to the other components such as evaporation, and surface runoff.

Water balance Soil Moisture Program description

The WATBAL Program is used to estimate recharge for 14 reference watersheds Awash Basin) from which rainfall and runoff data are available or generated. A brief description of WATBAL is given below. The WATBAL is soil moisture and water balance program developed by Thornwaite and Mather (1955), which is a simple book-keeping procedure that uses average monthly values of precipitation and potential evapotranspiration. Soil and vegetation characteristics are also combined by the program. It comprises two elements. The first is a water balance component that describes water movement into and out of a conceptualized basin. The second is the calculation of actual evapotranspiration.

Soil moisture calculations

$$Sm = W.exp(-Lam/W) \qquad (3)$$

Where

Sm soil moisture during month M (mm).

Lam accumulated potential water loss at month M (mm).

W available water capacity of the root zone (mm).

And, the monthly change in soil moisture is calculated as

$$d_{sm} = Sm - S(m-1)$$

where d_{Sm} is the difference in soil moisture between month M and month M-1 (mm) and Sm is the soil moisture during month M (mm).

AET (Actual evapotranspiration)

$$AETm = Rm + dSm \qquad (4)$$

AETm actual evapotranspiration during month M (mm)

Rm average rainfall of month M (mm)

d_{Sm} difference in soil moisture between month M and month M-1 (mm)

Catchment Recharge Estimation

WATBAL requires concomitant monthly data of rainfall, runoff, potential evapotranspiration and crop coefficient. In addition to the above mentioned monthly data the spatial distribution of land use-land cover and soil of the study area is required. The land use-land cover and soil data of the area is important to determine the available water capacity of the area. The available water capacity of any area can be determined using a standard table that shows the vegetation and corresponding soil texture after Thornwaite (1955) as cited in (Dunne, 1978).

The water balances of sub basins in Upper Awash River catchment were evaluated using areal depth of rainfalls, record and generated river flows, land use land cover data, soil data, and potential evapotranspiration data calculated from Penman Montheithmethod..Using the spatially distributed land use land cover and soil map of the catchment; the available water capacity is determined and used in Soil Moisture Water Balance accounting program to estimate the monthly and annual recharge in the catchment. In this method of water balance evaluation, actual evapotranspiration and recharge to groundwater are the two most important outputs for which the researcher were interested. Therefore, monthly and annual values of these components were determined for each of the sub-basins and from the analysis most of the precipitation is lost as actual evapotranspiration. The annual water balance analyses of the catchments are displayed in table. The evaluation result showed that from the average annual rainfall of the overall catchment, actual evapotranspirtion accounts 71.24%, the recharge 10.22% and direct runoff 18.49%.

Table 2: Summary of Annual Water Balance (mm) of Catchments in the study area

Name of Catchment	Area in Sq. km	Shape length (km)	Average Elevation (m)	Average Slope (%)	Min Slope (%)	Max. Slope (%)
Chereti	376.3	156.9	1603	12.9	0.004	69.9
Upper Millie	265.7	113.3	2200	14.8	0	64.4
Cheleka	1572.5	308.1	1537	13.86	0.0052	67.84
Borkena Kombolcha	284.2	153.7	2356	13.7	0.005	65.1
Borkena nr Swamp	1698.7	406.4	2030	14.2	0	75.3
Jara	252.6	111.5	1924	15.6	0.006	66.3
Ataye	132.5	86.8	1854.7	17.03	0.013	64.2
Sembete	117.6	70.1	1712	13.6	0.003	89.5
Jewuha	485.1	168.0	1845.2	17.1	0.007	69.1
Shewa Rob it	277.5	111.3	1877	15.6	0.011	76.4
Awadi	720.1	195.8	1729	15.5	0.008	77.3
Kebena	1285.9	313.6	1285.9	17	0.012	76.4
Kesem	2845.9	503.3	2139	12.4	0.001	76.8
Melkajilo	2045.2	376.3	1456	5.3	0	66.3

4. Conclusions

In this hydrological study, analysis and interpretation of hydro-meteorological data in the study area, watershed delineation, catchment geomorphologic characteristics identification, water balance evaluation of 14 watersheds i.e. annual recharge estimation and conceptualization of the effluent and influent type of streams in the study were identified.

From the rainfall data analysis in and around the study area, there are two peak rainfall seasons that is the rainfall pattern is bimodal in nature. The months July, August and September, April, March, June and May are rainy months. July, August, and September are heavy rainfall months, and the months with small rainfall are March, April and May. The months January, February, October, November and December are dry months with rainfall coefficient less than 0.6. The rainfall coefficient ranges from 0.1 to 3.6, in the months of December and July respectively. The rainfall decreases from the highland to the low lands. There is no clear trend of rainfall pattern in the area.

There is a spatial variability in the monthly maximum and minimum temperature. The maximum mean monthly temperature in the study area is observed is 34.7^{o}C at Abayatir and the minimum is 3.2^{o}C at Debire Birhan in the months of June and December respectively. The maximum relative humidity is 85.5% in August at Eneway and the minimum is 35.63% in June at ChefaRobit. Sunshine duration is maximum at Wogeltena in November with 9.9 hours and minimum at DebireBirhan in August with recorded value of 4.1 hours.

The water balance evaluation showed that the annual rechargeable rainfall in the study area ranges from 2.88 % to 13.57%. The Maximum percentage of recharge is at Awadi catchment and the minimum is at Melkajillo catchment. The catchments Awadi, ShewaRobit, Jewuha, Borkena, Upper Millie, Sembete, Ataye, Alawuha, Chereiti and Kebena have recharge in between 9.94 to 13.57 % ,Kesem,Kebena and Cheleka have recharge ranging from 7.51 to 8.54 % and Melkajillo catchment is with very small percentage of recharge i.e. 2.88% .

The recharges are concentrated in the months July, August and some catchments in September. The overall recharge in the whole of the study area accounts 10.22% of the total rainfall. Most of the rainfall lost to the atmosphere as actual evapotranspiration. Direct runoff takes 18.49% of the total rainfall In the study area the evapotranspiration loss ranges from 59.11% to 82.70%. The minimum evapotranspiration loss is at Jewuha catchment.

The total volume of water that is lost as evapotranspiration in the study area accounts is 158385.01MCM(million cubic meter) per year which is 71.24% of the total rainfall and the percentage of water that leaves the catchment as direct runoff is maximum at Kesem River outlet point which is 32.59%. The total volume of water the leaves the study area as direct runoff is 41097.88MCM per year which is 18.49% of total volume of annual rainfall and the rechargeable volume of water in year is 22713.90 MCM which is 10.22%.

The base flow component of effluent rivers, during dry months in the study area are contributed either from the groundwater flows. These are clearly depicted from specific discharges (discharge per unit area). In rivers that gains flows from groundwater have high specific discharge with high catchment area, Borkena Catchment shows this situation, Borkena up stream of Combolcha has low specific discharge but Borkena up stream of Swamp area has a specific discharge of larger value compared to the former one i.e. specific discharge increases as catchment area increases. When we compare the specific discharges of Ataye and Jara with larger watershed area in case of Jara, the specific discharges are smaller in the latter case indicating that the stream is influent (losing). Similar situation is observed in ShewaRobit and Jewuha Catchments.

5. References

Dunne, T. (1978).Water in Environmental Planning . Sanfransisco.

FAO. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements - Irrigation and drainage paper 56. Rome, Italy.

Gamachu, D. (1977). Aspect of Climate Change and Water Budget in Ethiopia.A Technical Monograph for Addis Ababa University. Addis Ababa, Ethiopia: Addis Ababa University Press.

HALCROW. (1989). Master Plan For the Development of Surface Water Resources In Awash Basin; Final Report, Volume 4, Annex A: Climate and Hydrology. Addis Ababa: Ethiopian Valley Development Studies Authority.

Mesfin, S. (2001).Hydrogeological Investigation of the Upper and Middle Borkena River Catchment. Addis Ababa: Addis Ababa University.

Metaferia Consulting Engineers. (2008). Kobo-Girana Pressurized Irrigation System Study and Detailed Design Project; Water Resources, Annex A; Hydrology. Addis Ababa: Monistry of Water Resourcs.

Molla, D. (2000). Hydrology, Hydrogeology and Hydrochemistry of the Lake System Haik- Hardibo. Addis Ababa: Addis Ababa University.

Nigussie, K. (2005). Water Resoureces Potential Evaluation of Beressa River Cachment, in Northern Showa, Amhara Region. Addis Ababa: Addis Ababa University.

Shaw E.M. (1994). Hydrology in Practice.Second Edition, Chapman and Hall, New York, 569pp.

Sileshi M.. (2007). Hydrogeology, Hydrogeochemistry and Isotope Hydrology of Raya and Kobo Valleys, Adjacent Plateau, Escarpment and Part of Afar Rift, Ethiopia: Hydrogeological Mapping, Recharge Evaluation and Water Quality Assessment. Addis Ababa: Ministry of Mines and Enegy.

Silesh., Y. (2002). Estimation of Monthly Reference Evapotranspiration (ETo) for Areas With Inadequate Meteorological Data in Ethiopia. The Ethiopian Journal of Enginners and architects , 19, 21-28.

Tenalem A and Tamiru A. (2001).Principle of hydrogeology. Addis Ababa: Addis Ababa University Press.

TIGABU, T. B. (2010). Water Resources Evaluation With Particular Reference to Groundwater. (T. Ayenew, Ed.) Beau Bassin, Mauritius, Germany: VDM Verlag Dr.Muller Aktiengesllschaft & Co.KG.

Response of Hot Pepper (Capsicum annuum L.) to Deficit Irrigation at Melkassa, Ethiopia

Abdissa Debela[1], Tilahun Hordofa[2] and Yibekal Alemayahu[3]

[1]Bule Hora Univesity
[2]EIAR/MARC, PO Box 346, Nazareth, Ethiopia; tilahun_hordofa@yahoo.com
[3]Haramaya University; PO Box 138, Drre Dawa, Ethiopia;

Abstract

Pepper is one of the most widely grown vegetable crops in the Central Rift Valley of Ethiopia. The increasing scarcity and competition for irrigation water entails adoption of innovative practices that compel efficient water use. In the CRV of Ethiopia rainfall is unreliable and insufficient to support crop production and as a result irrigation is indispensable practice .Deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield. Field experiment was conducted to determine the effects of DI on yield and yield component of hot pepper and estimate water use efficiency of hot pepper at Melkassa Agricultural Research Centre. The experiment consisted of five DI treatments, viz., 10, 20, 30, 40, and 50% DI levels of crop water need and a control treatment of 0.0% DI. The experiment was arranged in a randomized complete block design with three replications. Statistical analysis revealed that except unmarketable fruit yield, all measured parameters were significantly (P<0.05) affected by the levels of DI. Significant delay in maturity and flowering was observed as the DI level decreases. The highest plant height, leaf number, fruit length and ,fruit number per plant were observed from a control treatment and were not significantly different with treatment receiving 90%ETc but significantly different from the all other treatment except quality parameter. The highest & lowest total fruit yield of 5270.7 & 1868.1 kg/ha were observed from a control treatment and treatment receiving 50%ETc, respectively. The DI application of 30%ETc gave the highest IWUE & CWUE of 11.7 & 13.0 kg/ha mm, respectively. Considering the highest water saving and maximum fruit yield, irrigation water application of 30%ET DI level was an optimal irrigation management for pepper production. With this irrigation regime the crop water saved and relative yield reduction were 103.9 mm and 14.1%, respectively.. Therefore, under condition of water shortage, it is better to irrigate Malkazalz hot pepper either with 90% of ETc or 70% of ETc depending on the availability of water resources.
\

Keywords: *Deficit irrigation; Crop water use; Water use efficiency; Hot pepper; Central Rift Valley*

1. Introduction

Pepper (*Capsicum* sp.) is among the major economic importance vegetable crops and the world's second most important of the family after tomatoes (Rubatzky and Yamaguchi, 1997). The pepper production grew worldwide from 11 million in 1990 to 23.2 million metric tons in 2003 (FAO, 2004) of which China was the largest producer, accounting for 50 percent of World production. According to FAO, (2003), the world production of hot pepper was 23.25 million tons of which 2.031 million tons was from African countries. Ethiopia is considered as one of the source of pepper diversity (Engles *et al*., 1991; Hearth and Lemma, 1992; Alemu and Ermias, 2000). The country has a vast potential for production vegetables for domestic and export markets, primarily for the densely populated urban areas such as Addis Ababa, and also for the neighbouring foreign markets such as Djibouti, Somalia and the Middle East (Lemma *et al.*, 1994; Tilahun, 2002; Seifu, 2003).

Climate and soil conditions favour pepper production in the Central Rift Valley (CRV) of Ethiopia. In this area, where vegetable production is widely cultivated as cash crop by small-scale, private and large-scale farmers, rainfall is unreliable and insufficient to support pepper production. Moreover, fruit development takes place in dry season and during the season irrigation is an indispensable practice to ensure stable yields of high quality pepper.

The crop requires adequate water supply and relatively moist soils during the total growing period. Reduction in water supply during the growing period in general has an adverse effect on yield and the greatest reduction in yield occurs when there is a continuous water shortage until the time of first peaking.

The period at the beginning of the flowering period is most sensitive to water shortage. Water shortage just prior and during early flowering reduces the number of fruits.

Controlled irrigation is essential for high yields because the crop is sensitive to both over and under irrigation (Doorenbos and Kassam, 1979).

As local water resources are increasingly scarce, more efficient water usage in agriculture is important. Since many farmers in this area now do not have enough water to meet the seasonal water requirements of many crops, maximizing the yield produced per unit of water under deficit irrigation conditions is becoming crucial to the long-term viability of the regional economy. Deficit irrigation has frequently been suggested as an alternative strategy for making better use of the available irrigation water.

Deficit irrigation is a practice of irrigating in an amount below that of the plant's maximum water demand. A variety of crops have been found to benefit from deficit irrigation strategy (Karam et al., 2003, 2005, 2006). Deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield (English and Nakamura, 1989; English and Raja, 1996; Mugabe and Nyakatawa, 2000; Bazza, 1999; Ghinassi and Trucchi, 2001; Kirda, 2002; Mao et al., 2003; Panda et al., 2003; Zhang et al., 2004).

Drip irrigation is one of the most efficient forms of irrigation technology. It is slow and frequent application of small amounts of water through emitters or tiny holes spaced along polyethylene tubing. With drip irrigation, it is possible to apply light and frequent irrigation. Growers of high-value crops, such as tomato, pepper, strawberry, and melons, were among the first to embrace this technology.. The experience from many countries show that farmers who switch from furrow system to drip systems can cut their water use by 30% to 60% and crop yields often increase at the same time. (Sijali, 2001).

The objective of this study was to (1) To determine the effects of different deficit irrigation levels on yield of hot pepper and (2) To estimate water use efficiency of hot pepper under different level of deficit irrigation.

2. Methodology

The study area

The study was conducted at Melkassa Agricultural Research Center (MARC) of Ethiopian Institute of Agricultural Research (EIAR) which is situated in CRV of Ethiopia (8^0 24' N lat. 39^0 21' E log. 1550 m a.s.l.). The climate of the location is arid to semi-arid type with mean monthly maximum and minimum temperature of 28.5ºC and 12.6ºC, respectively. The average annual rainfall in the area is about 768 mm with a mono-modal rainfall pattern, and the mean maximum and minimum temperatures are 28.5ºC and 12.6ºC, respectively The dominant soil textures of the area is clay loam soils (Tilahun *et al.*, 2004).

Experimental design and data collection

The experiment was laid out in a Randomized Compete Block Design (RCBD) with three replicates. The treatments consisted of five soil moisture deficit levels, viz., 90% ETc (10% deficit); 80% ETc (20% deficit); 70% ETc (30% deficit); 60% ETc (40% deficit) and 50% ETc (50% deficit) and a control treatment of 100% ETc (no deficit).

Pepper variety Melkazala was seeded on nursery and transplanted to field plots (2.8 m X 4.2 m) containing four rows of pepper crop with row length of 4.2 m. The inter plant and inter- row spacing were 30 cm and 70 cm, respectively. Drip irrigation system was used for applying the required quantity of irrigation water. Irrigation water was applied at allowable soil moisture depletion (p = 0.25) from effective root zone depth (Doorenbos and Kassam, 1979).

Data collected comprised plant height, leaf number, number of branches per plant, number of fruits per plant, fruit yield and yield component that include fruit weight, length, number of fruits per plant, marketable and unmarketable fruit yield. Water productivity and effect of water stress on crop performance were quantified from WUE and yield response factors (ky), respectively. Estimation of WUE was carried out as a ratio of total bulb yield to the total water applied and expressed as:

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

$$\mathbf{ETc = I + Re + \Delta S - D + Ge}$$

$$WUE\ \ (kgmm^{-1}) = \frac{Total\ \ bulb\ yied\ (kg)}{Crop\ \ water\ use\ (mm)}$$

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

Table 1: Soil moisture contents before and after irrigation events and net irrigation requirement

Treatment	Soil moisture contents /SMC (mm)								
	Depth of soil (cm)								
	0-30			30-45			45-60		
	Before irrig.	**After irrig.**	**Net irrigation**	**Before irrig.**	**After irrig.**	**Net irrigation**	**Before irrig.**	**After Irrig.**	**Net irrigation**
100% ETc	48.1	51.35	3.25	99.09	107.5	8.44	175.6	196.5	20.9
90% ETc	48.1	51.03	2.93	99.09	106.7	7.60	175.6	194.4	18.9
80% ETc	48.1	50.70	2.60	99.09	105.8	6.75	175.6	192.3	16.8
70% ETc	48.1	50.38	2.28	99.09	105.0	5.91	175.6	190.3	14.7
60% ETc	48.1	50.05	1.95	99.09	104.2	5.06	175.6	188.2	12.6
50% ETc	48.1	49.73	1.63	99.09	103.3	4.22	175.6	186.1	10.5

ky was estimated from the relationship:

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

where:
- Ya = actual harvested yield
- Ym = maximum harvested yield
- ky = yield response factor
- ETa = actual evapotranspiration
- ETm = maximum evapotranspiration

All measured variables were subjected to analysis of variance appropriate for RCBD. Whenever treatment effects were significant, Least Significance Differences (LSD) test was used to assess the mean difference among treatments. MSTATC soft ware was used for analysis of variance.

3. Results

The response of hot pepper to deficit irrigation was statistical significant ($P<0.05$) for all measured parameters except for unmarketable fruit yield. In all case control irrigation application (100%ETc) and DI at 50%ETc application respectively gave the highest and lowest measured values except for unmarketable fruit yield. The data on Table 2 to 8 provide measured plant physiological parameters and measured yield and yield parameters of hot pepper.

Days to flowering and maturity

Days to flowering and maturity have shown no significant different between control and 90%ETc applications, but significantly different to all other treatments. These treatments took longer time to flowering and maturity days (Table 2). Irrigation application at 50 and 60%ETc took shorter time to flowering and maturity days and had no significantly difference between them.

Plant height and growth parameters

The plant height ranged from 50 and 36cm. The highest and lowest plant height was observed from treatment receiving 100%ETc and 50%ETc, respectively (Table 3). However, no significant difference was observed between control and 90%ETc application. Irrigation application of 60%ET gave below the average plant height and was not significantly different to 50%ETc application.

Table 2: Effect of deficit irrigation on flowering and maturity days of pepper after transplanting

Irrigation treatment	FDAT	MDAT
100%ETc	84.3a	135.3a
90%ETc	83.0a	134.7ab
80%ETc	81.0b	132.0b
70%ETc	79.7b	127.7c
60%ETc	76.3c	125.7cd
50%ETc	75.3c	123.7d
SE ±	1.0	2.30
CV (%)	1.3	1.2
Mean	79.9	129.8
LSD (5%)	1.8	2.8

FDAT – Flowering days after transplanting, MDAT - Maturity days after transplanting
Values carrying same letter within a column are not significantly different at 5%

Leaf number and number of primary and secondary branches per plant were affected significantly (P<0.05) by level of deficit irrigation. The leaf number, number of primary and secondary branches per plant significantly (P < 0.05) decreased as deficit irrigation level increased. The control treatment gave the highest number and was not significantly different to 90%ETc application. Deficit irrigation application of 50%ETc gave the lowest number and is not significantly different to 60%ETc application (Table 3).

Table 3: Effect of deficit irrigation on plant growth parameters

Irrigation treatment	PH (cm)	LN	PBP	SBP
100%ETc	50.2a	200.2a	11.3a	14.9a
90%ETc	46.2ab	186.7ab	11.3a	14.0abc
80%ETc	43.6b	181.3b	9.9b	12.7bc
70%ETc	43.4b	181.3b	10.0b	14.1ab
60%ETc	38.0c	154.5c	9.3b	12.4c
50%ETc	36.0c	137.3c	8.8b	12.4c
SE ±	7.9	104.3	0.5	0.8
CV (%)	6.54	5.9	7.0	6.6
Mean	42.9	173.5	10.1	13.4
LSD (5%)	5.1	18.6	1.3	1.6

PH-Plant height, LN-Leaf number per plant, PBP-Primary branches per plant and SBS-Secondary branches per plant
Values carrying same letter within a column are not significantly different at 5%

Yield and yield parameters

Fruit length and width were highest for the control treatment and these were not significant different to treatment receiving 90 and 80%ETc. The highest fruit weight was also recorded from the control treatment and this was not significantly different to treatments receiving 70, 80 and 90%ETc. In all case, the least was measured from treatment receiving 50%ETc and had no significant difference with treatments receiving 60% ETc (Table 4).

Fruit number per plant and total fruit per plant were significantly (p<0.05) affected by the level of deficit irrigation. The highest and lowest number of fruits per plant was obtained from the control and 50%ETc application, respectively. These are not significantly different from 90 and 60%ETC, respectively. The highest and lowest total fruit per plant was also recorded from the control and 50% ETc application, respectively. These are significantly different to all other treatments (Table 5) .

The total and marketable fruit yield were highest for the control treatment and these were significantly (P<0.5) different to all other treatments. The least total and marketable fruit yield was recorded from treatment receiving 50%ETc and significantly different to all other treatments.

Table 4: Effects of deficit irrigation on fruit length, width and fruit weight of pepper

Irrigation treatment	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)
100%ETc	17.9a	1.5a	9.2a
90%ETc	17.6a	1.5a	9.4a
80%ETc	17.1a	1.5a	9.1a
70%ETc	16.3b	1.4b	8.6ab
60%ETc	15.6bc	1.3c	7.8bc
50%ETc	15.4c	1.3c	7.2c
SEm±	0.2	0.001	0.2
CV%	2.7	2.69	5.4
Mean	16.6	1.40	8.5
LSD(5%	0.8	0.06	0.8

Values carrying same letter within a column are not significantly different at 5%

Table 5. Effects of deficit irrigation on fruit number and total fruit per plant

Irrigation treatment	FN (No/plant)	TFPP(g)	Fruit reduction
100%ETc	20.0a	144.9a	0.0
90%ETc	16.5ab	93.0b	3.5
80%ETc	13.7bc	81.2b	6.5
70%ETc	14.5bc	77.0b	5.5
60%ETc	12.6cd	70.1b	7.4
50%ETc	9.4d	43.4c	10.6
SE ±	4.5	159.6	
CV%	14.7	14.9	
Mean	14.4	84.9	
LSD(5%	3.9	23.0	

FN-Fruit number, TFPP-total fruit per plant
Values carrying same letter within a column are not significantly different at 5%

However, a 10% water deficit gave the next highest total and marketable fruit yield and this had no significant difference with 80 and 70%ETc application. Unmarketable fruit yield was not affected by the level of deficit irrigation. The highest and lowest unmarketable fruit yields were recorded from 90 and 50%ETc application (Table 6).

Table 7 shows water-use efficiencies, yield reduction and water saved for total fruit yield. The control treatment resulted in higher WUEs and practically had no much difference with 70%ETc application. With 70% ETc application the water saved was 103.9mm. The lowest WUE was recoded from treatment receiving 50%. Nevertheless, the difference in WUE among treatments is very small except for 50%ETc application.

Observed yield response factors (Ky) ranged between 1.0 and 2.4 for pepper. The lowest and highest ky values were obtained from 70% and 90% ETc applications, respectively. The ky observed seems decreasing as irrigation water application decreased except for treatments receiving 50 and 60% application,

Table 6: Effect of deficit irrigation on fruit yield, marketable and unmarketable fruit yield of pepper

Irrigation treatment	TFY	MY	UMY
100%ETc	5270.7a	4350.2a	920.5a
90%ETc	4139.9b	3089.6b	1050.3a
80%ETc	3715.7bc	2751.6b	964.3a
70%ETc	3856.9b	2990.5b	866.5a
60%ETc	3257.5c	2191.5c	766.0a
50%ETc	1868.1d	1386.4d	481.7a
SE ±	75662.1	42893.2	44566.8
CV%	7.5	7.4	25.1
Mean	3684.8	2793.3	841.5
LSD(5%	500.4	376.8	384.1

TFY-Total fruit yield, MY-Marketable yield, UMY-Unmarketable yield
Values carrying same letter within a column are not significantly different at 5%

Table 7: Average applied water, crop water use and irrigation water use efficiency of hot pepper

Irrigation treatment	Yield Kg/ha	irrigation (mm)	ETc (mm)	IWUE Kg/mm	CWUE Kg/ mm	Yield reduction (%)	Water saved (mm)
100%ETc	5270.7	446.2	401.6	11.8	13.1	0	0
90%ETc	4140.0	407.0	366.3	10.2	11.3	11.3	35.3
80%ETc	3715.7	368.6	331.7	10.1	11.2	15.6	69.9
70%ETc	3856.9	330.8	297.7	11.7	13.0	14.1	103.9
60%ETc	3257.5	293.6	264.3	11.1	12.3	20.1	137.4
50%ETc	1868.1	257.0	231.3	7.3	8.1	34.0	170.3

Table 8: Relative yield decrease, Relative ETc deficit and yield response factor for pepper

Treatment	Fruit yield(Kg/ha)	CWR/IRn	1-Ya/Ym	1-ET a/ETm	Ky
100%ETc	5270.7	401.6	0.00	0.00	-
90%ETc	4139.9	366.3	0.21	0.09	2.4
80%ETc	3715.7	331.7	0.30	0.17	1.7
70%ETc	3856.9	297.7	0.27	0.26	1.0
60%ETc	3257.5	264.2	0.38	0.34	1.1
50%ETc	1868.1	231.3	0.65	0.42	1.5

Conclusions

- Except unmarketable fruit yield, all measured parameters were significantly ($P<0.05$) affected by the levels of DI
- The control treatment and 50%ETc application gave the highest and lowest measured values except for unmarketable fruit yield
- Significant delay in maturity and flowering was observed as the DI level decreases.
- Increasing the level of deficit irrigation decreased plant height and other plant physiological parameters as well as crop yield and yield parameters
- The control treatment resulted in higher WUEs and practically had no much difference with 70%ETc application
- With 70% ETc application the water saved was 103.9mm
- Observed yield response factors (Ky) ranged between 1.0 and 2.4 for pepper
- Generally, Ky>1 in this situation indicate the crop is most sensitive to soil moisture stress
- Under condition of water shortage, it is better to irrigate Malkazalz hot pepper either with 90%ETc or 70%ETc depending on the availability of water

4. Reference

Alemu Hailiye and Ermias Abate, 2000. Horticultural crops production and associated constraints in Northwest Ethiopia. Working Paper. Agricultural Economics Research Division. Agricultural Research Center, Adet. pp.18.

Bazza, M., 1999. Improving irrigation management practices with water-deficit irrigation. In: Kirda, C., Moutonner, P., Hera, C., Nielsen, D.R. (Eds.), Crop Yield Response to Deficit Irrigation, Developments in Plant and Soil Sciences, vol. 84. Kluwer Academic Publishers, pp. 21–38.

Doorenbos, J. and A.H. Kassam, 1979. Yield response to water. *FAO Irrigation and Drainage paper* 33, Rome, Italy.

Engles, J.M.M., J.G. Hawkes and Melaku Worede, 1991. Plant genetic resource of Ethiopia. Cambridge University press, Cambridge, UK. p. 126.

English, M., and B. Nakamura, 1989. Effects of deficit irrigation and irrigation frequency on wheat yields. J. Irrig. Drain. Eng. 115 (2), 172–184.

English, M. and S.N. Raja, 1996. Perspectives on deficit irrigation. Agric. Water Manage. 32 (1), 1–14.

FAO (Food and Agricultural Organization), 2003. Production Year Book: FAO, Rome, Italy. Vol. 56.

FAO (Food and Agricultural Organization), 2004. FAOSTAT database result for chilies and peppers.*http://apps.fao.org/cgi-bin/nph-db.pl*. Accessed on 3/10/2008.

Ghinassi, G. and P. Trucchi, 2001. Deficit irrigation trials on maize in a Mediterranean semi-arid environment. Int. Water Irrig. 21 (1), 12–17.

Hearth, E. and Lemma Desalegn, 1992. Horticulture research and development in Ethiopia. Proceedings of the 2nd National Horticultural workshop of Ethiopia. 1-3 December 1992. IAR.Addis Ababa. pp. 24.

Karam, F., J. Breidy, C. Stephan, and Y. Rouphael, 2003. Evapotranspiration, yield and water use efficiency of drip irrigated corn in the bekaa Valley of Lebanon. Agric. Water Manage. 63, 125–137.

Karam, F., R. Lahoud, R. Masaad, A. Daccache, O. Mounzer and Y. Rouphael, 2006. Water use and lint yield response of drip irrigated cotton to the length of irrigation season. Agric. Water Manage. 85, 287–295.

Karam, F., R. Masaad, T. Sfeir, O. Mounzer and Y. Rouphael, 2005. Evapotranspiration and seed yield of field grown soybean under deficit irrigation conditions. Agric. Water Manage. 75 (3), 226–244.

Kirda, C.R., 2002. Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. In: Deficit Irrigation Practices, FAO Water Reports 22, pp. 3–10.

Lemma Desalegn, H. Edward, Terefe B., Berga L. and. Seifu G, 1994. Horticultural research: Past, Present and Future Trends. Proceedings of the second national horticultural workshop of Ethiopia. IAR/FAO, Addis Ababa.

Mao, X., M. Liu, X. Wang, C. Liu, Z. Hou and J. Shi, 2003. Effects of deficit irrigation on yield and water use of greenhouse grown cucumber in the North China Plain. Agric. Water Manage. 61, 219–228.

Mugabe, F.T. and E.Z. Nyakatawa, 2000. Effect of deficit irrigation on wheat and opportunities of growing wheat on residual soil moisture in southeast Zimbabwe. Agric. Water Manage. 46, 111–119.

Panda, R.K. S.K. Behera and P.S. Kashyap, 2003. Effective management of irrigation water for wheat under stressed conditions. Agric. Water Manage. 63 (1), 37–56.

Rubatzky, V.E and M. Yamaguchi, 1997. World vegetables: principles, production and nutritive values, 2nd edition, Chapman and Hall International, Thomson Publishing, New York. pp.843.

Seifu G., 2003. Status of commercial fruit production in Ethiopia. *In* Proceeding of the second horticultural workshop of Ethiopia, Ethiopian Agricultural Research Organization, Addis Ababa.

Sijali, I. V., 2001. Drip irrigation: Options for smallholder farmers in Eastern and Southern Africa. RELMA Technical Hand Book Series 24. Nairobi, Kenya.

Tilahun, S., 2002. The improvement of the shelf life of vegetables through pre and postharvest treatment. Ph.D. Dissertation presented to the University of Free State. South Africa. pp. 270.

Zhang, Y. E. Kendy, Y. Qiang, L. Changming, S. Yanjun and S. Hongyong, 2004. Effect of soil water deficit on evapotranspiration, crop yield, and water use efficiency in the North China Plain. Agric. Water Manage. 64, 107–122.

Evaluating Factors Affecting Phosphorus Removal and Recovery from Wastewater using Fluidized Bed Reactor

Awoke Guadie[1] and Siqing Xia[2]

1. UNEP-Tongji Institute of Environment for Sustainable Development, College of Environmental Science and Engineering, Tongji University, Shanghai 200092, China. *E-mail:awokeguadie@gmail.com*
2. State Key Laboratory of Pollution Control and Resource Reuse Research, College of Environmental Science and Engineering, Tongji University, Shanghai 200092, China. *E-mail: siqingxia@mail.tongji.edu.cn.*

Abstract

Phosphorus, an important element for life and fertilizer industry is stated to be exhausted shortly in the near future. On the contrary, large quantity of phosphorus in wastewater is considered to be one of the main causes of eutrophication which negatively affects many natural water bodies. Thus, phosphorus removal and recovery from wastewater as struvite is a more sustainable approach that consolidates these issues. Although struvite is a promising phosphorus recovery method, its application is still an infant stage. This is mainly due to various precipitation and crystal growth influencing factors. Therefore, the objective of this research was developed to evaluate the impact of different parameters affecting fluidized bed reactor performance of phosphorus removal and recovery from wastewater. By considering various conditions, laboratory experiments have been performed using appropriate tools and standard methods. The results showed that phosphorus removal was increased with increasing pH and Mg:P molar ratio. To achieve more than 90% of phosphorus removal efficiency, pH ⩾9 and Mg:P molar ratio ⩾1.25:1 was required. Phosphorus removal efficiency was also enhanced when the fluidized bed reactor received feed from an external recycler. In order to achieve more visible precipitate and nearly 90% phosphorus removal efficiency, 12 hours contact time was also required. Furthermore, Scanning Electron Microscope, X-ray diffraction and chemical composition results revealed that the precipitate harvested in the fluidized bed reactor was struvite. The purity of the crystal qualifies the theoretical value of struvite. Overall, the results of contact time, pH, external recycler and Mg:P molar ratio were found to be the potential factors that affect the efficiency of phosphorus removal and recovery in fluidized bed reactor.

Keywords*: Efficiency, Recovery, Removal, Struvite, Sustainable*

1. Introduction

The simultaneous depletion of natural rock phosphorus (P) resource available for phosphate industry and the increasing awareness of pollution problems due to phosphorus discharge in wastewater effluent (Shu *et al.*, 2006) have led to research in to new process to remove and recover phosphorus from effluents.

Phosphorus which is vital to life and fertilizer industry is reported to be exhausted < 100 years (European Fertilizer Manufacturers Association, 2000; Isherwood, 2000; de-Bashan and Bashan, 2007) with a current exploitation rate of 1.5 % each year (Steen, 1998). It is estimated that there are 7000 million tons of phosphate rocks as P_2O_5 remaining in reserves that could be economically mined and human population consumes 40 million tons of P as P_2O_5 each year (Florida Institute of Phosphate Research, 2005; Steen, 1998). Moreover, 80 % of global phosphate reserve located only in four countries (Morocco, China, South Africa and United State of America) and unable to recycle in natural ecosystem more aggravate the question of phosphorus future sustainability (USGS, 2005; Mavinic, 2011).

Furthermore, the release of phosphorus to surface waters and its consequent contribution to eutrophication have led to increasing concerns about water quality sanitation. Policies are therefore being implemented globally to reduce the levels of phosphorus entering the surface waters from domestic and industrial wastewater for the betterment of ecological health. So far in traditional methods, phosphorus treatment was done fixing it with either by using chemical precipitation (using iron or aluminum salts) or utilizing enhanced biological phosphorus removal processes (Mulkerrins *et al.*, 2004). Both processes are efficient as they are capable of reducing phosphorus concentration in treated effluent below $1 mgL^{-1}$as required by most regulatory legislations (example, European legislation) (Adinan *et al.*, 2003).

However, the very tricky nature of traditional method is that after treatment has been made phosphate bioaccumulation and high sludge volume becomes a big problem (Woods *et al*., 1999). The sludge wasted from biological nutrient removal, if anaerobically digested, will rehydrolyse the polyphosphates, consequently releasing magnesium and phosphate ions into the solution (Jardin and Popel, 1996). It is estimated that as much as 80–90% of phosphorus removed during treatment may be released and reintroduced to the process from the digester supernatants. This can lead to potential process failure (Mavinic *et al*, 1998).

Currently, phosphorus removal and recovery from wastewater as viable sustainable approach gets the attention of many researchers (Driver *et al.*, 1999; Greaves *et al.*, 1999; Dastur, 2001; Burns and Moody, 2002; Doyle and Parsons, 2002, Adinan *et al.*, 2003; Britton *et al.*, 2005). In many developed countries, research is underway to recover phosphorus from the potential wastewater sources such as municipal, agricultural and other biological systems. Japan is a leader in establish full-scale P-recovery plants and marketed to fertilizer industries (Doyle and Parsons, 2002). It is mentioned that recovering 10-80% of phosphorus from wastewater is economically feasible and the product quality is superior to currently available phosphate rock (de-Bashen and Bashan, 2007).The most promising compound for recovery of phosphorus from wastewater is struvite.

Struvite is an orthophosphate, containing magnesium, ammonium, and phosphate in equal molar concentrations. The general formula for struvite precipitation is given by equation 1 (with n = 0, 1, and 2) (Corre *et al.*, 2005; Fattah *et al.*, 2008)]:

$$Mg^{2+} + NH_4^+ + H_nPO_4^{n-4} + 6H_2O \rightarrow MgNH_4PO_4.6H_2O + nH^+ \quad \text{(Equation 1)}$$

Struvite crystallization can be achieved with various plant configurations but fluidized-bed reactors (FBR) appear to be of particular interest (Dastur, 2001; Adinan, 2003; Britton *et al.*, 2005) and their utilization is widespread in the field of nutrient removal (Fujimoto *et al.*, 1991).

Although struvite crystallization is promising, phosphorus recycling from wastewaters has not been widely adopted. This is mainly due to a number of factors including pH control, magnesium concentration, retention time, presence of foreign ions and seed materials (Ohlinger, 1999; Corre *et al.*, 2005). Moreover, lack of proven technologies currently available for phosphorus recovery at low cost also a challenge (Yaffer *et al.*, 2002). The focus of this work was considering these issues.

2. Research Objectives

The main objective of this work was to **evaluate factors which affect the removal and recovery of phosphorus from wastewater using FBR**. In order to achieve this goal, FBR was designed and evaluated under different pH, Mg:P molar ratio and external pump flow rate.

3. Materials and Methods

Reactor design and operation

To study struvite nucleation and growth, FBR was designed at Tongji University, College of Environmental Science and Engineering. The reactor has three parts made of transparent polyvinyl chloride plastic. The bottom, middle and top parts have different length, volume and diameter in which the later increased from bottom to top (Table 1 and Figure 1). The total volume and height of the reactor is about 9.5 liter and 1.1 meter.

Since the reactor design follows the concept of fluidized bed, the cross-sectional area and upflow velocity differ in the three parts (Table 1). Area and upflow velocity of the reactor was competed by applying equation 2 and equation 3 (Dastur, 2001). While the liquid moves up from bottom to top, upflow velocity were created which progressively decrease in FBR (Adinan *et al*., 2003).

$$A = \pi r^2 \qquad (Equation \quad 2)$$

$$Upflow\ velocity = \frac{Q}{A} \qquad (Equation\ 3)$$

Where,
A = area, r^2 = Radius and Q= Flow rate (in this case considered constant 72 $ml \cdot min^{-1}$)

As part of FBR system, an external recycler (height 84 cm and volume 13 liter) constructed from the same transparent material and different tanks (60 liter each) were used during this study. Wastewater was fed into the bottom of the reactor along with the recycle stream using pumps which could be adjustable up to 100 revolutions per minute (rpm). Before, a continuous mode of operation was functional, the flow rate capacity of each pump was checked (1rpm=3$ml \cdot min^{-1}$) by allowing the liquid drop to measuring cylinder for one minute.

Table 1: The dimensions and working condition of FBR

Parts	Length (mm)	Diameter (mm)	Volume (ml)	Area (mm^2)	Upflow Velocity ($mm \cdot min^{-1}$)
Top	220	170	4440	22686.5	$3.2x10^{-3}$
Middle	535	100	4142	7850	$9.2x10^{-3}$
Bottom	340	60	884	2826	$2.55x10^{-2}$

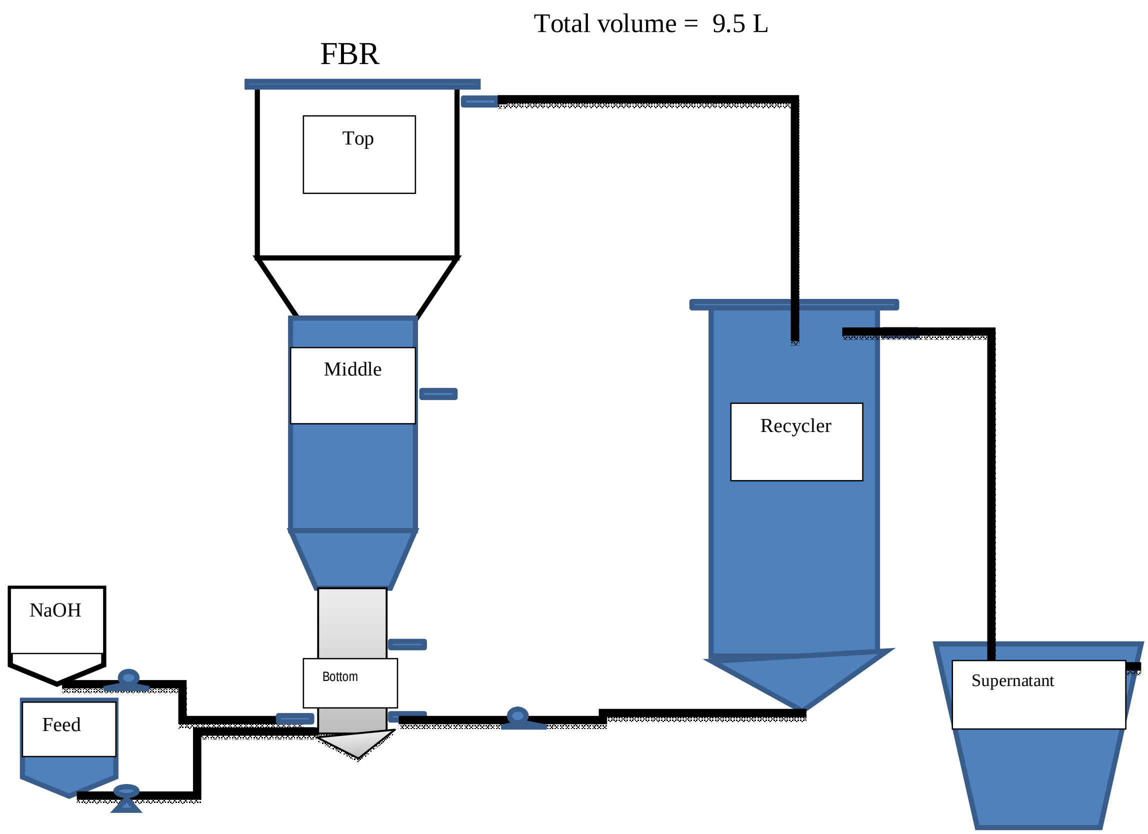


Figure 1: Fluidized bed reactor units

The whole system was operated in a continuous mode in that feed and NaOH supplied to the FBR at the bottom ports. Then, the liquid moves-up (fluidized) on different cross-sectional areas where crystals progressively getting larger and larger. As time elapsed, the bigger precipitates withstanding the turbulence get down and accumulated at the bottom section.

The liquid plus very fine precipitates were down flow from FBR to external recycler through plastic tube fitting. Finally, the system was allowed external recycler return portion of the effluent to FBR with pump and the remaining liquid volume to the supernatant tank connected by tube at the top part of the external recycler (Figure 1).

Chemicals

Synthetic feed water containing the constituent ions of struvite was used as an influent. The reason why we used synthetic waste is due to the need for optimizing the working condition of the new FBR.

The salts used to make the synthetic feed were commercial-grade magnesium chloride hexahydrate ($MgCl_2.6H_2O$), potassium dihydrogen phosphate (KH_2PO_4) and ammonium chloride (NH_4Cl). The feed was prepared by using tape water. Summary of synthetic feed and tape water constituent is given in Table 2.

pH control

Since struvite formation is highly dependent on pH in the reactor, commercial grade sodium hydroxide (NaOH) was separately prepared and feed to the FBR. However, different pH increasing methods were stated NaOH, selected in this study was due to its more effectiveness recommended by different scholars (Fujimoto *et al.*, 1991; Adinan *et al*., 2003, Fattah *et al.*, 2008).We used low concentration of NaOH (0.0125N) based on our preliminary work of pH control achieved easily to the required range. When we used 0.1 and 0.2 N NaOH recommended concentration, manipulating the pump head to the required range founds difficult. Samples were taken at each part of the reactor zone and measured using pH meter. Whenever, pH deviation was observed, the pump head rpm was adjusted to raise or lower the value.

Sampling and analyses

Influent and effluent samples were collected daily for chemical analysis. The constituents of magnesium (Mg), ammonia-nitrogen (NH_4^+-N) and orthophosphate (PO_4^{3-}-P) were analyzed following standard methods. While NH_4^+-N and PO_4^{3-}-P were analyzed using UV-visible spectrophotometer (UV 1700, Shimadzu), magnesium was analyzed using flame atomic absorption spectrophotometry (PE-AA400, Perkin Elmer, USA).

The concentration of aluminum, calcium, iron, potassium and sodium was measured using an Inductively Coupled Plasma-Optimal Emission Spectrophotometer (ICP-OES) (ICP-720ES, Agilent, USA) (Table 2).

Table 2.Synthetic feed and tape water ICP-OES measured average results.

Table 2: Synthetic feed and tape water ICP-OES measured average results

	Feed			Tape water				
Chemical	KH_2PO_4	$MgCl_2.6H_2O$	NH_4Cl	Ca	Al	Fe	Na	K
Value(mg· L^{-1})	55	62-145	160	2.65$\pm$0.75	*	*	13.2$\pm$0.05	2.6$\pm$0.01

Phosphorus removal efficiency

The primary objective of this research was evaluating the phosphorus removal efficiency of the FBR. For monitoring the removal efficiency, the idea of mass balance was used to compute removal percentage (Adinan *et al.*, 2001, Brittion *et al.*, 2005; Fattah *et al.*, 2008):

$$P-removal(\%)=\frac{(P_{ifluent}-P_{effluent})}{P_{influent}}\times 100 \qquad (eq.\ 4)$$

Where *P* influent= Concentration of PO_4^{3-}-P at the inlet and *P*effluent = Concentration of PO_4^{3-}-P in the effluent

Crystal harvest procedure and analysis

Products were harvested from the reactor after the feed, recycle and chemical feed flows were stopped and then crystals were allowed to settle on the bottom part. To remove the crystals for harvesting, the valve was opened and the crystals were allowed to fall into a beaker. The harvested crystals were then air dried at room temperature before analysis.

Crystal product analyses

Samples of harvested crystals were dissolved in a 0.5% nitric acid solution to determine the composition and purity of the crystals grown in the reactor. These solutions were subsequently analyzed for the components of struvite, as well as calcium, aluminum, iron and potassium. For each sample analyzed, a 0.03g of precipitate was dissolved in 50 ml of 0.5% nitric acid solution (Fattah *et al.*, 2008).

Morphology of the harvested crystals was examined using Scanning Electron Microscope (SEM) (XL30, Philips, the Netherlands) and X-ray Diffraction (XRD) (D/MAX-rB, Rigaku, Japan).

3. Results and Discussions

The main objective of this study was constructing reactor working an excellent p-removal which is applicable for wastewater treatment. The reactor operational conditions and summary of the result is given in Table1 and Table 3.The description of each run is given in the following sections.

Table3: Range of the operational conditions and summary of results of the FBR

Parameters	Run1	Run 2	Run 3	Run 4
Influent PO_4^{3-}-P concentration ($mg{\cdot}L^{-1}$)	19.98~21.79	21.01~21.9	19.89~21.9	18.30~21.87
Effluent PO_4^{3-}-P concentration ($mg{\cdot}L^{-1}$)	1.41~7.48	1.41~21.00	0.87~9.46	1.48~7.07
P-Removal efficiency (%)	65.1~93.5	70.77~93.46	48.71~95.96	54.85~93.23
Mg:P molar ratio	1.25:1	1.25:1	1.25:1	0.75-1.75:1
N:P molar ratio	7.44:1	7.44:1	7.44:1	7.44:1
Temperature (^oC)	21~25	20-25	20-23	21-26
Conductivity ($mS{\cdot}cm^{-1}$)	0.87~0.93	0.75~0.90	0.84~0.93	0.68~0.87

Run 1= Recycler supply, Run 2= Contact Time, Run 3= pH, Run 4=Mg:P molar ratio

Reactor performance

A preliminary FBR design was made and evaluated for its precipitation potential. After we made minor modification, we came up the best design of FBR which had an efficient precipitation potential of phosphorus without wasting at each junctions that was the problem for the first reactor we made (Figure 2A).

As shown in Table1, the reactor design purposely varied the area. The rationale behind we employed the varying cross-section areas and, hence, the different upflow velocities was to avoid the washout of the tiny crystals in the effluent. The high upflow velocity is in the bottom section of the reactor which progressively decreases to top. As the crystals increase in size, they are able to overcome the higher upflow velocities and move towards the lower section. Different studies said that higher upflow velocity at the bottom section enhance crystal growth because of the high turbulence (Ohlinger, 1999; Dastur, 2001).

A) Precipitation in FBR B) Precipitation in FBR with Recycler

Figure 2: Struvite precipitation in FBR

We collected products (precipitates) at the end of every experimental runs. Most of the time products were collected after 3-4 days. The settle bed height was measured from the bottom section of FBR before the product was drawn. The bed height results were found variable (6.25-15 cm) depending on conditions considered. We obtained the minimum bed height when the system runs without external recycler and at lower pH and Mg:P molar ratio (Data not shown).

As visually seen in Figure 2B, the reactor precipitation potential becomes more enhanced when the external recycler employed in the system. This is because of wasted fine particle from the FBR in the first pass get a chance to stay in the recycler and return back to the reactor. Phosphorus removal efficiency with and without external recycle also investigated (Figure 3) to confirm this issue. The percentage p-removal efficiency improved from 72 to 93% when the volume of liquid from external recycler returned increased from 15 to 45 ml (1rpm=3ml per minute). However, removal efficiency increased with increasing volume of return, the visible precipitate was not encouraging when recycle pump rpm $\geqslant$ feed pump rpm. We critically observed very promising precipitate when our FBR received equal amount of liquid from feed and recycle. This might be due to the dilution effect which inhibits crystal growth..

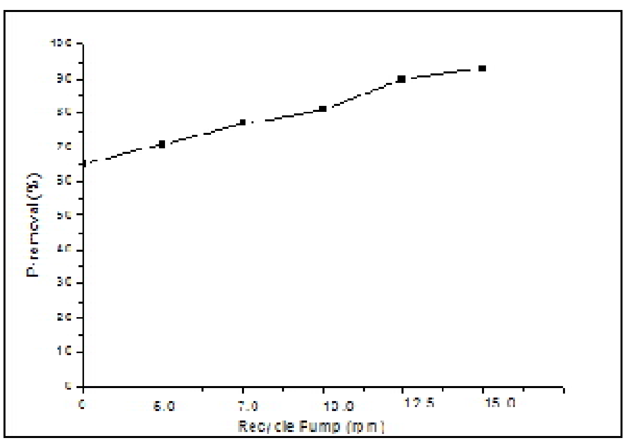


Figure 3: Effect of Recycle on P-removal

Effect of contact time on p-removal

The detention time required to fill the whole volume of FBR (V= 9466 ml) is about 130 minutes (2:20 hours) at flow rate of 72 ml min^{-1}. The external recycler with a volume of 12970 ml capacity also need 180 minutes (3:00 hours) to be full and released its effluent to the supernatant tank. In general, both (FBR and Recycler) container to be fully operational until effluent flow to the supernatant tank, 5:20 h total hydraulic retention time was required. Often, visible precipitates were formed at the middle part of the reactor after 3:30-4:00 h.

In order to investigate contact time as a factor of p-removal, analysis was done by taking sample at different interval (Figure 4). To achieve more than 90% of p-removal, the reactor required $\geq$12 hours. P-removal was also greater than 80% after 6 h but efficiency was low before this time. Moreover, having more elapsed time (48 hours) did not show significant removal efficiency but crystal bed volume growth become high. It is therefore, important to consider time factor to achieve very good removal efficiency and crystal growth.

The current result agrees with results obtained in other studies (Adinan *et al.*, 2003; Britton *et al.*, 2005; Huang *et al.*, 2006; Liu *et al.*, 2008). According to Liu *et al.*, (2008) mentioned that the reactor they constructed enhanced phosphorus recovery with increasing total hydraulic retention time. They also noted that further increasing highly improved reduction of effluent concentration.

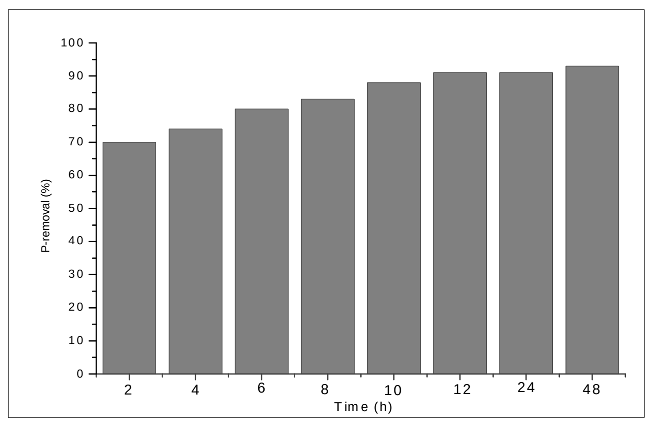


Figure 4: Effect of contact time on p-removal

The effect of pH on p-removal

As shown in Figure 5, experiment without and with NaOH supply was made. The pH value investigated here ranged 7-10 which was made by adjusting the flow rate of NaOH pump. To achieve over 90% P-removal, the operating pH had to be raised to 9. Compared to without NaOH adjustment (<50%), the efficiency of p-removal increased progressively from 55 to 96% with adjusting the pH from 7 to 10.

Similar studies were made on pH by other researchers (Ohlinger, 1999; Celen and Turker, 200; Munch and Barr 2001; Stratful *et al.*, 2001). All these studies have shown that there is an increase in P-removal with an increase in pH as we succeeded. They also stated struvite is soluble at acidic pH conditions and highly insoluble at alkaline pH.

The effect of Mg:P molar ratio on p-removal

It is stated in many literatures that high p-removal accompanied with struvite formation required a theoretical Mg:N:P molar ratio of 1:1:1.Therefore, magnesium ion supplementation of at least the stoichiometric requirement would be required to ensure that magnesium ions did not become a limiting factor (Adinan *et al.*, 2003). However, this does not imply that the process of struvite crystallization and p-removal can proceed only if Mg:P has a molar ratio of 1:1.We achieved almost 55% of p-removal without any addition of magnesium in the system.

As shown below in Figure 6 at lower Mg:P molar ratio (0.75), removal efficiency was low (78%). When the Mg:P molar ratio increases from 0.75 to 1.75, the FBR P-removal improved from 78 to 93%. The reactor also achieved more than 80% of P-removal at theoretical (1:1) Mg:P molar ratio. After 90% removal efficiency achieved at 1.25:1 Mg:P molar ratio further increasing the ratio (1.75:1) did not show significant percentage reduction, however, the condition contribute lower effluent concentration (< 1.5 mgL^{-1}) in the reactor.

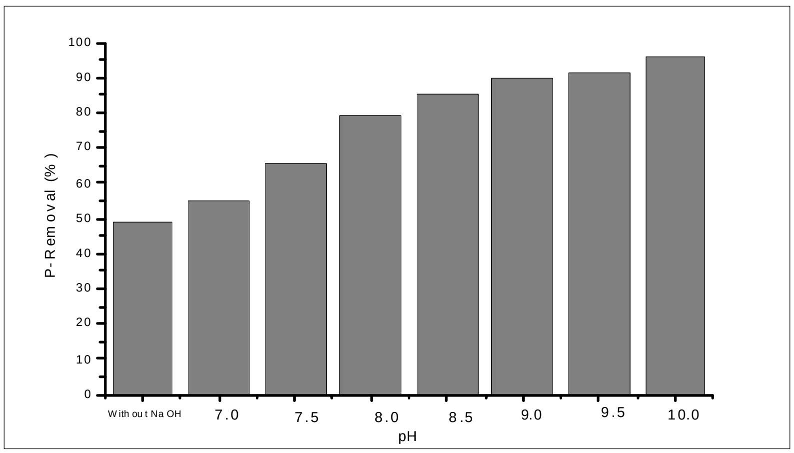


Figure 5: Effect of pH on P-removal

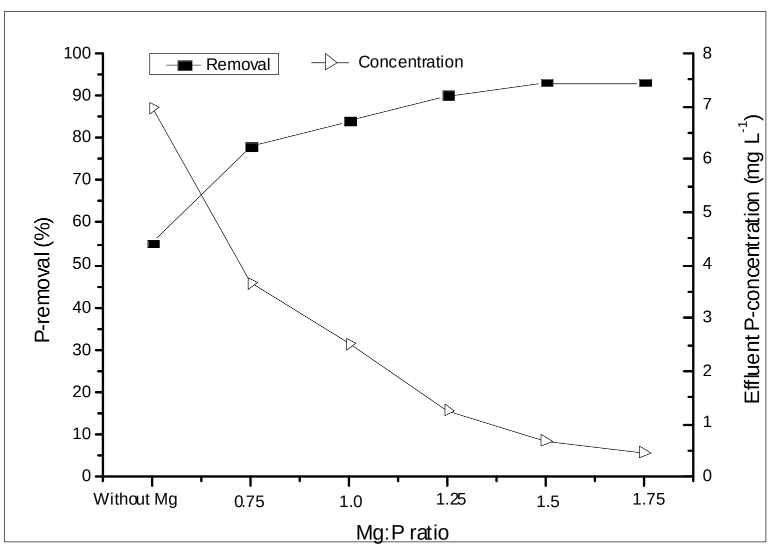


Figure 6: Effect of Mg:P ratio on P-removal

This study result is in consistent with other studies (Hirasawa *et al.*, 1997; Munch and Barr, 2001; Stratful *et al.*, 2001; Huang *et al.*, 2006). They stated as an increased in Mg:P molar ratio increase the P-removal efficiency.

Struvite crystal composition

To verify the composition of the crystals grown in this study, 6 samples were analyzed. Table 2 shows the average crystal compositions compared with the expected theoretical composition of pure struvite. Results showed that the crystal contains struvite reacting species more than the theoretical value. Deviation of the results was observed which could be errors during analysis. However, the deviation does not mean the product do not qualify struvite property rather indicates our FBR was able to produce high-grade crystals. Adinan *et al.*, 2003 achieved 99.8 % of crystal purity. The crystal samples were also analyzed for content of Fe, Al, K, and Ca. The main impurity found in the crystals was Ca followed by Na and Al (data not shown).

Basic crystal morphology

In this study, precipitates with various size, density and hardness were harvested. In order to understand whether the precipitate formed was struvite or not, products were observed under the Scanning Electron Microscope (SEM). The results showed that products collected at various conditions have different morphology. Some of the precipitates were found amorphous in shape and unacceptable as struvite (Figure 7A). The amorphous shape was resulted when the system was operated at lower pH and Mg:P molar ratio. When the pH in the system was operated above 9 and the molar ratio of Mg:P $\geqslant$ 1:1, the crystal product was very hard (Figure 7 B) which qualify the rhombic shape of struvite. These struvite products were confirmed with X-ray Diffraction analysis (Figure 8).

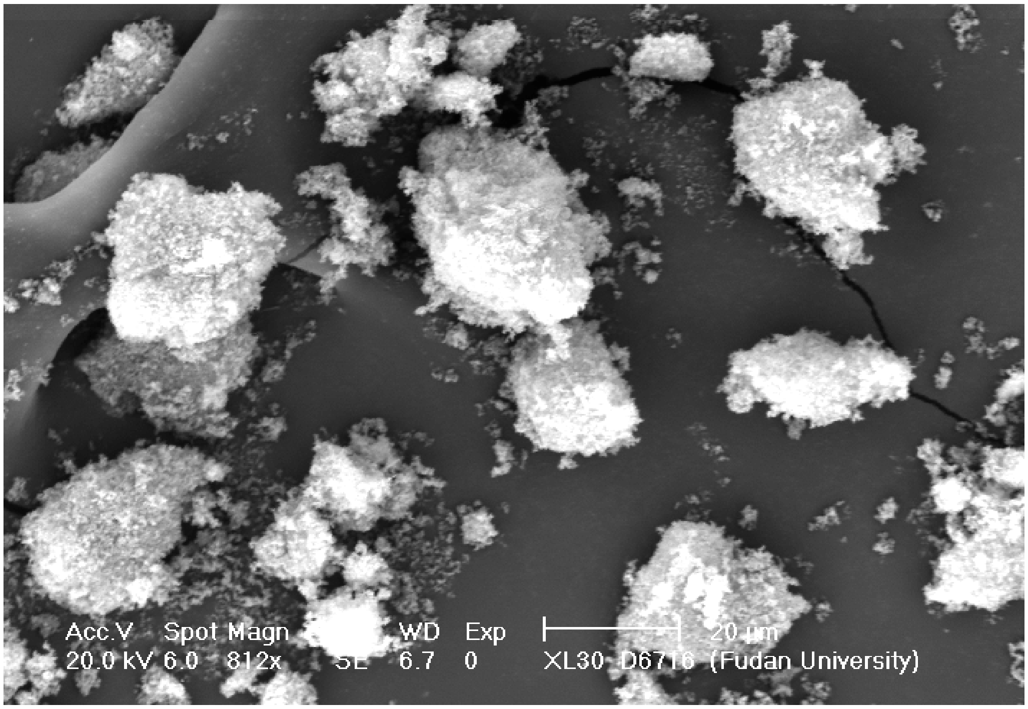
Table4: average results of purity composition analysis and theoretical values (Dastur, 2001; Fattah *et al.*, 2008)

Struvite reacting species /Element	Weight ($mg{\cdot}L^{-1}$)		Composition (%)	
	Theoretical	Measured	Theoretical	Measured
Mg	24.5	25.550±1.265	9.9	10.4
N	14.3	14.525±17.160	5.7	5.9
P	31.6	31.709±3.223	12.8	12.9
Struvite (estimated)			~100	~100

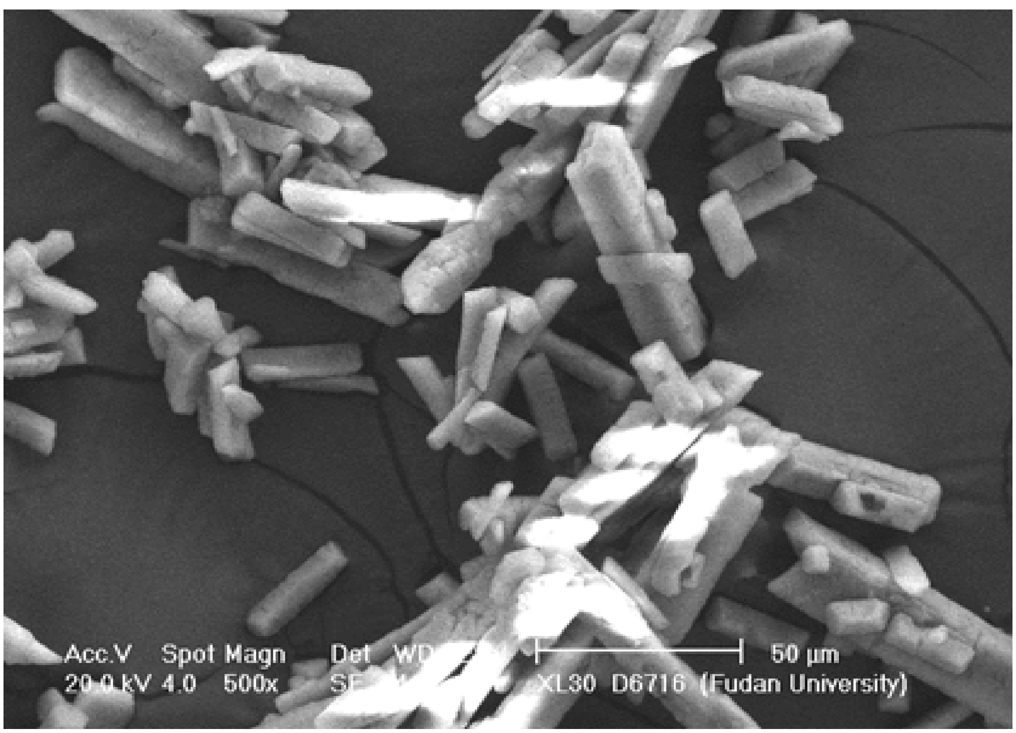
4. Conclusions

Phosphorus is the growth limiting factor in aquatic ecology which causes eutrophication. Its source is direct disposal of untreated effluent to water bodies. Currently, for the betterment of environmental and aquatic health stringent laws are set for nutrient (phosphorus) reduction in wastewater. On the other hand, global phosphate reserve depletion leads a question of sustainability which forces the modern society to think phosphorus recovery instead of removal from wastewater. The present study was considering both issues and results were found promising even at lower PO_4^{3-}-P concentration (18.30-21.90 $mg{\cdot}L^{-1}$). As to our current knowledge, (except Liu *et al.*, 2008 did at 21.7 $mg{\cdot}L^{-1}$ PO_4^{3-}-P concentration and achieved 78% p-removal efficiency) no one tried to recover phosphorus at lower concentration and achieved high removal efficiency.

The new FBR we constructed effectively remove and recovery phosphorus from synthetic wastewater. Performance of the reactor was optimal ($\geqslant$ 90 %) when higher pH ($\geqslant$9) and Mg:P molar ratio ($\geqslant$1.25:1) used. The reactor efficiency was also enhanced when higher recycle flow rate and longer contact time maintained in the FBR. The SEM, XRD and chemical composition results showed that the crystal harvested qualify the characteristic of struvite. The overall finding showed that FBR will be successfully used in phosphorus removal and recovery (in the form of struvite) from wastewater by monitoring pH, Mg:P molar ratio, time and recycle conditions.



A. Amorphous Precipitate



B) Struvite

Figure 7: Scanning Electron Microscope (SEM) picture A) Amorphous Precipitate B) Struvite

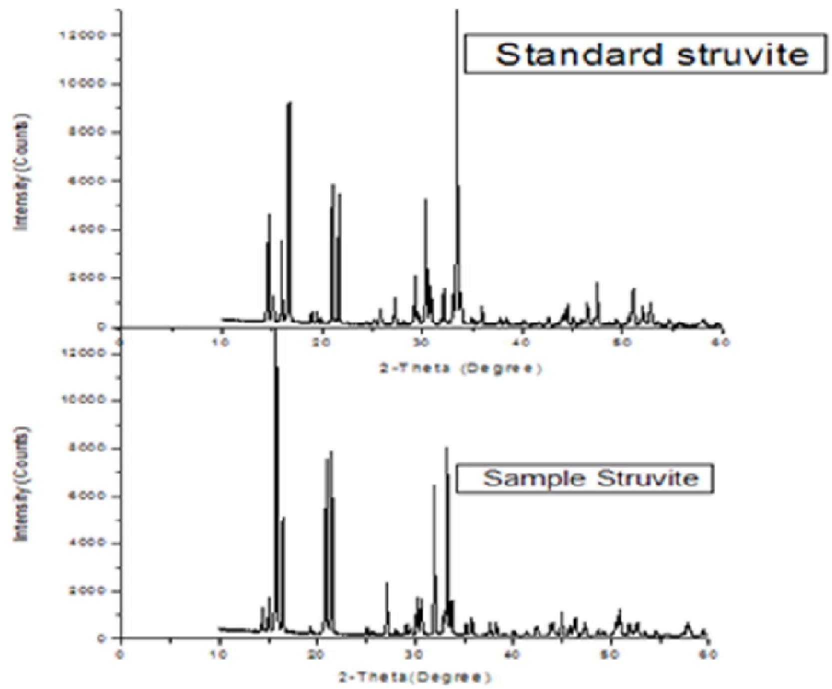


Figure 8: Struvite sample and standard XRD results

Acknowledgement

The authors would like to thank Tongji University and Chinese Government Scholarship for providing financial support. This work was supported by the National High Technology Research and Development Program of China (No.2009AA062902),National Water Pollution Control Program (No. 2009ZX07317-008-5), and Shanghai Shuguang Tracking Program (No. 10GG12).

5. Reference

Adnan, A., Mavinic, D.S. and Koch, F.A. (2003). Pilot-scale study of phosphorus recovery through struvite Crystallization-examining the process feasibility. *J. Environ. Engin. Sci.,* **2**: 315–324. 22.

Britton, A., Koch, F.A., Mavinic, D.S., Adnan A., Oldham, W.K. and Udala, B. (2005). Pilot-scale struvite recovery from anaerobic digester supernatant at an enhanced biological phosphorus removal wastewater treatment plant. *J. Environ. Eng. Sci.* **4**: 265–277

Burns, R.T., and Moody, L.B. (2002). Phosphorus recovery from animal manures using optimized struvite precipitation. *In* Proceedings of Coagulations and Flocculants: Global Market and Technical Opportunities for Water Treatment Chemicals, Chicago, Ill., 22–24 May 2002. American Chemical Society, Washington.

Celen D.C., and Turker, M. (2001). Recovery of ammonia as struvite from anaerobic digester effluents. *Environ. Technol.* **22**: 1263–1272

Corre, K.S.L., Valsami-Jones, E., Hobbs, P. and Parsons, S.A. (2005). Impact of calcium on struvite crystal size, shape and purity. *Journal of crystal growth*, **283**: 514-522

Dastur, M.B. (2001). *Investigation into the factors affecting controlled struvite crystallization at the bench-scale*. M.A.Sc. Thesis, Department of Civil Engineering, The University of British Columbia, Vancouver, B.C.

de-Bashan, L.E. and Bashan, Y. (2007). Fertilizer potential of phosphorus recovered from wastewater treatments, E.velazquez and C. Rodriguez-Barrueco (eds). First International Meeting on Microbial Phosphate Solubilization, 179-184, Springer 2007.

Doyle, J.D., and Parsons, S.A. (2002). Struvite formation, control and recovery. *Water Res.*, **36**: 3925–3940.

Driver, J., Lijmbach, D., and Steen, I. (1999). Why recover phosphorus for recycling and how? *Environ. Technol.* **20**: 651–662.

European Fertilizer Manufacturers Association (2000). Phosphorus essential element for food production, pp. 9–10.

Fattah, K. P., Mavinic, D. S., Koch, F. A. and Jacob, C. (2008). Determining the feasibility of phosphorus recovery as struvite from filter press centrate in a secondary wastewater treatment plant. *Journal of Environmental Science and Health*, **43**: 756-764.

Florida Institute of Phosphate Research (2005). Phospho rus prime.

Fujimoto, N., Mizuochi, T. and Togami, Y. (1991). Phosphorus fixation in the sludge treatment system of a biological phosphorus removal process. *Water Sci. Tech*. **23**: 635–640.

Greaves, J., Hobbs, P., Chadwick, D., and Haygarth, P. (1999). Prospects for recovery of phosphorus from animal manures: a review. *Environ. Technol*. **20**: 697–708.

Mavinic, D.S., Koch, F.A., Hall, E.R., Abraham, K. and Niedbala, D. (1998). Anaerobic co-digestion of combined sludges from a BNR wastewater treatment plant. *Environ. Technol.* **19**: 35–44.

Mavinic, D. (2011). A Green and Sustainable Solution to Global Phosphorus Depletion. The University of British Colombia, B, C. Canada. Available from: [http://www.metrovancouver.org/ region/breakfasts /Presentations/ PhosphorusRecovery.pdf](http://www.metrovancouver.org/region/breakfasts/Presentations/PhosphorusRecovery.pdf)

Munch, E.V., and Barr, K. (200). Controlled struvite crystallization for removing phosphorus from anaerobic digester side streams. *Water Res.* **35**: 151–159.

Ohlinger, K. (1999). Struvite controls in anaerobic digestion and post digestion wastewater treatment processes. Ph.D. thesis, University of California, Davis, Calif.

Shu, L., Schneider, P., Jegatheesan, V., and Johnson, J. (2006). An economic evaluation of phosphorus recovery as struvite from digester supernatant. *Bioresource Techn.* **97**: 2211–2216.

Steen, I., (1998). Phosphorus availability in the 21st century management of a non-renewable resource. Phosphorus and Potassium 217, 25–31.

Stratful, I., Scrimshaw, M.D. and Lester, J.N. (2001). Conditions influencing the precipitation of magnesium ammonium phosphate. *Water Res.* **35**: 4191–4199.

USGS, US Geological Survey (2005). Phosphate rock ([http://minerals.er.usgs.gov/minerals/pubs/ commodity/](http://minerals.er.usgs.gov/minerals/pubs/commodity/).

Woods, N.C., Sock, S.M., and Daigger, G.T. (1999). Phosphorus recovery technology modelling and feasibility evaluation for municipal wastewater treatment plants. *Environ.Techn.* **20**:743–748.

Yaffer, Y., Clark, T.A., Pearce, P. and Parsons, S.A. (2002). Potential phosphorus recovery by struvite formation. Water Res. **36**: 1834–1842.

Hirasawa, I., Nakagawa, H., Yosikawa, O. and Itoh, M. (1997). Phosphate recovery by reactive crystallization of magnesium ammonium phosphate: application to wastewater. In: *Separation and Purification By Crystallization. ACS Symposium Series.***667**, American Chemical Society, 267-276.

Huang, H., D.S. Mavinic, Lo, K.V. and Koch, F. A. (2006). Production and Basic Morphology of Struvite Crystals from a Pilot-Scale Crystallization Process, *Environ. Techn*, **27**:233-245.

Isherwood, K. F. (2000). Mineral fertilizer use and the environment. International Fertilizer Industry Association / United Nations Environment Programme, Paris. pp. 106.

Jardin, N. and Popel, J.J. (1996). Behaviour of waste activated sludge from enhanced biological phosphorus removal during sludge treatment. *Water Environ. Res*. **68**: 965–973.

Liu,Z., Zhao,Q., Lee, D. and Yang, N. (2008). Enhancing phosphorus recovery by a new internal recycle seeding MAP reactor. *Bioresource Techenology.* **99**: 6488–6493.

Mulkerrins, D., Dobson, A.D.W. and Colleran, E. (2004). Parameters affecting biological phosphate removal from wastewaters. *Environment International*, **30**: 249–259.

Simulation of Lake Tana Reservoir under Climate Change and development Scenario

Getachew Tegegne
Adama Science and Technology University

Abstract

This paper presents simulation of Lake Tana reservoir future water use under emerging scenario with and without climate change impacts. Two different development and climate change scenarios were developed to simulate Lake Tana water level i.e., i) Base line scenario (1991-2000) ,ii) Future development scenario on short term periods(2031-2040) , and ii) Future development scenario on long term periods (2091-2100). River head flow estimated by Soil and Water Assessment Tool (SWAT) was used as an input to Water Evaluation And Planning (WEAP) model to simulate the Lake level for each scenario. Based on WEAP model simulation results, demand coverage and reliability of 100% was observed in all scenarios for Tana-Beles hydropower project. For scenarios without climate change impacts, there are longer periods of time when mean monthly lake levels are below 1785 masl (i.e., the minimum lake level required for shipping). Under natural conditions (lake level without project), they exceed this level in 100%.under current conditions (Base line scenario, BLS), they exceed this level in 89% of the months. In the full development scenario (FDSC'), this will decrease to 83%. For all scenarios with climate change impacts, Lake water Level will not significantly be affected by climate change impacts.

1. Introduction

The increased demand of water for agriculture, industries, domestic, and power generation in Lake Tana sub-basin requires proper planning and management of water resources in the basin. The basin has more than 40 rivers inflow in to Lake Tana and about 93% of the inflow is coming from the four major rivers Gilgel Abbay, Gummera, Rib and Megech [3]. The purpose of this study is therefore applying a physically based semi distributed model called Soil and water assessment tool (SWAT), to understand the hydrology of the basin, to know the water resource potential as a whole from gauged and un-gauged catchments as well as water evaluation and planning (WEAP) model[6] were used to asses upstream catchment development and climate change impact on Lake Tana water level and to assess the sustainability of Tana –belles Hydropower plant on the basis of adjusting the operation rule of Lake Tana reservoir.

The analysis presented in this paper is the first of its kind which was done using actual data in Lake Tana sub-basin. The study addresses; The assessment of water resources potential of Lake Tana basin, Assessment of Impact of upstream irrigation development on Lake Tana water level and Tana-belles Hydropower plant, Assessment of impact of climate change on Lake Tana and Beles hydro power plant with and without emerging upstream irrigation project, and assessment of the sustainability of Tana-Beles development on the basis of adjusting the operation rule of the Lake.. The output of this study can be used as an input for decision support for water resources planning, development, and management of water resources in the basin.

Study area description

Lake Tana Basin is part of the Blue Nile basin, which lies in a natural drainage basin of about 15114 Km^2 as per this research work using SWAT delineation. Among which about 20.47% is covered by the Lake Tana. Lake Tana basin is found in North West part of Ethiopia and it extends between 10.95^0N to 12.78^oN latitude and from 36.89^oE to 38.25^oE longitude (highlighted in fig.1).

Topography is generally uniform and quite well adapted to irrigation development surrounding Lake Tana [5, 9]. The elevation ranges between 914 m to 4096 m +MSL, which is extracted from DEM (90*90m) resolution. There are two seasons rainy and dry. The rainy season has two periods, the little rains, during April and May, and the big rains, which last from mid- June to mid-September. The rainfall distribution in the basin is found to be a mono-modal pattern i.e. one peak value observed during rainy season especially in July, and August.
Considering the rainfall stations in the basin for a period of 1996-2006 the mean annual rainfall amount ranges between 813 mm in Yifag and 2328 mm in Enjibara.

Similarly the mean annual minimum and maximum temperature ranges between 9.3 ^{o}C in Dangila and 29.6 ^{o}C in Gorgora respectively.

Land use of study area was classified based on Abay river master plan study conducted by BCEOM, in 1996-1999 [2], about 51.37 % of the watershed area was covered by Agriculture, 21.94 % by Agro-pastoral, 20.41 % by Lake Tana, 0.39 % by Agro-Sylvicultural, 0.13 % by wetland, 5.47 % by Pastoral, 0.15 % by Sylvicultural, 0.03 % by sylvo-pastoral and 0.11 % by Urban. The soil classification for the study area is also adopted from Abay river master plan study in 1996-1999 conducted by BCEOM [2]. Based on the classification Halpic luvisol which covers about 20.68 % of the watershed area is considered to be the major dominant soil in the study area .

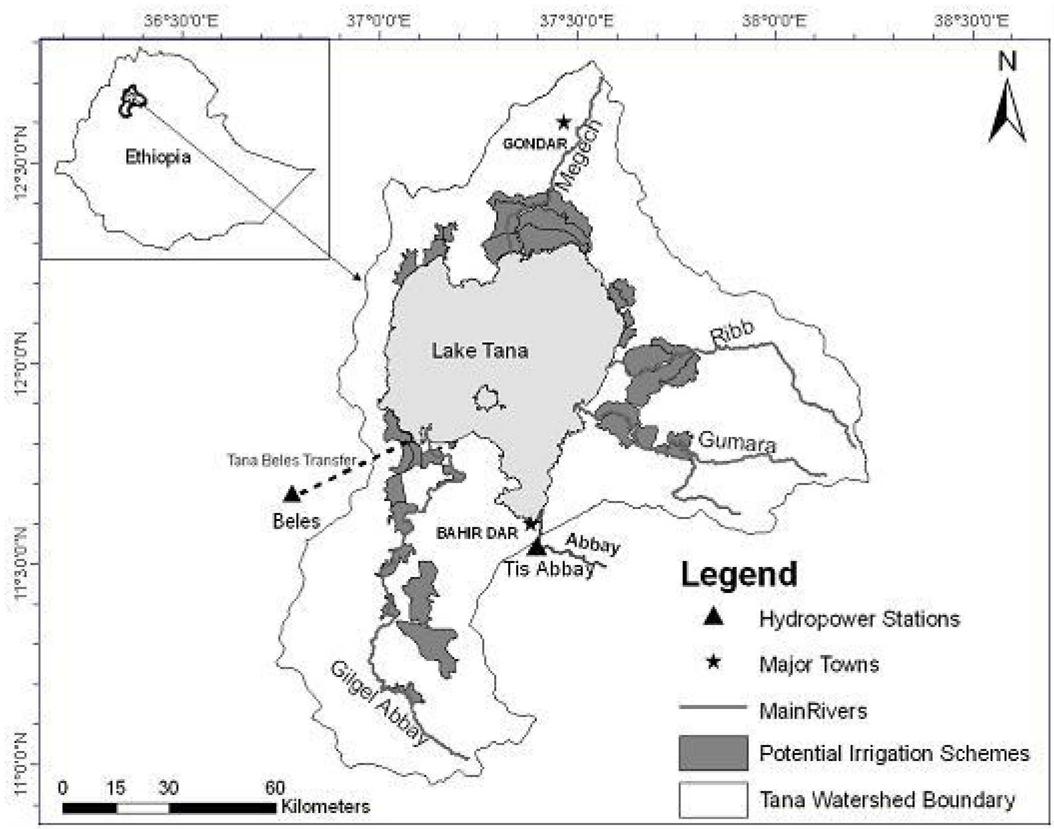


Figure 1: Location Map of Lake Tana Basin

Scenario Development

In this study the model was set-up to simulate two scenarios based on development plans of the basin. The model is first configured to simulate a base line scenario, for which the water availability and demands can be confidently determined. It is then used to simulate for future development scenarios to assess the impact of development and climate change on the hydrology and water resources.

a) Scenario BLS: Base line scenario(1991-2000),
b) Scenario FDSC′: Future development scenario (future water demand without climate change);
c) Scenario $FDSC_1$: Future development scenario under climate change on short term basis (2031-2040), and
d) Scenario $FDSC_2$: Future development scenario under climate change on long term basis (2091-2100).

Interventions in the water sector in Abbay basin fall in to three main areas: irrigation, hydropower, and water supply. However, water supply requirements are small relative to those for irrigation and hydropower [2].

2. Methodology

The following flow chart indicates the overall framework of the methodology to be followed throughout the study

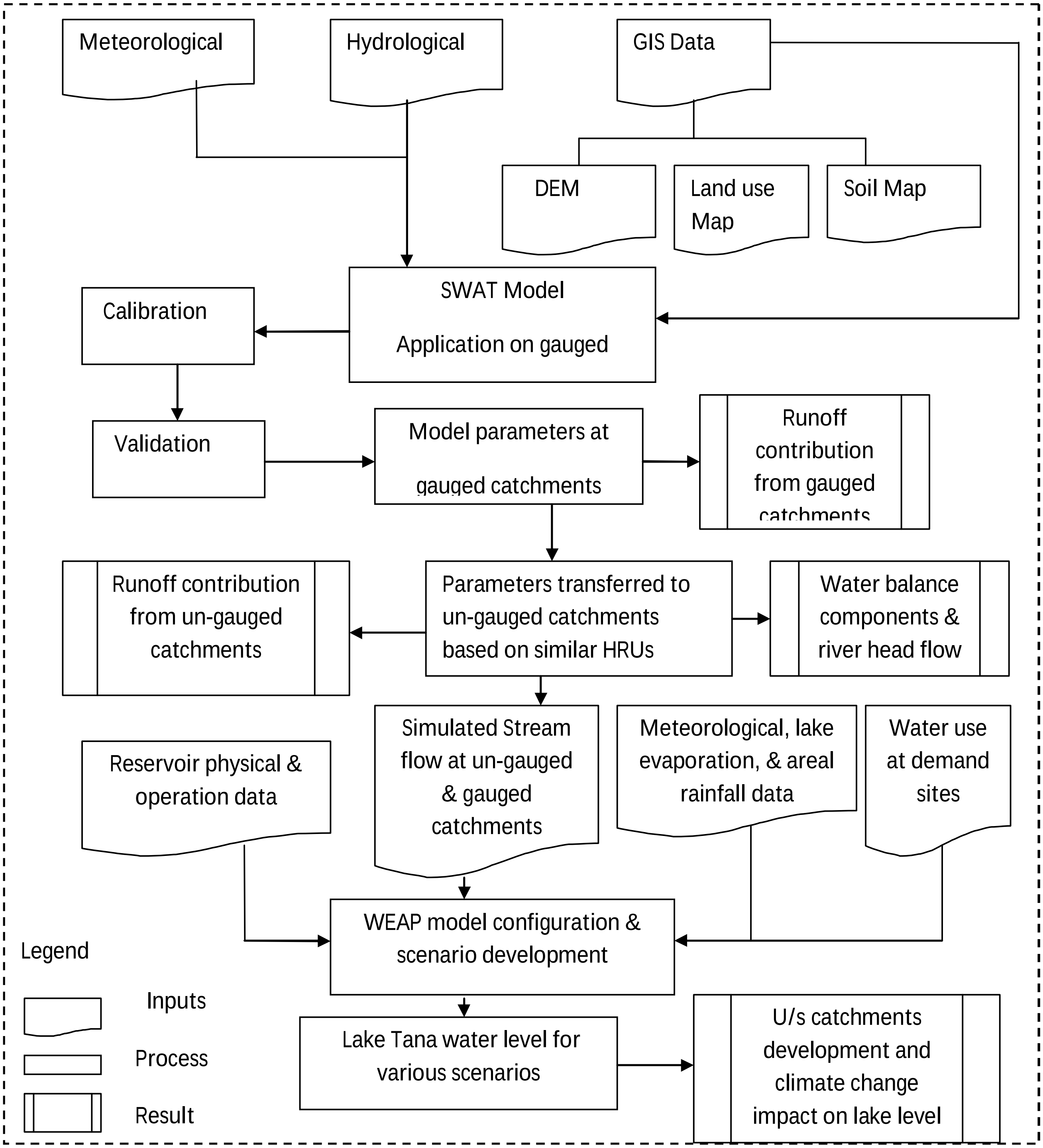


Figure 2: General framework adopted for the study

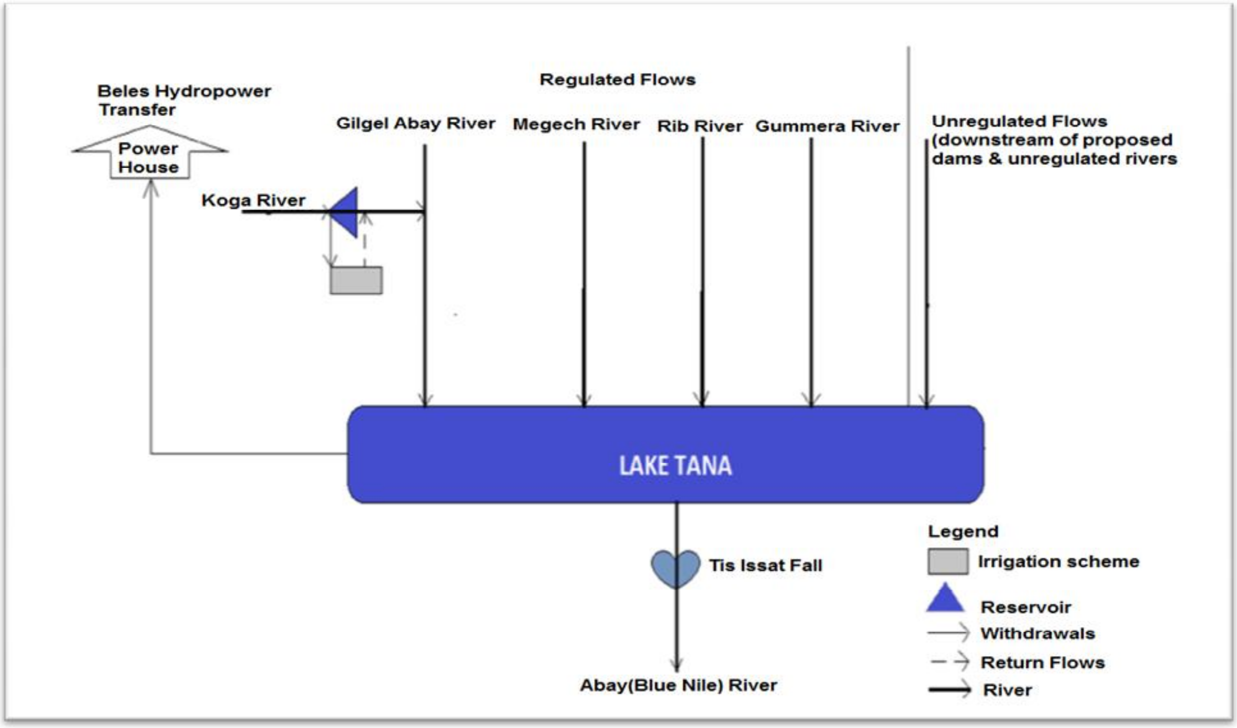


Figure 3: Schematic of the model configuration for the Current situation Scenario

Projects, like water supply and sanitation, that do not significantly influence the results of water availability in the basin was not also be considered.

. *Scenario BLS*

This Scenario represents the existing development in the basin. Relative to the basin water resource potential; development activities achieved yet is insignificant. Koga irrigation, Tis Issat fall and Tana Beles Hydropower schemes was considered for the base line scenario. When Tana Beles transfer become operational Tiss Abbay I and II hydropower stations will be used as standby stations, only to operate as a backup system when problems in the National grid may require [2,7]. Hence they are not considered in this scenario.

B. Scenario FDSC′

This Scenario represents full development activities in the basin which are expected to be operational in future period of time. The analysis includes projects which are currently operational, ongoing development, and likely development activities. The scenario not considers the impact of climate change on hydrology and water resources in the basin.

C. Scenario $FDSC_1$ & $FDSC_2$

This Scenario represents full development activities which are expected to be operational in the long period of time in the future. Scenario $FDSC_1$ represents future development scenario with climate change for time periods of 2031-2040 and scenario $FDSC_2$ represents future development scenario with climate change for time periods of 2091-2100.The analysis includes projects which are currently operational, ongoing development, and likely development activities.

The scenario considers the impact of climate change on hydrology and water resources in the basin. i.e., the climate variables are under the influence of climate change in the future.

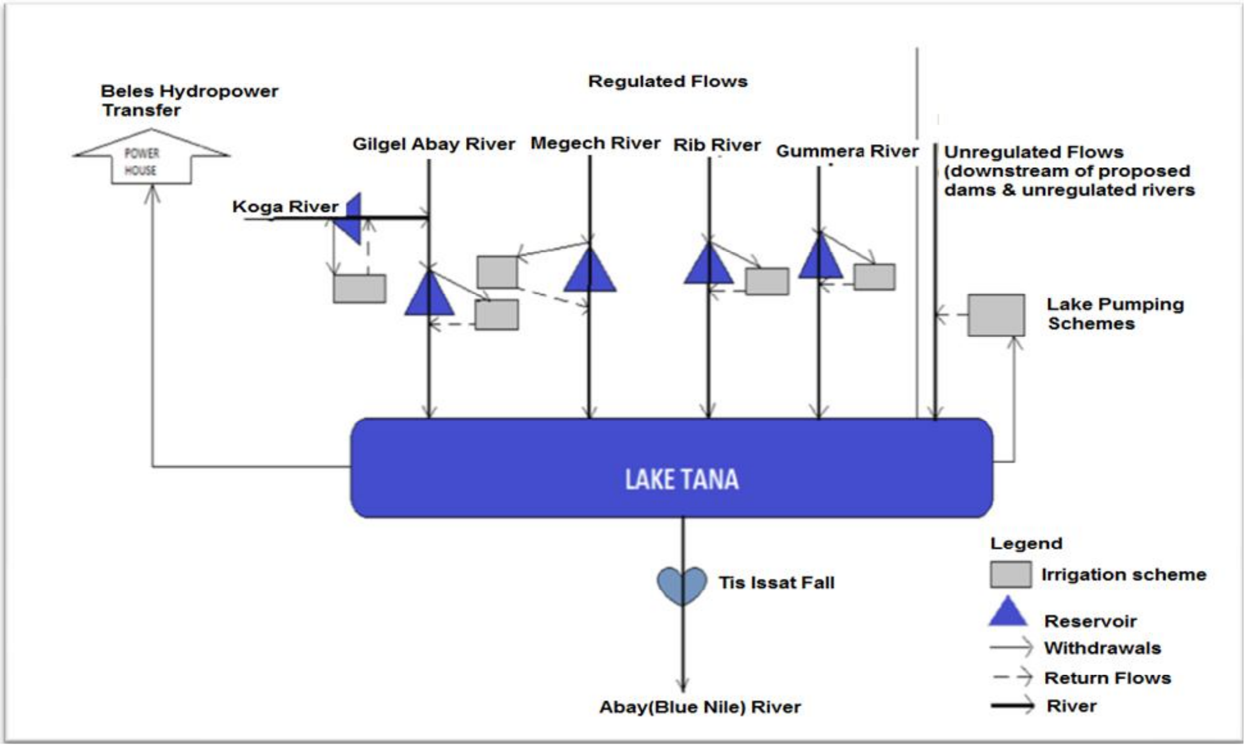


Figure 4: Schematic of the model configuration for the future development Scenario

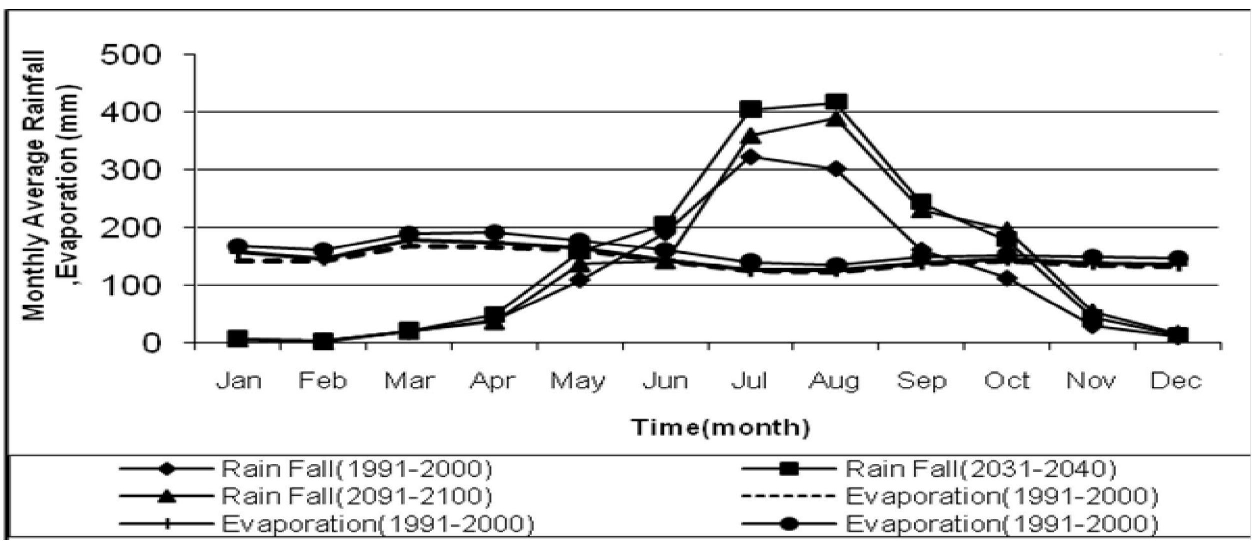


Figure 5: Monthly average rainfall and evaporation over Lake Tana

3. Results and Discussions

A. Evaporation and rainfall over the lake

From the Thissen polygon analysis, the annual average areal rainfall over the Lake for the simulation periods of (1991-2000), (2031-2040), and (2091-2100) found to be 1291mm/year, 1737.693mm/year, and 1690.104 mm/year respectively.

From CROPWAT model the average annual evaporation over the Lake for the simulation periods of (1991-2000), (2031-2040), and (2091-2100) found to be 1618 mm/year, 1767 mm/year, and 1909 mm/year respectively.

B. Modeling of Gauged Catchments

Historical observed stream flow of Gilgel Abay at Merawi, Gummera at Bahirdar, Rib at Addiszemen and Megech at Azezo were calibrated from a period of 1996-2002 and validated from a period of 2003- 2005 .

C. The inflow hydrograph from gauged and ungauged catchments

Once the model is calibrated and verified at the gauged location the model output during that period were quantified and taken as simulated inflow series. Later this inflow series will be used for water balance analysis.

Table 1: Calibration & validation

Average monthly flow (m^3/sec.)		R^2	NSE
Observed	Simulated		
Gilgel Abay River (Calibration period 1996-2002)			
57.26	58.21	0.91	0.91
Gilgel Abay River (Validation period 2003-2005)			
34.64	32.95	0.93	0.92
Gummera River (Calibration period 1996-2002)			
37.74	38.8	0.70	0.70
Gummera River (Validation period 2003-2005)			
34.06	27.69	0.91	0.90
Rib River (Calibration period 1996-2002)			
14.93	15.82	0.82	0.82
Rib River (Validation period 2003-2005)			
13.88	13.28	0.84	0.83
Megech River (Calibration period 1996-2002)			
7.18	7.04	0.8	0.76
Megech River (Validation period 2003-2005)			
8.06	4.53	0.92	0.91

Similarly, the inflow series for ungauged catchments were done by transferring calibrated parameters having the same HRUs as gauged catchments. The total inflow in to the Lake mouth was determined after having the inflow from gauged catchments and inflow from ungauged catchments separately and later the total inflow was taken as the aggregate of inflow series from gauged and ungauged catchments.

From the model result total inflow from gauged catchments was found 2850.727MCM, 3595.137MCM, and 3311.873MCM for time period (1991-2000), (2031-2040), and (2091-2100) respectively. Total inflow from ungauged catchments was found 3759.228MCM, 5382.034MCM, and5006.76MCM for time periods of (1991-2000), (2031-2040), and (2091-2100) respectively.

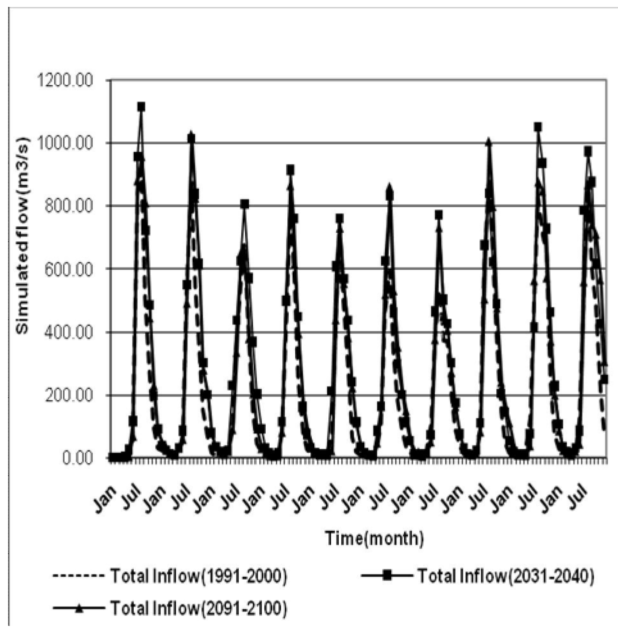


Figure 6: Total Inflow Hydrograph from gauged and ungauged catchment for all scenarios.

D. Elevation Area Volume Relation ship

The elevation Area Volume relation ship of Lake Tana reservoir was calculated for the calibration period (1996-2002). The polynomial fitted bathymetry by Pietrangeli and Abeyou [1, 8] used in this research work takes into account Elevation-Volume-Area relationship (Table 2).

Table 2: Elevation Volume Area relationship

Pietrangeli	*$E = 1.08*10^{-9}(V)^2+3.88*10^{-4}(V)+1775.58$* *$A = 6.20*10^{-8}(V)^2+1.72*10^{-2}(V)+2516.3$*
Abeyou	$E = 1.21*10^{-13}(V)^3-1.02*10^{-8}(V)^2+6.20*10^{-4}(V)+1774.63$, $A = 7.93*10^{-11}(V)^3-5.81*10^{-6}(V)^2+1.65*10^{-1}(V)+1147.51$

Where E= Lake level elevation, m. +MSL
A= Surface area of the Lake, Km^2
V= Lake volume, MCM

The basic equation used in the water balance:

$$S_t = S_{t-1} + I(t) + P(t) - O(t) - E(t) + G_{in} - G_{out} - \Delta S$$

Where:
S_t = Lake storage volume at the end of current month,
S_{t-1} = Lake storage volume at the end of previous month,
I(t) = Simulated inflow volume from gauged and un-gauged catchments at current month,
O(t) = Outflow volume at the Lake outlet,
P(t) = Areal rainfall volume on the Lake surface,
E(t) = Evaporation volume on the Lake surface,
G_{in} (t) = Ground water inflow in to the Lake at the end of current month,
G_{out}(t)= Ground water outflow from the Lake at the end of current month.
Δs = other losses.

The water balance terms were computed using EXCEL spread sheet model and the monthly water balance result obtained by using the relationship developed by Abeyou, (2008) has been best fitted than Pietrangeli, (1990). The results are presented in Table 3 and Figure 7.

Table 3: Lake Tana Annual water balance components simulated from 1996-2002

Water balance components	mm/year
Lake areal rainfall	+1291
Gauged River inflow	+822
Un-gauged river inflow	+1297
Lake Evaporation	-1618
River outflow	-1725
Change in storage	67

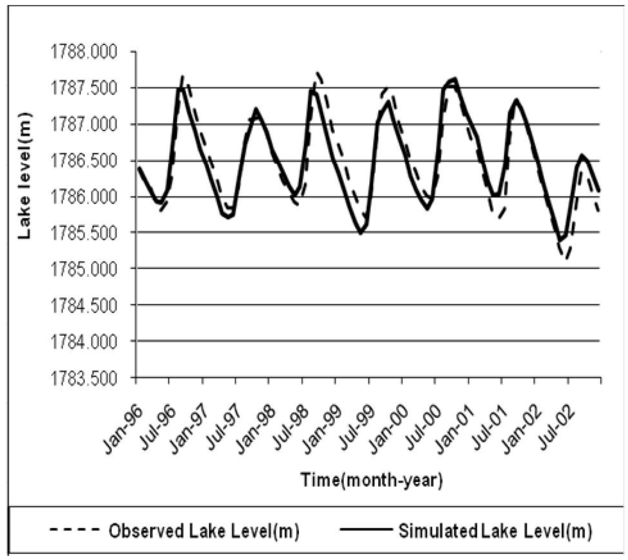


Figure 7: Observed and Simulated Lake Level without project for the period 1996-2002.

E. Upstream Catchment Development Impact on Lake Tana Water Level

Figure 8 presents a comparison of the time series of simulated lake levels with project and without project for all scenarios. The results indicate the decline in mean annual lake levels, and consequently lake area, as water resources development in the catchment increases. As water resources development increases there are longer periods of time when mean monthly lake levels are below 1785 masl (i.e., the minimum lake level required for shipping) [4]. Under natural conditions (lake level without project), they exceed this level in 100%.under current conditions (Base line scenario, BLS), they exceed this level in 89% of the months. In the full development scenario (FDSC′), this will decrease to 83%.

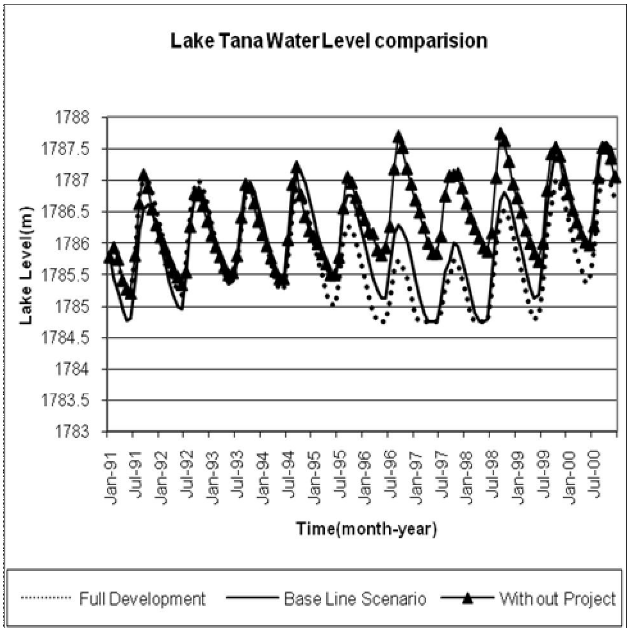


Figure 8: Comparison of simulated lake level with project and without project (1991-2000)

F. Upstream Catchment Development Impact on Tana-Beles Hydropower Plant

Table 4 and 5 presents annual unmet demand in million cubic meter for base line scenario and full development scenario respectively. From the result, 100 percent reliability of Tana-Beles hydropower project was observed for base line scenario and full development scenario.

G.Climate Change Impacts on Lake Tana Water Level

Currently, there is great uncertainty about the likely impacts of climate change in the Abay Basin. Results from Global climate models (GCMs) are contradictory; some show increases in rainfall whilst others show decreases. A recent study of 17 GCMs indicated that precipitation changes between -15% and +14% which, compounded by the high climatic sensitivity of the basin [4].

Table 4: Yearly unmet demands (MCM) for BLS scenario (1991-2000)

Scheme	1991*	1992*	1993	1994	1995	1996	1997	1998	1999	2000	Sum
Tana Beles Hydropower	0	0	0	0	0	0	0	0	0	0	0
Koga Irrigation	47.4446	0.00407	0	0	0	0	0	0	0	0	47.44
Sum	47.4446	0.00407	0	0	0	0	0	0	0	0	47.44

Table 5: Yearly unmet demands (MCM) for FDSC′ scenario (1991-2000)

Scheme	1991*	1992*	1993*	1994	1995	1996	1997	1998	1999	2000	Sum
Tana Beles Hydropower	0	0	0	0	0	0	0	0	0	0	0
Gilgel Abay Irrigation	91.37	46.72	34.31		0	0	0	0	0	0	172.40
Gumera Irrigation	26.01	0	0	0	0	0	0	0	0	0	26.01
Koga Irrigation	48.300	33.21	0	0	0	0	0	0	0	0	81.51
Megech Irrigation	39.639	29.15	13.61	0	0	0	0	0	0	0	82.41
Rib Irrigation	166.94	42.64	19.86		0	0	0	0	0	0	229.44
Tana Pump Irrigation	0	0	0	0	0	0	0	0	0	0	0
Sum	372.26	151.73	67.79	0	0	0	0	0	0	0	591.79

*shows the "warm up" period for reservoirs filling and not considered for analysis.

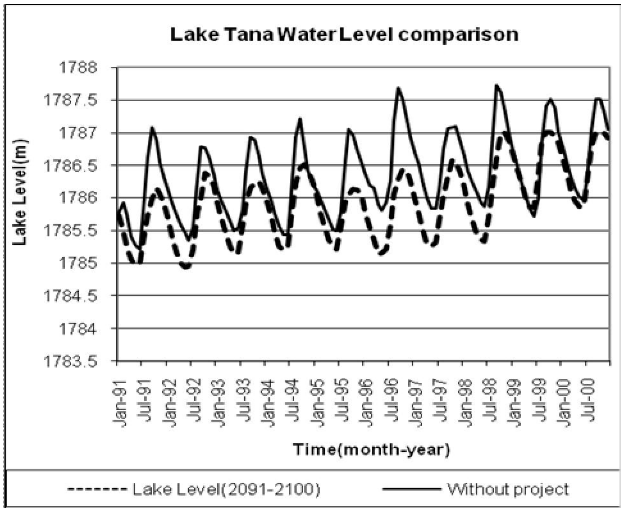


Figure 9: Comparison of simulated Lake Levels with and without project (2031-2040)

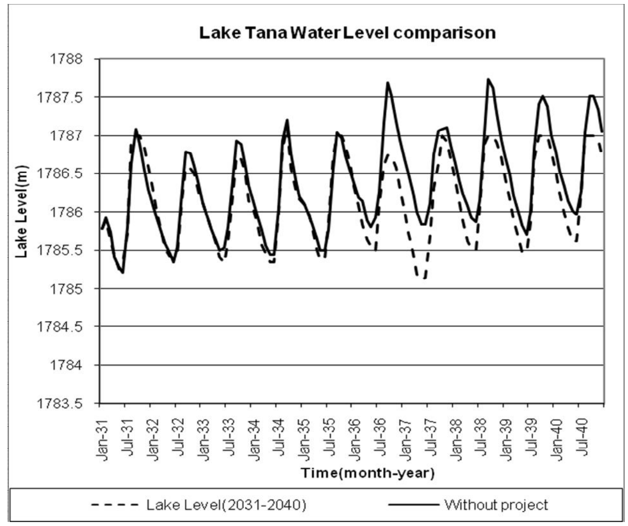


Figure 10: Comparison of simulated Lake Levels with and without project (2091-2100)

Generally there is an increasing trend in both precipitation and runoff in the basin for the time period of 2031-2040 and 2091-2100. PET and reservoir evaporation shows an increasing trend for all future scenarios. The cumulative impacts of these hydrologic parameters on Lake water Level were checked using WEAP simulation model.

The results of the WEAP model simulation shows that Lake water Level will not significantly be affected by climate change impacts for all future scenarios. Figure 9 and 10 presents a comparison of the time series of simulated lake levels for all future scenarios with and without project.

H. Climate Change Impacts on Tana-Beles Hydropower Project

The result shows climate change impacts are not significant in the basin and hence, there is no problem of water shortage for proposed development activities due to climate change impacts. By giving higher priority for hydropower schemes than irrigation schemes, the demand coverage and reliability of 100 percent was observed for Tana – Beles hydropower project

Table 6: Yearly unmet demands (MCM) for $FDSC_1$ scenario (2031-2040

Scheme	2031*	2032*	2033	2034	2035	2036	2037	2038	2039	2040	Sum
Tana Beles Hydropower	0	0	0	0	0	0	0	0	0	0	0
Gilgel Abay Irrigation	97.63	0.002	0	0	0	0	0	0	0	0	97.63
Gummera Irrigation	25.42	0	0	0	0	0	0	0	0	0	25.42
Koga Irrigation	48.14	0.004	0	0	0	0	0	0	0	0	48.14
Megech Irrigation	39.44	0.01	0	0	0	0	0	0	0	0	39.45
Rib Irrigation	164.12	0.99	0	0	0	0	0	0	0	0	165.11
Tana Pump Irrigation	0	0	0	0	0	0	0	0	0	0	0
Sum	374.77	1.01	0	0	0	0	0	0	0	0	377.7

*shows the "warm up" period for reservoirs filling and not considered for analysis.

Table 7: Yearly unmet demands (MCM) for $FDSC_2$ scenario (2091-2100)

Scheme	2091*	2092*	2093*	2094	2095	2096	2097	2098	2099	2100	Sum
Tana Beles Hydropower	0	0	0	0	0	0	0	0	0	0	0
Gilgel Abay Irrigation	106.71	0.006	0	0	0	0	0	0	0	0	106.71
Gummera Irrigation	26.14	0.01	0	0	0	0	0	0	0	0	26.15
Koga Irrigation	48.30	0	0	0	0	0	0	0	0	0	48.31
Megech Irrigation	39.64	30.41	15.74	0	0	0	0	0	0	0	85.80
Rib Irrigation	167.93	19.27		0	0	0	0	0	0	0	187.20
Tana Pump Irrigation	0	0	0	0	0	0	0	0	0	0	0
Sum	388.72	49.70	15.74	0	0	0	0	0	0	0	454.18

* shows the "warm up" period for reservoirs filling and not considered for analysis

VI. Summary and Conclusion

A cascade of two models was used in this study. The SWAT model was setup from January 1985 - December 2006.Calibration and validation was done for seven years monthly time step (1996-2002) and three years monthly time step (2003-2005) respectively. After modeling the gauged watershed, calibrated parameters were transferred to ungauged watershed by lumping the parameters having the same hydrologic response unit (HRUs). The model output indicates that, the total annual inflow volume from gauged and ungauged catchments estimated to be 6229.115 MCM for calibration period. From the Thissen polygon analysis, the annual average areal rainfall over the Lake for the simulation periods of (1991-2000), (2031 -2040), and (2091-2100) found to be 1291mm/year, 1737.693mm/year, and 1690.104 mm/year respectively. From CROPWAT model the average annual evaporation over the Lake for the simulation periods of (1991-2000), (2031-2040), and (2091-2100) found to be 1618 mm/year, 1767 mm/year, and 1909 mm/year respectively.

Water demand analysis were done by using WEAP Simulation Model for entire projects in the basin for three different development scenarios, which will assist the water experts and decision makers in making a realistic estimate of water availability and allocation.

The WEAP model simulation results indicate the decline in mean annual lake levels, and consequently lake area, as water resources development in the catchment increases. As water resources development increases there are longer periods of time when mean monthly lake levels are below 1785 masl (i.e., the minimum lake level required for shipping). Under natural conditions (lake level without project), they exceed this level in 100%. Under current conditions (Base line scenario, BLS), they exceed this level in 89% of the months. In the full development scenario (FDSC′), this will decrease to 83%. The results of the WEAP model simulation shows that Lake water Level will not significantly be affected by climate change impacts for all future scenarios. By giving higher priority for hydropower schemes than irrigation schemes, the demand coverage and reliability of 100 percent was observed for Tana – Beles hydropower project under all scenarios with and without climate change.

V. References

[1] Abeyou W., (2008). Hydrological balance of Lake Tana, Upper Blue Nile Basin, Ethiopia, a M.Sc. thesis, International Institute for Geo-information science and Earth observation, Netherlands.

[2] BCEOM (1999): Abbay River Basin Integrated Development Master Plan Project and Associates (1999).

[3] Kebede, S.; Travi, Y.; Alemayehu, T.; Marc, V (2006). Water Balance of Lake Tana and its Sensitivity to fluctuations in rainfall, Blue Nile Basin, Ethiopia. Journal of hydrology 316: 233-247.

[4] McCartney; Alemayehu; Shiferaw; Awulachew, S.B. (2010). Evaluation of Current and Future Water Resources Development in the Lake Tana basin, Ethiopia. Colombo, Srilanka: International Water Management Institute.39p. (IWMI Research Report 134).

[5] MoWR (Ministry of Water Resources) (1998). Abbay River Basin Integrated Development Mater Plan Project: Phase 2, vol. VI, Water Resources Development, part 2, Large Irrigation and Hydropower Dams. Report, Addis Ababa, Ethiopia.

[6] SEI (Stockholm Environment Institute).(2007). WEAP: Water Evaluation and Planning System user guide. Boston, Stockholm Environment Institute.

[7] SMEC (Snowy Mountains Engineering Corporation). (2008): Hydrological Study of the Tana – Beles Sub-basins, main report. Addis Ababa, Ethiopia: Ministry of Water Resources.

[8] Studio Pietrangeli, (1990). Tana Beles Project studies document.

[9] WWDSE (Water Works Design and Supervision Enterprise) and TAHAL Consulting Engineers Ltd. (2008). Lake Tana sub-basin four dams project, final feasibility report for Megech Irrigation Project, Vol. III: hydrological report. Addis Ababa, Ethiopia.

GIS Based Hydrological Zones of Ethiopia

Belete Berhanu[1,3*], Assefa M. Melesse[2] and Yilma Seleshi[3]

[1] Ethiopian Institute of Water Resources (EIWR), Addis Ababa University, Addis Ababa

[2]*Departments of Earth and Environment, Florida International University, Miami, FL, 33199, USA*

[3]Department of Civil Engineering, Addis Ababa Institute of Technology (AAiT), Addis Ababa

Abstract

Land and water resources are important to maintain the environmental and livelihood security of human being. They are also the basis for their survival and economic development of agrarian society like Ethiopia. The understanding of their spatial variability has significant importance for planning and management of these vital resources. Although there are lots of efforts to characterize the land resource, its properties, capability and suitability for different production system, there is limited effort to characterize the spatial and temporal distribution of water resources at a national scale. Thus, a review based research aimed to generate the hydrological zone of the country based on the surface runoff potential is reported. The annual areal rainfall, annual areal potential evapotranspiration, soil, and land slope maps of the country are used as the base layer to develop the hydrological zones of the country. The analysis which uses the weighted overlay technique within ArcGIS relied on the data from various sources and scales. An iterative analysis and expert knowledge was also used to determine the weights of the four layers for the hydrological zoning. Results of this analysis provide valuable information about the hydrological zones of Ethiopia, which will improve the hydrological understanding of the country.

Key words: Hydrologic zoning, surface runoff, Ethiopia, GIS, rainfall, Evapotranspiration, soil, slope

1. Introduction

Land and water resources are important to maintain the environmental and livelihood security of human being. They are also the basis for the survival and economic development of agrarian society like Ethiopia. The understanding of their spatial variability in the boundary of the country has significance importance on the planning and management of these vital resources. All the process and interactions of the ecosystem are responsible for the heterogeneity of the land and water resource potentials and constraints. Understanding of this naturally occurred variability become the first step for utilizing the potentials and manages the constraints of the land as well as the water resource. Particularly, Water is the most complex natural resource correlating its availability from atmosphere to lithosphere through hydrosphere. Its availability is highly uneven in space and time. The characterizing and understanding of the water resources with space and time will be the base for any land base development, which is the core element of watershed management.

A number of watershed management activities were implemented in the Ethiopia without clear characterizations of the spatial distribution of the base resources. Of course there are a number of efforts that done for the characterization of the land resources. Ethiopia land capability classification for soil conservation (Escobedo 1988), agro-ecological based of land use potential assessment (NRMRD-MOA, 1998), and desertification convection based classification of moisture zones (Engida-2000) were some of the efforts done for the characterization of the land resources with its potential and constraints for food production. However there is no any recorded effort in the characterization of the water resources of the country. In most case the amount of the surface water and ground water potential of the basins are also described with hesitation. Most of the hydrological studies are model dependent and also focused on the calibration and validation of externally developed rainfall-runoff methods and models. Hence this review-based research is done to understand the spatial distribution of the soil, climatic elements and surface runoff of the country for the formulation of hydrological zones, which will be crucial information for characterization of watersheds.

2. Objectives of the study

The overall objective of this study is to characterize the spatial variability of soils, climate topography and surface runoff of the country for the formulation of hydrological zones. With this general objective the research aim to address the following specific objectives

- To develop soil textural classification of the country
- To develop rainfall and potential evapotranspiration regimes of the country
- To develop the slope classification of the country
- To formulate hydrological zones of the country based on the surface runoff potential

3. Methods of the research

Study area

Ethiopia, commonly known as 'The Horn of Africa', is located in the northeastern corner of Africa between latitude 3^0 and 15^0 North and longitude 33^0 and 48^0 East. The Country, which is the 9th largest in Africa, has the area of about 1.13 million km^2. Out of this, 1.12 million $km^2$is land area and the remaining 7, 444 km^2 is water area (rivers, lakes, ponds etc.). Ethiopia is intersected by deep running rivers. The general terrain of the country has high plateau with central mountain range divided by Great Rift Valley. It creates three major relief regions: the Western Highlands, the Eastern Highlands, and the low-lying Rift Valley and Western Lowlands. The elevation is ranging between two extremes from 125 m high Denakil Depression to 4,620 m high RasDejen (Dashen) peak. These wide ranges of topographic variation together with its climatic diversity lead the country to have wide variability in land and water resources.

Methods of the study

Weighting overlay approach within ArcGIS is selected as the basic tool for the development of qualitative hydrological zone classification of the country. Four GIS layers namely, rainfall, evapotranspiration, soil and land slope are prepared with different scale factor classes in raster format and then overlay using weighted overlay technique in the Spatial Analysis of ArcGIS to get different hydrological class/zone of the country based on their contribution for the generation of surface runoff.

The soil and land slope classes are created with seven and six scale factor classes, respectively using the land capability classification tool as the base for their classification (Eszobedo 1998). In this classification, the land slope classification is done using 90-m resolution digital elevation model (DEM) data of the country and classified into six classes with different slope range starting from flat to steep slope classes. Similarly, the soil classes classified into seven soil class based on the soil textural classification and the scale grade is given with their infiltration capacity (Table 2). Sand texture is assigned with one with high infiltration capacity or low runoff generation potential and the last scale grade is assigned for heavy clay soil or water bodies with very low infiltration capacity and surface runoff.

Climatic information that include monthly rainfall and minimum and maximum temperature is collected from the National Meteorological Authority of Ethiopia (NMA). Long-term annual average rainfall data of about 930 rainfall stations distributed over the country are used and interpolated using Inverse Distance Weighted (IDW) method in the ArcGIS environment to analysis the spatial variability of rainfall in the country (ESRI 2008). Then it was classified into 7 scale factors based on the length of growing period's classification of Ethiopian Agro-Ecological zones with 1 for the smallest annual rainfall and 7 for the largest annual rainfall (Table 2).

Table 1: Soil texture and slope class with scale factor

Soil texture class	Scale factor	Slope class	Slope range (%)	Scale factor
Sand	1	Flat or almost flat	0 - 3	1
Sandy loam	2	Gently sloping	3 - 8	2
Loam	3	Sloping	8 - 15	3
Silt loam	4	Moderately steep	15 - 30	4
Clay loam	5	Steep	30 - 50	5
Silt clay, clay	6	Very steep	> 50	6
Heavy clay	7			

Source: Assistance of soil and water conservation program, Phase III, Field Document No. 19 ETH/85/016. CFSCDD, MOA, FAO, October 1998

The minimum and maximum monthly temperature data of 212 meteorological stations are used as input of CROPWAT 8, software to compute the monthly potential evapotranspiration (ETo) (FAO, 2009). In order to increase spatial coverage of the ETo, information the annual ETo of the stations are correlated with the altitude of the stations, which yield equation (1).

$$AETo = 2350 - 0.383\ Altitude \qquad (1)$$

Where AETo is annual potential evapotranspiration in mm and Altitude is the elevation of a place above sea level in meter. Equation (1) gave a very good result with coefficient of determination (R^2) of 0.91. Using this regression equation and the elevation information of 90-m DEM the spatially distributed ETo of the whole country is computed in the ArcGIS spatial Analysis environment. Spatially distributed ETo information also again classified into 6 scale factors classes based on the thermal zone classification of the agro-ecological classification of Ethiopia. (NRMRD-M0A 1998) using 1 for the smallest annual ETo and 6 for the largest annual ETo class (Table 2).

Table 2: Annual rainfall and ETo classification

Standard name	LGP* (in days)	Annual** RF (mm)	Scale factor	Thermal zone	Temperature range (^{o}c)	Annual ETo (mm)	Scale factor
Arid (A)	< 45	< 302	1	Hot	> 27.5	< 500	1
Semi-Arid (SA)	46- 60	302-350	2	Warm	27.5 – 21	500 –1600	2
Sub-Moist (SM)	61-120	350-566	3	Tepid	21 – 16	1600 – 2400	3
Moist (M)	121-180	566-835	4	Cool	16 – 11	2400 – 3200	4
Sub-Humid (SH)	181-240	835-1189	5	Cold	11 – 7.2	3200 – 3800	5
Humid (H)	241-300	1189-1711	6	Very cold	<7.5	> 3800	6
Per-Humid (PH)	> 300	>1711	7				

***Source:** Agro-ecological zones of Ethiopia, Natural Resources Management and Regulation Department of MOA, March 1998, Addis Ababa
**Source: Agro-ecological land resource assessment for agricultural development planning: A case study of Kenya, Resources database and land productivity main report, Technical annex 2, 1992

Table 3: Relation and percent of influence of layers with runoff generation

Layer	Scale factor	Relation of the scale factor with runoff generation	Percent of influence assigned
Annual Rainfall	1 to 7	Direct	40
Annual ET_o	1 to 6	Indirect	30
Soil textural class	1 to 7	Direct	20
Slope class	1 to 6	Direct	10

Finally, the hydrological zones of the country are developed by using the weighted overlay methods of ArcGIS spatial analyst and the relation of the rainfall, evapotranspiration, soil texture and slope with surface runoff generation. Since there is no such similar work for the development of the hydrological zones using ArcGIS weighted overlay method, the weight of influence of the four source layers and their relation is fixed after a number of iteration (Table 3).

Thus the following percentage of influence and relation is used for the final hydrological classification of the country.

3. Results and Discussion

Soil textural classification

Soil texture is the entry point to avail all information that required for the hydrological analysis of any catchment. Thus in this study the soil classification of the country is generated using the soil type class and their content ratio for clay, silt and sand (FAO, 2009). The USDA textural triangle is used as a tool to classify the textural class of each soil map unit (Wischmeierm, 1971). Accordingly, we have 10 soil textural classes in the country with different range of area coverage. And the soil textural class is regrouped into seven textural classes for the purpose of the hydrological zoning. (Figure1).

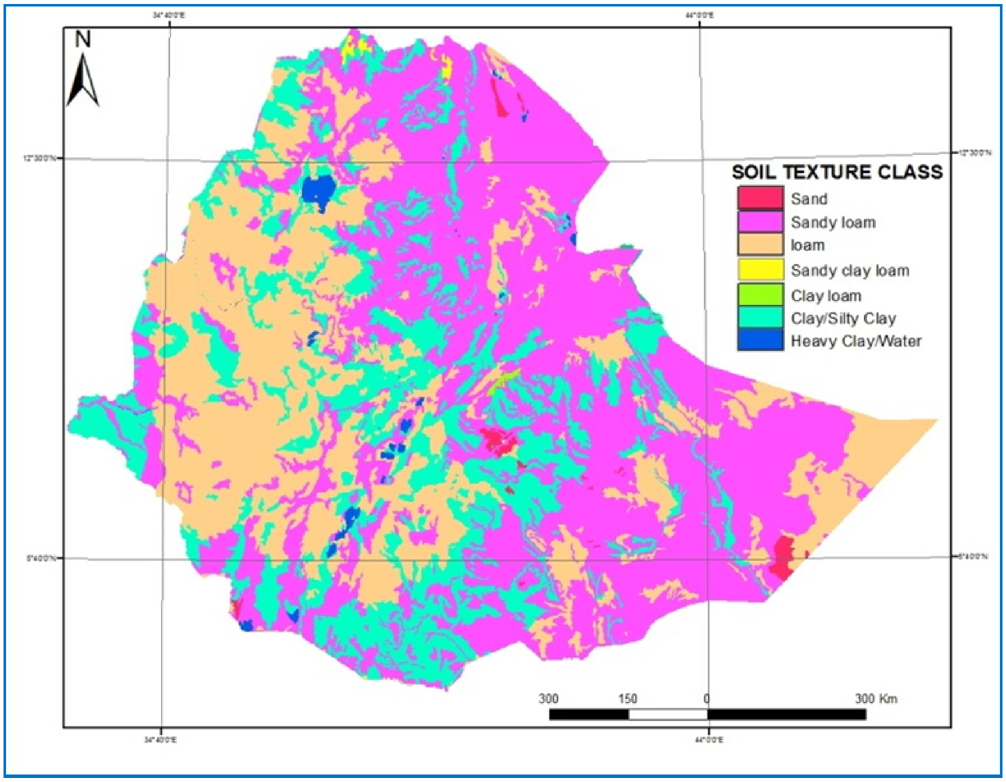


Figure1: Soil Textural classification of Ethiopia

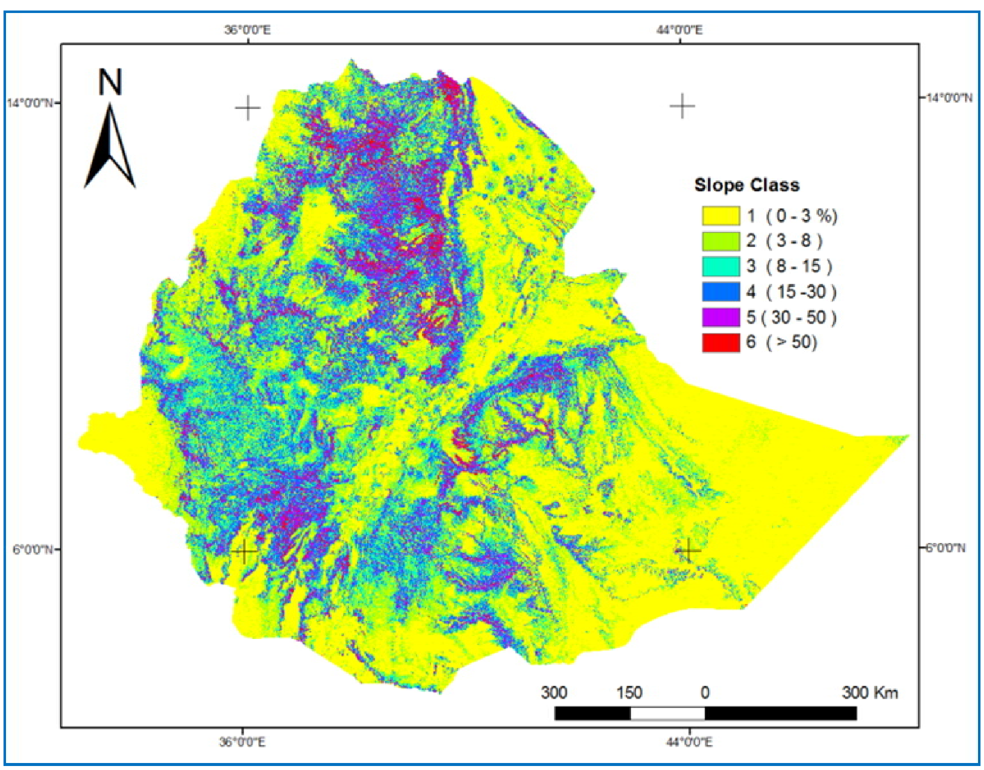


Figure 2: Slope class of Ethiopia

Slope class classification

The land mass of the country further characterized using the six slope class classification. Most of the low land area especially the low lands of the eastern parts of the country has flat slope. In the contrary, the central and western highlands have steep and very steep slope (Figure2).

Climatic variability

Using the annual rainfall and annual evapotranspiration the spatial climatic variability of the country is mapped. The map shows the range and distributions of the moist and arid area of the country. The annual rainfall of the country ranges from 141mm at the arid area of eastern and north eastern borders of the country to 2275mm at the south western highlands. Similarly, the annual ETo of the country ranges from 620mm in the central highlands of the country to 2350mm in the southeastern and northeastern lowlands of the country (Figures 3 and 4).

Hydrological Zoning

Using the weighted overlay analysis of the four source layers, the country is classified into five hydrological zones, namely no runoff, low runoff, moderate runoff, high runoff and very high runoff zones. This analysis shows that most part of the country, which covers 40.4% of the country area, is in high runoff zone, and followed by moderate and low runoff zone with 26.8% and 17.2% coverage, respectively. The high runoff generation area of the country has large coverage, which is the good indication for the availability of high surface water potential. And also its spatial distribution is to the western and central highlands of the country (Table 4 and Figure 5).

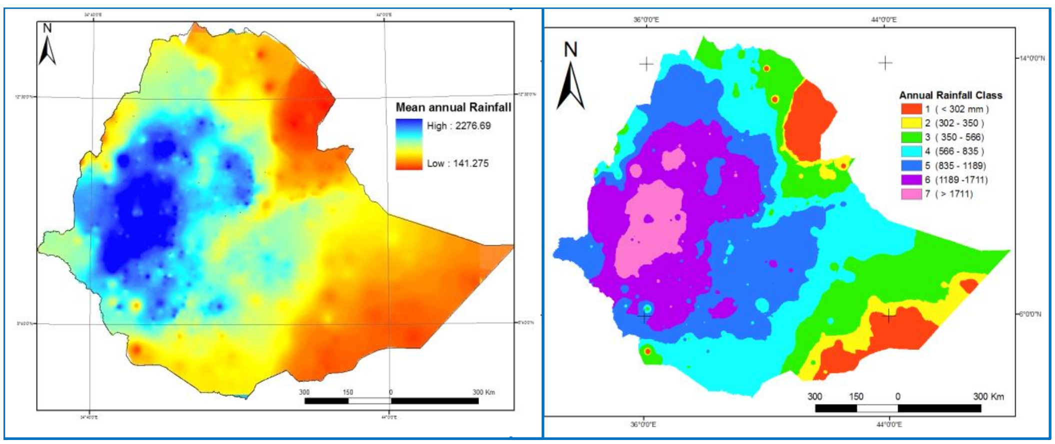


Figure 3: Mean Annual Rainfall variation and classification of Ethiopia

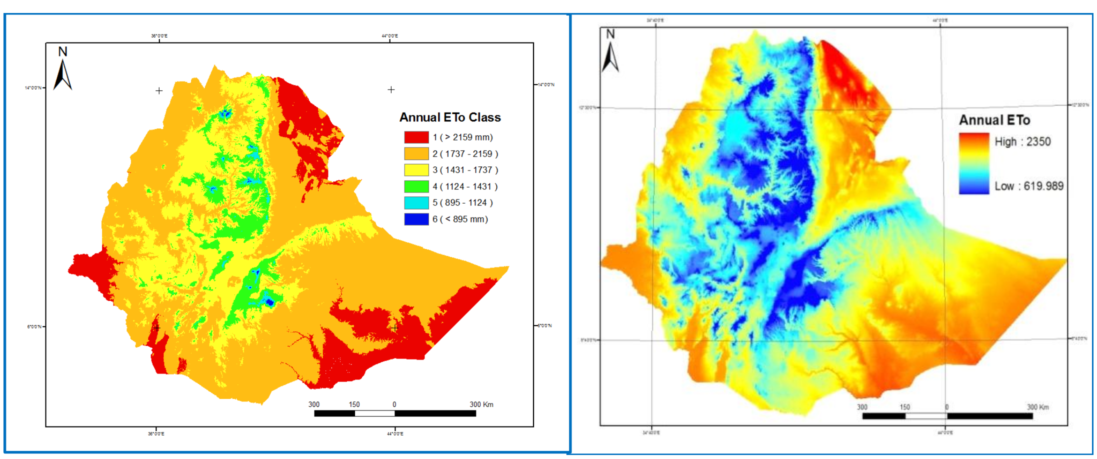


Figure 4: Annual ETo variation and classification of Ethiopia

Table 4: Hydrological Zones of Ethiopian and their areal and percent of coverage

Class	Hydrological Zone	Area Coverage (Km^2)	Area Coverage (%)
1	No runoff Zone	60891.63	5.40
2	Low runoff Zone	193277.14	17.15
3	Moderate runoff Zone	301403.00	26.75
4	High runoff Zone	455497.14	40.42
5	Very High runoff Zone	115823.41	10.28

5. Conclusion

A study was conducted with objective to develop hydrological zones that indicate the potential for surface runoff. Based on results of the study, it can be concluded that the outputs of this study have a paramount of importance for the understanding and characterizing of country's land and water resource bases. Results of this study can be used as the basis for further analysis of the surface water potential of the country, soil erosion rate and watershed degradation susceptibility, which have significance in the watershed management effort of the country.

The use of ArcGIS weighted overlay analysis has a very good capability to generate spatially distributed classification with the scale factor and weights for each input layers qualitatively without quantifying values of all runoff generation factors. The authors believe that this a good starting point for further refining results of this study and improve the spatial representation as well as its scope.

6. References

EngidaMersha 1999 A desertification convention based classification of moisture zones of Ethiopia: In Ethiopian Journal of Natural Resources Vol 2 No 1 pp 1-9.

ESIR 2008: ArcGIS 9.3, ArcINFoLicence, Copyright © 1999-2008 ESRI

Eszobedo, J. 1998: Assistance to soil and water conservation program, Phase III, Field Document No. 19 ETH/85/016. CFSCDD, MOA, FAO, October 1998, Addis Ababa, Ethiopia.

FAO, 2009 CROPWAT8.0 Software, Water Resources Development and Management Service, Land and Water Development Division, FAO, Vialedelle Terme di Caracalla, 00153 Rome, Italy

FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009: Harmonized World Soil Database (version 1.1), FAO, Rome, Italy and IIASA, Ladenburg, Austria.

Kassam, A.H. H.T. van Velthuizen, G.W.Fischer and MM. Shah 1992: Agro-ecological land resource assessment for agricultural development planning: A case study of Kenya, Resources database and land productivity main report, Technical annex 2, World Soil Resources Reports No 71/2 FAO and ILSA

NRMRD-M0A 1998: Agro-ecological zones of Ethiopia, Natural Resources Management and Regulation Department of MOA, March 1998, Addis Ababa.

Wischmeierm W.H., C.B. Johanson, and B.V. Cross 1971: A soil erodibility nomograph for farmland and construction sites Journal of Soil and Water Conservation 26:189-193

Evaluation of Climate Change Impact on Blue Nile Basin Cascaded Reservoir Operation

Demelash Wondimagegnehu[1] and Dr. Kassa Tadele[2]

[1,2]Arba Minch University, P.O.Box 21, Arba Minch, Ethiopia, demewon21@gmail.com and 2 kassatad@yahoo.com

Abstract

This study mainly deals with evaluation of climate change impact on Blue Nile Basin cascaded reservoir operation in particular to Beko-Abo, Mandaya and Border reservoir, which are proposed cascade hydropower development on main stream of Abbay river basin. To evaluate the impact of climate change, climate change scenarios of evapotranspiration and precipitation were developed for three periods using output of ECHAM5 with RCM for A1B emission scenarios were used to develop future climate scenarios. A hydrological model, HEC_HMS, was used in order to simulate the current and future inflow volume to the reservoir. The performance of the model was assessed through calibration and validation process and resulted NSE from 0.74 to 0.88 during calibration and from 0.71 to 0.84 during validation at he four gauge stations. The projected future climate variable show an increasing trend for both maximum and minimum temperature and evapotranspiration but precipitation shows fluctuating trend in the next century. Relative to the current condition, the average annual open water evaporation for Beko-Abo reservoir might increase by 4.02% and 5.93% for Mandaya reservoir. It might also increase by 8.1% and 10.2% and for Border reservoir also shows an increase of 8.6% and 17.1% in 2011-2026 and 2026-2041 scenarios respectively. Comparison to the base period and the future period average annual inflow volume shows an increase of 9.1% and 6% at Beko-Abo and an increase of 7.2% and 4.4% at Manaya during 2011-2026 and 2026-2041 periods respectively and at Boarder reservoir a decrease of 12.3% during 2011-2026 and 14.6% during 2026-2041 periods. A reservoir simulation model, HEC-ResSim, was used to simulate the hydropower potential of the reservoir and to determine the reservoirs operation rule curve.

The average annual power generation might increase by 1.53% and 1.11% at Beko-Abo and might also increase by 2.56% and 1.47% at Mandaya hydropower station during 2011-2026 and 2026 -2041 periods respectively. For Border hydropower station, the average annual power generation might decrease by 0.95% and 2.91% for both periods in comparison to the base period. The reservoirs cascade operation using tandem rule for two upstream and a release rule for downstream reservoir shows insignificant variation of water level for future condition in comparison to the base period. On average the time based and volumetric reliability of the reservoirs estimated to be more than 90% .The resilience of the reservoirs is below 50% and their vulnerability is less than 50%. Therefore, these performance indices reveals good performance of the reservoirs except the speed of recovery of the reservoir from failure because the reservoir will not able to recover rapidly from failure to safe state, instead reservoir translate to safe state after continuous failure state.

1. Introduction

The impact of climate change on water resources are becoming a critical issue for many countries in the developed and developing world. Climate change is likely to alter the hydrologic cycle in many ways that may cause substantial impacts on water resource availability and changes in water quality (Schindler, 1997).

The study area, Abbay River Basin , which is found in th e northwestern part of Ethiopia between $7^0$45’ and $12^0$45’ N latitude, and $34^0$05’ and $39^0$45’E longitude.. It covers an area of approximately 199,812km^2 with a total perimeter of 2440km.The annual rainfall varies between about 800mm to 2,220 mm with a mean of about 1420mm.The rainfall pattern is almost uni-modal (BCEOM, 1999).

The aim of this paper is to evaluate the impact of climate change on selected Blue Nile Basin cascade reservoirs operation under climate change scenarios on inflow volume or stream flow, open water evaporation loss, operation rule, hydropower production capabilities of each reservoirs and thereby examine the reservoirs capability to meet the target demand in the future climate condition.

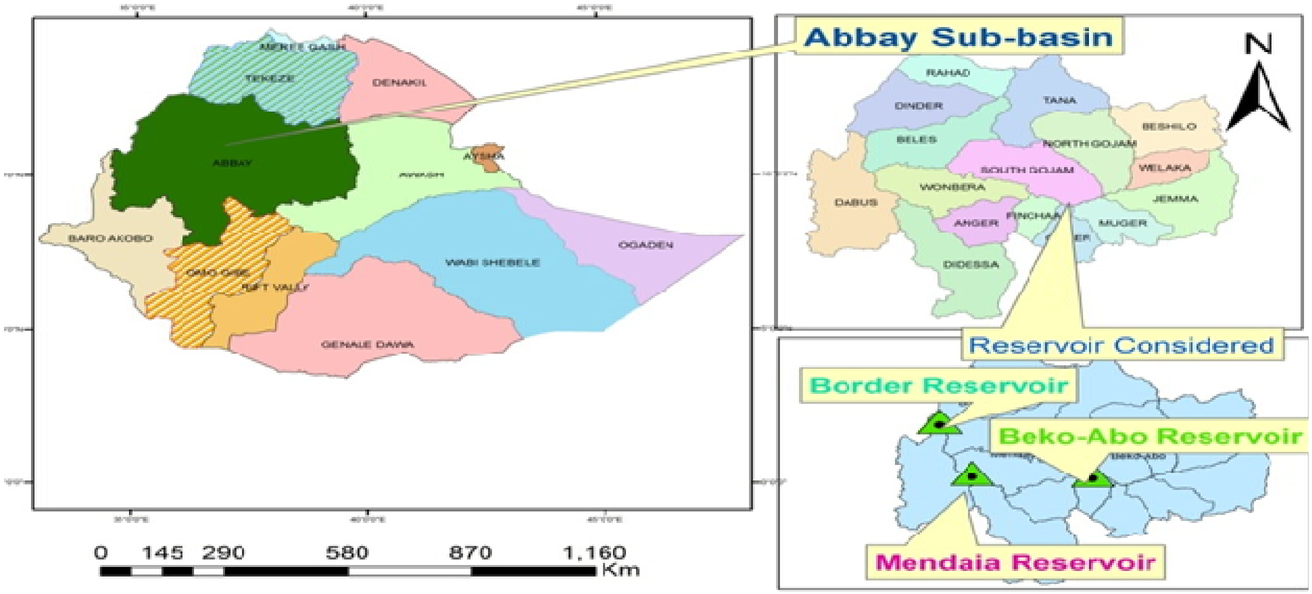


Figure 1: Location and basin map of the study area

2. Objectives of the study

The general objective of the study is to evaluate the impact of climate change on selected Blue Nile Basin cascade reservoirs operation under climate change scenarios.
The Specific objectives are:-

- To evaluate climate change scenarios using Regional Climate Model.
- To estimate current and future inflow volume in to each reservoir by employing a hydrological model.
- To evaluate the rate of change in open water evaporation losses from Cascaded reservoirs with future climate change.
- To assess the impact of climate change on the hydropower production capabilities of the each reservoirs and thereby examine the reservoirs capability to meet the target demand in the future climate condition.
- To develop current and future reservoir operation rule curve for cascaded reservoirs using HEC-ResSim model.

3. Materials and Methods

Model Description

For climate change downscaling purpose dynamical downscaling model, Climate Local Models (CLM) which is designed to downscale climate was utilized as to get future trend and scenarios. Arc-GIS for spatial data analysis and making connection with Arc-Hydro and HEC-GeoHMS were used to estimate initial parameter and to prepare basin and meteorological models for HEC-HMS hydrologic modeling for runoff generation and HEC-ResSim model for reservoir operation are the models used for this study. The performance of the reservoirs was evaluated using RRV-Criteria.

Physiographical Data

Hydrological, DEM of 90mx 90m resolution, Land use/ land cover, Soil and geology shape file data for the study area taken from Ministry of water and Energy. The meteorological data have been collected from National Meteorological Agency (NMA).

The predicted future climate change parameter on daily basis for a period of 30 years (2011 to 2041) was collected from International Water Management Institute (IWMI). For this specific study Penman-Monteith method is adopted to calculate the daily potential evaporation.

Hydrological Modeling & HEC-HMS Model Performance

The model performance in simulating observed discharge was evaluated during calibration and validation by inspecting simulated and observed hydrograph visually and by calculating Nash and Sutcliffe efficiency criteria (NSE), coefficient of determination (R^2), and Percent difference/Relative Volume Error (D) were used using the following selected methods.

Table 3.1: Methodological approach

Method	Loss Method	Transform Method	Base flow	Calibration& Validation	Objective Function	Optimization algorithm
Selected	Deficit and Constant	Clark unit hydrograph	Monthly Constant	Automated & Manual	PWRMSE	Nealder & Mead(NM)

3. Results and Discussions

The climate scenario was generated (RCM forced by ECHAM5 with A1B emission scenario) for the sub-basins for 30 years period from 2011-2041. the projected future climate change scenario shows an increasing trend for both maximum and minimum temperature and evapotranspiration but precipitation shows fluctuating trend in the next century.

HEC-HMS Hydrological Model Result

For all gauging station daily and monthly data for the sub-basin from 1996-2001 was used for calibration and from 2002-2005 for validation and 1995 was used for warm up the model (warm up period). The results are presented in Table 3.1, Figures 3.1 and 3.2.

Reservoir Inflow Volume

For comparison purpose the generated inflow is compared with the baseline (1996-2011) mean monthly flow. Comparison to the base period and the future period average annual inflow volume shows an increase of 9.05% and 6.04% at Beko-Abo and an increase of 7.17% and 4.39% at Mandaya during 2011-2026 and 2026-2041 periods respectively and at Border reservoir a decrease of 12.29% during 2011-2026 and 14.55% during 2026-2041 periods.

Table 3.2: Calibration and validation results

S.No	Catchment	Calibration		Validation	
		Daily	Monthly	Daily	Monthly
1	Kessie	0.64	0.82	0.60	0.80
2	Border	0.75	0.88	0.72	0.84
3	Didessa	0.63	0.80	0.63	0.79
4	Beles	0.52	0.74	0.51	0.71

Reservoirs Evaporation

The future reservoir evaporation shows an increasing trend for all three reservoirs. Relative to the current condition, the average annual open water evaporation for Beko-Abo reservoir might increase by 4.02% and 5.934%, for Mandaya reservoir it might also increase by 8.11% and 10.23% and for Border reservoir also shows an increase of 8.68% and 17.05% in 2011-2026 and 2026-2041 scenarios respectively.

Evaluating of the Performance Indices of Reservoirs

From reservoir performance indices, on average the time based and volumetric reliability of the reservoirs estimated to be more than 90% .The resilience of the reservoirs is below 50% and their vulnerability is less than 50%. Therefore, these performance indices reveals good performance of the reservoirs except the speed of recovery of the reservoir from failure because the reservoir will not able to recover rapidly from failure to safe state, instead reservoir translate to safe state after continuous failure state.

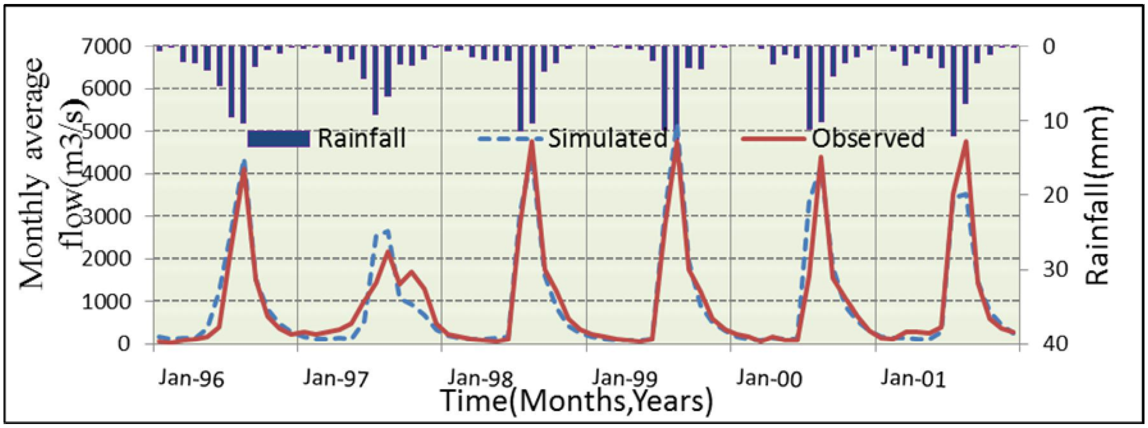


Figure 3.1: Monthly model calibration for Kessie gauge station

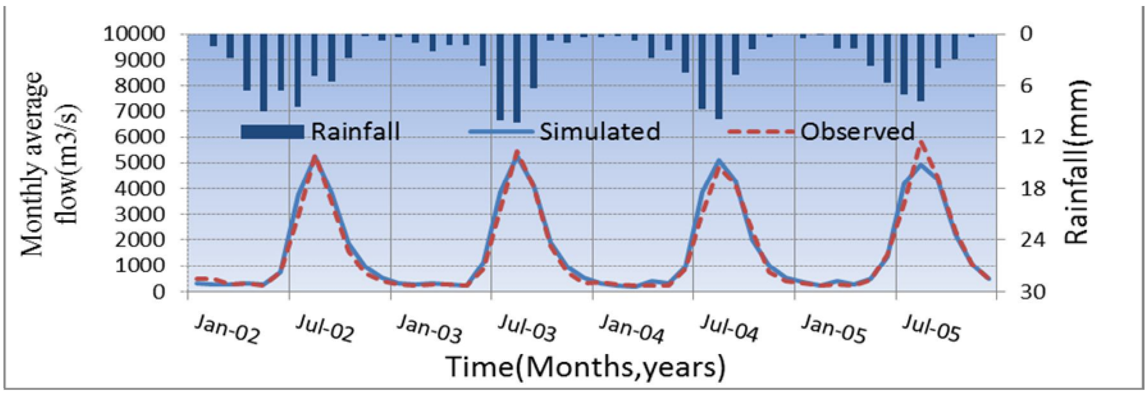


Figure 3.2: Monthly model validation for Border gauge station

Generally all three reservoirs have good ability to meet the target demand for the simulation period and from volume point of view or no shortage of flow to meet the demand but the three reservoirs require somewhat a longer period to meet the demand once the failure to meet the target demand is occurred.

Reservoirs Evaporation

The future reservoir evaporation shows an increasing trend for all three reservoirs. Relative to the current condition, the average annual open water evaporation for Beko-Abo reservoir might increase by 4.02% and 5.934%, for Mandaya reservoir it might also increase by 8.11% and 10.23% and for Border reservoir also shows an increase of 8.68% and 17.05% in 2011-2026 and 2026-2041 scenarios respectively.

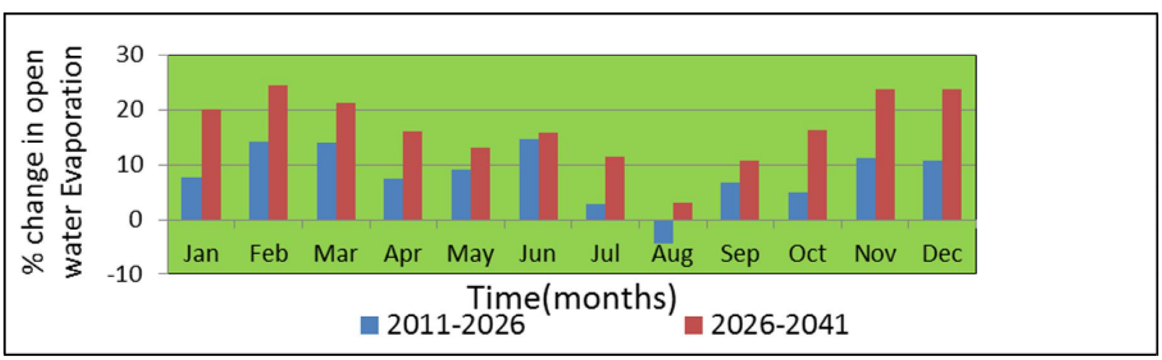


Figure 3.3: Border reservoir projected monthly percentage change in open water evaporation

Reservoir Hydropower Generation

A reservoir simulation model, HEC-ResSim, was used to simulate the hydropower potential of the reservoirs and to determine the reservoirs operation rule curve. The average annual power generation might increase by 1.53% and 1.11 % at Beko-Abo and might also increase by 2.56% and 1.47% at Mandaya hydropower station during 2011-2026 and 2026-2041 periods respectively. For Border hydropower station, the average annual power generation might decrease by 0.95% and 2.91% for both periods in comparison to the base period. The reservoirs cascade operation using tandem rule for two upstream and a release rule for downstream reservoir shows insignificant variation of water level for future condition in comparison to the base period.

4. Conclusions

The following conclusions have been drawn from the results of this research:

- The projected future climate change scenario shows a n increasing trend for both Tmax &Tmin and ETO but PCP shows fluctuating trend in the next century.
- The average annual open water evaporation in all reservoirs shows an increasing trend in future climatic condition.
- The HEC-HMS hydrological model which is calibrated and validated, simulate the observed discharge in reasonably well manner. Hence, it is concluded that the HEC-HMS model is an acceptable hydrological model in order to generate inflow for such type of studies.
- From reservoir operation (HEC-ResSim), the average annual power generation shows an increasing in Beko -Abo and Mandaya where as a decreasing in Border reservoir.
- For all reservoirs the increasing or decreasing of power generation was in proportion with the increasing or decreasing of the inflow in to the reservoir.
- Under the current design of the reservoir and the hydropower stations, the future climate change under A1B emission scenarios might not impose any consequence in the
    - power generation capability
    - performance of the reservoirs in meeting the target demand
    - Rule curve of the reservoirs with the consideration of described research limitations.

Recommendations

- Climate is not static and assumptions made about the future based on the climate of the past may be inappropriate. Assumptions about the probability, frequency, and severity of extreme events used for planning should be carefully re-evaluated.
- Further studies which incorporate the impact of climate change with land use and land cover change, plus sediment inflow to the reservoirs should be undertaken using a physically distributed hydrological modeling.
- The HEC-ResSim optimal result is based on a successive trial and error procedure that is not fully assured for the optimal value. Hence, further study should undertake other optimization method for reservoir operation by including "**Grand Ethiopian Renaissance Dam" (5250MW).**

5. References

Abeyou, W. (2008). *Hydrological balance of Lake Tana, Upper Blue Nile Basin, Ethiopia*, M.Sc. thesis, International Institute for Geo-information sci ence and Earth observation, Netherlands.

Arnell, N.W. (2006a): *Global impacts of abrupt climate c hange*: an initial assessment. Working Paper 99, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, 37.

Genet,E. (2008)."*Reservoirs water balance analysis, Joint operation and optimal operation rules for system performance.*" A case proposed reser voirs on the main Blue Nile River, Ethiopia, MSc thesis, Arba-Minch University, AMU.

Hailay, Z .(2010). *Assessment of Potential Surface Water Storage Options to Cope Up With Climate Change and Variability in Abbay River Basin*: The Case of Tana and Fincha Sub-basins. MSc thesis, Arba-Minch University,AMU.

Hashimoto,S.J.R., Loucks, D.P.T.(1982). *Reliabil ity, resiliency and vulnerability criteria for water resource system performance evaluation*. Water Resources Research 18 , 14–20.

Muluneh, B. (2008). Evaluation *of Impact of Climate Change on Water Resource Availability in the Catchments of Blue Nile Basin*, MSc thesis, Arba -Minch University, AMU.

Integrating GIS and Remote Sensing Techniques for the Assessment of Erosion Vulnerable Area: The case of Jabi Techinan Woreda, West Gojjam Zone, Amahara Region

Abebe Mengaw[1] and Ferede Zewdu[2]
[1,2]Mizan-Tepi University[1] and Bahir Dar University[2]

Abstract

Soil degradation in the form of soil erosion is a serious and continuous environmental problem in Jabi Tehinan Woreda. Uncontrolled land use, deforestation, land over cultivation, overgrazing and exploitation of biomass for firewood, construction and other household uses due to increasing population ultimately leads to severe soil erosion. The impact of natural hazards like erosion hazard can be minimized and ultimately controlled by disaster preparedness maps. Therefore, the overall objective of this paper is to identify and map erosion vulnerable areas for the planning and implementations of sustainable soil conservation and management system in the study area.

This study had integrated GIS, RS and MCE models to assess and map erosion vulnerable areas and RUSLE model to quantify an estimated soil loss in Jabi Tehinan Woreda. Slope gradient, soil type, LULC, rainfall and drainage pattern were used as input model parameters/variables. The data had been collected and analyzed from different land sat imageries, SRTM data, topomaps and point interpolations of primary data. Finally the aggregated effects of all parameters had been analyzed and priority rating of erosion vulnerable area was calculated using weighted overlay techniques.

After analyzing all model parameters, areas in steeper slope with Lithosols, Eutric Nitosols, Orthic Luvisols, croplands, bare lands and river banks have been identified as the most erosion vulnerable areas. Quantitatively, 3,644 ha (3.1%), 12,867.8 ha (11%) and 33,995.5 ha (29%) of the entire land is endangered to extremely vulnerable, highly vulnerable and vulnerable areas respectively. The remaining almost half 59,310.7 ha (50.7%) and 7,165.5 ha (6.2%) of the land is explained to less and very less erosion vulnerable areas respectively. In general the northern, northeastern and a little bit of the southern margins of the woreda is the most exposed or vulnerable areas to erosion. While the south and central parts of the study areas are insignificantly vulnerable to erosion by water. The estimated annual soil loss in Jabi Tehinan Woreda ranges from nearly 0 in south and central parts of the study area to 504.6 t/ha/yr in the steeply sloping mountainous areas of the north and north- eastern parts of the catchments.

Key words: *GIS, Remote Sensing, Multi-Criteria Evaluation (MCE), RUSLE, Weighted Overlay, Land Use/Land Cover (LULC), Erosion Vulnerability and Soil Loss.*

1. Introduction

Nowadays, people in developing countries are increasingly forced to use more marginal and sensitive lands for agricultural purposes in every aspect to sustain their living. These uncontrolled uses of land due to population growth ultimately leads to deforestation, land over cultivation, overgrazing and exploitation of biomass for firewood, construction and other household uses, often causing severe soil erosion. Studies reported that, cultivation without using specific control techniques and unplanned land use, such as uncontrolled urban development, deforestation and mal-agricultural practice are fundamental factors of soil erosion (Biard and Baret, 1997). Due to uncontrolled and unmanageable interference of people to the land, world wide 80% of agricultural land suffers from moderate to severe erosion. Consequently, 65% of the soil in sub-Saharan Africa is said to have undergone degradation cycle (Ludi, 2004). Because of favorable topographical factors and strong human impact over the environment, especially the northern highlands of Ethiopia have been characterized by severe erosion. At country level, total soil loss by erosion from all land is estimated at almost 1.5 billion tons per year and on average 42 tones per hectare, of which 45% originates from croplands alone. But, in the highlands of Ethiopia, annual soil loss reaches up to 200 - 300 ton per hectare, making the total loss 23,400 million ton per year (FAO, 1984; Hurni, 1993).

In addition to severe sheet and rill erosion, today, cultivated and grazing lands of the study area is commonly dissected by gullies of different size. In this regard, it is completely correct to say that the obvious potential and beauty of the area is overshadowed by environmental degradation of unbelievable magnitude (Gete Zeleke, 2000).

With the increment of such environmental problems, identification and mapping of erosion (hazard) vulnerable area has become an important discipline in the world of Geo-Information Systems. Thus, by this study GIS and RS technologies were employed to evaluate and map potential erosion vulnerable area.

2. Objectives of the Study

The overall objective of this paper is to assess and map erosion vulnerable areas and to quantify an estimated soil loss by examining different topographic and anthropogenic factors for the planning and implementations of sustainable soil conservation and management systems in the study area.

3. Materials and Methods

The research used both primary and secondary data. Secondary data (Satellite image, aerial photo, topographic map, soil map (data), meteorological data, population data and others) were collected from different governmental and non-governmental organizations. In addition to this, frequent field observations using Global Positioning System (GPS) were carried out to generate primary information regarding the ground truth for image classification and erosion vulnerability verification.

Primary data were collected using expertise discussions and filed survey or ground truth observations and verification using GPS instruments. Secondary data includes satellite image, aerial photo, topographic map, soil map (data), meteorological data, population data and others which are desirable to the study purpose were collected from various governmental and non governmental organizations.

Data analysis and processing were made by digitizing, calculating and classifying the necessary information of each thematic layers using ERDAS IMGINE 8.7 and ArcGIS 9.2 software. Finally all parameter influences were weighted using MCE and Analytical Hierarchy Principle (Saaty, 1980). Furthermore, some simple statistical methods, such as percentage, average and graphic tabulation were also employed for the analysis and interpretations. The flow chart indicating the basic methodological approach adopted for the study is presented in figure 3.1.

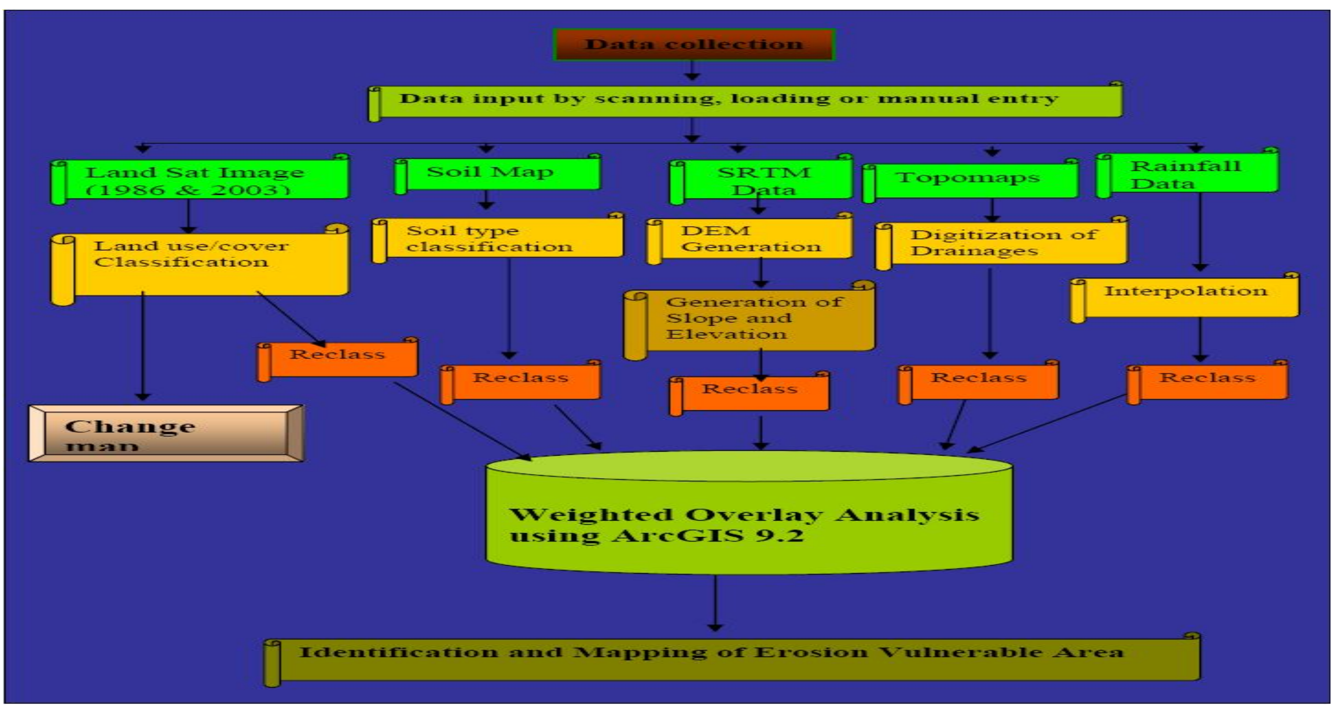


Figure 3.1: Flow chart showing the basic methodological approach adopted for the study

The basic methodological approach followed in RUSLE has been detailed in the following simplified flow chart (Figure 3.2)

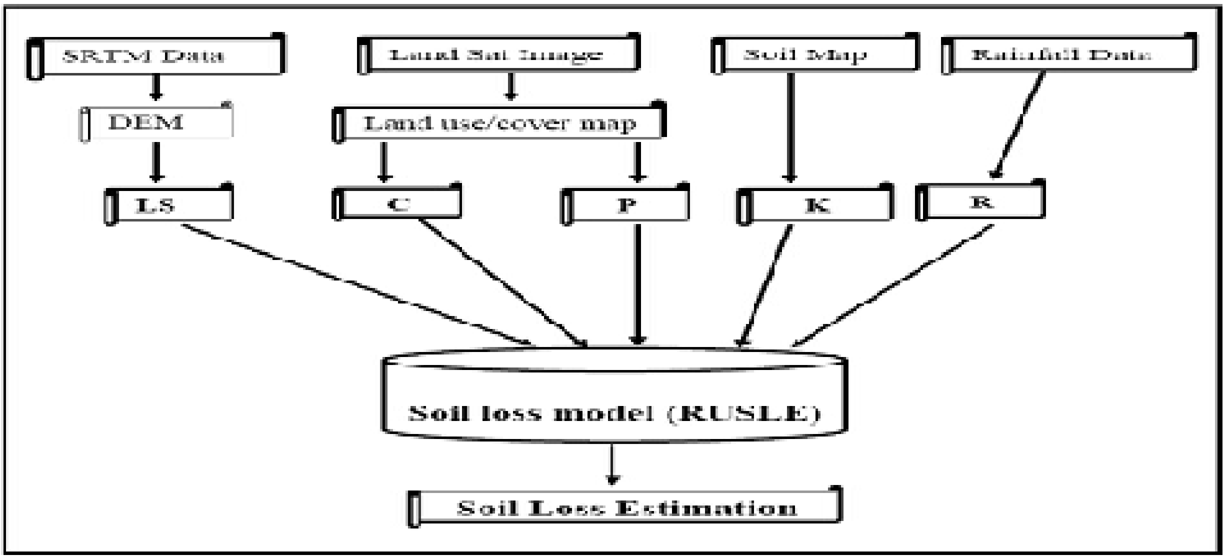


Figure 3.2: Flow chart showing the methodology adopted for soil loss estimation

4. Results and Discussions

Erosion vulnerability Distribution

Soil erosion is a function of spatial and temporal variation and interaction of different natural and anthropogenic factors. Topography (slope and elevation), soil type, land use/land cover, drainage pattern, rainfall and population growth have been identified as model parameters for the study. In the context of weighted overlay analysis model, the highest raster values indicate areas that are extremely vulnerable to erosion whereas lowest raster values imply areas in a very less vulnerable to erosion. Accordingly, five erosion vulnerability classes have been identified with a varying degree of vulnerability to soil erosion.

As clearly portrayed in the map (Figure.4.1), the northern, north-eastern and a little bit of the southern margins of the catchments were found the most exposing or vulnerable areas to erosion due to unplanned, unwise and unmanageable interference of humans in to steeply sloping mountainous areas. These uncontrolled uses of land due to population growth ultimately leads to deforestation, land over cultivation, overgrazing and exploitation of biomass for firewood, construction and other household uses, often exposing the area in to severe soil erosion. While nearly flat areas of the south, west and central parts of the study areas are insignificantly vulnerable to erosion due to low erosivity power of runoff in flat areas.

In general, the result of the study indicated that, areas in steeper slope with Lithosols, Eutric Nitosols, Orthic Luvisols, croplands, bare lands and river banks have been identified as the most erosion vulnerable areas. The main reasons why areas in steeper slope with Lithosols, Eutric Nitosols, Orthic Luvisols, crop and bare lands increasingly vulnerable to erosion is due to the absence of any types of soil covers, over grazing, land over cultivation, lack of soil conservation practice and its rugged topographical feature and steeper slopes which increased the eroding power of the water during the rainy seasons. On the other extremes, areas in flat slope covered by forest and bush lands with Chromic and Pellic Vertisols were found in a very less to less vulnerable areas due to its flat areas and surface cover which intercept raindrops, increase infiltration, slow down runoff and reduce transporting capacity of water flow. In addition Chromic and Pellic Vertisols have high clay content which tends to be joined each other not to detach easily by erosion. Clay textured soils resist wind and water erosion better than silty and sandy textured soils, because the particles are more tightly joined to each other.

Estimated Soil loss

The spatial distributions of amount of soil loss in Jabi Tehinan Woreda is quite different and ranges nearly insignificant (0) in south, west and central parts of the study area to extremely high (504.6 t/ha/yr) in the north and north-eastern parts of the catchments (Figure.4.2). The mean annual soil loss of the study area is 30.6 t/ha/yr, which makes an estimated total loss of 3,580,528 ton per year from 116983.5 ha of land.

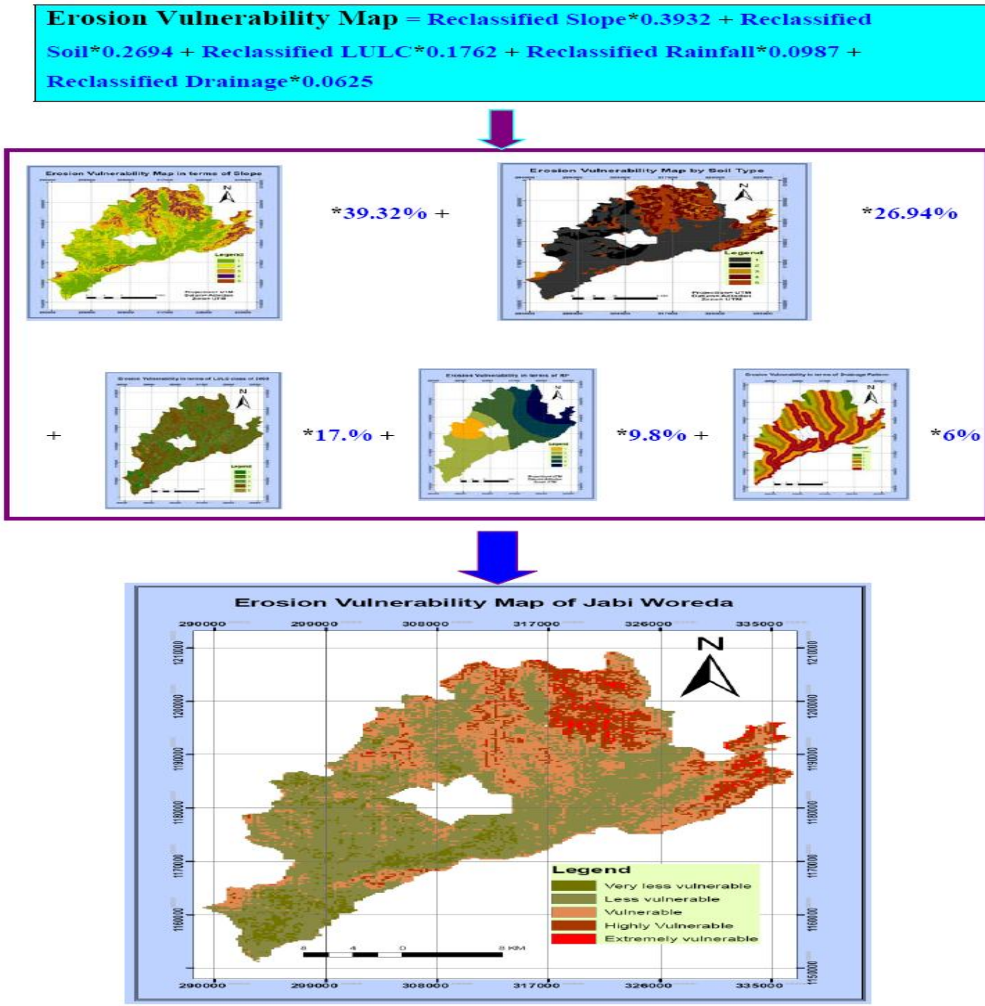


Figure 4.1: Weighted Erosion Vulnerability Model and Map Result

Since the north and north-eastern parts of the catchments is dominated by steeply sloping areas, an estimated soil loss in this area is greater than the soil loss estimation of the Ethiopian highlands by Anjeni research unit of SCRP (1988) and (Hurni, 1993). According to the Anjeni research unit of SCRP (1988), measured annual soil loss from Northwestern Highlands of Gojjam reaches up to 320 t/ha/year. In addition to its steep terrain features, poor land management, land over cultivation, over grazing and absence soil cover during the first periods of raindrops as well as water flows are also the major driving force for the recording of worst soil loss in the north and north-eastern parts of the woreda.

The overall result of the study was found in line with the findings of Gete Zeleke (2000), Anjeni research unit of SCRP (1988), Hurni (1993), Markos Ezra (1997), Solomon Abate (1994), MOA (1984) and FAO (1986). According to FAO (1984), MOA (1984) and Solomon Abate (1994) analysis and estimations, the Northern Highlands of Ethiopia including the study area has been affected by severe to moderate soil loss. In the same context different researchers indicated that, measured annual soil loss from Northwestern Highlands of Gojjam reaches up to 320 t/ha/year (Anjeni research unit of SCRP, 1988), 243 t/ha/year (Gete Zeleke, 2000) and 300 t/ha/year (Hurni, 1993) from bare and agricultural lands of the area.

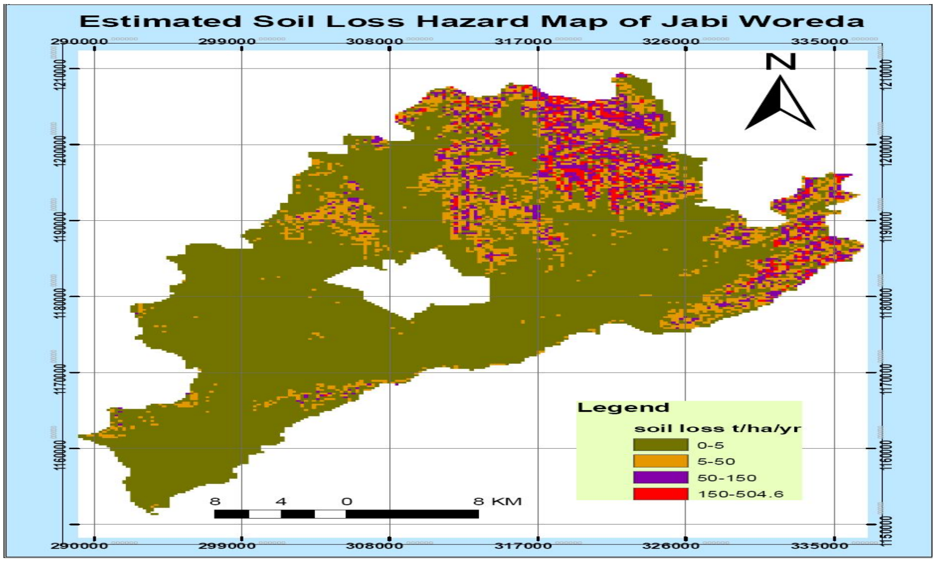


Figure 4.2: Estimated soil loss hazard map

5. Conclusion

The following conclusions have been drawn from this research results:

- Based on the result of the study it is possible to conclude the following important points.
- Assessment of erosion vulnerable area and estimate values of soil loss can be well computed by the application of GIS and remote sensing techniques.
- Derivation of slope length from the DEM in GIS environment is a very good cost and time effective methods than measuring at the field level.
- SRTM data from remote sensing image was found to be a very good data source for the derivation of slope gradients. Land sat imageries is also very popular data for land use/land cover change analysis which is the most important factor for erosion vulnerability correlation.
- Erosion vulnerable areas and estimated soil loss was found to be different in different land use/land cover type and slope gradients. The estimated values of soil erosion have direct relationship with slope gradients. In connection with land use/land cover types, there is no distinct pattern observed but erosion vulnerability potential increases in bare and cultivated lands.
- The erosion vulnerability model that has been developed can be used as one of the main inputs in decision-making support system of soil resource management and it may influence policy decisions of land use planning in the study area.

References

Biard F. and Baret F. (1997). Crop Residue Estimation Multiband Reflectance Using. Remote Sensing of Environment, 59: 530-536.

FAO (1984). Ethiopian Highland Reclamation Study (EHRS). Final Report, Vol 1-2. Rome, Italy.

FAO (1986). Ethiopian Highland Reclamation Study. Final Report of Food and Agricultural Organization. Rome, Italy.

Gete Zeleke (2000). Landscape Dynamics and Soil Erosion Process Modeling in the North Western Ethiopian High lands. African Studies Series A16 Berne Switzerland Geographic Bernensia.

Hurni H. (1993). Land Degradation, famine and resource scenarios in Ethiopia. In World Soil Erosion and Conservation, ed. D. Pimentel. Cambridge University press,Cambridge.

Ludi E. (2004). Economic Analysis of Soil Conservation: Case Studies from the Highlands of Amhara Region, Ethiopia. University of Berne, Switzerland.

Markos Ezra (1997). Demographic Responses to Ecological Degradation and Food Insecurity. Drought prone areas in Northern Ethiopia. Rijksunjvesiteit, Groningen.

MOA (Ministry of Agriculture) (1984). Land Use Planning Project. Land Use Planning and Regulatory Department. Addis Ababa, Ethiopia.

Saaty T. (1980). The Analytic Hierarchy Process. New York: McGraw Hill.

SCRP (1988). Soil Conservation Research Programme, Fifth Progress report (1985) University of Bern, Switzerland in Association with Ministry of Agriculture, Ethiopia.

Solomon Abate (1994). Land use Dynamics Soil Degradation and Potential for sustainable use in Metu area, Illubabur Region, Ethiopia. African studies series A13 Berne, Switzerland Geographical Bernensia.

Assessment of Climate Change Impacts on Cascade Reservoirs Operations: a case study on Gibe Hydropower Schemes, Ethiopia

Tilaye Kassaw, Dr. Nigussie Teklie and Ermias Alemu, Arba Minch University

Abstract

The research focuses on assessment of climate change impacts on hydropower project in Upper Omo-Gibe River Basin of Ethiopia. The study specifically aims to evaluate the impacts of climate change on cascade hydropower reservoirs operations of the current functional power plant; Gilgel Gibe-I and Gilgel Gibe-II; and currently under construction, Gibe – III. This study presents three steps for analyzing climate change impacts on cascade reservoir operation. The first step is construction of climate change scenarios. The climate change impact studies on water availability were done based on the outputs of the Regional Climate Model (RegCM3 forced by ECHAM5 GCM model output) for scenarios of A1B. The second steps of study are to generate future runoff into each reservoir systems for each climate scenarios by HEC-HMS hydrological model. HEC-HMS model was first calibrated and validated using historically observed daily climate and stream flow data by incorporating different watershed characteristics of the sub basin. Then, HEC-HMS model uses the future climate data as input to generate stream inflows to each reservoir systems. Finally, Gilgel Gibe-I,II,III cascade hydropower reservoirs are simulated using HEC-ResSim model in baselines period and future climate scenarios by incorporating different physical characteristics of dams, reservoir systems, power plants, river reaches etc. Then, impacts of climate change on cascade reservoirs operations are assessed. The generated climate results suggest that most of Upper Omo-Gibe River Basin is likely to become warmer (increase in temperature) and wetter (increase precipitation) in 2030s (2031-2040) and 2090s (2091-2100). The future generated stream inflows to each reservoirs system shows slightly decrease in scenarios of 2030s and increase somewhat in 2090s. The results of decreasing trend inflows to each reservoir in 2030s are due to the higher increase rate of potential evaporation than precipitation. The hydropower energy generation in each power plant shows a slightly decrease in 2030s and somewhat increase in 2090s like the trend of inflows to each reservoir systems.

Key words: *climate change, hydrological modeling, Omo-Gibe River Basin, Cascade Reservoir systems, hydropower energy generations.*

1. Background and Rationale

Marked changes in the global climate have been observed over recent decades. These are attributable to both natural and human factors that act upon the climate. Natural drivers include changes in solar radiation, gases and particles from volcanic eruptions, and possibly changes in the earth's magnetic field. Because of these, global climate is known to have oscillated over the millennia between cold and hot periods, with accompanying changes in precipitation over parts of the world (Houghton et al., 2001).

Recent observations, however, show that global temperatures are now rising at a substantially higher rate than can be observed or derived from past records. This is largely attributable to human impacts such as the release of greenhouse gases into the atmosphere and changes in land surface properties. In the most recent reports from the Intergovernmental Panel on Climate Change (IPCC), it was stated that "warming of the climate is unequivocal" and that "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations (IPCC, 2007a) .

Regarding hydrology and water resources, such changes phenomena of climate variables (temperature, precipitations, relative humidity, etc) will potentially affect local hydrological cycle in ways that deviate from past-observed records (Bates et al., 2008). For instance, the changes on temperature and precipitation can have a direct consequence on the quantity of evapotranspiration and runoff component. Consequently, the spatial and temporal availability of water resource, or in general the water balance, can be significantly affected.

However, most engineering designs of water resources projects, such as hydropower, are typically based on past climate conditions and are, therefore, subjects to impacts from changes in the climate, both in terms of its long-term averages; and its seasonal and monthly variability.

For instance, hydroelectric power potential depends on the amount of available run off, which is highly, depends on the climate variables of precipitation, temperature and potential evapotranspiration etc. of a sub basin. Then, the impact of climate change on a sub basin is directly or indirectly influences the production of hydropower energy.

Despite the fact that the impact of climate change is forecasted at the global scale, the type, and magnitude of the impact at sub basin scale of water resources project, for instance hydropower is not investigated in most part of the world. Therefore, it is necessary to study the effect of climate change on water resources development project at sub basin level in order to consider the effect by the policy and decision makers during operations and managements in coming century.

The effect of climate change is not addressed in expansion of Gibe cascade hydropower projects, Ethiopia. The IPCC findings indicate that developing countries, like Ethiopia, will be more vulnerable to climate change. It may have far -reaching implications to Ethiopia for various reasons, mainly as its economy largely depends on agriculture (Sirte et al., 2008) and (ENMSA, 2009). This Climate change could have significant impacts on hydropower production because of the close connections between the climate and water resources (Arnell N.W, 1999a).

Climate change and its impacts are, therefore, a case for concern issues on Gibe cascade hydropower schemes. Hence, the objective of this researches to identify and investigates the possible future climate change effects on hydropower energy generation of Gibe cascade reservoir systems.

2. Objective of the Research

The general objective of the research is to assess climate change impacts on Gibe Cascade Hydropower Reservoirs Operations.

The research has following specific objectives

- Developing and evaluating future climate variables of maximum temperature, minimum temperature, precipitation and potential evapotranspiration ;
- Building up hydrological model by incorporating different basin characteristics and generate future streams inflows to cascade reservoirs systems;
- Evaluating effects of climate change on reservoir pool level and hydropower energy generation of cascade reservoirs system in the next century.

3. Methodologies and Materials

Description of the Study Area

The Omo-Gibe River Basin is situated in South-West of Ethiopia, between 4°00' N, 9°22' N latitude, 34°44' E, and 38°24' E longitude as shown in Figure -1. It covers approximately 79,000 km^2 areas. It is an enclosed river basin that flows into Lake Turkana in Kenya, which forms its southern boundary. (Richard Woodroofe and Associ-

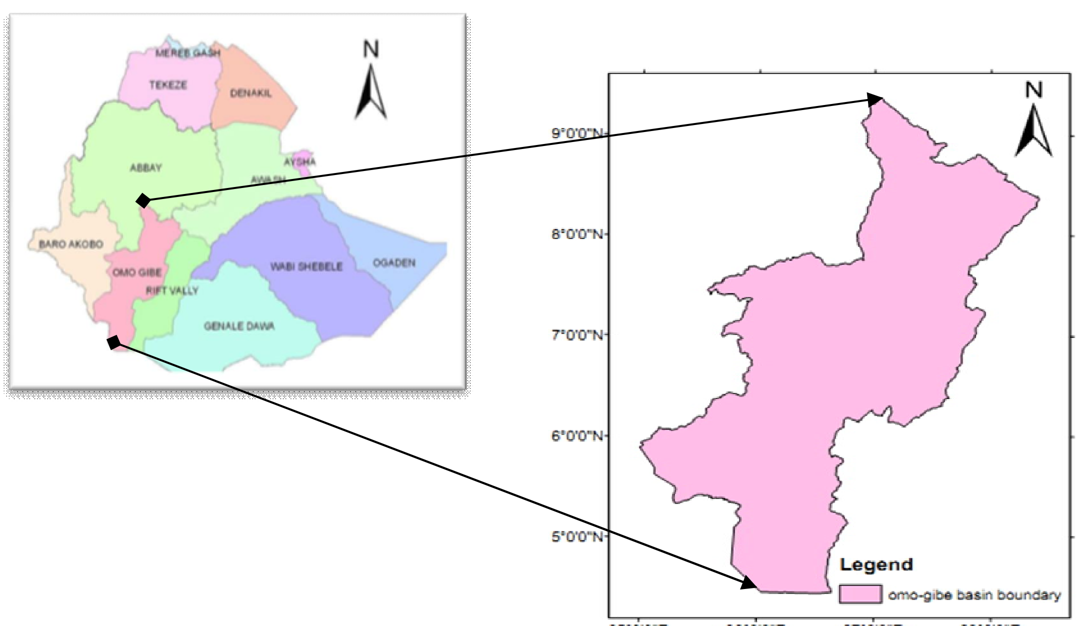


Figure 1: Locations of the Research area

Materials

A number of equipments and materials or models were used in this research. The main materials used for this research are ArcGIS 9.3 tool to obtain hydrological and physical parameters and spatial information. HEC-GeoHMS hydrological software is used to delineate the basin and sub basin of the study area HEC-HMS to simulate the hydrological and meteorological characteristics of the basin so that surface runoff can be estimated at desire place and time, and HEC-ResSIM to simulate cascade reservoir operations on different scenarios.

Data Availability

the primary assignment of the study was getting relevant information and data of the research area considered. The following are primary and secondary data of the research works.

Time series data

Metrological data (daily minimum and maximum temperature, precipitation, sunshine duration, wind speed relative humidity) and Hydrological/stream flow data,

Geo-spatial

suitable map (soil map, land use and land covers maps, topographic map , digital elevation map of Ethiopia (DEM), maps of the catchments area for identification of the river networks).

Secondary data

Secondary data used includes the original design documents of the different structural schemes of dam and apparent structures, hydropower structures, dams and hydropower plant physical and hydrological characteristics, minimum or maximum storage volume capacity, seepage loss rate and evaporation rate and storage – area-elevation curve of the reservoir systems.

Future Predicted Climate data

Methodologies (General Frame Works)

Changes in global climate are believed to have significant impacts on local hydrological regimes, such as stream flows, which support aquatic ecosystems, navigation, hydropower generation, irrigation systems, etc.

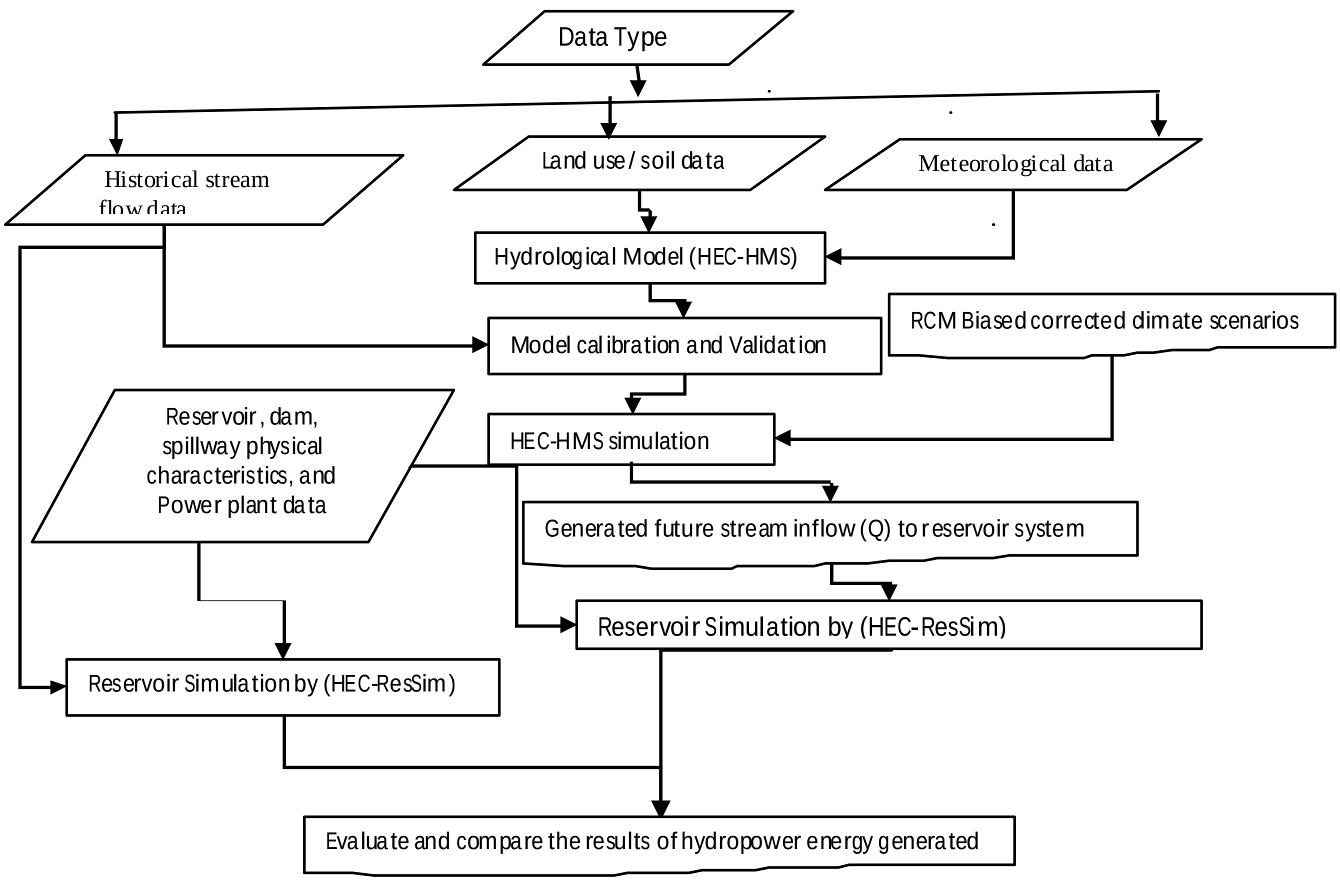


Figure 2 : General Conceptual frame works of the study

Such hydrologic impacts of climate change on a watershed can be estimated by developing hydrological models of the watershed and simulating river flows resulting from the downscaled precipitation and temperature data corresponding to the climate change scenario considered. For hydropower projects, the river flow generated in future scenarios further used as input for reservoir system operation and simulation models. The overall procedures adopted for this research work can be described in Figure 2.

The general steps followed in the research works are outlined below:

1. Collection of important data for the study such as hydrological, methodological, topographical, physical characteristics of dam and reservoir, power plant physical characteristics and digitized map of the study area from the respective organization and agency.
2. Developing future climate change scenarios of precipitation, maximum and minimum temperatures, and potential evapotranspiration on the study area.
3. Setting up and calibration (and verification) of a HEC-HMS hydrologic model with climate, land use/land cover, soil and stream flow data representing the current climate condition.
4. Analyses the observed and projected stream inflow corresponding to the different time periods of 1990s (1991-2000), 2030s (2031-2040) and 2090s (2091-2100) notice if there will be a significant trend in the annual and monthly stream inflow to each reservoirs system of Gilgel Gibe-I,II and Gibe-III.
5. Analysis the cascade reservoir simulation and operation by HEC-ResSim model based on baselines stream inflows data (1991-2000) and future projected stream inflows corresponds to scenarios of 2030s and 2090s.

3. Results and Discussions

HEC-HMS: Calibrations and Validations

The HEC-HMS model was calibrated (manually and automatically) and validated using measured daily stream flow data collected at the four (4) selected gauged stations. The calibration and validation is demonstrated by the coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (ENS) values. Both values for the four (4) gauged stations fulfilled the requirement of $R^2 > 0.6$ and ENS > 0.5, which is recommended (Santhi et al., 2001). The calibration and validation results for four gauged stations are summarized Table 1.

Table 1 : Summary of calibration and validation results

Gauging Station	Calibration		Validation	
	R^2	ENS	R^2	ENS
Gilgel gibe	0.70	0.65	0.64	0.63
Abaliti	0.69	0.68	0.688	0.68
Gojeb	0.71	0.7	0.66	0.64
Wabi	0.57	0.567	0.54	0.53

HEC-HMS: Hydrograph Comparison of Observed and Simulated Flow

The hydrograph comparisons of observed and simulated daily stream flow at four gauging stations are as follows in figures 3, 4 and 5. It is obvious to see from daily hydrograph that the simulated results of stream flow have a good fitting with the observed stream flow in calibration period (1986-1999) as well as validation period (2000-2005) in all four hydrometric stations.

Impact of Climate Change: on Reservoir Inflows Volumes

The comparison of monthly mean future generated stream flow of 2030s and 2090s with the baseline period inflows for Gilgel Gibe-I and Gibe-III reservoirs are shown in figures 6 and 7 respectively. Accordingly, the Gilgel Gibe-I reservoir inflows volumes will be decrease by 2.0% and increase by 9.5% in the main rainy season (June-September) for A1B global emission scenarios in 2030s and 2090s respectively. Whereas, the mean annual inflows volumes of Gibe- III dam is decrease by 5.30% and slightly increased by 1.45% in 2030s and 2090s respectively for A1B global emission scenarios (Figures 6 and 7).

Impacts of Climate Change: on Reservoirs Evaporation

The future reservoirs evaporation for both Gilgel Gibe-I and Gibe-III reservoirs are as shown in Figures 8 and 9. The mean annual increase of evaporation is 3.6% and 12.28% in 2030s and 2090s respectively for Gilgel Gibe-I and 3.84% and 12.319% in 2030s and 2090s respectively for Gibe-III on A1B global emission scenarios.

HEC-ResSim Simulation of Gibe Cascade Reservoirs System in Baseline Periods

The daily inflows from year 1991 to 2000 have been used in simulation of Gibe cascade hydropower using HEC-ResSim model by applying tandem operation rules.

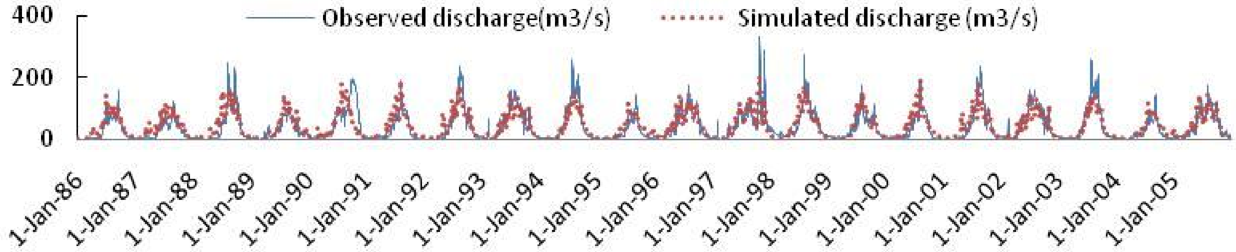


Figure 3: Comparison of daily simulated and observed flow hydrograph for Gilgel Gibe River gauging station daily during calibration (1986-1999) and validation (2000-2005)

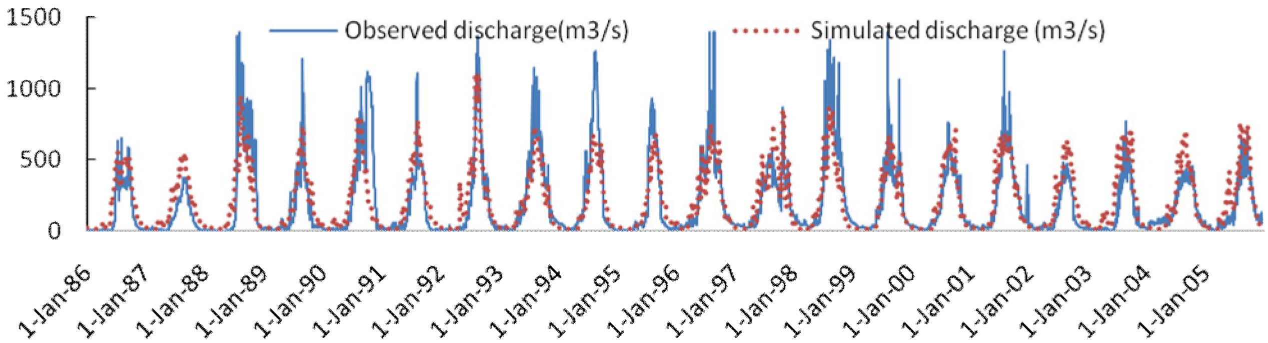


Figure 4: Comparison of hydrograph for Abaliti Gauging station during daily calibration (1986-2000) and validation (2000-2005)

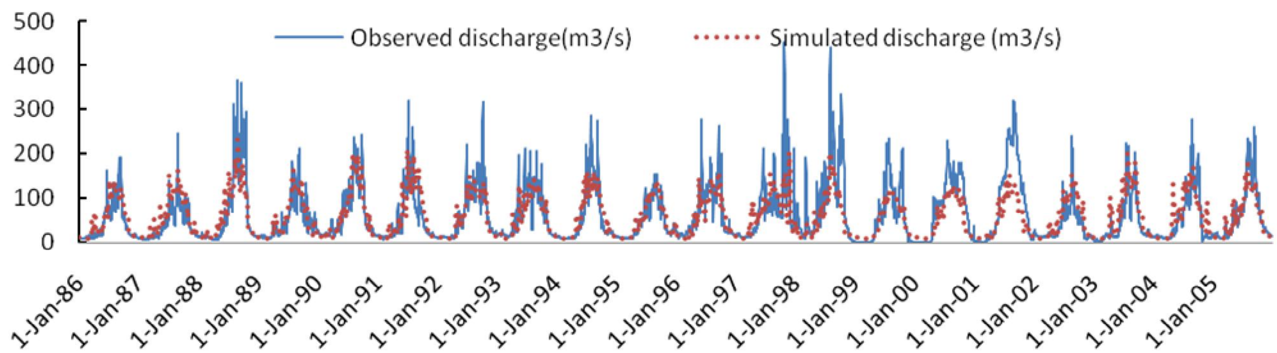


Figure 5: Comparison of hydrograph for Gojeb River Gauge station during daily calibration (1986-1999) and validation (2000-2005)

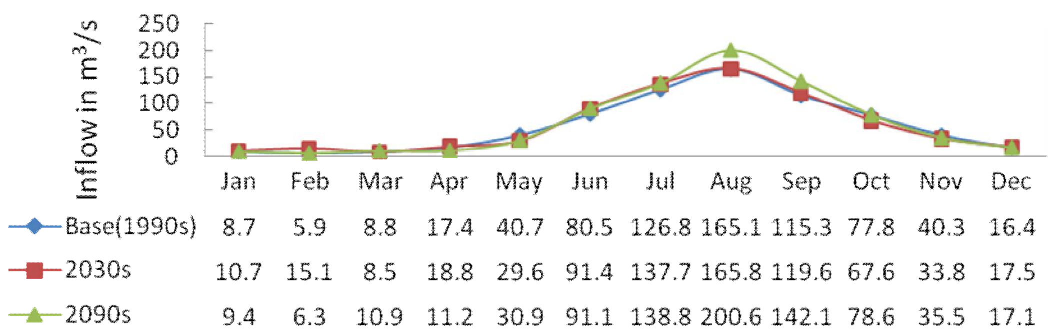


Figure 6: Future Reservoir inflows trend to Gilgel Gibe-I for A1B global climate emission scenarios

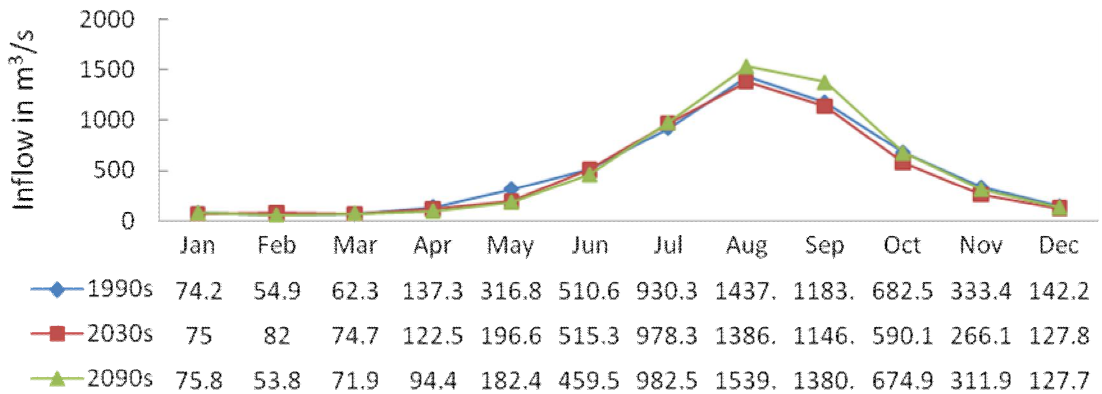


Figure 7: Future Reservoir inflows trend to Gilgel Gibe-I for A1B global climate emission scenarios

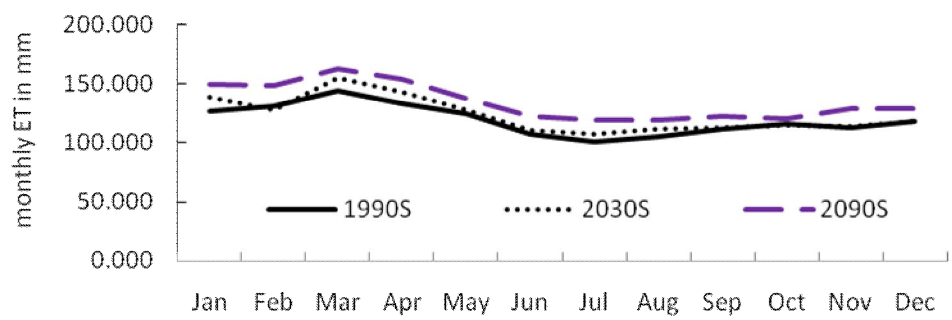


Figure 8: Future Reservoir evaporation of Gilgel Gibe-I for A1B emission scenarios

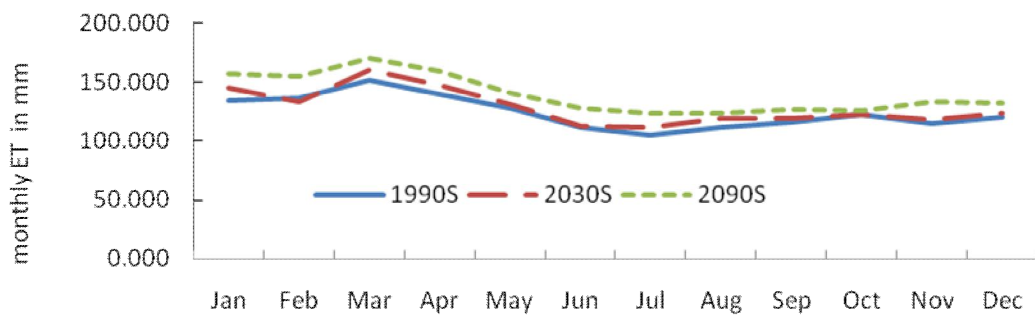


Figure 9: Future Reservoir evaporation of Gibe-III for A1B emission scenarios

Different simulations trial have been carried out by changing the values of initial reservoir storage and acceptable reservoir release for power generation with the aim to obtain maximized yearly energy output with improved uniformity of energy production. All simulations were done within the given limitation of reservoirs capacity, water conveyance system capacity, and maximum design flow for plant, spill over the dam and spillway, power plant capacity and bottom outlet release to downstream ecosystem. Simulations results of the three cascade reservoir operational characteristics in baseline periods are summarized in Table 2 .

Impacts of Climate Change: on Hydropower Energy Generation

The comparisons of mean monthly hydropower energy generated for the scenarios of 2030s and 2090s with the baselines period for Gilgel Gibe-I, II and Gibe-III are as shown in the figures 12 13 and 14. This comparison shows good trend of present and future hydropower production in all month except September, October, and November. The monthly and seasonal changes of the hydropower energy generation are relatively higher than the annual change because of the higher seasonal and monthly changes of future stream inflows volumes to each reservoirs system.

Table 2 : Gibe cascade hydropower plant reservoir operational characteristics in baselines period (1991-2000)

Power plant	Plant parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gibe-I	Power(MW)	79.4	78.5	77.6	76.6	76	76.3	80.6	113.7	148.1	100.4	93.4	84.2
	Energy(GWh)	59.1	53.2	57.7	55.2	56.5	54.9	60	84.6	96	84	67.2	62.6
	Q-power(m^3/s)	42.5	42.5	42.5	42.5	42.5	42.5	43.6	60.3	69.3	51.3	44.6	42.5
	Pool level	1667.4	1665	1662.4	1659.9	1658.5	1659.3	1663.6	1668.7	1670.8	1671	1670.8	1669.4
Gibe-II	Power(MW)	170.4	171.8	174.9	176.4	176.4	179.5	199.6	273.8	338.8	258.8	205.8	178.3
	Energy(GWh)	126.8	116.5	130.2	127	131.3	129.2	148.5	203.7	244	192.6	148.1	132.6
	Q-power(m^3/s)	41	41.3	42.1	42.5	42.5	43.2	47.6	64.7	80.1	61.2	49.1	42.8
	Pool level(m)	1422.8	1423	1422.1	1422	1422	1422.7	1425.7	1428.6	1429.1	1429.7	1424.7	1422.5
ibe-III	Power(MW)	665.2	714.3	723.5	706.9	690.6	686.4	699.9	710	1081.9	858.8	664.2	628.9
	Energy(GWh)	494.9	484.3	538.3	509	513.8	494.2	520.8	528.3	779	638.9	478.2	467.9
	Q-power(m^3/s)	365.1	403.8	421.3	426.7	427.7	427.7	424.3	402.6	572.2	450.5	349.5	337.3
	Pool level(m)	883.6	877.7	871.8	865.1	860.6	859.6	864.9	877.9	889	891.9	891.5	888.1

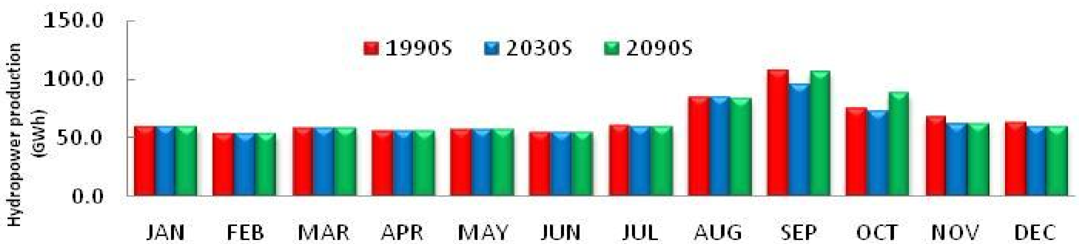


Figure 10: Comparison of mean monthly hydropower energy production in scenarios of 1990s, 2030s and 2090s for Gilgel Gibe-I

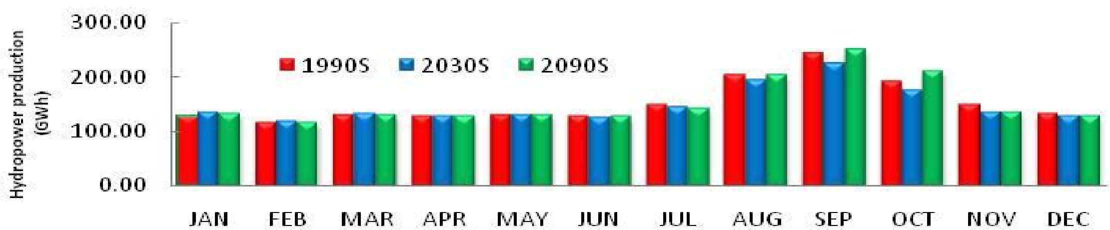


Figure 11: Comparison of mean monthly hydropower energy production in scenarios of 1990s, 2030s and 2090s for Gibe-II power plant

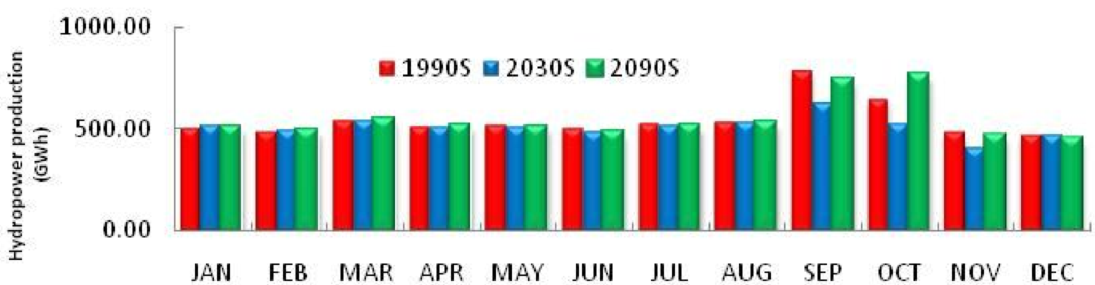


Figure 12: Comparison of mean monthly hydropower energy production in scenarios of 1990s, 2030s and 2090s for Gibe-III power plant

Hydrological Impact of Gibe Cascade Reservoirs Operations on Lower Omo-Valley

The Gibe cascade reservoir Operations will regulate the flows in the Omo River just downstream of Gibe-III power plant. In broad terms, there will be an increase in the flows during the dry season and a reduction of the flows during the rainy season when the water is retained to fill the reservoir, with a substantial decrease of peak flood flows as shown in Figure 18. Therefore, the hydrological predominant influence of the Gibe III dam project will be to smooth monthly distribution of contributions from Upper Omo-Gibe basin. Hence, Gibe Cascade hydropower reservoir Operations will protects the downstream life and properties from damage caused from flooding especially during summer seasons (July-September) by releasing the regulated outflows.

The cascade reservoir Operations decreases flow volumes by 53.5% ,just downstream Gibe-III dam power plant, in summer season (July-September) and increase the dry season flow volumes (January-March) by 340% for lower Omo-Valley and Lake Turkana aquatic habitat biodiversity and peoples, who engage in flood recession agricultures.

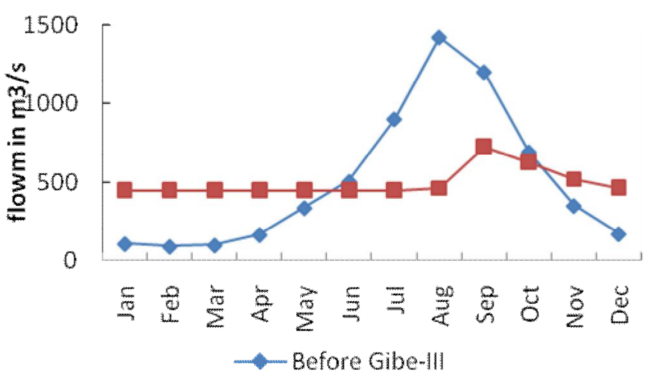


Figure 13: Comparison of natural and regulated hydrograph downstream of Gibe-III power plant (1991-2000)

4. Conclusions and Recommendations

Conclusions

The study has provided a quantitative assessment of the impacts of climate on the operation of Gibe cascade hydropower plants. This research shows the combined capability of HEC-HMS hydrological model and HEC-ResSim reservoir simulation model for assessment of climate change impact on hydropower reservoir operation and performances so that decision maker can forecast and plan adaption measures in the future time horizon. The following points can be concluded from the research

1. The A1B global emission climate scenarios developed for 2030s and 2090s showed that both maximum and minimum temperature and potential evaporation are likely to show an increasing trend on Upper Omo- Gibe River basin. However, future precipitation scenarios show an unusual increasing or decreasing trend. The projected maximum and minimum temperature change in future is within the range projected by IPCC, which indicate that the average temperature will be rises by 1.4-5.8 oC towards the end of this century.
2. The Simulation results of HEC-HMS hydrological modeling in future climate scenarios show that stream inflows to each reservoirs system are somewhat decrease in 2030s and increase in 2090s for A1B global emission scenarios.
3. Simulations of the cascade reservoirs in 2030s and 2090s shows different results of reservoirs pool level, and amount of hydropower energy generated from the baseline scenario. The hydropower energy generated in each reservoir systems is slightly decreasing in scenarios of 2030s due to decreasing trend of inflows volumes. Nevertheless, hydropower production increases in each reservoir in scenarios of 2090s as reservoir inflows volumes are increased.
4. The hydrologic impact of Gibe III dam is simulated and long-term effects over the period of simulation shown that operation of Gibe III power plant would increase the dry season contribution of the Omo-Gibe river system to the Turkana Lake and decrease in flood season contribution.

Recommendations

This study has recommended the following important activities to be included in future studies and shall be carried out in the Upper Omo-Gibe basin for better management ,operation and performance of Gibe cascades reservoir systems.

- The outcome of this study is based one single GCM (RegCM3 forced by ECHAM5 model output) and one single global emission scenarios of A1B. Hence, this work should be extended in the future by including different GCMs and emission scenarios.
- This study has not considered seepage from three reservoir systems. Then, further study should incorporate the effect of seepage from each reservoir system.

- The study has not considered the effect of future land use and land cover change in Gibe-III watershed. It is recommended to investigate the combined effect of climate and land use change for assessment of operation of Gibe cascade reservoir system.
- The study has not considered future water resources development activities in the Omo-Gibe basin. Hence, further study should incorporate different water resources projects either in lower and upper parts of Omo-Gibe basin during simulation of HEC-ResSim model
- Sediment is one of the major problems on reservoir systems by decreasing the live storage capacity. To minimize sediment accumulation rate integrated watershed management practice should be done on the upstream of Omo-Gibe basin.

References

1. Arnell, N.W. (1999a). Climate change and global water resources. *Global Environmental Change*
2. Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds. (2008). Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change . IPCC Secretariat, Geneva, 2 10 pp.
3. Houghton, John Theodore, ed. (2001). Climate change 2001: the scientific basis: contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK.
4. on Climate Change, Task Group on Data and Scenario Support for Impact and Climate Assess ment, 66 pp. .
5. Sirte, Libyan Arab Jamahiriya. (15-17 December 2008). High-Level Conference on: Water for Agriculture and Energy in Africa: the Challenges of Climate Change.
6. ENMSA. (2009, Jun). Initial National Communication of Ethiopia to the United Nations Frame work Convention on Climate Change. Addis Ababa, Ethiopia.

Temperature based Evapotranspiration estimation: A case study for Rift valley of Ethiopia

Temesgen E.Nigussie[1] , Dr. Assefa M. Melesse[3]
[1]Ethiopian Institute of Water Resources, Addis Ababa University, Ethiopia,
temesgenku@gmail.com , Tel. +251 910 489482
[3] Department of Earth and Environment, Florida International University, USA, melessea@fiu.edu

Abstract
Accurate estimation of evapotranspiration (ET) is essential in water resources management and hydrological practices. The FAO-56 Penman–Monteith (FAO-56 PM) is a sole global standard method, but it requires numerous weather data for the estimation of reference ET. A new simple temperature method is developed which uses only maximum temperature data to estimate ET. Four class I weather stations data were collected from the National Meteorological Agency of Ethiopia. These stations were distributed in the rift valley to represent different climatic setting. This method was compared with the global standard PM method and the well-known Hargreaves (HAR) temperature method. The coefficient of determination (R^2) of the new method was as high as 0.74 and 0.91, when compared with PM ETo and HAR methods, respectively. The annual average coefficients of determinations over the four stations when compared with PM and HAR methods were 0.65 and 0.86, respectively. The method is able to estimate daily ETo with an average Root Mean Square Error (RMSE) and an average Absolute Mean Error(AME) of 0.56 mm and 0.44 mm, respectively from the global standard PM ETo method. The method is also able to estimate annual ETo with an average error of about2% from the PM ETo estimations. The method was also tested in dry and wet seasons in the study area and found performing well in both seasons; with an average R^2, RMSE, and AME of 0.60, 0.48mm, and 0.38 mm in dry season and 0.60, 0.55 mm, and 0.43 mm in wet seasons, respectively when compared to the PM method. The average R^2 of the new method with the HAR method was 0.84 and 0.87 in dry and wet seasons, respectively. The method could be used for the estimation of daily ETo where there is insufficient data. Locally calibrated coefficients of this method provide better results and is most recommended for annual estimation of ETo in the study of hydrology.

Key words: *Evapotranspiration, air temperature, Penman–Monteith method, Hargreaves method, new simple method, Rift valley*

1. Introduction

Evapotranspiration (ET) is one of the main components of the hydrologic cycle. It is the major component next to precipitation and its accurate estimation is essential in agricultural and hydrological practices. The FAO-56 Penman–Monteith (FAO-56 PM) is a physically based approach which requires numerous weather data: maximum and minimum air temperature, maximum and minimum relative humidity, solar radiation (or sunshine hours), and wind speed at height of 2m. The main limitation for widely using the globally accepted FAO-56 PM method is the numerous required data that are not available at many weather stations. The quality of these numerous data is also another problem. Solar radiation data are always lacking reliability. The reliability of the average 24-hr wind speed at 2m height is also questionable. Relative humidity measurement by electronic sensors is commonly full of errors. But maximum temperature is largely and easily available in many regions of the world. In regions where there is insufficient data, a simple temperature method which requires only temperature data is important for the estimation of reference ET.

There are different ET estimation methods developed in different time and space. Some methods work well in an area where they have been developed. When tested in other climatic conditions it performs less. The PM ET_o is the only globally accepted method which performs well in many climatic conditions in the world. Many of the methods available are either data intensive and/or the data they require are not easily available.

The objective of this study is not to develop a new method which replaces FAO-56 PM, but to develop a new simple temperature method that uses only maximum temperature for areas where other climatic parameters are not available at the required scale.

The FAO-56 PM will be used as standard method in the development of this new temperature method. The specific objectives are to (1) develop an air temperature based method for estimating ET, (2) evaluate the performance of the new approach by comparing it to the most commonly used complex ET method (Penman–Monteith) and simple but widely used Hargreaves approach [2], and (3) evaluate the seasonal variation of simulated ET using dry and wet season temperature data.

Study area and data

There is high altitude difference in Ethiopia which ranges from an elevation of about 116m below sea level, in the Dallol depression of the Afar region, to an elevation of about 4620m above sea level at Ras-Dashen, in the Semien Mountains in the northern part of the country. Due to this high altitude difference, there is high spatial variability of temperature. Whereas, seasonal variability of temperature in relatively minimum due to its geographic location. The Ethiopian National Meteorological Agency (ENMA) defines three seasons in Ethiopia: rainy season (June to September), dry season (October to January) and short rainy season (February to May). Camberlin [3] reported that the Indian monsoon activity is a major cause for summer rainfall variability in the East African highlands.

Meteorological data were collected from the National Meteorological Agency of Ethiopia. Nine to eleven years of data were collected from four “class I” stations distributed over the rift valley. The data collected from the stations include: daily maximum and minimum temperature, daily maximum and minimum relative humidity, sunshine hours, and wind speed at 2m. The stations are chosen because, they represent majority of the climatic in the Rift valley. Station names, their respective locations and data periods are shown in Table 1. Short period missed data were filled by simple averaging; whereas relatively longer periods of missed data were discarded from further analysis in this study. The distributions of the meteorological stations over the study area are shown in Fig. 1

Table 1: Station locations and the respective period of data

Stations	Location		Elevation amsl (m)	Time Period	No. of years
	Latitude	Longitude			
Addis Ababa	8.59°	38.48°	2324	1995-2005	9
Arba Minch	6.04°	37.04°	1330	1995-2005	10
Awassa	7.04°	38.3°	1652	1995-2005	11
Dire Dawa	9.36°	41.52°	1146	1995-2005	10

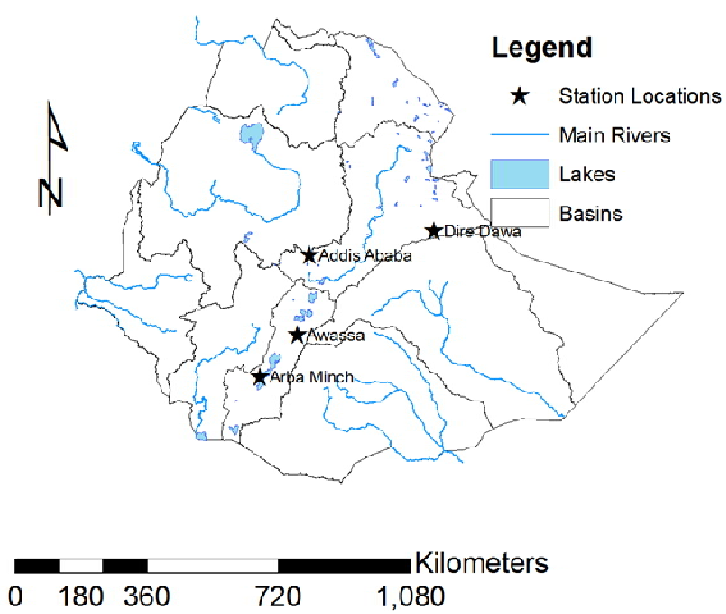


Figure 1: Location map of the study area

2. Theory and methods

The FAO-56 Penman–Monteith (PM) is a physically based approach which requires measurements of air temperature, relative humidity, solar radiation (or sunshine hours), and wind speed. Reference evapotranspiration (ET_o) is the potential ET from a reference surface of a hypothetical green grass of uniform height, 0.12m, well watered actively growing and a constant albedo of 0.23 with fixed surface resistance of 70s m^{-1}[1]. After the aerodynamic resistance, $r_a = 208/u_2$ and the surface resistance r_s = 70s $m^{-1}$are estimated; for such a reference crop, the PM equation can be rewritten as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

where,
ET_o =reference evapotranspiration (mm day^{-1})
R_n = the net radiation at the crop surface (MJ m^{-2} day^{-1}),
G = soil heat flux density (MJ m^{-2} day^{-1}), assumed zero on daily basis,
T = mean daily air temperature at 2 m height (°C),
U2 =wind speed at 2m height (m s^{-1}),
e_s = saturation vapour pressure (kPa),
ea = actual vapor pressure (kPa),
e_s = e_a saturation vapour pressure deficit (kPa),
Δ = slope of vapour pressure curve (kPa^0C^{-1}),
γ= psychrometric constant (kPa^0C^{-1}).

The FAO-56 PM combination equation (Eq. 1) was proposed as the sole standard method for estimating reference evapotranspiration, and for evaluating other equations [4, 5, 6]. It has been proved that this equation could overcome shortcomings of the previous methods and provided more consistent values in different regions of the world [7, 8, 9, 10, 11, 12, 13, and 14].

In this study, the FAO-56 PM method was used as a standard method for the development of a new simple temperature method that use only maximum temperature for the estimation of reference ET. This study was based on the sensitivity analysis result over the study area. Temesgen[15] has showed that solar radiation and air temperature were almost equally sensitive to PM ET_o. If temperature is then equally sensitive as solar radiation to PM ET_o; and since, simple radiation methods like Abtew [16] and Modified Makkink [17] were performing well in the estimation of ET over the area, then there could be a simple temperature method that could perform as good as radiation methods.

It is this sensitivity analysis result leads to the development of a new simple empirical temperature method which uses only maximum temperature data for the estimation reference ET. The new simple empirical temperature method, which we named it "*Enku's simple temperature method*", was developed as:

$$ET_o = \frac{(T_{\max})^n}{k} \qquad (2)$$

where,
ET_o = reference evapotranspiration (mm day^{-1}),
n = 2.5 which can be calibrated for local conditions,
k = coefficient which can be calibrated for local conditions.
The coefficient, k could be approximated as
k = 38*T_{mm} – 44 for combined wet and dry conditions,
k = 56*T_{mm} – 530 for dry seasons, and
k = 34*T_{mm} + 47 for wet seasons,

where T_{mm}(°C) is the mean annual/seasonal maximum temperature.

The coefficients of this new method were first calibrated using the global standard PM ETo method as a true value of ET. With these calibrated coefficients, the new method was compared with the PM ETo and a promising result was found. This new method was also compared with the known temperature method. The comparison of the new method with the Hargreaves (HAR) method was only to see the coefficient of determination (R^2). This is because the Hargreaves method was also required local calibration of the coefficient over the study area.
The Hargreaves and Samani[2]equation is well known temperature based method for the estimation of daily reference ET. This method requires daily maximum and minimum air temperature, and extraterrestrial solar radiation data. The extraterrestrial solar radiation is computed from the information of latitudes of the study site and Julian day of the year. The Hargreaves and Samani[2] equation is defined as:

$$ETo = 0.0023(T_{max} - T_{min})^{0.5}(T_m - 17.8)R_a \qquad (3)$$

where,
ET_o = daily reference evapotranspiration (mm day^{-1}),
T_{max} = daily maximum temperature (°C),
T_{min} = daily minimum temperature (°C),
Tm = daily mean temperature (°C), and
R_a = is the daily extraterrestrial solar radiation (mm day^{-1}).

3. Results and Discussion

A. Combined dry and wet season

The simple new temperature model result was compared with the global standard PM ET_o method and the well-known Hargreaves temperature method at all four stations. In semi-arid region, where the mean annual maximum temperature is higher, the coefficient k requires to be as larger and lower in areas where the mean annual maximum temperature is relatively lower.

The comparison is made with coefficient of determination (R^2), Root Mean Square Error (RMSE), Absolute Mean Error (AME), and annual percentage error of the new method with the PM ET_o. The coefficient of determination (R^2) of the new method, when compared with PM ET_o was as high as 0.74 at Ariba Minch, and as low as 0.58 at Awassa station. The annual average coefficients of determinations over the four stations were 0.65 and 0.86 when compared with PM and HAR methods, respectively. The coefficients of determinations (R^2) of this new method were also compared with the Hargreaves temperature method. The coefficient of determination (R^2) of the new method with the Hargreaves temperature method was as high as 0.91 at Ariba Minch, and as low as, 0.81at Dire Dawa station.

Generally, this new simple method was able to estimate daily ET_o with an average Root Mean Square Error (RMSE) and an average Absolute Mean Error of 0.56mm and 0.44mm, respectively from the global standard PM ET_o method. The method was able to estimate annual ET_o with an annual average error of less than 2% from the PM ET_o estimations. The summary of comparison results of the new method with PM ET_o method and the Hargreaves method is presented in Table 2.The comparison scatter plots of the new method with the PM ET_o and the Hargreaves methods are also shown in Figs. 2 and 3, respectively.

B. Dry and wet season variation

The performance of this simple new temperature model result was also tested in the dry and wet seasons in the study area. The comparison was based on: coefficient of determination (R^2), Root Mean Square Error (RMSE), and Absolute Mean Error (AME) of the new method with the PM ETo, and only R^2 for comparison of the new method with the HAR method.

Table 2: Combined wet and dry season comparison results new method with PM and HAR methods.

Stations	**Period (years)**	**R^2**		**PM**		
		PM	**HAR**	**RMSE**	**AME**	**Annual avg. % error**
Addis Ababa	1995-2005	0.61	0.85	0.51	0.4	1.7
Ariba Minch	1995-2005	0.74	0.91	0.5	0.4	2.2
Awassa	1995-2005	0.58	0.87	0.55	0.44	1
Dire Dawa	1995-2005	0.67	0.81	0.69	0.53	2.5
	Average	**0.65**	**0.86**	**0.56**	**0.44**	**1.85**

Table 3: Dry season comparison results new method with PM and HAR methods

Stations	**Period (years)**	**R^2**		**PM**	
		PM	**HAR**	**RMSE**	**AME**
Addis Ababa	1995-2005	0.51	0.85	0.51	0.39
Arba Minch	1995-2005	0.72	0.91	0.43	0.33
Awassa	1995-2005	0.52	0.84	0.45	0.36
Dire Dawa	1995-2005	0.65	0.75	0.53	0.42
	Average	**0.6**	**0.84**	**0.48**	**0.37**

Dry seasons

In dry seasons, the new method comparison with the PM method; $R^2$was as high as 0.72 at Arba Minch, and as low as 0.52 at Awassa with an average R^2 value of 0.60 over the four stations. The averages of RMSE and AME of the new method from the standard PM method were 0.48 and 0.37, respectively. The R^2 comparison of the new method with HAR was as high as 0.91 at Arba Minch and as low as 0.75 at Dire Dawas stations. The average R^2 of new method with HAR was 0.84 over the stations. The detail results are shown in Table 3. The scatter plots of the dry season's comparison of the new method with the PM and HAR methods are shown Figs. 4 and 5, respectively.

Wet Season

In wet seasons, the new method comparison with the PM method; R^2 was as high as 0.68 at Arba Minch and as low as 0.42 at Dire Dawa, with an average R^2 value of 0.60 over the stations. The averages of RMSE and AME of the new method from the standard PM method were 0.55 and 0.43, respectively. The average R^2 comparison of the new method with HAR was 0.87 over the four stations. The detail results are shown in Table 4. The scatter plots of the wet season's comparison of the new method with the PM and HAR methods are shown Figs. 6 and 7, respectively

Generally, the method performs well in the study area in both dry and wet seasons too with an average R^2, RMSE, and AME of0.60, 0.48, and 0.37 in dry seasons and 0.60, 0.55mm, and 0.43mm in wet seasons, respectively when compared to the PM method. The average R^2 of the new method with the HAR method was 0.84 and 0.87 in dry and wet seasons, respectively.

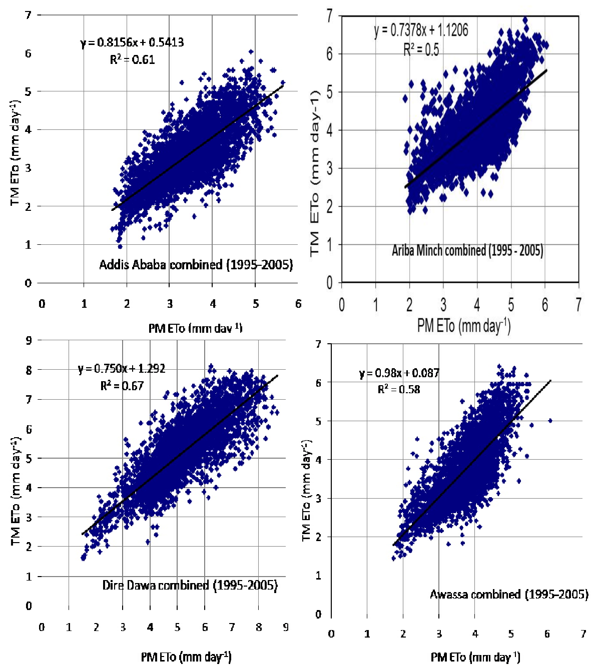


Figure 2: Combined dry and wet season comparison of new method with PM

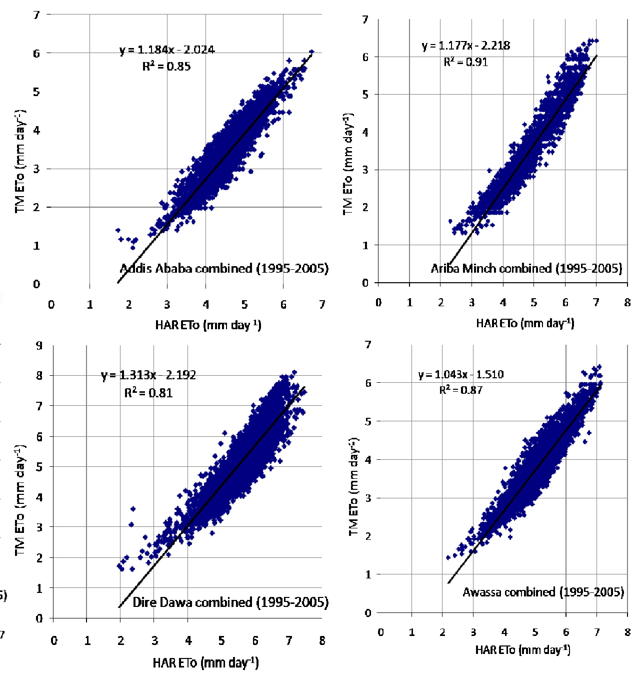


Figure 3: Combined dry and wet season comparison of new method with HAR

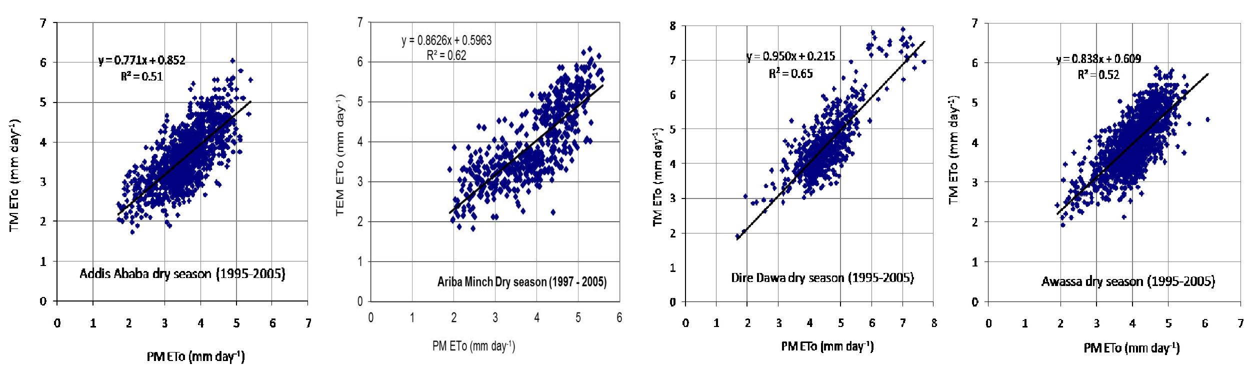


Figure 4: Dry season comparison of the new method with PM

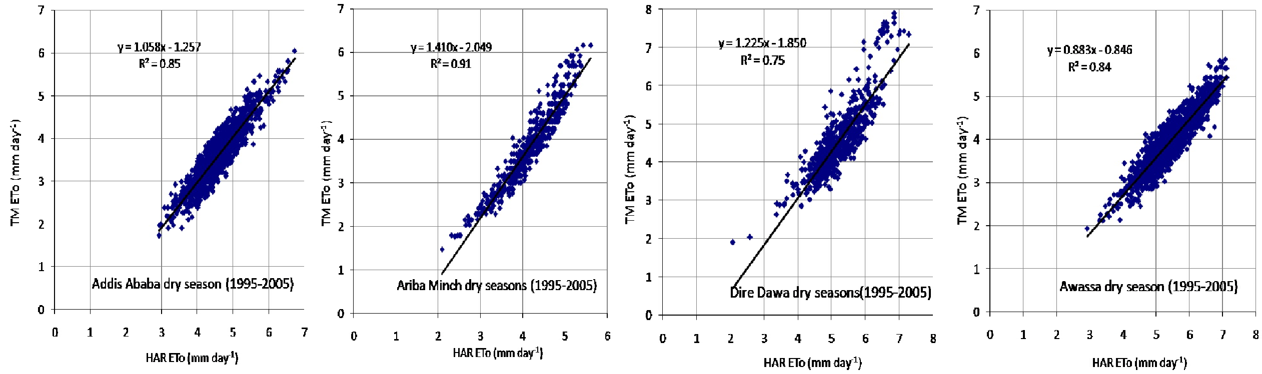


Figure 5: Dry season comparison of the new method with HAR

Table 4: Wet season comparison results new method with PM and HAR methods

Stations	Period (years)	R^2		PM	
		PM	HAR	RMSE	AME
A-Ababa	1995-2005	0.63	0.85	0.38	0.3
Ariba Minch	1995-2005	0.68	0.87	0.53	0.43
Awassa	1995-2005	0.66	0.92	0.53	0.41
D-Dawa	1995-2005	0.42	0.84	0.76	0.59
	Average	**0.60**	**0.87**	**0.55**	**0.43**

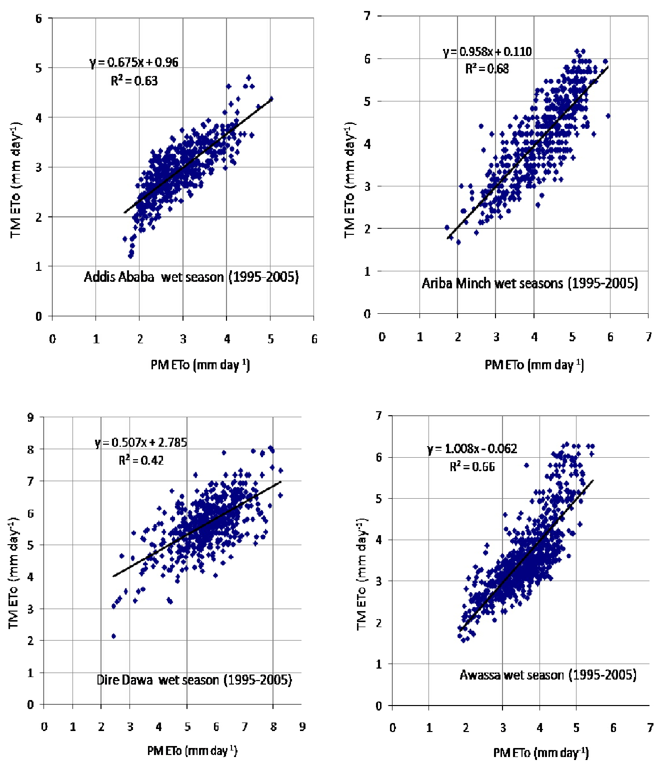


Figure 6: Wet season comparison of the new method with PM

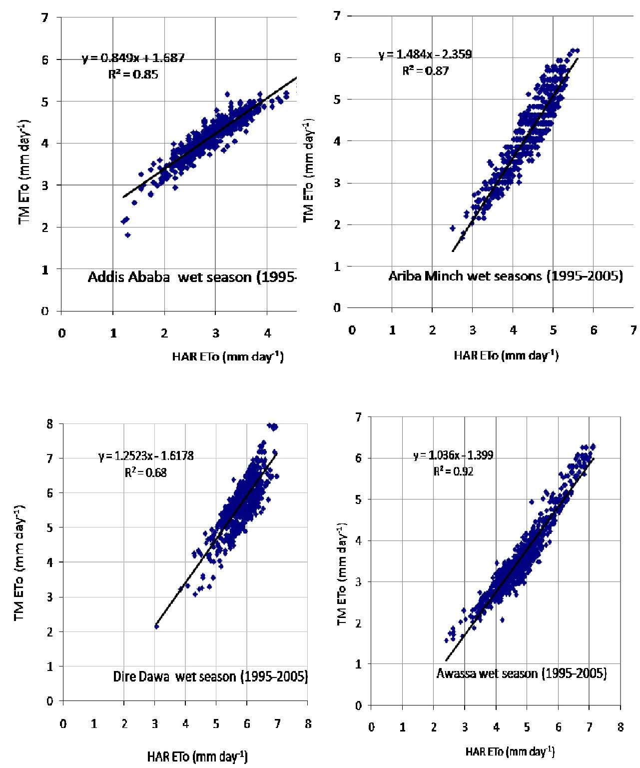


Figure 7 : Wet season comparison of the new method with HAR

5. Conclusions and Recommendations

This simple method which requires only daily maximum temperature is able to estimate daily ET_o with average R^2, RMSE and AME of 0.65, 0.56mm and 0.44 mm, respectively and an average annual percentage error of less than 2 % from the global standard PM ET_o method.

The method could be used for the estimation daily ET_o where data is insufficient. Calibration of the coefficients is recommended. If there is no sufficient data for calibration, the coefficient k can be approximated as $k = 38*T_{mm} - 44$ for combined wet and dry seasons, $k = 56*T_{mm} - 530$ for dry season, and $k = 34*T_{mm} + 47$ for wet season, where T_{mm} (^oC) is the mean annual/seasonal maximum temperature. This method is most recommended for the estimation of annual ET_o in the study of hydrology.

Acknowledgment

We thank the School of Civil and Water Resources Engineering, Institute of Technology of Bahir Dar University for supporting this work, and we also acknowledge the Ethiopian Meteorological Agency for providing data.

References

1. Allen RG, Pereira LS. 1998,"Crop Evapotranspiration -Guidelines for Computing Crop Water Requirement", Rome, FAO Papers No.56, Roma
2. Hargreaves GH, SamniZA. 1985, "Reference crop evapotranspiration from temperature." *Transactions of the American Society of Agricultural Engineers*
3. Camberlin P. 1997, "Rainfall anomalies in the Source Region of the Nile and their connection with the Indian Summer Monsoon"*J. Climate*1380–1392.
4. Allen RG, Smith M, Perrier A, Pereira LS. 1994a, "An update for the calculation of reference evapotranspiration",*ICID Bull*43(2): 35–92.
5. Allen RG, Smith M, PerrierA, Pereira LS. 1994b, "An update for the definition of reference evapotranspiration", ICID Bull 43(2):1–34.
6. Slavisa T. 2005, "Temperature-Based Approaches for Estimating Reference Evapotranspiration",*J. Irrig. Drain. Eng.* Vol. 131, No. 4, July/August 2005, pp. 316-323.
7. Bois B, Pieri P, Van LeeuwenC, Wald L, Huard F, Gaudillere JP, Saur E. 2008," Using a remotely sensed solar radiation data for reference evapotranspiration estimation at a daily timestep",*Agricultural and Forest Meteorology* 148(4): 619-630.
8. Dingman SL. 2002, "Physical hydrology. Prentice Hall, Upper Saddle River", 646 pp.
9. Liu Y, Pereira LS, Teixira JL. 1997, "Update definition and computation of reference evapotranspiration comparison with former method" *Journal of hydraulic engineering* 6: 27-33.(In Chinese with English abstract)
10. Rana, G. and Katerji, N., 2000,"Measurement and estimation of actual evapotranspiration in the field under Mediterranean climate: a review", *European Journal of Agronomy* 13(2-3): 125-153.
11. Ventura F,Spano D, Duce P. 1999, "An evaluation of common evapotranspiration equations"*Irrig. Sci*. 18.163-170.
12. Du YD, Liu ZX, Zhang YF. 2000,"Evaluation of two reference crop evapotranspiration calculation methods",*Journal of Henan Agricultural University* 35(1):57-31. (In Chinese with English abstract)
13. Nandagiri L, Kovoor GM. 2005, "Sensitivity of the food and agriculture organization Penman-Monteith evapotranspiration estimates to alternative procedures for estimation of parameters, "*J. Irrig. Drain. Eng*131(3):238-248
14. Temesgen B, Eching S, Davidoff B. 2005, "Comparison of some reference evapotranspiration equations for California",*J. Irrig. Drain. Eng.* 131(1): 73-84
15. Temesgen E.N. 2009, "Estimation of evaporation from satellite remote sensing and meteorological data over the Fogera flood plain, Ethiopia", Enschede, MSc thesis ITC, p. 89, 2009.
16. Abtew W. 1996, "Evapotranspiration measurements and modeling for three wetland systems in South Florida". *In: Water Resources Bulletin,* 32 (1996)3: 465-473.
17. De Bruin HAR.1981,"The determination of (reference crop) evapotranspiration from routine weather data",*Proc. and Inform.Comm.Hydr. Research* TNO, The Hague 28: 25-37.

Environmental Impacts of Small Scale Irrigation Schemes: Evidence from Ethiopian Rift Valley Lake Basins

Mihret Dananto[1], Ermias Alemu[2] and Dr. Mekonen Ayana[2]
[1]Hawassa University, mihret@gmail.com, [2]Arba Minch University

Abstract
*The research was carried out in the Rift Valley Lakes Basin (RVLB), which is one of the twelve major river basins in Ethiopia. The basin extends between latitude of 07°00' and 08°30' N and between longitude of 38°00' and 39°30'E. The RVLB was considered for this research due to the high priority that comes from the significant ecological and environmental interest from different sectors. It has substantial areas of productive rainfed agricultural land, good rangelands and also irrigation lands due to the great demand for economic and social development. This priority and multifaceted situation makes worth to do this research in Rift Valley basin for a possible duplication in other basins. The research tried to compare the relative environmental impact of Bedene Alemtena, Eballa, Argeda and Gedemso irrigation projects. Impact assessment at the community level was collected based on key informant interviews and ad- hock technique. For the study a summary of two set of structured questioners were also used. In addition with environmental issues, the questioner also addresses participation of the beneficiaries at different level of the life cycle of the project. Check lists, matrices and rule based analysis were used to aggregate a scaled value of the individual parameters collected through interviews and physical observations at the four sites. The projects were compared based on their environmental impacts using the aggregated values specific for the project. 7%, 8% and 4% Soil fertility deterioration were observed in Argeda, Gedemso and Bedene Alemtena irrigation projects respectively after the projects implementation (X^2, 97.7***). Land degradation scenario after the implementation of the projects showed that Argeda (19.9%), Gedemso (10.4%), Ebala (23.8%), Bedene Alemtena (33.3%) (X^2, 86.3***). 76.2 % (X^2, 198.3***) farmers in Argeda irrigation project perceived that soil erosion in their plot is accelerated after the project.*

1. Introduction

The challenge of food insecurity in many developing countries is a concern and it is also a bottleneck problem in Ethiopia. Ethiopia has about twelve river basins with a potential to irrigate an estimated area of 3.5 million ha, out of which only 190,000 ha (4.3 %) is actually under irrigation (Makombe et al., 2007; Tesfaye et al., 2008). It is indicated that escalating irrigation development is crucial for reliable and sustainable food security in the country (Awulachew et al, 2007), (Angood et al, 2002, 2003) (Awulachew and Merrey, 2007). The need for production and productivity improvement to alleviate the challenge of food insecurity obligates the use of irrigation particularly in water deficit areas (Barrow, 1993), (MoWR,2001).
Despite the positive contribution of irrigation development for food security and poverty reduction, many irrigation schemes have been unsuccessful and even have had negative impacts (De Fraiture et al., 2009). Irrigation planners need to consider evaluating whether existing small scale irrigation (SSI) schemes are performing to the required level with substantial food security and environmental quality to make further irrigation development desirable and justified.
Most studies on SSI schemes focus on technical irrigation performance evaluation but better availability of water by itself is not a sufficient condition while several factors determines to maximize agricultural production thereby improving household food security. Van Den Burg and Ruben, (2006) also stated that studies focus on technical evaluation of irrigation schemes in Ethiopia and only little is known about Environmental issues, food security and socioeconomic implications. Even though assessing the contribution of SSI interventions for food security and livelihood diversification in Ethiopia are limited (IFAD, 2005), and some results found out that no difference is observed sometimes between rainfed and SSI user smallholders in their food security status (Peden et al., 2002). Developing an understanding of the role SSI plays in rural livelihood diversification with their potential environmental impact (Dougherty and Hall 1995) on the users helps to take appropriate measures in the ongoing irrigation development efforts of the country.

Rift Valley Lake Basin & the Four Irrigation Schemes
The Rift Valley Basin (RVB) has an area of 52,739 Km^2, covering parts of the Oromia, SNNPR regions (Awulachew et al, 2007). The total mean annual flow from the River Basins is estimated at about 5.6 BMC (Awulachew et al, 2007).

Irrigation development is growing in the basin where about 10% of the estimated irrigation potential of 139,300 ha of irrigation land is under irrigation, out of which about 4627 ha is provided by small scale irrigation schemes.

For this study, four sites namely Gedemso 01, Argeda, Bedene Alemtena and Eballa located within the basin were selected; of which the former two are located in the Oromiya and the latter two are located in the SNNP Administrative Regions. The reasons for the selection of these sites were: accessibility, scale, management type, agro ecological similarity and market outlet.

Gedemso 01 SSI scheme, constructed in 2001 by Oromiya Regional Government is located in West Arsi zone in Arsi Nagelle district, Buku Woldaya *Kebele*, 30 kilometers to the East of the district capital, Arsi Nagelle and 224 kilometers to the south East of Addis Ababa, Ethiopia. The scheme has a potential to irrigate 180 hectares (BoA, 2009/10); out of which 80 hectares are located in Gedemso 01 (BoA, 2009/10; Awulachew et al., 2007), and the remains 100 hectares is located in Gedemso 02.

Argeda SSI scheme, constructed by Oromiya regional government in 2004 is also located in West Arsi Zone in Arsi Nagelle district in Argeda Shaldo *Kebele*, 39 kilometers to the east of Arsi Nagelle and 233 kilometers to the Southeast of Addis Ababa, Ethiopia. The potential irrigable land of the scheme is 80 hectares (Awulachew et al., 2007).

Bedene Alemtena SSI project is located in SNNP administrative region in Halaba special *Woreda*. The project is located 12 kilometers from the *Woreda* capital, Halaba Kulito town. The scheme was constructed by CoSAERSAR to irrigate 200 ha (Awulachew et al., 2007).

Eballa SSI scheme is located in SNNP administrative region in Kembata Tembaro Zone in Hamido Goforo *kebele*. It is located at a distance of 120 kilometres to the Northwest of Hawassa, the regional capital. The scheme was constructed by CoSAERSAR in 1997 to irrigate an area of 120 hectares (Awulachew et al., 2007; Mihret, 2006). The planned beneficiaries of the scheme are 627 households. Both schemes use similar diversion structures to guide the water into a gravity water distribution system.

The Policy Context

In Ethiopia, although irrigation has long been practiced at different farm levels, there is no efficient and well managed irrigation water practice (Dessalegn, 1999) which directly or indirectly affects the environment. Environmental impact refers to any change to the environment or to its components that may affect human health or safety, flora, fauna, soil, air, water, climate, natural or cultural heritage, and other physical structures, social, economic or cultural conditions (EEPA, 2003). The most important step in setting up the legal framework for the environment in Ethiopia has been the establishment of Ethiopian Environmental Protection Authority (EEPA, 1995) by proclamation No. 9/1995. EEPA is the front runner in issues related with environment in Ethiopians' day to day life. The issue of environmental impact assessment (EIA) gets momentum since 2002 after the parliament endorsed EIA proclamation number 299/2002(FNG, 2002). Then onwards the issue of EIA is a prerequisite before the approval of most projects before their implementation.

Those projects, listed in the guidelines prepared by EEPA that are likely to entail significant adverse environmental impacts require EIA (EEPA, 2003). They are broadly categorized under the sectors agriculture (including irrigation), industry, transport, mining, dams and reservoirs, tannery, textile, hydropower generation, irrigation, and resettlement projects. Currently about 193 specific projects are identified under "projects that need complete EIA" category. For these projects it is a compulsory to submit Environmental Impact Study report prior to project implementation (EEPA, 2003).

Indicators

The indicators presented in Table 1 were used to assess environmental performance of SSI projects. The indicators were selected according to the context of this investigation, major anticipated impacts and the cost of data collection and processing (Asit, 1985). They are also based on the monitoring criteria of environmental impact assessment guidelines of irrigation for the Federal Democratic Republic of Ethiopia (EEPA, 2004).

Objectives of the Study

The general objective of this research was to understand the present and future environmental impacts of small-holder irrigation schemes at the Ethiopian Rift Valley lake basin through careful investigation of cases from the four irrigation schemes.

The specific objectives were

- Assessing and characterizing the schemes in their level of environmental aspects;
- Identify environmental impact assessment indicators and design means on how to measure these indicators that are workable and easily measurable for future up-scaling at a national level;
- Evaluating the environmental situations of the four projects and extracting lessons for other schemes in the basin.

2. Environmental Impact Assessment Approach and Methods

In view of the current situation of each projects, this post project impact assessment investigation employed a range of tools to gather and analyse data from both primary and secondary sources. The study approach basically followed the requirements stipulated in the irrigation EIA guidelines for the federal democratic republic of Ethiopia (EEPA, 2004).

The data collection methods include the following:

Document Review and Secondary data collection

Relevant project documents have been reviewed during preparation of field data collection tools and thoroughly reviewed during the preparation of the report.

The reports include performance report, midterm review, baselines, beneficiary assessment, inventory, project completion report and others.

Focus Group Discussion

Focus group discussions were made with community representatives, Health extension workers and DA's with special attention to the Environmental indicators listed above. In all irrigation schemes, focus group discussions with organized groups were the main sources of information on the environmental performances of SSI projects.

Key Informant Interview

Key informant interview with different professionals working in various government sector offices, regional level irrigation offices and community level workers and with individuals, mainly with community representatives, women, elders, scheme representatives were made. A scaling checklist is used to capture the relative rating of each impact and guides the evaluation of the different criteria. The Battelle Environment Evaluation Index (EIV) was used to aggregate the data collected by scaled checklists.

$$EIV = \sum_{i=1}^{n} (V_i) W_i$$

Where, EIV is Battelle Environmental Index Value; V_i is Relative change of the environmental quality of parameters; W_i is Relative importance or weight or parameter; and n is total number of environmental parameters. *Relative changes of environmental parameters* were given numerical values according to their impact extent as: Severe (+5 or -5), Higher (+4 or -4), Moderate (+3 or -3), Low (+2 or -2), Very Low (+1 or -1) and No change (0).

Field Visit and Observation (transect walk)

Field investigation and site observation with scheme's users by research team were the approach used under this technique. The team made field visits to each irrigation schemes plot-by-plot to visually observe the current environmental situations in the schemes. Observations into various schemes helped in knowing their status and identify constraints in sustaining the services of the schemes to the targeted communities. On the spot discussions with the scheme management committees and scheme users were conducted so as to have first hand information. The structured walk through the schemes helped to assess particular indicators (water availability, maintenance status, soil type, soil characteristics, crops irrigated, landuse, and watershed status).

Household Survey

Household survey in the four irrigation schemes was conducted using structured questioner. Adverse impacts of irrigation schemes and harmful traditional practices that affected the community were identified. Farm households who are directly using irrigation schemes were surveyed to see the environmental impacts of the irrigation schemes. The study employed a 'before' and 'after' irrigation and 'with' and 'without' irrigation approach. A probability sampling method involving simple random sampling technique was used to select the respondents. Proportional sampling was employed to pick female headed HH and male headed households from each strata. Abut 147 irrigation scheme user households were involved in the study.

Soil Sample Analysis

Soil samples were taken for pH, texture, electric conductivity of soil saturated extracts and bulk density analysis. Six sampling points (three from irrigated and three from rain fed farms) at the head (field 1), middle reach (field 2) and tail (field 3) were considered.

Table 1: Indicators used for investigation

	Indicators
:ation	• Acquired irrigation systems management skills by trained men and women (Survey and FGD).
l alk and	• Maintenance expenses on irrigation canals (FGD, KII). • Number of breakdowns of the irrigation systems.(KII, transect walk)
	• Household survey to investigate "before" and "after" irrigation scenario of human health problems • Prevalence rates of diseases such as malaria, schistosomiasis, diarrhoea. (FGD, KII) • Number of vector breeding sites and vector density.(transect walk) • Availability of impregnated bednets, mosquito repellents. (FGD, KII)
	• Household survey to investigate "before" and "after" irrigation scenario of water borne diseases.
	• Household survey to investigate "before" and "after" irrigation scenario of malaria incidences. • Prevalence rates of malaria(FGD, KII)
	• Household survey to investigate "before" and "after" irrigation scenario of soil fertility
	• Observation of the extent of erosion in Irrigation schemes • Household survey to investigate "before" and "after" irrigation scenario of soil erosion
	• Observation of the extent of sedimentation in Irrigation infrastructures
	• Changes in soil chemical parameters (ECe)
	• Changes in soil chemical parameters (pH).
	• Household survey to investigate "before" and "after" irrigation scenario of land degradation • Observation of the extent of land degradation in Irrigation schemes
	• Household survey to investigate "before" and "after" irrigation scenario of land productivity • Observation of the extent of land degradation in Irrigation schemes
	• Observation of the extent of drainage problems and water logging in Irrigation schemes
	• Observation of back water effects Irrigation schemes headwork structures
	• Observation of movement obstructions for humans and livestock
	• Inventory of wild animals and plant species before and after the project. (FGD and KII). Base flow release during irrigation peak seasons (transect walk)
	• Irrigation infrastructures visit (transect walk)
	• Household survey to investigate "before" and "after" irrigation scenario of forest land
	• Upstream catchments visit (transect walk)

3. Result and Discussion

Transect walk, FGD and KII Summary

Although irrigated agriculture in the study areas has contributed to increased food production and to over all socio -economic development, the schemes observation and interviews made with the users confirmed an increased environmental degradation. Even though the extent is different; off-farm and on-farm soil erosion, aquatic weeds infestation, sedimentation, infrastructural deterioration, unjust water distribution and overgrazing are observed on the four irrigation schemes. Farmer's opinion and the field observation proofed that ploughing of sloppy irrigated fields are the main cause for this problem. In Argeda 01 SSI scheme, the head work is filled with sediments to almost more than three quarter of the height of the weir. The two under sluice gates are functioning properly but it is difficult to operate them because of rust and clogging.

Scheme conveyance structures cracking, breaching, weed growth, sedimentation on the main canal and side scouring by livestock hooves jumping and walking over the main canal are problems frequent observed in Gedemso 01, Argeda, Bedene Alemtena and Eballa SSI schemes. In all schemes, there is no strategically constructed main canal crossing structure for safe passage of livestock. Weed growth and sedimentation is the major problems especially along the earthen canal in all schemes. Poor design of some drainage structures and lack of proper watershed management consideration at the upper catchment above the diversion weir during scheme study & design were the causes for the problems.

In Gedemso 01, Bedene Alemtena and Eballa SSI, the off takes have no water controlling mechanisms, no gates installed, and farmers are using locally available materials to manage the gates. Division boxes are full of silts and rubbish. Generally, the main canal and the accompanying irrigation infrastructures lack continuous follow up and frequent maintenance. Aquatic and terrestrial weeds, water theft, drainage problems, seepage, flow obstruction and ploughing of sloppy lands without conservation techniques are additional environmental problems observed in these three schemes.

Due to upstream abstraction, recently the farmers in Argeda 01 SSI scheme are facing water shortage particularly during the driest season (March). Downstream users are complaining about their water use right. Unless appropriate water sharing mechanism is implemented, this could be a possible cause for conflict in the near future. Though farmers have got technical training on irrigated field preparation in all schemes, there are still problems of improper furrow layout (length, spacing and direction). Furrows are laid in some field along the slope which aggravates erosion and non-uniform distribution of water among the plots. In recent times, farmers are complaining about the reduction in productivity of their farms because of fertile top soil erosion.

Summary of results from the household survey

Soil Fertility

The sample households have different opinions regarding fertility of their plots after irrigation, i.e. 36, 57 and 7% of the respondents in Argeda-01; 29, 63 and 8% of the respondents in Gedemso 01; 93, 7 and 0% of the respondents in Eballa, and 90, 7 and 3% in Bedene Alemtena stated that it is good, medium and low after the implementation of the irrigation schemes respectively (Table 2). Eballa irrigation scheme users are settlers coming from the neighbouring village. That could be the reason why 93% of the respondents argued the betterment in fertility after the use of irrigation. The use of manure and chemical fertilizers were mentioned during the FGD as a reason for increased soil fertility while the continuous cultivation, intensification of agricultural production through irrigation, removal of nutrients more rapidly than their replenishment either through leaching or crop residue removed from the field for livestock feed, fuel and house construction is mentioned as a reason for decreasing soil fertility.

Table 2: Soil fertility status after irrigation scheme constructed (%)

	Low	Medium	Good	X^2
Argeda 01	7	57	36	97.7***
Gedemso 01	8	63	29	
Ebala	0	7	93	
Bedene	3	7	90	
Total	4	30	66	

***** indicates there is a highly significant difference at (P<0.01)*

Soil erosion

Most of the households perceived soil erosion as a major environmental treat to irrigated crop production. Even though the extent is different, 87.8% of the total households (Table 3) faced medium to high level of soil erosion on their plot. Two major types of soil erosion were identified in this case study. Sheet erosion due to overtopping irrigation water and rill erosion created due to seepage. Erosion due to wrongly aligned furrows was observed in Argeda 01 and Gedemso 01 irrigation schemes.

Table 3: Soil erosion exposure

	Low	Medium	High	X^2
Argeda 01	2.6	21.1	76.2	
Gedemso 01	33.0	55.4	10.7	
Ebala	0.0	90.4	9.6	198.3***
Bedene	12.1	80.3	7.6	
Total	11.9	61.8	26	

Sedimentation

There is an evidence for the loss of irrigation structures due to sedimentation (Abebe et al, 2003) Soil erosion and subsequent transport of sediments (and adsorbed chemicals) is caused by runoff of excess irrigation water from cropland. Sediments transported by irrigation tail waters eventually return to streams and rivers, negatively impacting canals and other water conveyance structures, causing sedimentation of irrigation structures, affecting the durability of irrigation structures and creating significant problems to aquatic ecosystems. 85 % of the respondents from the household survey believed that the problems of sedimentation in irrigated fields are increased year to year after the implementation of the irrigation schemes (Figure 1).

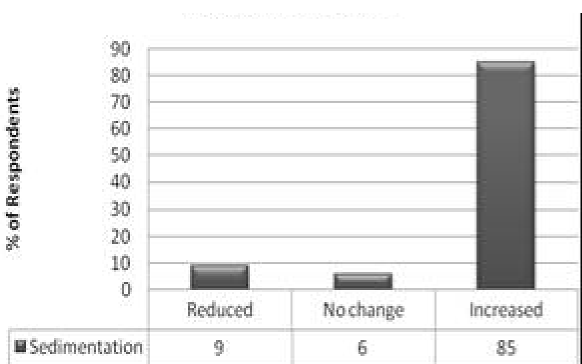


Figure 3: Perception of farmers about sedimentation problems

Deforestation, overgrazing and intensive cultivation of the watershed upstream of irrigation headwork exposed the watershed to erosion and high surface runoff. Population pressure aggravates this problem even more. The eroded material from the steep escarpments which is deposited on the irrigated canals and other infrastructures can lead to soil sedimentation.

Soil salinity

As compared with rain-fed fields, elevated salinity levels were measured in Eballa, Bedene Alemtena, Argeda 01 and Gedemso 01 irrigation schemes. As the soil gets deeper (Table 4), both Irrigated and Rain-fed fields showed a nearly similar electric conductivity. This indicates that the source of salinity is not a natural weathering process but from irrigation water. Most irrigation waters contain some salts.

The main causes for the development of salts are use of saline irrigation water, seepage fromthe canals and poor drainage as observed during the transect walk. As compared with fields located at the head, tail fields suffer more to salinity problem due to drainage.

Soil Acidity

Compared with rainfed fields, most irrigated field exhibited lower pH values. Particularly higher soil acidity is observed at Eballa irrigation project (Table 5). Intensive commercial fertilizer application and pesticide uses for tobacco cultivation are the main reason in this project. A similar trend is observed in Bedene Alemtena and Gedemso 01 irrigation projects too.

Land Degradation

More than 70% of respondent households believed that land degradation was observed in their plots since the implementation of irrigation schemes (Table 6).

Soil quality deterioration, erosion hazard, continuous cultivation, intensification of agricultural production through irrigation, removal of nutrients more rapidly than their replenishment either through leaching; or crop residue removed from the field for livestock feed, fuel and house construction is mentioned as a reason for land degradation. Crop and land suitability study has to be made for alternative crop rotation in Gedemso 01 and Argeda 01 irrigation schemes. Prolonged land cooling due to poor land drainage during the rainy season is observed in Bedene Alemtena irrigation project as a main cause for land degradation. Use of broad bed maker (BBM) is suggested to drain water ponding areas in irrigated fields. Similarly, in Eballa irrigation project, rotation of tobacco with millet is not an advisable strategy. Better nitrogen fixing crops should have to be used here. Cover crop, crop residue management and control grazing is a good option to minimize the risk of soil erosion in the watershed.

Land productivity

Water is a limiting factor in crop production. Provision of water through irrigation is believed to improve land productivity. However, about 60% of the respondent in the four irrigation projects believed no change in productivity after irrigation (Figure 2).

Table 4: Electric conductivity in irrigation schemes

Field location	Soil depth (cm)	Electrical conductivity (ECe in dS m^{-1})							
		Argeda		Bedene AT		Eballa		Gedemso 01	
		Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed
Head	0-30	0.415	0.252	0.397	0.135	0.065	0.063	0.191	0.129
	30-60	0.314	0.155	0.346	0.089	0.059	0.118	0.066	0.096
	60-90	0.221	0.16	0.231	0.189	0.05	0.08	0.065	0.139
Middle	0-30	0.414	0.28	0.426	0.099	0.235	0.108	0.091	0.058
	30-60	0.322	0.173	0.321	0.094	0.132	0.068	0.101	0.094
	60-90	0.232	0.152	0.237	0.116	0.087	0.082	0.011	0.134
Tail	0-30	0.499	0.423	0.433	0.149	0.111	0.059	0.259	0.066
	30-60	0.557	0.312	0.302	0.14	0.071	0.052	0.304	0.132
	60-90	0.557	0.234	0.209	0.255	0.075	0.08	0.274	0.25

Table 5: Soil pH in irrigation schemes

Field location	Soil depth (cm)	Electrical conductivity of soil extract (dS m^{-1})							
		Argeda		Bedene AT		Eballa		Gedemso 01	
		Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed
Head	0-30	0.415	0.252	0.397	0.135	0.065	0.063	0.191	0.129
	30-60	0.314	0.155	0.346	0.089	0.059	0.118	0.066	0.096
	60-90	0.221	0.16	0.231	0.189	0.05	0.08	0.065	0.139
Middle	0-30	0.414	0.28	0.426	0.099	0.235	0.108	0.091	0.058
	30-60	0.322	0.173	0.321	0.094	0.132	0.068	0.101	0.094
	60-90	0.232	0.152	0.237	0.116	0.087	0.082	0.011	0.134
Tail	0-30	0.499	0.423	0.433	0.149	0.111	0.059	0.259	0.066
	30-60	0.557	0.312	0.302	0.14	0.071	0.052	0.304	0.132
	60-90	0.557	0.234	0.209	0.255	0.075	0.08	0.274	0.25

Even in Gedemso 01 irrigation projects, significant proportion of the respondent replayed a reduction in land productivity after irrigation. About 5% of the total irrigable land in Gedemso 01, 3% in Argeda 01 and 5% in Bedene Alemttena irrigation projects suffers from water logging. As a result, productivity may have fallen significantly in these areas .

Drainage problems affect large areas of land in the four irrigation projects investigated; in many cases these problems are compounded by salinization. As compared with fields located at the head, tail fields suffer more to salinity problems due to drainage. This response may also be substantiated by poor water management, increased intensity of birds and wild animals attack, erosion and low soil temperature.

Table 6: Level of land degradation

	low	medium	High	
Argeda 01	55.6	24.5	19.9	X^2
Gedemso 01	45	45	10	86.3***
Ebala	0	76.3	23.7	
Bedene	11.7	55	33.3	
Total	28.1	50.2	21.7	

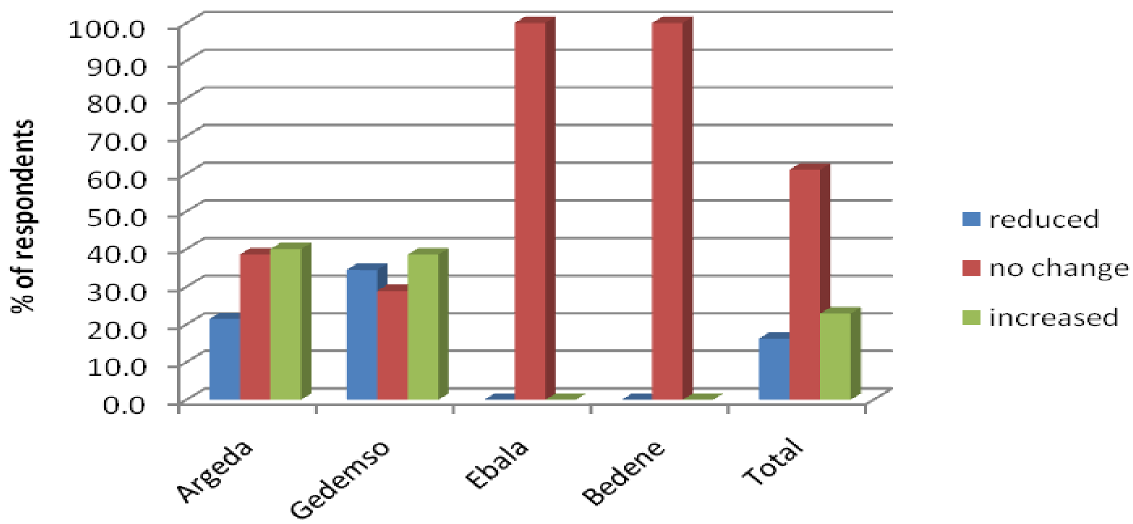


Figure 2: Land productivity after irrigation

Change in grazing and forestland

About 91 and 85 % of the total respondents indicated that there is a reduction in the size of grazing land (Figure 3) and forest coverage (Figure 4) in all irrigation schemes, respectively. Loss of species diversity (flora and fauna) was reported in all schemes. The current irrigation command area in Eballa irrigation project was used for communal grazing land. In Bedene Alemtena irrigation project the current command area was under rain fed crop production and mainly used for grazing land in the past. A similar trend was observed in Argeda 01 and Gedemso 01 projects too. After the project was implemented, all new comers other than the original scheme users took and changed the existing grazing land to irrigated land. Demographic change and livestock increment is also another reason for the reduction of grazing land in the four irrigation schemes.

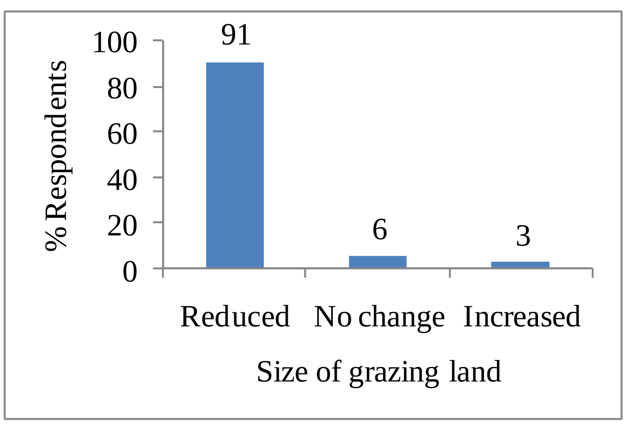


Figure 3: Perception of farmers about grazing land status

A similar justification was made for the reduction of forest in the four irrigation projects.

According to the FGD, dried out trees were freely used in the four projects to fulfil their needs of firewood. On the other hand no strong attempt was reported on replacement of the dried ones and mitigation of cutting the existing trees and shrubs. Thus in the future due to the increase in population pressure & need for farm land to maximum deforestation is expected unless solution is devised to conserve available forest.

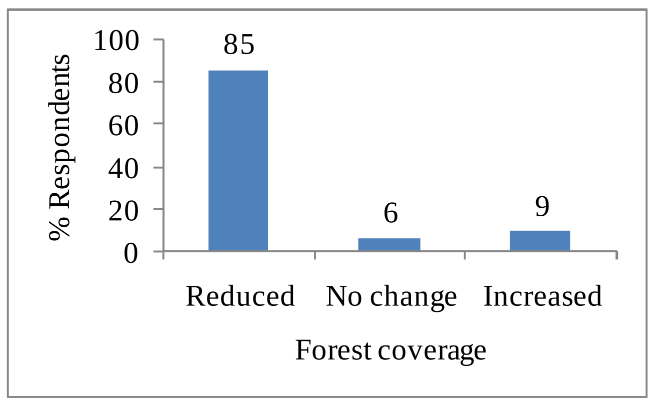


Figure 4: Perception of farmers about forest coverage

Watershed Management Practice

Sedimentation problem usually arises from human disturbance of the prehistoric geologic pattern. Cutting and burning of bushes, shrubs, trees and forestlands lead to reduced vegetation cover and aggravates the process of erosion. Thus an increased erosion problem causes transported sediments from unmanaged watersheds that directly affect the irrigation structures.

In all irrigation schemes investigated, even though 78% (Figure 5) of the respondents believed that an increased watershed management practices after irrigation schemes, physical observation on irrigation schemes showed irrigation infrastructure deterioration due to sedimentation problems. Even if field sediment test is not done, the entire weirs in the four irrigation projects are loaded heavily with sediments. Engineering interventions that protect head work structures from sediment load is suggested for Bedene Alemtena, Gedemso 01 and Eballa irrigation projects.

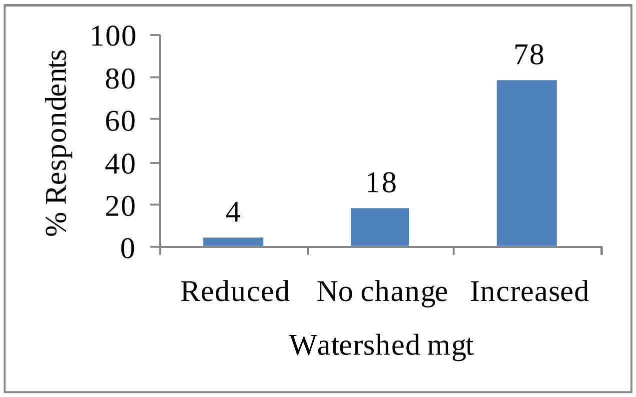


Figure 5: Perception of farmers about watershed Management

Human Interest

Irrigation canals and the accompanying infrastructures are a source of water mainly for the growth of crops. But it also serves different purposes such as recreation, washing and drinking for livestock and humans. However, the canals in the study area created swamp in different reaches. With the formation of the swamps, different pests and insects majorly mosquitoes, has been introduced in most schemes. Due to this malaria become the major problem of the area that adds expenses of medication and reducing labor force for irrigation.

Human health problems after irrigation

Polluted water is a major cause of human disease. 30% of Argeda 01 and 33% of Gedemso 01 irrigation scheme users agreed the increment of water borne disease after the implementation of the irrigation projects. (Figure 6).

As can be seen from the figure, bout 95% of Irrigation scheme users from Eballa and Bedene Alemtena irrigation projects do not agree with the change in water borne disease scenario after irrigation.

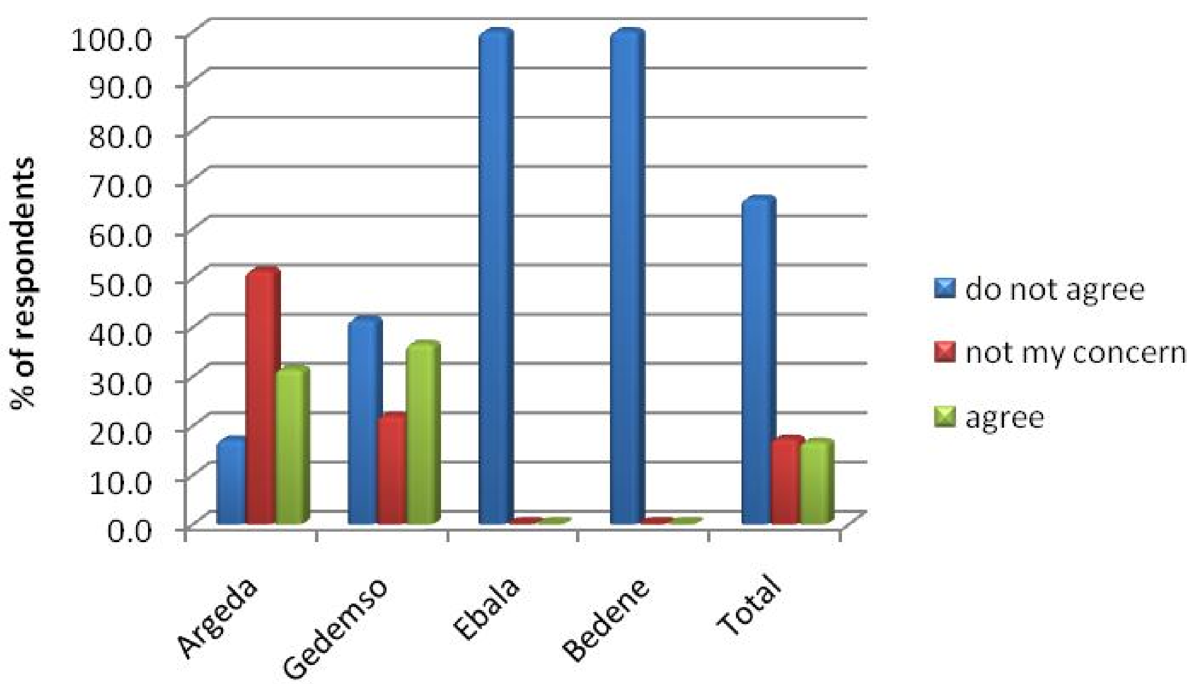


Figure 6: After irrigation, water borne diseases

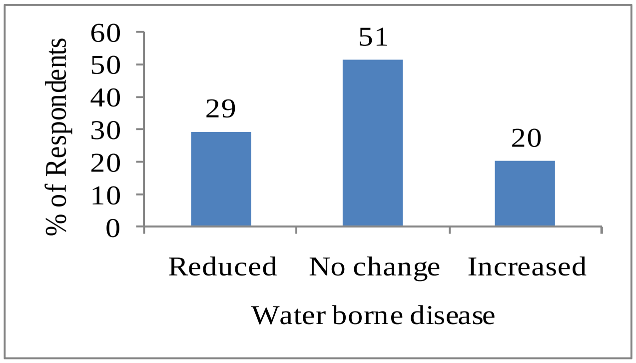


Figure 7: Perception of farmers about water borne disease status

The major reasons could be the users in both Eballa and Bedene Alemtena irrigation projects have alternative places to live different from the irrigated fields. The other reason could be farmers in Eballa and Bedene Alemtena irrigation project cultivates tobacco and pepper both of them are commercial crops most of the time not consumed raw at a household level.

Malaria incidence after irrigation

About 63% of respondents from all irrigation projects testified the increase in malaria incidences after the implementations of irrigation projects (Figure 8).

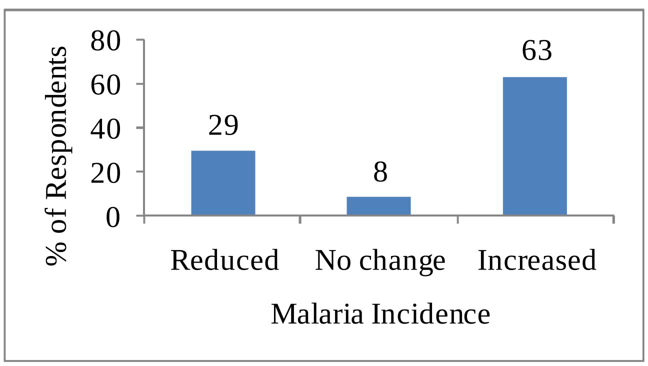


Figure 8: Perception of farmers about malaria incidence

The survey proved that most child and adult deaths in the four irrigation schemes are caused from malaria. Malaria do have also forced the irrigators to spent their time and money for treatment and diminished effective labour availability at the household for production.

Unlined canals in all irrigation projects posed other health problem for both human and livestock. Water seeping from irrigation canals joining dwelling houses created unwanted humidity of living homes which creates a fertile ground for fungal, viral and bacterial diseases and infestations.

Aggregation of Environmental Impacts

Overall environmental impacts of the four irrigation projects were aggregated using the Battelle Environment Evaluation Index (EIV). The result showed that Argeda 01 and Gedemso 01 irrigation projects environmentally performed better than Eballa and Bedene Alemtena irrigation projects (Table 7). Better organization of the schemes may attribute for the result. However there exist a number of environmental issues which need an immediate attention in all the projects investigated. All the negative figures in Table 7 in front of each parameter need immediate attention to reverse the impact.

4. Conclusions and Recommendations

In general, irrigation reduces the risk of expensive inputs being not wasted by crop failure resulting from moisture stress (FAO, 1997). Report towards environmental impact assessment of small scale irrigation project is mainly meant to minimize human and environmental hazards which are to strengthen better living towards humanity without destroying the ecological balance of nature.

In all the projects investigated, the problem of deforestation, overgrazing, poor watershed management, soil salinity, soil acidity, communicable and non communicable diseases, and water logging problems are significant. The fact that, the command, main canal, weir site and access roads in each project is on the undulating plain which was covered with wood land, forest, bushes & riverine tress before. All this landscape phenomena were either sparsely existent or completely removed. For subduing these problems, compensation environmentally friendly tree planting like *Cordia africana* is very important.

In addition to crop production, livestock production in its traditional form of husbandry supports the livelihood of the community in the four irrigation projects. Irrigated forage production is suggested to minimize the risk of overgrazing and compensating forage from the lost grazing land. Other impacts such as effect on wild life and species diversity need better consideration in Eballa and Gedemso 01 irrigation projects.

Due emphasis should have to be given for proper soil and water conservation practices on the degraded upstream catchment of Bedene Alemtena and Eballa irrigation projects. The existing weak farming system need to be developed and supported by technological inputs thus the schemes will enhance return and contributes for and answer the prevailing food self-sufficiency at micro level with improved environmental quality.

The following irrigation scheme impacts related to projects operation and management needs immediate attention before they worsened.

- Water logging due to inefficient use of water in Bedene Alemetena irrigation project.
- Ecological and demographic changes created due to the projects favours the formation of conducive habitats for disease vectors. E.g. Malaria. Coordinated field ditches drainage in tail water location of Bedene Alemetena irrigation project is recommended. Night storage pond in Gedemso 01 irrigation project is another location for mosquito breeding. Frequent weeding of aquatic plants is recommended.
- Pesticide residues are the main cause for lowering the soil pH in Eballa irrigation project. Integrated pest management (IPM) other than complete dependency on commercial pesticides is recommended. If the present application continued, it may cause risk not only to irrigated fields but also to health for both man & animals.
- Irrigated agriculture provided improved condition for aquatic weeds in all projects. Diseases and weeds also propagated quickly via the use of drainage water. Proper drainage water reuse and mechanical weed control strategy is recommended in all projects.

Table 7: Environmental Index Value of the Four Irrigation Projects

Parameters	**RIV***	**DI****				**EIV*****			
		Eballa	Gedemso	Argeda	Bedene	Eballa	Gedemso	Argeda	Bedene
Physicochemical parameter									
Soil fertility	3	0	-3	-2	-1	0	-9	-6	-3
Soil erosion	3	-2	-3	-5	-1	-6	-9	-15	-3
Sedimentation	4	-3	-2	-1	-4	-12	-8	-4	-16
Soil salinity	4	-4	-3	-1	-5	-16	-12	-4	-20
Soil acidity	4	-3	-4	-1	-5	-12	-16	-4	-20
Land degradation	3	-3	-1	-2	-4	-9	-3	-6	-12
Land productivity	3	0	-3	-2	0	0	-9	-6	0
Hydrology/Flooding	3	1	1	5	5	3	3	15	15
Obstruction of movement	3	-4	-3	-3	-4	-12	-9	-9	-12
Ecology									
Species diversity	6	-1	-1	1	1	-6	-6	6	6
Aquatic weeds	8	-3	-3	-3	-3	-24	-24	-24	-24
Grazing land reduction	6	-3	-3	-3	-3	-18	-18	-18	-18
Forest land reduction	6	-3	-3	-3	-3	-18	-18	-18	-18
Watershed management	7	-5	-2	-2	-5	-35	-14	-14	-35
Human Interest									
Human health	6	0	-3	-2	0	0	-18	-12	0
Water borne diseases	4	-3	0	0	-3	-12	0	0	-12
Malaria incidence	5	-3	-3	-3	-4	-15	-15	-15	-20

References

Abebe, Y. D. and Geheb, K. (Eds), 2003.Wetlands of Ethiopia. Proceedings of a seminar on the resources and status of Ethiopia's wetlands, VI + 116pp.

Angood, C., Chancellor, F., Hasnip, N., Morrison, J., Smith, L. (2002). Contribution of irrigation to sustaining rural livelihoods: Nepal case study. HR Wallingford technical report OD/TN 113, Wallingford, UK.

Angood, C., Chancellor, F., Morrison, J., Smith, L. (2003). Contribution of irrigation to sustaining rural livelihoods: Bangladesh case study. HR Wallingford technical report OD/TN 114, Wallingford, UK.

Asit,K.B.(1985). Evaluating irrigation's impact: guide lines for project monitoring, Ceres,Vol 18, No 4,pp 26-32.

Awulachew S. B., Merrey D. J., Kamara A. B., Van Koppen B., F. Penning de Vries and Boelee E.(2005) Experiences and Opportunities for promoting Small-Scale/ Micro Irrigation and Rainwater Harvesting for Food Security in Ethiopia. Addis Ababa International Water Management Institute, Working Paper 98.

Awulachew, S. B.; Yilma, A. D.; Loulseged, M.; Loiskandl, W., Ayana, M.; Alamirew, T. (2007). Water Resources and Irrigation Development in Ethiopia. Colombo, Sri Lanka: International Water Management Institute. 78p. (Working Paper 123)

Awulachew,S.B. and Merrey,J.D.(2007). Assessment of Smale Scale Irrigation and Water Harvesting in Ethiopian Agricultural Development. International Water Management Institute (IWMI), Addis Ababa, Ethiopia.

Bureau of Agriculture (BoA). 2009/2010. Arsi Nagelle District Agriculture and Rural Development office. Arsi Nagelle, Ethiopia. Unpublished report.

Barrow Chris (1993).Water Resources and Agricultural Development in the Tropics. John Wiley and Sons, Inc., New York, USA.

Brabben,T.;Angod,C.;Skutsch,J.;Smith,L., (2004).Irrigation can sustain rural livelihood: evidence from Bangladesh and Nepal. HR Wallingford Ltd. UK.

De Fraiture,C.; Molden, D.; Wichelns, D.(2009). Investing in water for food, ecosystems, and livelihoods: An overview of the comprehensive assessment of water management in agriculture. International Water Management Institute PMB, CT 112, Cantonments, Accra, Ghana.

Dessalegn Rahmato (1999): Water Resource Development in Ethiopia. Forum for Social Studies, Addis Ababa, Ethiopia.

Dougherty T.C., Hall A.W (1995). Environmental impact assessment of irrigation and drainage projects. FAO. Rome Italy.

Environmental Policy of the Federal Democratic Republic of Ethiopia (April 2, 1997) Addis Ababa, Ethiopia.

Ethiopian Environmental Protection Authority (EEPA) (November, 2003). Environmental Impact Assessment Procedural Guideline Series 1. Addis Ababa, Ethiopia.

Ethiopian Environmental Protection Authority (EEPA), 2004.Environmental impact assessment guidelines on irrigation. Addis Ababa, Ethiopia.

FAO (1997). Irrigation potential in Africa: A basin approach. Roam, Italy.

FAO (2005).Global information and early warning system on food and agriculture. World food program. Special report. Italy, Rome

Federal Negarit Gazeta (FNG) of the Federal Democratic Republic of Ethiopia (December3,2002).Proclamation No. 299/2002.Environmental Impact Assessment Proclamation. Addis Ababa, Ethiopia.

Gebregziabher, G.;Namara,E.R.;Holden,S., (2009). Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia. Agricultural Water development.

IFAD (International Fund for Agricultural Development) (2005). Special country program phase II. Interim evaluation report number 1643-ET, Ethiopia IFAD (International Fund for Agricultural Development)

Makombe, G., Kelemework, D., Aredo, D., (2007). A comparative analysis of rain-fed and irrigated agricultural production in Ethiopia. Irrigation and Drainage Systems 21, 35–44.

MoWR (Ministry of Water Resources) (2001). Irrigation development strategy (Component of the water sector development program). Draft report. Ethiopia, Addis Ababa.

Peden, D.; Dubale, P.; Tsegaye, E.; Behailu, M.; Tadesse, G.; Gebremedhin,G.,(2002). Community-based irrigation management in Ethiopia: Strategies to enhance human health, livestock and crop production, and natural resource management. International Water Institute Management Institute (IWMI), Addis Ababa, Ethiopia.

Tesfaye, A.; Bogale, A.;Namara, E.R.;Bacha,D.,(2008). The impact of small-scale irrigation on household food security: The case of Filtino and Godino irrigation schemes in Ethiopia. Irrigation and Drainage System 22:145–158.

An Artificial Neural Networks Approach to Forecast Short Term Urban Water Demand: A Case of Adama Town, Ethiopia

Andinet Kebede[1] and Dr. Bogale G/Mariam[2]
[1]Adama Science and Technology University, Civil Engineering Department, +251 911 704944
[2]Arba Minch University

Abstract
Short-term forecast of water demand is essential to the effective operation of water supply systems. This paper presented an approach to determine the best performing Artificial Neural Network (ANN) model to forecast short-term water demand for Adama town. The significance of climatic variables (rainfall and maximum air temperature), in addition to past water demand, on water demand management was investigated. Various experiments were conducted to justify the high performing and adaptive network amongst Multilayer Perceptron (MLP), Radial Basis Functions (RBF), Coactive Neuro Fuzzy Inference System (CANFIS) and Kohonen's Self-Organizing Feature Maps (SOFM) methods. The performance of the ANN models in training and testing stages were compared with the observed water consumption values to identify the best fit forecasting model based upon a number of selected performance criteria. The best results were obtained when water demand from the previous week, average maximum temperature from the current week, and the amount of rainfall from the current week, are used as input data. The lowest value of the average absolute relative error (3.37%) and the highest value of Nash-Sutcliffe efficiency (0.66) of the forecasting models were obtained from the SOFM Network; depicting that Self-Organizing Feature Maps are the overall genius model among the ANNs considered in this study. The performances of all the ANN models were also compared with a multiple regression method and the ANN models consistently outperformed the regression models developed in this study. It had also been found that water demand on a weekly basis is more significantly correlated with the rainfall amount than the occurrence of rainfall.

Keywords | *Adama, Artificial neural networks (ANN), short term forecasting, Urban water demand.*

1. Introduction

Short-term demand forecasts have traditionally been made using causal models, time series analysis, or a combination of the two. ANNs have been recently accepted as an efficient alternative tool for modelling complex water resource systems and they are widely used for forecasting. Maier and Dandy (2000) conducted a study reviewing 43 research papers which sufficiently justified the need to use neural networks in the modeling of water resource variables. The literature is rich in the applications of one or two particular ANN technique to a specific water resources system, including water demand modelling. However, as there is a range of ANN types, there is an obvious need to compare these ANN techniques based on how well they perform.

On the other hand, many types of data may be needed in forecasting, most of which may be grouped into two classes: socio-economic variables and climatic variables. The climatic variables such as rainfall and maximum air temperature are responsible for the short-term seasonal variations in the water demands (Miaou, 1990 and Jain et al., 2001). A primary goal of the short-term model is to capture the weekly variability that is associated with climate. It is suggested that daily time-step models are likely to be highly inaccurate because of the unpredictability and variability of various parameters. Daily models can also be less appropriate for management decisions that are made less frequently. In contrast, weekly models provide strong seasonal signals without the extremes represented by daily values.

Moreover, the inputs to ANN should not be too numerous. Usually, the practice is to go for simple models which have few input variables. Thus, only the two more general climatic variables, temperature and rainfall, are considered in this study. Hence, the present study focuses on the modeling of short-term water demand forecasts using the climatic variables such as rainfall and maximum air temperature, in addition to the past water demands. Four separate architectures of the neural networks are investigated to model the weekly water demands in this study: the MLP, RBF, CANFIS and SOFM. Based on these architectures, different ANN models are developed. Finally, the best ANN model to forecast the Adama town water demand is judged in terms of various standard statistical parameters describing the errors associated with the model forecasts. For comparison purpose, the linear and non-linear multiple regression techniques are also investigated.

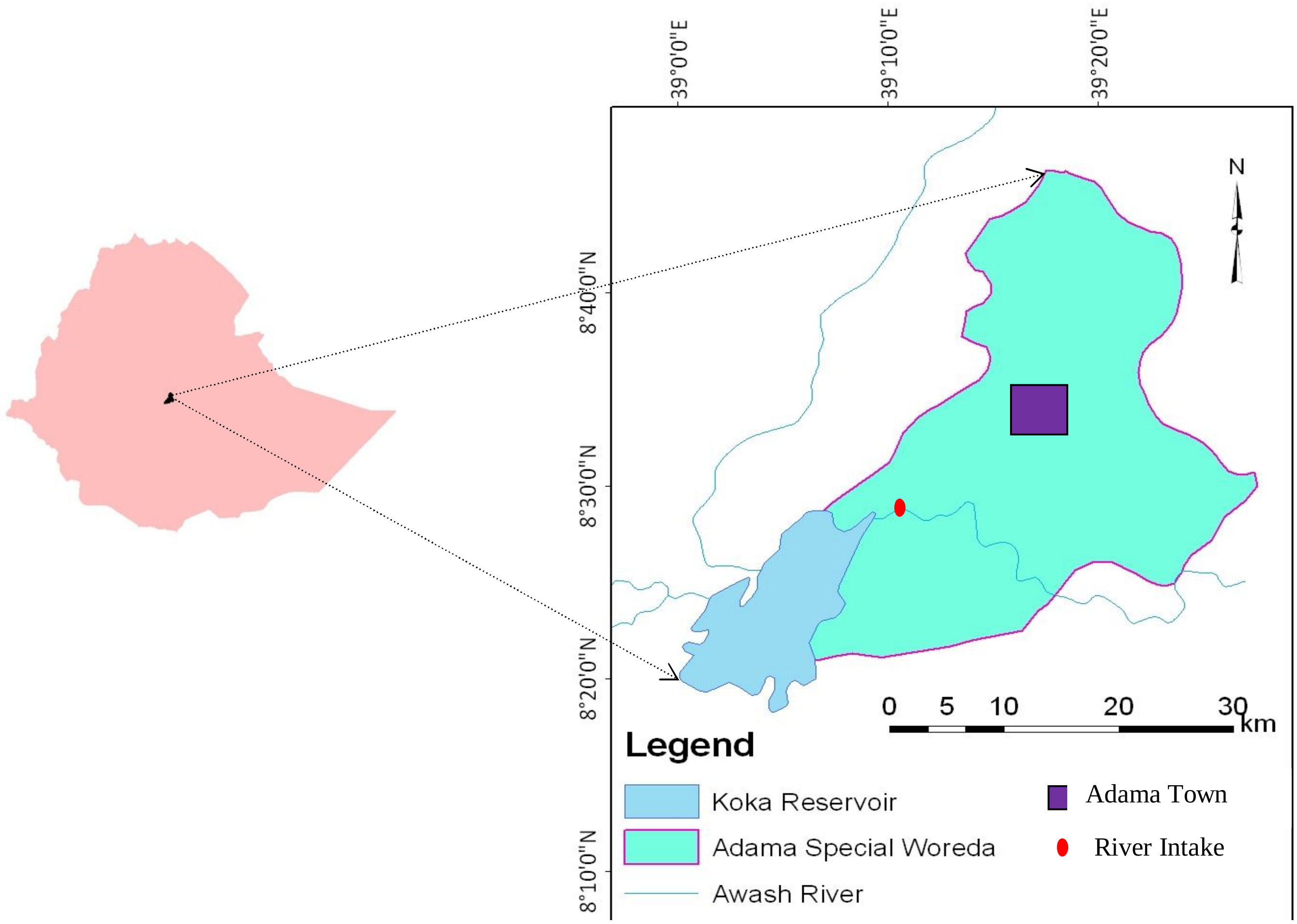


Figure 1: Location Map of the study area (Adama Town & the River Intake are not to their true size and shape)

Description of the study area

The town of Adama is located about 100 km SE of Addis Ababa at latitude of $8^0$33'N and longitude $39^0$17'E. The town is quickly developing as political and economic centre. Recently, it has become more and more attractive as an industrial and residential area. The population of Adama town was officially estimated at 222,035 in 2007. Demographically, Adama is one of the fast growing towns in the region.

The current source of water supply is Awash River, which is located 15 km from the centre of the town and 3 km downstream of Koka Dam. The water supply system also provides drinking water to area around Adama Town (Adama Woreda) which has additional population of 155, 035. Thus the system supplies water to the Adama Special Woreda, with total population of 377, 356 and total area of 1007.66 square kilometers.

2. Objective of the Study

The General objective of this study is to investigate the best performing Artificial Neural Network (ANN) to forecast short-term water demand for Adama town. A secondary objective is to test the following two hypotheses: (i) the short-term water demand process at the town is mainly driven by maximum air temperature and is reduced by the occurrence of rainfall, and (ii) the amount of rainfall is a more significant explanatory variable than the occurrence of rainfall in modelling short-term water demand process. In order to test the second hypothesis, the rainfall was employed as a binary input in the regression and ANN models. This was accomplished by representing the non-occurrence of rainfall as zero and the occurrence of rainfall by one in the models, irrespective of the amount of rainfall.

3. Methodology

Artificial Neural Networks (ANN)

A neural network performs a human-like reasoning, learns the attitude and stores the relationship of the processes on the basis of a representative data set that already ex-

From a mathematical point of view, ANN is a complex non-linear function with many parameters that are adjusted (calibrated, or trained) in such a way that the ANN output becomes similar to the measured output on a known data set. While developing an ANN model, one presents an ANN with input patterns and their associated outputs. The network then internally organizes itself to reconstruct the complex relationships among inputs and outputs. Typically, the architecture of ANNs consists of a series of processing elements (PEs), arranged in layers.
The input from each PE in the previous layer *Xi* is multiplied by an adjustable connection weight *Wji*. At each PE, the weighted input signals are summed and a threshold value *θj* is added. This combined input *Ij* is then passed through a nonlinear transfer function *f* (*Ij*) to produce the output of the PE *Yj*. The output of one PE provides the input to the PEs in the next layer. There are many different connections of how the data flow between the input, hidden and output layers. By choosing appropriate architecture and activation, neural networks can be trained to capture knowledge from the data available with acceptable performance.

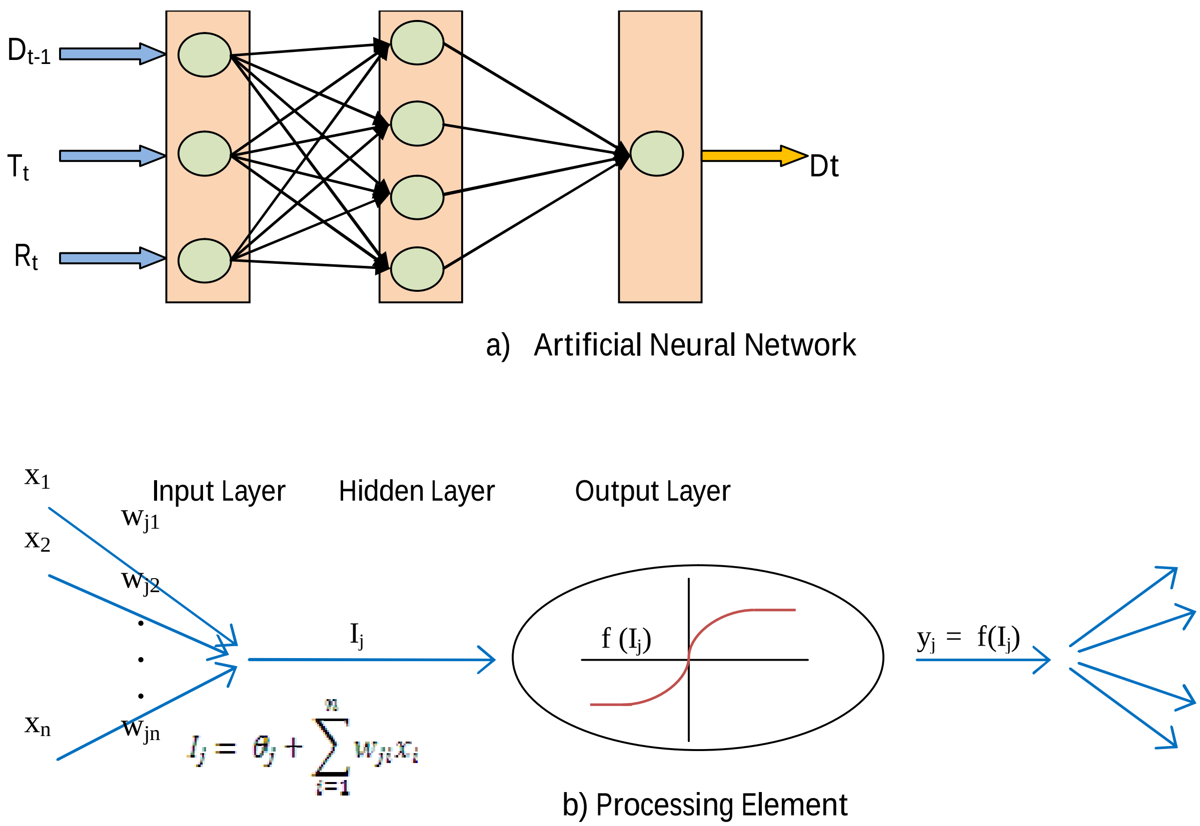


Figure 2: Typical Structure and Operation of ANNs

The majority of the variations among ANN models stem from the various learning rules and how those rules modify a network's typical topology. MLP, RBFs, CANFIS and SOFM architectures are selected in this research, as they are efficient and appropriate for non-linear predictions. MLP and CANFIS networks are driven by targets by adapting supervised learning whereas RBF and SOFM network adjust their weights and achieve the target using unsupervised learning. These four network models are experimented with respect to their learning rule, transfer function, number of epochs and weight update methods.

Non-Linear Multiple Regression Model

Relationships between demand and meteorological conditions are often non-linear and generally, the problems of non-linear relationships are overcome by using a multiplicative model form, which involves applying a log transformation to both the demand (the dependent variable) and the independent variables. A limitation of log-transformed models is that they cannot be applied if one of the variables at time t is zero. In this study, some of the values of rainfall are zero.

In this study, some of the values of rainfall are zero. Alternatively, just the response variable may be logarithmically transformed and linearly regressed against the untransformed explanatory variables to form a semi-log model (Fane et al., 2011).

$$\log(y_t) = \beta_0 + \sum_{i=1}^{n} \beta_i x_{i,t} \quad (1)$$

Retransforming equation 1:

$$y_t = 10^{(\beta_0+\beta_1 x_{1,t}+\beta_2 x_{2,t}+\ldots+\beta_n x_{n,t})} \quad (2)$$

Model Performance Evaluation

Although there can be many performance measures for an ANN forecaster like the modelling time and training time, the ultimate and the most important measure of performance is the prediction accuracy it can achieve beyond the training data. Moriasi et al. (2007) recommended that quantitative statistics, Nash-Sutcliffe efficiency (NSE), and ratio of the root mean square error to the standard deviation of measured data (RSR), in addition to the graphical techniques, to be used in model evaluation. Besides, to check consistency in forecasting, statistical parameter, called 'threshold statistic for a level of x%' is used. Pearson's correlation coefficient (r) or the coefficient of determination (R^2 = r), describes the degree of colinearity between simulated and measured data.

Data Collection, Division and Analysis

The water demand data is obtained from the Adama Town Water Supply Service Enterprise, and the weather data from the Ethiopian Meteorological Agency for a station called Nazareth. The most recent weather data available at the Agency is considered, which is from 2004 up to 2008. The water demand data were available for a period from 2003 to 2011; however, the data were scattered with a lot of missing records. The water demand data for the continuous 108 weeks, from January 2005 to January 2007, are considered for model development and testing in this study. Corresponding to the chosen period of water demand data, the meteorological weekly total rainfall and weekly average maximum temperatures are taken.

All the data is divided into two sets: training or calibration set consisting of first 86 weeks of data, and a testing set consisting of the remaining 22 weeks of data. The training data set is used to train all the ANN models and calibrate all the regression models, while the testing data set is used to test the performance of models and calibrate all the regression models, while the testing data set is used to test the performance of all the models in terms of various standard statistical measures considered in this study. The range of the total weather data (2004 – 2008) and the data considered for model development (Jan 2005 – Jan 2007) are compared to guarantee the representativeness of the data and found safe.

Even though ANN models are basically black box models which require no understanding of the underlying physical principles and processes, a complete understanding of relations between the output and factors that influence it can lead to a better choice of input variables, minimize loss of information and prevent inclusion of redundant inputs which may complicate the training process. Thus, the input variables are analyzed. Figure 3 shows the weekly water demand, temperature, and rainfall data for the same period on the same diagram.

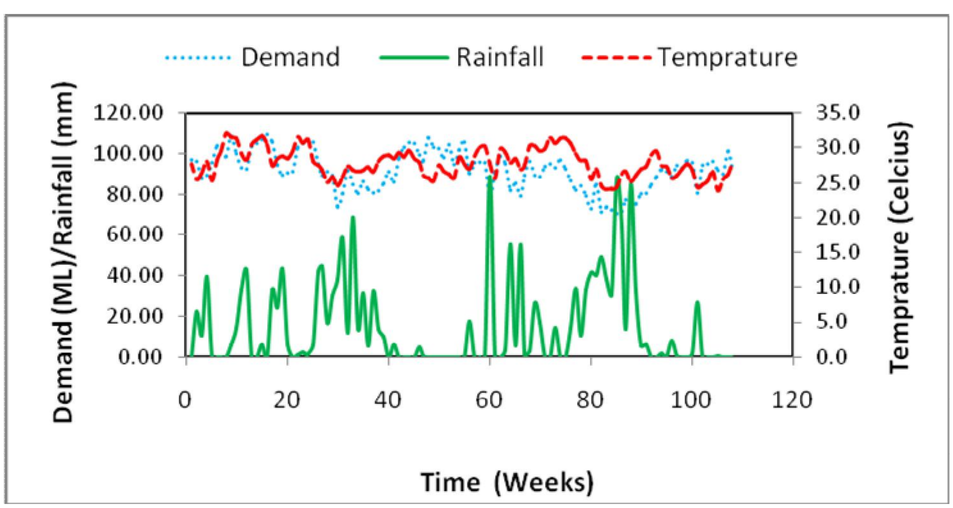


Figure 3: Weekly water demand, temperature and rainfall series, for Jan. 2005 to Jan. 2007

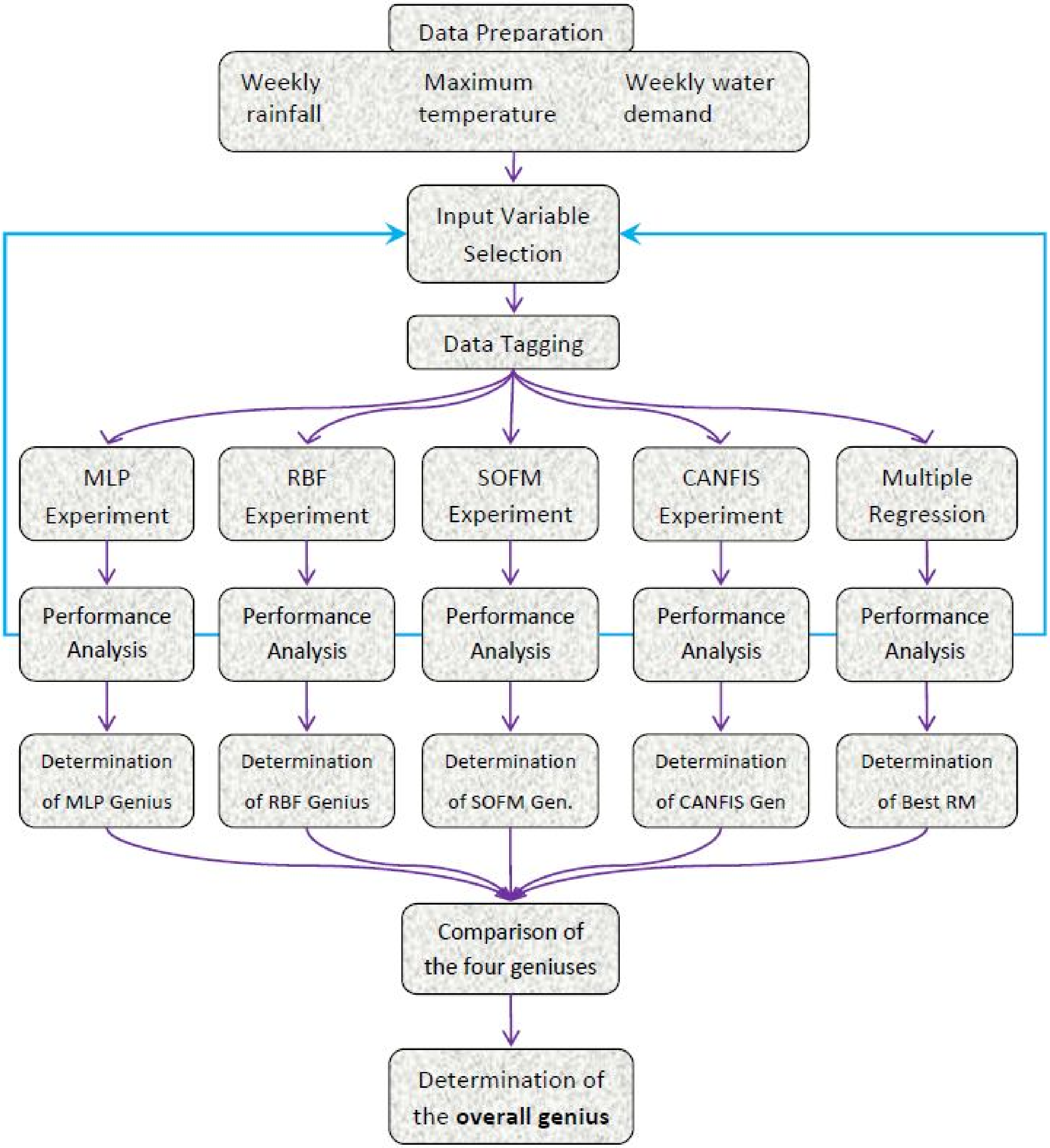


Figure 4: Modeling steps followed in this study

Model Structure Setup

First is identifying the physical variables affecting the process. In the modelling, physical variables considered are weekly average maximum air temperature, T (^oC) and total weekly rainfall, R (mm), in addition to the water demand, D (ML) observed in the past. It is preferable to explore the rainfall as one of the explanatory variables to model the weekly water demand forecasts at Adama. The rainfall is employed as a binary input also in the regression and ANN models.

After data tagging, five experiments (4 ANN and 1 for RM) are run in parallel. A performance analysis is then executed on all sides, using the different multiple input options and that is followed by the determination of the MLP genius, RBF genius, CANFIS genius and SOFM genius. The MLP Genius is the MLP model that outperforms all the other MLP models in the MLP experiment; the same is true for the other cases. The genius models of the four ANN are also compared with the best regression model. The artificial neural genius (ANG) is the ANN architecture that outperforms all the geniuses of other models in the ANN experiment. The MLPG, RBFG, CANFISG and the SOFMG are thereafter compared in order to establish the overall Genius in the study.

3. Results and Discussions

The calibration results in terms of regression coefficients from various linear and non-linear multiple regression models indicate an increase in weekly water demand with an increase in temperature values. On the other hand, a decrease in weekly water demand is indicated with increase in rainfall or occurrence of rainfall.

The results in terms of all the discussed standard statistical parameters are also analysed. The model with parameters D_{t-1}, T_t and R_t performed the best among each of the ANN models in terms of NSE, RSR and threshold statistics. The SOFM-2 model produced the least AARE of 3.73% and the least RSR of 0.58. The maximum NSE value of 0.66, which is sign of good performance, also matches with SOFM-2. Nearly 23% of the forecasted water demand from SOFM-2 model had absolute relative errors less than 1%; whereas, the same statistic from the corresponding models was either 9.09% or 18.18% only.

The best ANN models of all the four neural architectures employed amount of rainfall as opposed to which considered binary inputs. Moving on to the regression models, NLMRM performed marginally better than their corresponding LMRM, confirming the presence of some nonlinearities in the underlying physical processes governing water demand. The NLMRM-2 model performed the best among all the regression models developed in this study in terms of NSE, RSR and threshold statistics for all levels. The NLMRM-2 is a function of maximum average weekly temperature at times t and t-1, weekly total rainfall at times t and t-1 and the previous weeks peak water demand. Based on coefficients obtained using In stat software, the model is given by the following equation:

$$D_t = 10^{\left(1.65+0.0051D_{t-1}+0.0051T_t-0.00092R_t-0.007T_{t-1}+10^{-5}R_{t-1}\right)}$$

As found in the ANN models, the occurrence or non-occurrence of rainfall models did not perform as well as model containing the actual rainfall total (NLMRM-2). The maximum value of coefficient of correlation during training and testing are 0.905 and 0.873, respectively, as obtained from the models using ANN technique. Even though the best regression model performed better than one of the ANN model during training (r=0.883), the coefficient during testing dropped below all the ANN values (r=0.802). This shows that the generalization ability of the four ANGs found out in this study is better than that of the best regression model.

The results in terms of observed and forecasted water demands are depicted in graphical form in Figures 4 from the SOFM-2 model.

Table 1: Results of the comparative analysis of the 4 ANN genius and the best regression model.

Statistic	MLP	RBF	CANFIS	SOFM	Regression
AARE	4.28	4.32	4.20	3.73	4.36
NSE	0.63	0.63	0.65	0.66	0.60
RSR	0.61	0.61	0.59	0.58	0.64
TS1	18.18	9.09	9.09	22.73	13.64
TS3	31.82	36.36	31.82	50.00	45.45
TS5	68.18	63.64	72.73	77.27	63.64
TS10	95.45	100.00	100.00	100.00	100.00
TS15	100.00	100.00	100.00	100.00	100.00
R (Training)	0.885	0.889	0.905	0.874	0.883
R (Testing)	0.846	0.862	0.873	0.844	0.802

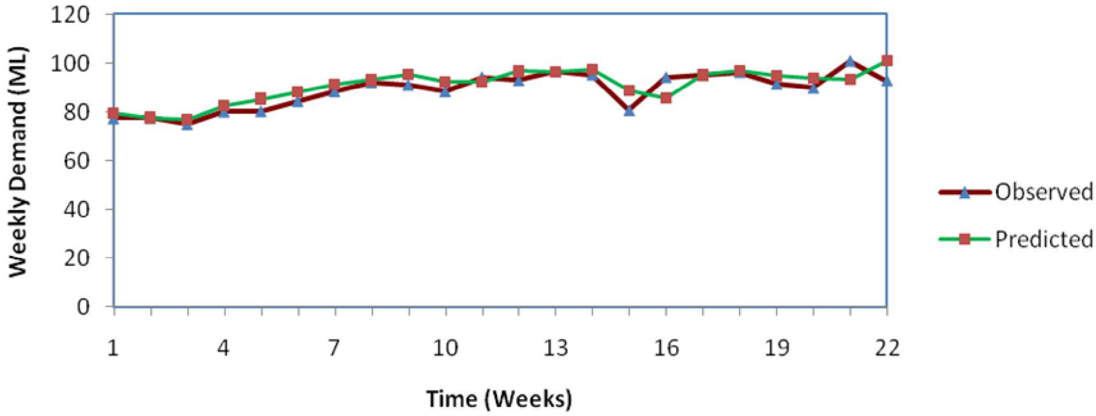


Figure 5: Observed and predicted water demand from the SOFM-2 model testing data set

4. Conclusions and Recommendations

Based upon the results obtained in this study and the consequent comparative analysis, the models employing the ANN technique have consistently outperformed the models using techniques of regression analysis. This clearly establishes the suitability and superiority of the technique of ANNs over the conventional techniques of regression for use in short-term water demand forecast modelling. Further, the models that employed rainfall amount as opposed to the rainfall occurrence as one of the explanatory variables performed more significantly than the rainfall occurrence.

The non-linear multiple regression model, NLMRM-2, has done the best among all the regression models. On the other hand, the ANN model considering the variables D_{t-1}, T_t and R_t performed the best in all the ANN models. The lowest value of the AARE and RSR and the highest value of NSE and TS of the forecasting models were found to be obtained from the SOFM-2 model. In this particular study, the self-organizing feature maps network can therefore be declared as the overall genius network architecture because it outperforms the other networks. Moreover, based upon the results obtained, it can also be concluded that the short-term water demand process at Adama town is a dynamic process mainly driven by the maximum air temperature and get reduced by the occurrences of rainfall.

On the other hand, it is always believed that no research effort is ever complete and there is always room for further argument and improvement. In light of the present research effort, the following limitation or improvements are cited. There is a potential to further increase the scope of the ANN's validity through the inclusion of additional explanatory variables selected based on sensitivity analysis. It is hoped that future research efforts will concentrate in overcoming some of the limitations.

References

Chang, N. and Makkeasorn, A. 2006. Water Demand Analysis in Urban Region by Neural Network Models. Department of Civil and Environmental Engineering, University of Central Florida.

CSA. 2008. Federal Democratic Republic of Ethiopia Population Census Commission. Summary and Statistical Report of the 2007 Population and Housing Census, Population Size by Age and Sex. Addis Ababa.

Dereje, W. 2003. Wastewater Study for Adama Town. Environmental Support Project, Component 3.

Fane et al., University of Technology Sydney, 2011. Integrated Resource Planning for Urban Water—resource Papers, Waterlines Report, National Water Commission, Canberra.

Jain, A., Varshney, A. K. and Joshi, U. C. 2001. Short-Term Water Demand Forecast Modeling at IIT Kanpur Using Artificial Neural Networks. J. of Water Resources Management, 15: 299–321.

Maier, H. R. and Dandy, G. C. 2000. Neural Networks for the Prediction and Forecasting of Water Resources Variables: A Review of Modelling Issues and Applications. Environmental Modelling and Software, 15:101-124.

Mekuriaw, A. and Jembere, K. 2008. Needs of Small to Medium Sized Utilities in the Water and Sanitation Sector in Ethiopia. Nile IWRM-Net. Final report submitted to Cap-Net.

Miaou, S. P. 1990. A class of Time Series Urban Water Demand Models with Nonlinear Climatic Effects. Water Resources Research, 26 (2): 169-178.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D. and Veith T. L. 2007. Model Evaluation Guidelines for Systematic Quantification of Accuracy In Watershed Simulations. American Society of Agricultural and Biological Engineers ISSN 0001−2351, 50(3): 885−900.

Trend Analysis of Runoff and Sediment Fluxes of the Upper Blue Nile Basin Using Statistical and Physically Based Model

Tesfaye Gebretsadkan[1, 4], Y.A. Mohamed[1,2,3], G.D. Betrie[1]

[1]UNESCO-IHE Institute for Water Education, P.O. Box 3015, 2601DA Delft, The Netherlands
[2]Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands
[3]Hydraulic Research Station, P.O.Box 318, Wad Medani, Sudan
[4]Tigray Agricultural Research Instite , Tigray, Ethiopia

Abstract
*The land use/cover changes in the Ethiopian highlands have significantly increased the variability of runoff and sediment fluxes of the Blue Nile River during the last few decades. The objectives of this study were to understand the long-term variations of those fluxes using statistical models, verify the statistical results using a physically-based hydrological model. The Mann-Kendall and Pettit tests were used to test the trends of Blue Nile discharge (1970 to 2009) and sediment load (1980 to 2009) at the outlet of Upper Blue Nile, at El Diem Station. These tests showed significant increasing trend of annual stream flow, wet season stream flows and sediment load respectively. The dry season flow showed a significant decreasing trend. However, during the same period the annual rainfall over the basin showed no significant trends. The results of the statistical tests found to be sensitive to the time domain. The Soil and Water Assessment tool (SWAT) model was used to simulate the runoff and sediment fluxes in the early 1970s and at the end of the time series (2000s) in order to detect the physical causes of the trends. A comparison of model parameters values between the 1970s against 2000s shows significant change, which could explain catchment response changes over the 28 years of record. The results of the statistical test and SWAT model have resulted in significant change of runoff and sediment load from the Upper Blue Nile. This is an important finding to guide optimal water resources development in the whole basin, both upstream in the Ethiopian highlands, and further downstream in the plains of Sudan and Egypt***.

***Keywords*:** Upper Blue Nile, SWAT, Trend analysis, Stream flow, Sediment transport

Introduction

The Upper Blue Nile River basin contributes more than 60% of the Nile water. It is crucial for the socio-economic development and environmental stability of the three riparian countries, Ethiopia, Sudan and Egypt. However, landuse/cover and climate changes have affected the value of the Blue Nile's water, through increasing inter-annual and inter-decadal variability of runoff and sediment fluxes [10], [25]. These changes result in negative impact for both upstream and downstream countries. In the Ethiopian highlands, landuse change has led to severe soil erosion which reduced soil moisture capacity and challenged food production [23], [43]. The downstream countries (Sudan and Egypt), have experienced problems on their storage reservoirs and irrigation canals due to excessive sediment loads [14]. The literature showed an increase of sediment yield at the Upper Blue Nile outlet (El Diem gauging station) from 111 to 140*106 ty-1 [5], [11], [18], [33].

A number of local and basin level studies about the Blue Nile have been reported in the literature, e.g., the long term trend analysis of runoff by [6], [16], [26], [28]. [41].They have shown no consensus on conclusions of the flow trends. [9] and [28] showed an increasing trend of the Blue Nile annual flow, while [6], [16] indicated a decreasing trend. Analyzing 40 years of data (1964 to 2003), [41] showed no change of annual flow from the Upper Blue Nile basin, but with an increase of flood season flow. There are a number of studies estimated the annual sediment load from the Upper Blue Nile basin, (e.g., [5], [11], [41], though showed a disparity among different researchers. To our knowledge, no study was done to analyse the long term trend of the sediment load. The disagreements on the hydrological trends and on the amount of annual sediment load show a limited understanding of the underlying causes.

Therefore, the objectives of this study were (i) assessing the long-term variability of runoff and sediment fluxes of the Upper Blue Nile using statistical methods, (ii) infer the causes of changes in runoff and sediment load as a function of landuse change derived from changes of physically based model parameters (SWAT), and (iii) verify results from statistical tests and SWAT model against landuse change derived from remote sensing images of 28 years time difference.

Description of study area

The Upper Blue Nile basin (locally called Abay) is located in the north western part of Ethiopia (Fig.1). The topography of the basin is composed of highlands, hilly in the north-eastern part and dominated by valleys in the southern and western parts. The elevation varies from 480m near the Sudan/Ethiopian border, to over 4000m near the center. The climate of the basin is tropical highland monsoonal with the majority of the rain falling between June and October. The average rainfall of the basin varies from 1000 mm/year in the north-east to above 2000 mm/year in south-east of the basin. Over 80% of the annual flow occurs from July to October flowing directly to the downstream countries [40].

The basin is composed of mainly volcanic rocks and pre-Cambrian basement rocks with small areas of sedimentary rock [8]. The dominant soil types are latosol and Alisols 21%, Nitosols 16%, Vertisols 15% and cambisols 9% (Betrie et al., 2011). The dominant land cover of the basin are Savannah, dry land crop and pastures, grassland, crop and woodland, water body and sparsely vegetated [2].

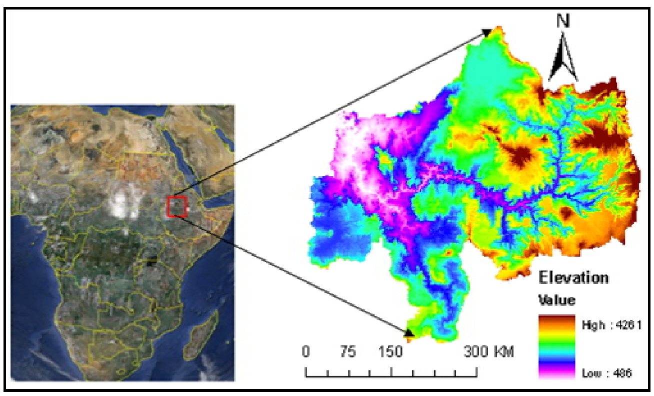


Figure 1: Location map of the Upper Blue Nile basin

3. Methodology

Input data

The datasets used in this study include: soil, climatic (e.g., rainfall and temperature), runoff, sediment, and landuse/cover maps. Long term records of monthly data on rainfall, runoff and sediment load were used for the statistical analysis. Daily climate, runoff, and sediment load data were used for the SWAT modelling. Satellite images (Landsat) of 1973 and 2000 were used to detect long-term landuse change.

The annual rainfall data from 1970 to 2005 of nine gauging stations were used to detect long term trends of rainfall over the Upper Blue Nile basin.

Because of limited spatial distribution, rainfall stations closer to headwater of the tributaries were selected to ensure better coverage. The monthly river discharge data from 1970 to 2009 and suspended sediment loads from 1980 to 2009 at El Deim station were used to assess seasonal and annual trends of flow and sediment, respectively. The observed daily data of discharge and sediment load were used for SWAT model simulations. The available data shows that there is a lack of adequate sediment data in Upper Blue Nile. Therefore, we assumed equal sediment concentrations at El Diem and Roseires (110 km apart) as both stations were linearly correlated. The data from the latter were used to fill in missing gaps at El Diem. The good correlation (R2=0.88) between sediment concentration of the two stations indicates realistic assumption.

The sediment concentration in the Blue Nile is measured only during the rainy season, from June to October, and assumed negligible during the remaining months [5], [11]. The observed sediment data were complete for simulation of the model in year 2000 to 2005, but with many missing values during 1970 to 1976 simulation period, with measurements only available for 1972 to 1973. Therefore, the model in the 2000s was calibrated from observed data whereas for 1970 to 1976 simulation period, sediment data derived from the NBCBN’s rating curve has been used. The NBCBN derived a sediment rating curve based on observed data during the early 1970s, [33]. However, the available measurements for period 1972 to 1973 have been used to verify data derived from the rating curves, and showed high correlation with coefficient of R2=0.80.

The observed daily data of precipitation and minimum and maximum temperature were obtained from 27 stations for daily rainfall and 19 stations for daily temperature. The daily data were used to run the SWAT model for two simulation periods (i) 1970 to 1976, and (ii) 2000 to 2005. A weather generator model based on statistical summaries of long-term monthly means was used to generate the relative humidity, solar radiation and wind speed data for 18 stations within the basin.

Experimental approach

Man-Kendall and Pettitt tests

The long term trends of the hydrological and sediment fluxes were estimated using the non parametric statistical tests of Mann-Kendall (MK) and Pettit [10], [25].

Mann-Kendall test is a rank based method for trend analysis of time series data [7], [41]. First the presence of monotonic increasing/decreasing trend was tested using Mann-Kendall test. Secondly, the Pettit test was applied to investigate the difference between cumulative distribution functions before and after a time instant. The significance of any trend in the data set is provided in 'no trend', 'an increasing or a decreasing trend' designation based on defined confidence level [29]). Man-Kendall calculates Kendall's statistics (s), the sum of difference between data points and a measure of associations between two samples (Kendall's tau) to indicate increasing or decreasing trend. Positive values of those parameters indicate a general tendency towards increasing trend while negative values show a decreasing trend. The Pettit test is a non parametric test that requires no assumption about the distribution of the data and is used to identify if there is a point change in the data series.

However, the presence of serial correlation can increase the expected number of false positive outcomes for those statistical tests [46], [48], [50]. The existence of positive and negative serial correlation results an overestimation and underestimation of the probability of trends, respectively. Therefore, it is essential to eliminate or reduce the influence of serial correlation on the tests and in this study, the trend-free pre-whitening (TFPW) method developed by [48] was used. This approach involves estimating a monotonic trend for the series and then removing the trend prior to pre-whitening the series [7].

The gradual trend test (Man-Kendall), and abrupt change test (Pettit) have been employed on seasonal and annual discharge series of 1970-2009 and sediment load series of 1980-2009 at the outlet of the basin (El Diem Station). The rainfall data series of nine stations were also tested against long term trends.

The SWAT model description

The SWAT model was used to interpret results of the statistical tests, and infer if the long-term trends are attributed to landuse change. The SWAT model describes the relationship between inputs (e.g. rainfall), the system condition (e.g. landuse/cover) and the outputs (e.g. stream flow and sediment load). To this effect, two independent SWAT simulations were performed from 1970 to 1976 and from 2000 to 2009. The difference between model parameters values of the two simulations could explain reasons for the envisaged trends of runoff and sediment fluxes [42]. The SWAT model is a conceptual, GIS interface tool that operates on daily time step to envisage the impact of landuse and climate change on water, sediment and agricultural yields from large watershed with varying soil, landuse and management practices over a certain period of time [4], [34]. The model divides the basin into subbasins and further into hydrological response units (HRUs) with homogenous soil type, slope, landuse and management practices.

The SWAT model computes surface runoff with two methods, the soil conservation service (SCS) curve number (CN) method [44] and the Green-Ampt infiltration method, [19]. The CN method was used in this study because of its capability to use daily input data [4], [5], [34], [37], [43].

The SWAT model simulates the hydrology into land phase and the routing phase. In the land phase, the amount of water, sediment and other non-point loads are calculated from each HRU and summed up to the level of subbasins. Each sub-basin also controls and guides the loads towards the basin outlet. The routing phase defines the flow of water, sediment, and other non-point sources of pollution through the channel network to the outlet of the whole catchment [34]. SWAT computes the soil erosion at an HRU level using the modified Universal Soil Loss Equation MUSLE [47]. This constitutes the sediment yield from each sub-basin and is routed to the basin outlet. Detailed steps for computing of hydrological and sediment components are available in the literature (e.g. [34]). Although SWAT provides three methods for estimating potential evapotranspiration: Penman-Monteith [30], [36] and Hargreaves methods [20], the Hargreaves method was used in this study since it is most suitable where data are limited.

The SWAT model setup

The SWAT model was built for two simulation periods 1970 to 1976 and 2000 to 2005. The Digital Elevation model (DEM) obtained from Global US geological survey) ite, soil map and landuse maps were used by SWAT to delineate the HRUs. The Landuse/cover maps were prepared from Landsat MSS and ETM+ imageries [17].

The soil map obtained from global soil map of the Food and Agriculture Organization [13]. It includes more than 500 soil types, at a spatial resolution of 10 km. The soil physical properties (e.g. bulk density, available water capacity, hydraulic conductivity, saturation hydraulic conductivity, particle-size distribution were taken from [5].

The landuse, soil and topography maps were overlaid to create a total number of 1553 HRUs over the Upper Blue Nile. The HRUs were selected by ignoring landuse, soil and slope areas covering less than 5% of the total subbasin area. This was necessary to reduce computation time of the model.

The simulation period of the first model was done from January 1, 1970 to December 31, 1976. The first year was used for model warm-up, the years 1971 to 1973 were used for model calibration, and the years 1974-1976 were used for model validation. The simulation of the second model was performed from January 1, 2000 to December 31, 2005 with the first three years (2000-2002) for model calibration and the last three years (2003-2005) for model validation. The two periods were selected to detect landuse change over a relatively long period. It includes the period of high landuse changes of the 1980s [49].
Sensitivity analysis was done to identify the most sensitive SWAT model parameters for model calibration. In this study, the automatic sensitivity analysis extension of SWAT, Latin-hypercube one factor at a time (LH-OAT) algorithm developed by [45] which is part of SWAT model was used to identify the most sensitive parameters. Next, the identified most sensitive parameters were automatically calibrated using sequential uncertainty fitting algorithm SUFI-2 [1]. The validation was done by running the same model for different simulation periods. The performance of the model for both runoff and sediment load was then evaluated using statistical indices [31], Nash-Sutcliffe coefficient of efficiency (E) and Coefficient of determination (R2). Graphical comparisons of the daily simulated and observed time series and water balance checks have been used in the validation as well.

After obtaining best fitting parameters for flow and sediment simulations from the early 1970s and late 2000s models, two different approaches were used to detect causes of runoff and sediment. First, we compared parameter values for the two periods assuming those values are not the same if landuse has changed in the basin. Next water balances and annual average sediment yields were compared.

4. Results and Discussions

The changes in catchment response as manifested in a modified pattern of stream flow and sediment load could be attributed to climate variation (mainly rainfall) or landuse change. Often landuse changes are attributed to anthropogenic impacts, for instance, large scale deforestation, urbanization, and/or agricultural expansions. To understand catchment response behaviour, it is important first to quantify the changes occurred in hydrological fluxes of runoff and sediment load.

Trend analysis
The Mann-Kendall and Pettitt tests were applied to the annual rainfall pattern at nine stations in Upper Blue Nile. The results showed no change of annual rainfall for the last 36 years (1970-2005). This result well agrees with earlier studies in the basin (e.g., [8]. [12], [42] This is an important conclusion, implies that interannual rainfall pattern is not the major driver for the trend changes of runoff and sediment fluxes in the Upper Blue Nile.

The trend analysis of the seasonal and annual stream flows as computed by Man-Kendall and Pettitt tests are summarized in Fig.2(a-d). The Man-Kendall results were given at 5% significance level.

The results from Mann-Kendall tests show a significant increasing trend of stream flow during the wet season, short rainy season, and annual time period and a decreasing trend of stream flow during the dry season. These results were supported by Pettitt test, which shows a significant abrupt upward change of stream flow. Most of these changes occurred in the early 1990s (Fig. 2a, and 2b). A significant abrupt downward change of the dry season stream flow occurred in 1979 (Fig.2c). Figure 2d shows the increasing trend of annual stream flow from the basin. To further validate the findings, the trend of annual flows at three key locations of the basin (Bahirdar, kessi and Dedesa) were analyzed. The change point at Bahir Dar and Kesssie is consistent, in 1991-92, while for Dedessa occurred 6 years later, and no reason to reject it. These results of dry and wet seasons well agree with [42] but the results of short rainy season and annual flows do not agree. [42] reported that short rainy season and annual flows are constant for the analysis period of 1964-2003, whereas our study (from 1970 to 2009) showed an increasing trend in both cases. However, we obtained similar results to [42] for the same period of analysis (1964 to 2003). Hence, it is clear that the period of analysis is a crucial factor to determine the given trends. Most likely that the last six years (2004 to 2009) showed relatively higher discharges.

As the rainfall over the basin has remained constant, the increasing trend of runoff from the Upper Blue Nile could be attributed to landuse change within the basin. A decreasing trend of the dry season flow (base flow), and an increasing trend of wet season flow (peak flow), while no change of the rainfall suggests modifications of catchment response that led to an enhanced surface runoff from the Upper Blue Nile basin.

The increase of the sediment load by 61% during the past 30 years could be attributed to modified runoff process associated with large scale landuse change that boosted soil erosion in the basin. Direct runoff is the only flow responsible for soil erosion and sediment transport in the stream [39]. The annual flow showed a significant increasing trend (Table 1), as both wet and spring season flows increased more than that the base flow was reduced.

The trend of the sediment load at basin outlet was examined using the same statistical tests, and the results indicated an increasing trend of sediment transport between 1980 and 2009, see last row of Table 1. The Man-Kendall test shows that the sediment load was significantly increased at 5% significance level. Similarly, the Pettitt test revealed an increasing sediment transport from 91*106 in 1980-1992 to 147 *106 ton/year in 1993-2009. To further confirm the result, silt concentration in the 1970's and 2000's were also inspected and the comparison indicated that the concentration has increased significantly, implies increasing of sediment load.

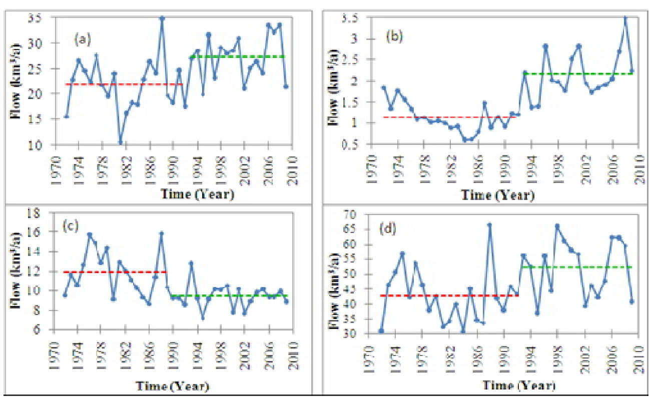


Figure 2: Pettitt homogeneity test of seasonal and annual flows: (a) wet season flow, (b) short rainy season flow, (c) dry season flow and (d) annual flow

SWAT Model results

The most sensitive parameters with their calibrated optimum values are presented in Table 3.

The 17 most sensitive parameters were used for model calibration of stream flow and sediment load also given in Table 2. Initial parameter estimates were taken from default lower and upper bound values of the SWAT's model database and from previous studies in the basin. Calibration parameters were derived for two periods, 1971 to 1973, and 2000 to 2002.

Parameters such as SCS curve number (CN2), Base flow alpha factor (ALPHA_BF), Soil evaporation compensation factor (ESCO), Threshold water depth in the shallow aquifer (GWQMN), Channel effective hydraulic conductivity (CH_K2), Ground water "revap" coefficient (GW_REVAP), surface runoff lag time (SURLAG), deep aquifer percolation fraction (RCHRG_DP), available water capacity (SOL_AWC), soil depth (SOL_Z), and Ground water delay (GW_DELAY) were the most sensitive parameter for flow predictions from the basin. Parameters including linear re-entrainment parameter for channel sediment routing (SPCON), USLE support practice (USLE_P), Channel effective hydraulic conductivity (CH_K2) were among the most sensitive parameters for sediment prediction only. SWAT uses those parameters to estimate the amount of flow and sediment yield from the catchment.

Figure 3 shows the calibration results of daily discharge hydrographs for two simulations periods. The model captured the daily runoff hydrographs both for low and high flows. The obtained models performances for calibration were E= 0.8, and R2= 0.89 for 1971-1973 and E=0.84 and R2=0.92 for 2000-2002 simulation periods. For the validation period E=0.78 and R2 =0.84 for 1974-1976 period, and E=0.82 and R2=0.88 for 2003-2005. The performance of both models found to be satisfactory and comparable to previous studies in the basin. For instance, [11] reported E=0.87 and R2=0.92 for calibration of daily flow, while [42] showed E=0.68 for daily calibration at El Diem station.

The last column of Table 1 gives the percentage change of best fitted model parameters for period 2000 to 2002 relative to 1971 to 1973, i.e., before and after landuse changes. As can be seen, higher percentage change was obtained for some of the parameters, which indicates significant changes of the catchment response behaviour he Surface runoff response parameters (e.g. CN2, ESCO and SOL_AWC) showed a higher change. An increase of CN2 value indicates that a higher amount of surface runoff was generated in the 2000s compared to the 1970s. The decrease of ESCO explains that more water was extracted from lower soils to meet evaporative demand, indicating a significant reduction of soil water. The available soil water capacity (SOL_AWC) was also significantly decreased for the past 35 years suggesting a shallower soil profile. Lower SOL_AWC implies the retention capacity of soil is reduced and as a result surface runoff generation is increased.

Table 1: SWAT sensitive model parameters and their (final) calibrated values for 1971 to 1973 and 2000 to

Parameter	Description	Best fitted values		
		1971-1973	2000-2002	Change (5%)
CN_2*	Curve number	-0.17	-0.03	14
ALPHA_BF**	Base flow alpha factor	0.21	0.15	-28.6
ESCO**	Soil evaporation compensation factor	0.72	0.43	-67.3
CH_K_2**	Channel Effective hydraulic conductivity	16.32	17.54	7.5
GWQMN***	Thresh hold water depth in shallow aquifer	1002.25	823.54	-21.8
GW_REVAP**	Ground water "revap" coefficient surface runoff lag time	0.12	0.17	41.7
SURLAG**	Deep aquifer percolation factor	6.35	4.68	--26.3
RCHRG_DP**	Available water capacity of soil	0.56	0.38	-32.1
SOL_AWC*	Maximum canopy storage	0.62	0.48	-22.6
CANMX**	Ground water delay	4.18	3.21	-23.2
GW_DELAY**	Linear re-entrainment parameter for channel sediment routing	78.16	72.96	-6.7
SPCON*	USLE support practice	0.01	0.01	0
USLE_P**	Exponentiation re-entrainment parameter for channel sediment routing	0.58	0.83	43.1
HRU_SLP**	Average slope steepness	0.08	0.08	0
SLSUBBSN*	Average slope length	-0.35	-0.27	8
SOL_Z*	Soil depth	0.22	0.21	1

Figure 3 shows the calibration results of daily discharge hydrographs for two simulations periods. The model captured the daily runoff hydrographs both for low and high flows. The obtained models performances for calibration were E= 0.8, and R2= 0.89 for 1971-1973 and E=0.84 and R2=0.92 for 2000-2002 simulation periods. For the validation period E=0.78 and R2 =0.84 for 1974-1976 period, and E=0.82 and R2=0.88 for 2003-2005. The performance of both models found to be satisfactory and comparable to previous studies in the basin. For instance, [11] reported E=0.87 and R2=0.92 for calibration of daily flow, while [42] showed E=0.68 for daily calibration at El Diem station.

The last column of Table 2 gives the percentage change of best fitted model parameters for period 2000 to 2002 relative to 1971 to 1973, i.e., before and after landuse changes. As can be seen, higher percentage change was obtained for some of the parameters, which indicates significant changes of the catchment response behaviour he Surface runoff response parameters (e.g. CN2, ESCO and SOL_AWC) showed a higher change. An increase of CN2 value indicates that a higher amount of surface runoff was generated in the 2000s compared to the 1970s. The decrease of ESCO explains that more water was extracted from lower soils to meet evaporative demand, indicating a significant reduction of soil water.

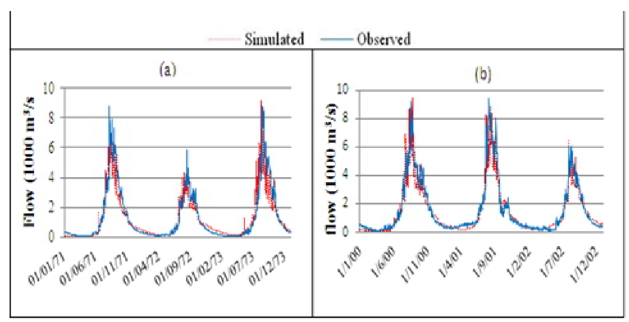


Figure 3: Calibration results of daily discharge values for the two periods: (a) 1971-1973, (b) 2000-2002

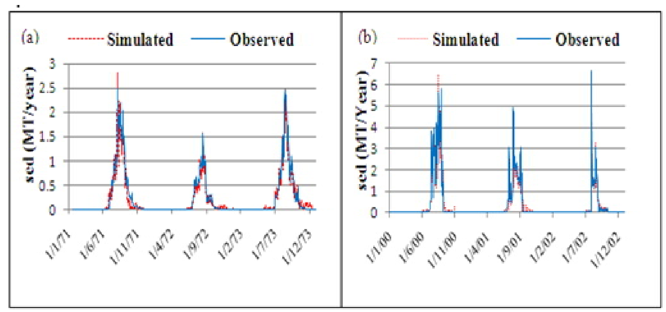


Figure 4: Calibration result of Upper Blue Nile daily sediment load at el Diem station for: (a) 1971-1973, (b) 2000-2002

The available soil water capacity (SOL_AWC) was also significantly decreased for the past 35 years suggesting a shallower soil profile. Lower SOL_AWC implies the retention capacity of soil is reduced and as a result surface runoff generation is increased.

Similarly, there was a clear change of subsurface response parameters (ALPHA_BF); Threshold water depth in the shallow aquifer (GWQMN), Ground water "revap" coefficient (GW_REVAP), deep aquifer percolation fraction (RCHRG_DP), Ground water delay (GW_DELAY) between the analysis periods. All changes indicated a faster response towards surface runoff generation. ALPHA_BF is a direct index of ground water flow response to ground water recharge, and its lower value implies a smaller contribution of base flow to the river discharge. The reduction of the GWQMN parameter means a decrease of the threshold value, implying faster surface flow response. The deep aquifer percolation coefficient (RCHRG_DP) that controls the movement of water to the lowest depth of the soil profile, showed a higher reduction. This indicates that less water percolates to the deep aquifer as compared to 1970s. Conversely, the Ground water "revap" coefficient that controls movement of water between the soil profile and shallow aquifer was increased. This may indicate that water from shallow aquifer moves back to the overlying dry material (unsaturated zone) during dry period. As water is evaporated from capillary fringes, it is substituted by water from underlying aquifer.

Similar to the flow simulation, the SWAT model was used to simulate the sediment load from the basin. The calibration results for the daily sediment yields at El Diem station are displayed in Figure 4. As can be seen from the Fig. 4a and 4b, the magnitude and temporal variation of simulated sediment yield closely matches observations. The performance of daily sediment load simulations results showed that E=0.76 and R2 =0.78 for the calibration period (1971 to 1973) and E=0.73 and R2=0.75 for the validation period (1974 to 1976).

Similarly, the performance of the second model shows acceptable model performance of E=0.78 and R2 =0.75 during calibration (2000 to 2002) and E=0.8 and R2=0.72 during validation (2003 to 2005). These results are comparable with model performances of recent studies by [5], [11], who obtained E=0.74 and E=0.88, respectively for sediment simulation using SWAT model.

Next, model results were checked using annual water and sediment balance. The validation period annual water balance components were presented as shown in Table 2. In which, ET=Evapotranspiration; Qsurf=Surface runoff; Qlat= Lateral flow; GWQ= Ground water flow; Water yield is the total water yield (Qsurf+QLat+GWQ-Transmission Losses); SW=soil water; PERC=percolation (ground water recharge).

The average annual water balance of the basin shows that the surface runoff (Qsurf) contribution to the total river discharge has increased by 75%, while the subsurface flow (Qlat) and ground water (GWQ) flow has decreased by 25% and 50%, respectively (Table 3). Even with negligible change of rainfall between the two periods (1.3%), the total water yield at the outlet has increased by 25%. This clearly depicts a modification of catchment response and thus a change of physical characteristics between 1970s and 2000s.

The simulations results of the three major components of the water balance (Rainfall, ET and water yield) resemble observed values of the basin at basin outlet, EI Deim. It seems that the model has unrealistically over-predicted the deep aquifer recharge PERC, 22% compared to total yield of 18.7%. SWAT considers PERC as a loss from the system, and doesn't contribute to the total yield from the basin [4], [34]. This may not be realistic and literature shows similar difficulties of estimating ground water flow and deep ground water recharge using SWAT model [39]. However, the uncertainty of the model on deep water recharge may have negligible effect in the conclusion of this study, assuming errors in both models can offset each other.

The annual average suspended sediment load from the basin were 4.46 t/ha and 6.8 t/ha during validation periods of 1974-1976 and 2003-2005, respectively. These results show that the total sediment yield from the basin has increased by 53% in the past 28 years. This could be due to high sediment production and soil erosion rates from the basin Therefore, the results of the SWAT simulations confirmed the earlier conclusions derived from the statistical tests, in that both runoff and sediment load from Upper Blue Nile basin has shown an increasing trend during the last 28 years. Moreover, the comparisons of the SWAT model parameters showed that the likely reasons for changes are attributed to increased surface runoff compared to ground water flow component.

The observed increasing trends of surface runoff and sediment load from Upper Blue Nile basin could be attributed to landuse change over large areas of the basin. Specifically, changes of natural vegetation cover into agricultural crop land.

Table 2: Annual water balance of the basin for 1974-1976 and 2003 -2005 validation periods

Simulation Period	units	Rain Fall	ET	Q_{surf}	Q_{lat}	GW_Q	Water yield	SW	PERC	TLosses
1974-1976	mm/year	1426	758	145	97	24	267	77	315	9
	% age	100	53	10.3	6.8	2.4	18.7	5.4	22.1	0.64
2003-2005	mm/year	1445	774	254	73	12	332	97	220	12
	% age	100	53.6	17.6	5.05	0.83	23.7	6.72	15.2	0.83

Therefore, the results of the SWAT simulations confirmed the earlier conclusions derived from the statistical tests, in that both runoff and sediment load from Upper Blue Nile basin has shown an increasing trend during the last 28 years. Moreover, the comparisons of the SWAT model parameters showed that the likely reasons for changes are attributed to increased surface runoff compared to ground water flow component.

The observed increasing trends of surface runoff and sediment load from Upper Blue Nile basin could be attributed to landuse change over large areas of the basin. Specifically, changes of natural vegetation cover into agricultural crop land.

5. Conclusions

The objectives of this study were to understand the long-term variations of hydrology and sediment fluxes of the Upper Blue Nile Basin using statistical models, and to verify the results using a physically-based hydrological model. The Man-Kendall and Pettitt tests showed that no change of annual rainfall over the Upper Blue basin between 1970s and 2000s. However, both tests showed a significant increasing trend of stream flow during the long wet season of from June to September and the short season from March to May, and a decreasing trend of dry season flow from October to February. The annual stream flow and sediment load from the basin were also increased significantly for the past 39 years (1971-2009). The Pettit test showed that most of these changes appeared in the early 1990s, and that a significant abrupt downward change of dry season stream flow occurred around 1979.

The SWAT daily model was used to predict runoff and sediment load at the basin outlet (El Deim station), which is at the Ethiopia-Sudan border. The null hypothesis was that optimal (calibrated) model parameters will remain unchanged. The modelling results showed that model parameters, specifically surface runoff and groundwater parameters, were significantly changed between 1970s and 2000s simulation periods. It is most probable that these changes are attributed to modification of catchment physical characteristics.

The results from the two methods of analysis based on statistical tests, and a physically based hydrological model, confirmed increasing trends of runoff and sediment load from the Upper Blue Nile. These increasing trends were attributed to change of natural land cover over large areas into agricultural crops, which modified runoff generation processes. These findings are very important for basin wide water resources management of the Blue Nile basin by providing insights on catchment behaviour, which is a big challenge for decision makers of both watershed management and downstream irrigation managers. Moreover, it can give a better understanding of embedded interdependencies between upstream and downstream areas.

Reference

1. Abbaspour, K., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., Zobrist, J., Srinivasan, R., 2007. Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT, J. Hydrol., 333,413-430.
2. Ahmed, S., 2010. Analysis of the impact of landuse change and Climate change on the flows in the Blue Nile River Using SWAT, Katholieke Universiteit Leuven, Belgium, Leuven.
3. Amsalu, A. L., Stroosnijder and de Graaf, J., 2007. Long-term dynamics in land resource use and the driving forces in the Beressa watershed, highlands of Ethiopia. Journal of Environmental Management 83 (4): 448-459.

4. Arnold,J., Srinivasan, R., Muttiah, R., Williams. J.,1998. Large area hydrologic modeling and assessment part i: model development1, JAWRA , 34, 73-89.
5. Betrie, G., Mohamed, Y., van Griensven, A., Srinivasan, R., Mynett, A.,2011. Sediment management modelling in Blue Nile Basin using SWAT model, Hydro. Earth Syst. Sci., 7, 5497-5524.
6. Bewket, W., 2004. Towards integrated watershed management in highland Ethiopia: the Chemoga watershed case study, Tropical resources management papers, 44, 2003.
7. Burn, D., Cunderlik, J., Pietroniro, A: Hydrological trends and variability in the Liard River basin, Hydrol. Sci. J., 49,53-68.
8. Conway, D., 2000. The climate and hydrology of the Upper Blue Nile River, Geog. J., 166, 49-62.
9. Conway, D., Hulme, M., 1993. Recent fluctuations in precipitation and runoff over the Nile sub-basins and their impact on main Nile discharge, Climatic Change, 25,127-151.
10. Conway,D., Mould, C., Bewket, W., 2004. Over one century of rainfall and temperature observations in Addis Ababa, Ethiopia, Int. J. Climatology, 24,77-91.
11. Easton, Z., Fuka, D., White, E., Collick, A., Asharge, B., McCartney, M., Awulachew, S., Ahmed A., Steenhuis, T., 2010. A multibasin SWAT model analysis of runoff and sedimentation in the Blue Nile, Ethiopia, Hydrol.Earth. Syst. Sci., 7, 3837-3878.
12. Elshamy M., Wheater, H., 2009. Performance assessment of a GCM land surface scheme using a fine-scale calibrated hydrological model: an evaluation of MOSES for the Nile Basin. Hydrol. Processes 23:1548-1564.
13. FAO, 1995. Digital Soil Map of the World and Derived Soil Properties, Food and Agriculture Organization of the United Nations , Rome, Italy.
14. Garzanti, E., And, S., Vezzoli, G., Ali Abdel Megid, A., El Kammar, A., 2006. Petrology of Nile River sands (Ethiopia and Sudan): sediment budgets and erosion patterns, Earth and Planetary Science Letters, 252,327-341.
15. Gassman, P.W., Reyes, M.R., Green,C.H., Arnold,J.G., 2007. The soil and water assessment tool: historical development, applications, and future research directions, American society of Agricultural and biological Engineers, 50, 1211-1250.
16. Gebrehiwot, S., Taye, A., Bishop, K., 2010. Forest Cover and Stream Flow in a Headwater of the Blue Nile: Complementing Observational Data Analysis with Community Perception, AMBIO: A J. Human Environment, 39, 284-294.
17. Global Land Cover Characterization (GLCC), 2010. http://edcsns17.cr.usgs.gov/glcc/glcc.html, last access: 12 December 2010.
18. Gordon, N., 2004. Stream hydrology: an introduction for ecologists, John Wiley & Sons Inc.
19. Green, W., Ampt, G., 1911. Studies on soil physics, the flow of air and water through soils, J. Agric. Sci., 4, 1-24.
20. Hargreaves, G., Hargreaves, G., and Riley, J., 1985. Agricultural benefits for Senegal River basin, J. Irrig. Drain. E-ASCE, 111, 113–124.
21. Herweg, K., Stillhardt., 1999. The variability of soil erosion in the highlands of Ethiopia and Eritrea, Research report, 42.
22. Huang, C.,Wylie, B., Yang, L., Homer, C., and Zylstra, G., 2002. Derivation of a Tassled Cap transformation based on Landsat and at-satellite reflectance, Int. J. Remote Sens., 23, 1741–1748.
23. Hurni, H., 1993a. Land degradation, famine, and land resource scenarios in Ethiopia:World siol erosiion and Conservation, edited by: Pimentel, D, Cambridge University Press, Cambridge, UK.
24. Hurni, H., 1993b. Land degradation, famine, and land resource scenarios in Ethiopia Cambridge University Press, Cambridge, UK.
25. Hurni, H., Tato, K., Zeleke, G., 2005. The implications of changes in population, landuse, and land management for surface runoff in the upper Nile Basin Area of Ethiopia, Mountain research and development, 25, 147-154.
26. Kebede, E.,2009. Hydrological responses to land cover changes in Gilgel Abbay catchment of Ethiopia, ITC, The Netherlands.
27. Kendall, M., 1975. Rank Correlation Methods, Charles Griffin, London.
28. Legesse, D., Vallet-Coulomb, C., Gasse, F., 2003. Hydrological response of a catchment to climate and landuse changes in Tropical Africa: Case study South Central Ethiopia. J. Hydrol., 275, 67-85.
29. Lu, X., 2005. Spatial variability and temporal change of water discharge and sediment flux in the Lower Jinsha tributary: impact of environmental changes, River Research and Applications, 21, 229-243.
30. Monteith, J. L., 1965. Evaporation and environment, Symp. Soc. Exp. Biol., 19 205–234.

31. Moriasi D., Arnold J., Van Liew M., Bingner R., Harmel R., Veith T., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. American society of Agricultural and biological Engineers, 50(3): 885−90.
32. Nash J, Sutcliffe, J., 1970. River flow forecasting through conceptual models part I--A discussion of principles. Journal of Hydrology 10: 282-290
33. NBCBN, 2005. Survey of litrature and data inventery in watershed erosion and sediment transport, Nile basin Capacity Buliding Network, Cairo.
34. Neitsch, S.L., Arnold, J.G., Kiniky, J.R., Williams, J.R., 2005. Soil and Water Assesement Tool Technical Docummemntation: Version 2005, United States Department of Agriculture, Agricultural Research Service.
35. Pettitt, A., 1979. A non-parametric approach to the change-point problem, Applied Statistics, 28, 126-135.
36. Priestley, C. and Taylor, R., 1972. On the assessment of surface heat flux and evaporation using large-scale parameters, Mon.Weather Rev., 100, 81–92.
37. Setegn, S., 2010. Modelling Hydrological and Hydrodynamic Processes in Lake Tana Basin, Ethiopia, Ph.D. thesis, TRITA-LWR, KTH., Sweden.
38. Setegn, S., Srinivasan, R., Dargahi, B., 2008. Hydrological modelling in the Lake Tana Basin, Ethiopia using SWAT model, The Open Hydrol. J., 2, 49-62.
39. Steenhuis, T.S., Collick, A.S., Easton, Z.M., Leggesse, E.S., Bayabil, H.K., White, E.D., Awulachew, S.B., Adgo E., Ahmed, A.A., 2009. Predicting discharge and sediment for the Abay (Blue Nile) with a simple model, Hydrol. Processes, 23, 3728-3737.
40. Sutcliffe, J., Parks, Y.,1999. The hydrology of the Nile, IHAS special publication no.5, Int. Hydrol. Sci. Wallingford, UK.
41. Tesemma, Z., 2009. Long term Hydrological trends in the Nile Basin, Integrated Watershed managemnt and hydrology, Cornell University, Bahirdar, Ethiopia.
42. Tesemma, Z.K., Mohamed, Y.A., Steenhuis, T.S., 2010. Trends in rainfall and runoff in the Blue Nile Basin: 1964–2003, Hydrol. Processes, DOI: 10.1002/hyp.7893.
43. Tibebe, D., Bewket, W., 2010. Surface runoff and soil erosion estimation using the SWAT model in the Keleta Watershed, Ethiopia. Land Degradation & Development, DOI: 10.1002/ldr.1034.
44. USDA, 1972. USDA Soil Conservation Service, National Engineering Handbook, Section 4.
45. Van Griensven A., Meixner, T., Grunwald, S., Bishop, T., Diluzio, M., Srinivasan, R., 2006. A global sensitivity analysis tool for the parameters of multi-variable catchment models, J. Hydrol. 324. 10-23.
46. Von Storch, H., 1995. Misuses of statistical analysis in climate research. In Analysis of Climate Variability: Applications of Statistical Techniques, eds. by H.V. Storch and A. Navarra, Springer–Verlag Berlin, 11–26
47. Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses: A guide to conservation planning, Agricultural Handbook No. 537, US Department of Agriculture, Washington, DC, 1-58.
48. Yue S., Pilon P., Phinney B., and Cavadias, G., 2002. The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrol Process, 16, 1807–1829.
49. Zeleke, G., Hurni, H., 2001. Implications of landuse and land cover dynamics for mountain resource degradation in the northwestern Ethiopian highlands, Mountain research and development, 21, 184-191.
50. Zhang, S., Lu, X.X., Higgitt, D.L., Chen, C.-T.A., Han, J., Sun, H., 2008. Recent changes of water discharge and sediment load in the Zhujiang (Pearl River) Basin, China. Globa and Planetary Change, 60, 365-380.