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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 16th cycle in the series. The organizing committee has received more than 250 papers in different thematic areas announced in call for papers. After review process, about 20 pares have been selected for oral presentation and 6 papers for poster presentation.
This proceeding contains the full contents of presented papers. I believe the research results presented in these papers can be useful references for the readers. On behalf of the organizing committee and myself I thank all contributors to this Symposium.

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

Welcome Address

Dr. Damtew Darza, President of Arba Minch University

H.E Ato Abiti Getanhe, Research Director of Ministry of Water Resources, Irrigation and Electricity
HE Mr. Jemes Dengchol Tot, State Minster, Ministry of Water, Irrigation and Electricity
H.E. Dr. Kebede Kanchula, General Director of Rift Valley Basin Lakes Basin Authority

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

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

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

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

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

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

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

Thank you!

Opening speech

HE Mr. Jemes Dengchol Tot, State Minster, Ministry of Water, Irrigation and Electricity

Dear Symposium Participants,

Ladies and Gentlemen,

First and foremost, it is my privilege and pleasure to address the opening of this important symposium which is organized for more than one and half decade.
The importance of water can never be stressed enough. As we all know, water is indispensable for life on Earth, for human survival, and for ecosystems which provide fundamental life-support services. However, water is also a source of tremendous risk and vulnerability, both through its potential for catastrophe through drought, flood, landslide, and epidemic, as well as more gradual and harmful through erosion, inundation, desertification, contamination, and disease. Because of its enormous power for both good and ill, water must be responsibly managed, to fully capture the opportunities while limiting the risks.

Ladies and Gentlemen,

In the current world the opportunities created by water can have significant national and global impact. Responsible and sustainable investment in water resources embraces great promise for increased productivity, more abundant food, cleaner energy, and more efficient trade and transport. Improvements in water management offer great potential to leverage economic growth and human well-being and to bind countries together in mutually beneficial cooperation. According to World Water Commission *"Every human being, now and in the future, should have enough clean water, appropriate sanitation and enough food and energy at reasonable cost providing adequate water to meet these basic need must be done in a manner that works in harmony with nature."* This underpins the importance of sustainable development of water resources. Although Ethiopia has considerable physical water resources potential, providing basic water security to the growing population and development needs has been a challenge. Lack of technical expertise, technology, institutions and finance are among the country's bottlenecks hindering the development of water resources.
Many authors agree that, if the potential of water as a driver of sustainable, responsible growth is to be successfully harnessed, two things are indispensable: sound infrastructure and sound institutions. The latter includes adequate management capacity and a commitment to good governance. Investment in booth infrastructure and institutions in all water-related sectors such as water resources management, water supply and sanitation, irrigation and drainage, hydropower, and environmental conservation is critical.
As evidenced by several completed and ongoing mega water resources projects as well as ongoing studies and design of new projects, our country is aggressively investing in development of water resources infrastructure. To realize its vision of reaching economic development levels of middle income countries by 2025, our country will uncompromisingly develop and use its resources on sustainable basis. This is why the country's economic development is governed by "climate resilient green economy" strategy which gained also global attention.

Ladies and Gentlemen,

It is important to note that with growing population and economies more water will be required in all sectors which sometimes have conflicting interests. The concern of water quality will also grow. The emerging climate change will also pose pressure on water demand and availability. Progressing degradation of watersheds due to deforestation, over-cultivation, overgrazing and unwise land use practices are the major area of concern. As a consequence, water resources development infrastructures which are created with huge investment are increasingly affected by soil erosion, sedimentation and flooding. Managing water requires managing land. This in turn requires capable and capacitated institutions. This is why integrated management is widely advocated in water resources management policy and strategy of the country.

In relation to other sectors, water resources, development, management, and capacity building institutions have short history in Ethiopia. To cope up with emerging challenges such as development needs, climate change resulting droughts and floods, use and management of trans boundary Rivers, there is a need to develop and strengthen water institutions at all level including those who are working in the capacity building as well.

Ladies and Gentlemen,

Handling this complex water resources management and utilization, policy and decision-maker rely on scientific community. The voice of the scientific community is critically important in providing scientific evidence to assist decision and policy process. We have a collective responsibility as policy-makers and you as scientists, to hold hands and assist one another in our effort to realize the development needs of this country. We need to understand that we are jointly responsible to ensure that the people of this country depend on us to get practical solution for problems facing the nation.

I am informed that **AMU** is organizing the symposium of this kind for almost two decades. I appreciate the University for such Uninterrupted Dedication to host this important annual gathering. I am also informed that the symposium covers a wide range of very interesting themes related to sustainable water resources development and professionals from different sectors. As you continue with your deliberations over the next two days, I encourage you to jointly develop ways to communicate your scientific findings and technologies to inform appropriate policy and development strategies useful for our country.

I hope this will give you a good opportunity to build collaboration and partnership with your peers and I advice all of you participants to make use of the knowledge acquired to provide support to stakeholders (governments, development partners, civil society, communities) on what investments are required to safeguard growth against growing water-related risks.

Finally, I wish you fruitful deliberations during the next two days workshop and I declare that the symposium is officially opened.

Thank you for your attention!

THEME ONE

HYDROLOGY AND INTEGRATED WATER RESOURCES MANAGEMENT

Smallholder Farmer's Willingness to Pay for Improved soil and Water conservation practice : A Contingent Valuation Study in ABARO - TOGA WATERSHED Ethiopia

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Abstract

This paper estimates the mean willingness to pay (WTP) of smallholder farmers for improved soil and water conservation (SWC) practices using a contingent valuation method(CVM) with a Double Bounded Dichotomous Choice technique followed by open-ended questions were applied. Seemingly unrelated bivariate probit and probit models were applied to determine the mean and factors affecting WTP for SWC practice, respectively. Data were collected from 150 randomly selected smallholder farm households through a structured questionnaire and focus group discussions using face-to-face interviews. The study findings have shown that the majority of the sample households has been affected by soil erosion problems, mainly because of deforestation, high intensity of rainfall, the slope of the land and the watershed shares common catchment with Abro Mountain that runs a long distance. Furthermore, the econometric result shows that the mean and total WTP from double bound elicitation method was computed 36.08 birr/year and 1336873 Birr/year (1 US$=20.8 birr) for five years respectively, while the mean and total WTP from open ended elicitation method was computed at 26.39 birr /year and 974,097.08 birr per year. The mean annual WTP for SWC from double bound elicitation method was greater than from open ended elicitation method. Hence, policy makers should target double bounded elicitation method than open ended elicitation method to eliciting the WTP for SWC activity. This study empirically proved that households' age, household size, education, income, total livestock unit, slop of land, perception and initial bids, are the key determinants of SWC activities.

Key Word: Contingent Valuation Method; Willingness to Pay; soil and water conservation, Double Bounded; Dichotomous Choice,

Introduction

The economic development of Ethiopia is highly dependent on the performance of its agricultural sector. Agriculture contributes 53% of the country's Gross Domestic Product (GDP), 85% of all exports (coffee, livestock and livestock product and oil seeds) and provides employment for 85% of the population (FAO, 2007). Agriculture provides raw material for 70% of industries in the country (MOFED, 2006). In spite of its remarkable potential, the performance of Ethiopian agriculture has been sluggish in the last decades. However the population grows at an average rate of 2.52% per annum (World Bank, 2004; FAO 2007). That means, food of industries in the country (MOFED, 2006). In spite of its remarkable potential, the performance of Ethiopian agriculture has been sluggish in the last decades. However the population grows at an average rate of 2.52% per annum (World Bank, 2004; FAO 2007). That means, food production lagged far behind population growth leading to food shortage and thereby resulted in national poverty of 44.2% of the population (FAO, 2007). The dominant economic activity is undertaken by smallholder farm household which are subsistent oriented. Low agricultural productivity due to land degradation mainly accelerated soil erosion is a critical problem throughout Africa (FAO, 2002).

Several studies in Ethiopia have revealed that soil erosion has become an alarming problem (Wagayehu and Drake (2003); Admasu (2005); Bewket and Teferi (2009); Haile and Fetene (2012); Wolka et al, 2015) and it is the major factor affecting the sustainability of agricultural production. The loss of soil and essential nutrients due to unsustainable agricultural practices is costing $139 million or 3-4% of its agricultural GDP (Berry, 2009). Similarly, Hurni (1993) estimated, soil loss due to water erosion is about 1493 million Mg per annum. On croplands, average soil loss rates reach 42 t/ha/year or 4 mm of soil depth per annum in the country as a whole. In individual fields however, the rate may reach up to 300 t/ha/year, which is by all measures exceeds the rate of soil formation.

Although estimates of the extent and rate of soil erosion lack consistency, the results of various studies highlight the severity of the problem (Amsalu & De Graaff, 2007). However, policy makers largely neglected land conservation until 1970s (Shiferaw & Holden, 1999), and the problem attracted policy attention only after the devastating famine problem in 1973/1974 (Shiferaw & Holden, 1998). Since then, several SWC and land reclamation projects were initiated with the support of donor agencies and efforts have been put in place in order to rehabilitate degraded areas. For these purpose various SWC measures were introduced (Dejene, 2003; Amsalu, 2006). The SWC works include planting trees on hillsides and catchments areas, water harvesting in drier areas, stream development, construction of earth dams, pond, gully plugging, traces, diversion of drains, and check dam (Asrat et al., 2004).

According to Wegayehu (2003), among the various forms of land degradation, soil erosion is the most important and an ominous threat to the food security and development prospects of Ethiopia and many other developing countries. In the study area Abaro Toga watershed is faced by intensive soil erosion problem because, it shares a common catchment with Abro Mountain that runs a long distance. Due to such distant setting flow of water it exhibits high runoff velocity that results in damaging fertile top soil resources. As perceived by local people year to year the productivity of crop production is decline. Hence, to grapple with the problem of soil erosion massive reforestation and soil and water conservation practices were launched since the 1970 and 1980s by mobilizing farmers in the country as well as in the study area (Bewket, 2007; kebede, 2014).

However, reports indicate that these conservation structures have not been as successful as they could be, because the farmers were not enthusiastic enough in accepting widely and maintaining the soil and water conservation practices (Fisum, et al, 2002; Betru, 2002; Yeraswork, 2000). Belay (1992) the failure of conservation practices partly emerge from the fact that planners and implementing agencies ignore or fail to consider socio-cultural factors as key determinants of the success or failure of conservation programs. Thus, the main objective of this study is of farmers' willingness to pay (participate) and in soil and determinant factors affecting soil and water conservation practices so as to solve existing problem in the area using CVM.

Methodological Approach

Description of the Study Area

Abaro Toga watershed is located at Shashemene district, West Arsi Zone, Oromia Regional State, Ethiopia. This watershed is situated at 259 km from capital city of Ethiopia to the south direction of Shashemene town. The watershed is bordered by Kofele district from the east, by Wondo district from the south direction, by Shashemene town from the north and by Bulchana Danaba peasant association from the west direction. According to woreda agricultural office the total land area of the watershed is 7,126 km^2. The watershed comprise of six peasant association kebele such as Abaro, Ebicha, Idola Burka, Alache Harabate, Waransa and Toga.

Sample Size and Data Collection Methods

A two-stage simple technique was used when selecting respondents. In the first stage four kebeles (Abaro, Ebicha, Woransa and Toga) were purposively selected out of the six kebeles. Abaro and Ebicha were upper catchment highland area where soil erosion begins whereas, woransa and toga from lower catchment which is perceived by intensive soil erosion problem. These numbers of kebeles were considered to be sufficiently large for drawing valid statistical inferences and were also manageable to be surveyed with the available resources of finance and time. In the second stage, total of 156 households were selected using random sampling techniques. Both secondary and primary data were used for this study. The primary data were collected from sample respondents through a structured questionnaire via face to face interview with the heads or working members of households. CVM method in the form of double-bounded dichotomous choice elicitation method with open ended follow up question was also employed to elicit households' WTP for soil and water conservation practice. The double-bounded dichotomous choice format (yes-no, no-yes responses) makes clear bounds on unobservable true WTP. Besides, the yes-yes, no-no response sharpens the true WTP (Haab and McConnell 2002). Finally, the double-bounded dichotomous choice format help to elicited more information about respondent's WTP than single bounded format (Hanemann *et al.* 1991; Arrow *et al*. 1993).

Preliminary Survey and Bids

Before the final survey was conducted a pre-test was done using 45 randomly selected households. Then based on the pilot results the starting point prices identified for WTP in birr were 40, 68 and 120 birr per year. Therefore, the total sampled households were divided randomly into three equal groups (about 52 households). The field survey was successfully completed with relatively small number of protest zeros (about 3.2%). These protesters provided wrong value and after checked for sample selection bias they excluded from the data set. The criteria for selecting protest zero was based on the report of the NOAA Panel on contingent valuation by Arrow *et al*. (1993). Arrow *et al*. (1993) suggested that a respondent actually willing to pay the stated amount might answer in the negative, if the respondent believes the proposed scenarios distributed the burden unfairly, doubt on the feasibility of the proposed action and refusal to accept the hypothetical choice problem.

Analytical Methods

The qualitative and quantitative data obtained through data collected were analyzed using descriptive statistics and Econometric model. Descriptive statistics such as mean, standard deviation and percentage were used along with the econometric model to analyze the collected data. In this study we used the probit and bivariate probit models. The probit model is used to identify factors affecting the WTP of households for soil and water conservation practice.

$$Y_i = X_i\beta + \varepsilon_i \qquad \text{.......... 1}$$

The model takes the following form (Cameron and Quiggin , 1994).

$I=1$ if $y_i \geq t_i$ $I=0$ if $y_i \leq t_i$ 1

where : Let $y_i = i^{th}$ respondents true unobserved point valuation for the environmental resource in question.

β = a coefficient for X

t_i = the offered threshold, assigned arbitrarily to the ith respondent

I = discrete response of a respondent for the WTP question (1=yes, 0= no)

ε_i= unobservable random component distributed $N(0, \sigma)$

X_i = observable attributes of the respondent

The probit model is applicable to CV studies with one dichotomous-choice question but by introducing a follow-up dichotomous-choice question, the statistical efficiency improves by the application of a bivariate probit model (Carson et al. 1986). For estimation of WTP, the Bivarate Probit Model is used i.e double bound Dichotomous choice model takes the following form (Haab and McConnell, 2002).

The j^{th} contribution to the Likelihood function is given as

$$L\ (m/t) = Pr(m + e \geq t\ ,\ m + e < t)\ * Pr(m + e > t\ ,\ m + e \geq t)\ YY*$$

$$Pr(m + e < t\ ,\ m + e < t)\ * Pr(m + e < t\ ,\ m + e \geq t)NY \text{ ....2}$$

This formulation is referred to as the bivariate discrete choice model

Where m = mean value for willingness to pay

YY = 1 for a yes-yes answer, 0 otherwise, NY =1 for a no-yes answer, 0 otherwise, etc.

And the j^{th} contribution to the bivariate probit Likelihood function becomes.

$$L\ (jm\ /\ t) = F\ 1\ (d\ \ ((t - m\ )/s\ ),\ d\ \ ((t - m\ )/s\ ),\ d\ \ d\ \ r). \text{ ....3}$$

Where

F 1e e2 = Standardized bivariate normal distribution function with zero means

Y 1j=1 if the response to the first question is yes, and 0 otherwise

Y 2j=1 if the response to the second question is yes, 0 otherwise

d1j = 2y 1j-1, and d 2j= 2y 2j-1

r = correlation coefficient

s = standard deviation of the errors

This general model is estimated using the standard bivarate probit algorithms. Finally, the mean willingness to pay (MWTP) from bivariate probit model were calculated using the formula specified by Haab and Mconnell, (2002).

$$\boldsymbol{MWTP}(\mu) = -\frac{\alpha}{\beta} \text{ ....4}$$

Where ß = coefficient offered bids to the respondent

But, before the probit model (Equation 1) was applied to analysis the effect of explanatory variables on WTP, variance inflation factor (VIF) was applied to test the collinearity between continuous explanatory variables. It was computed as:

$$VIF(Xi) = \frac{1}{1-Ri^2}; \quad \ldots\ldots 5$$

Where R^2 is the coefficient of determination in the regression of one explanatory variable (X) on the other explanatory variables (Xj). If there is no collinearity between repressors, the value VIF is 1. A VIF value of a variable exceeds 10, which happened when R2i exceeds 0.90, and that variable is said to be highly collinear (Gujarati, 2004). Contingency coefficients also estimated to see the degree of association between the dummy explanatory variables. A value of 0.75 or more indicates a stronger relationship between the two variables (Healy, 1984). The contingency coefficients (C) were computed as:

$$CC = \sqrt{\frac{x^2}{N + x^2}} \quad \ldots\ldots 6$$

Where CC= coefficient of contingency, X^2= Chi-square test and N= total sample size. The pseudo-R square and the chi-square were used to measure the goodness of fit of the model and the significance of the model used.

Analysis of Survey Results And Discussion

Descriptive Statistics (Households Characteristics)

Sex The majority of the respondents 124 (82.7 %) were male . Since males have decision making power in the family, the proportion of male was slightly higher. The share of male in the willing respondents is higher 64.5% than the share of female 35.48 % from the non-willing respondents. The reason may be males have decision-making power, more educated, more aware and involvement in environmental activity like SWC practice than female. In addition to this , SWC activities were more labor intensive which are difficult to be performed by female, except material transportation that used for construction of soil and water conservation structures. This finding is analogous with PRESA/ICRAF (2011) study in Nairobi city, Kenya, Hassen, 2014, The chi-square statistics test revealed that there is significant association between sex and WTP decisions for SWC practice (P≤ 0.01). The marital status figure reveals that 96 (76.6 %) of the respondents were married. Share of willing to pay of married respondents 63.4% was higher. The proportion of willing and non-willing respondents did vary significantly with marital status. The access of credit figure reveals that 52.66 % of the respondents were access to credit. Share of credit user in the willing respondents is higher 64.66 % than the non-willing. The proportion of willing and non-willing respondents did not vary significantly with credit user respondents.

Table 1: Descriptive statistics of some socio-economic characteristics for willing and non-willing to pay respondents .

Variables	**Willing (N=97)**	**Non willing (N=53)**	**Total (N=150)**	X^2
sex	80	44	124	1.00
	17	9	26	
Marital status	27	11	38	0.433
	70	42	112	
Credit access	54	25	79	0.393
	43	28	71	

Note: Variables in which willing respondents have significant differences from non-

Age: The data on age revealed a wide range of responses starting from 22 to 84 years where the average was found to be 43 years. The mean age of non-willing respondents is higher than mean age of willing respondents, but it is not statistically significant.

Education: The education figures reveal that about 57.3 % were found literates/ have attended formal education. With the consideration of all respondents, average years of schooling is estimated at apparently 6 years, to range from a minimum of 0 years of schooling to a maximum of 15 (12+3) years of schooling. The estimated average years of education of the willing respondents is higher than the non-willing respondents and estimated to 7 years of education and 4 years of education/schooling respectively. The respective independent t-test result showed that, the difference in mean years of education between the willing respondents and the non-willing ones is statistically significant at $p<0.01$ (Table 2). This might be because as years of education increases respondents will become more concerned of environmental degradation and aware of the benefits of SWC practice. In addition, more educational attainment has a positive impact on ability to pay which in turn increases their probability of willing to pay.

Income : The surveyed households on the average earn was Birr 28886 annually income. The main sources of income are crop production, livestock selling, laboring and off farm activities. The income level ranges from a minimum of Birr 11050 to a maximum of Birr 41000 per year. Taking the average family size of 11, the average per capita income was Birr 2626 per year. Willing households earn Birr 29792.78 mean income per year which is significantly higher ($p<0.01$) than Birr 27227.55 mean yearly income of the non-willing households. This shows that as annually income of the household increases their probability of willingness to pay also increases. This might because higher income earners are more flexible to invest for a good/service which secures them a higher level of utility.

livestock unit : The average livestock number of sampled respondent was 4 with a minimum of 1 livestock and a maximum of 9. In Ethiopia, livestock are important source of cash income, food, household energy and manure. hence the chi-square statics reveled that there is significant association between number willing and non willing respondents. Households with higher total live stock unit are more willing to pay and prefer to have improved availability of soil and water conservation practice.

Household size : The average household size of sampled respondents was 11 with a minimum of 1 household member and a maximum of 38 household members. The average family size was is higher but closer to the rural average of 10.9 persons per household of CSA, 2010 report of population statistics. The average household size was about 11.28 and 10.19 for willing and non-willing households, respectively. The mean difference is significantly varied between households in the two groups.

Distance to the farm area and land size : Table 2 shows summary of distance from home and land of the sampled households. Data with regard to distance showed that the households' farm is located from very near (0 m) to 2750 m with an average of 398.9 m away from the home. Distance is also an important factor of access. Soils and water can be managed more easily when farmland is located at close proximity to the household. However, the chi- square taste indicates

that there is no significant association between mean distance to the farm area of willing and non willing respondents. The total size of the total land holdings of the sampled households was also estimated at 1.98 ha. That is, the land holdings of the households' ranges from 0.5 ha to 6 ha with average cultivated farm size per household of 1.98 ha.

Table 2 : Descriptive statistics of some socio-economic characteristics for total willing and non-willing to pay respondents (Mean, Std. Dev, and t-value)

Variables	WTP	Min	Mean	Max	Std. Dev.	μ diff	t-
Age	WTP	22	42.13	82	14.6	2.29	.864
	NWTP	22	44.43	84	17.13		
Total		22	42.95	84	15.56		
Income	WTP	17000	29793	41000	6178	-2565	-2.13
	NWTP	11050	27228	41000	8412		
Total		11050	28886	41000	7128		
livestock	WTP	2	4.18	9	1.27	.126	.532
	NWTP	1	4.30	9	1.58		
Total		1	4.22	9	1.39		
HH size	WTP	2	11.28	9	8.43	-1.08	-.842
	NWTP	4	10.19	38	5.66		
Total		9	10.89	38	7.57		
Distance to farm area	WTP	0	370.46	2750	518.3	80.4	.897
	NWTP	0	450.9	2500	5378		
Total		0	398.9	2750	524.9		
Land Size	WTP	1	2.06	6	1.36	-0.22	-1.01
	NWTP	0.5	1.83	6	1.15		
Total		1	1.98	6	1.292		
Education	WTP	0	7.422	15.00	4.53	-2.66	-3.49
	NWTP	0	4.641	10	4.14		
Total		0	6.48	15	4.63		

Note:

- Variables in which willing respondents have significant differences from non-willing respondents: *** = at 0.01 level of significance
- mean diff = mean (non wiling)-mean (willing), H0: mean diff=0 and HA: mean diff > < = 0

Specifically, about 69.3 % of the surveyed household controlled less than 0.5 ha of farm land. About 30.7% of the sampled respondents owned a farm size from 1.98 ha to 6 ha. The

independent t-test square statics revealed that there is significant association between willing and non willing respondents. This indicates that households with higher land often rich and have access to more resources, and they are more willing to pay than households with small land size. This indicated that the average farm size of the study area is similar than the national average of ≤ 1ha (FDRE, 2010). In addition the physical soil and water conservation structures occupy much land surfaces in fragmented and small plots which cause reduction of production and productivity of the cultivable land that could not be compensated by the benefits of conservation (Wagayehu and Drake, 2003; Chilot, 2007). The survey result indicated that area of land had significant influence on the use of improved physical SWC practices.

Farmers' Awareness about the Causes and Indicators of Soil Erosion Problems

To corroborate the presence of soil erosion in the study area sampled households were asked the indicator of soil erosion problem on their own farm plots, 75.3% of farmers reported that the presence of gullies and rills as a major indicator on their cultivated plot and communal grazing land. The rest, 17.3% and 7.4%, of farmers also reported that the decline of agricultural productivity of their farm plots and the change of soil color were the indicators of soil erosion, respectively. This observation of the farmers is most closely associated with the scientific finding of most researchers.

According to the survey result, soil erosion was severe on farm plots and communal grazing lands at rainy or summer season. This shows that the major causes of soil erosion in the study area is water erosion. Hence, this is a call for community awareness about the problem and causes of soil erosion as well as its consequences will help to motivate farmers to use soil conservation practices.

Major Soil Conservation Practice Implemented by Farmers in the Study Area

According to the finding of the survey, most of household farmers agreed that soil and water conservation practices are important to minimize the rate of soil erosion on farm plots and communal lands. This indicates that households had good perception and participation towards the importance of soil and water conservation methods on farm plots and communal lands. All sampled farmers stated that they use both traditional and introduced soil and water conservation methods on their own farm plots to prevent soil erosion and enhance soil fertility.

According to the survey results there are various soil and water conservation practices applied by farmers on their own farm plots and communal lands erosion control methods used in the study area include, plantation of trees (especially *kulkual*), contour plowing, check dams, soil and stone bunds, diversion ditches (cut of drain) locally called *"feses*", crop rotation and terracing, application of manure. Terracing, soil and stand protection, Tree planting are the three top practices appreciated by the respondents, on the other hand, the check dam, intercropping and diversion of ditches are also less appreciated SWC methods (fig 1).

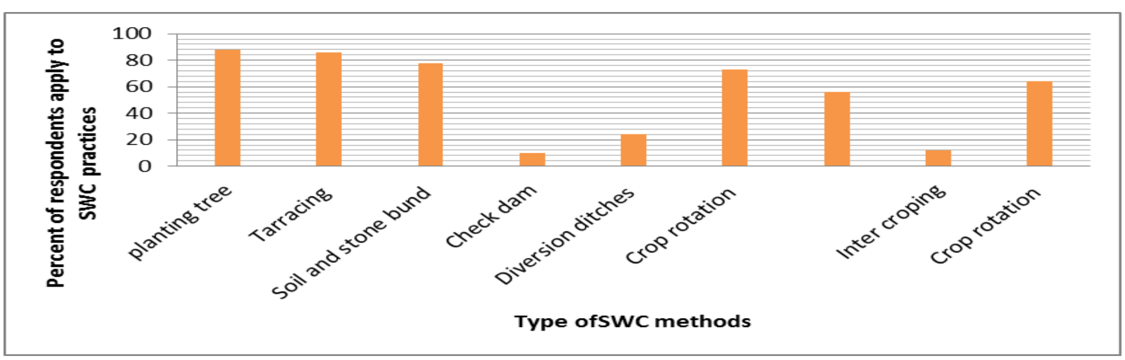

Figure 1. Farmers' response regard to the major soil conservation methods they implemented

Households WTP for SWC Practices

Using double bounded dichotomous choice format the mean WTP from responses of both the first and the second bids were estimated. The analysis was conducted using seemingly unrelated bivariate probit model. The result revealed that the correlation coefficient of the error term is less than one implying that the random component of WTP for the first question is not perfect correlation with the random component from the follow-up question.

Table 3 : Parameter estimates of bivariate probit model

Variable	Coeff	Std. Err	z
Initial bid	-0.0326	0.00612	- 6.61
Constant	1.2001	0.18267	2.80
Second bid	-0.0105	0.00482	- 6.77
Constant	0.4122	0.24078	4.57
/athrho	0.20745	0.21222	0.98
Rho	0.20453	0.20334	
Prob > chi2 = 0.0000	Wald chi2(2) = 77.17	Log likelihood =92.6309	
Likelihood-ratio test of rho=0:	chi2(1) = .959754	Prob > chi2 = 0.3272	

The annual mean WTP (equation 4) was computed at 38.03 birr per year per household for five years. At 95% confidence interval the WTP for SWC practice between 36.81 to 39.25 birr per year per households for five years (See Table 3). The mean WTP of the respondents from open ended elicitation method also computed at 26.39 birr per household per year for five years with the minimum 0 and maximum 120 birr. The result shows that the mean WTP from open ended response was less than the mean WTP from the double bound format. This may indicate the respondents' wants or free service from the government or free riding in the open ended questions. This result is consistent with the findings of Jonse, (2005), Bamlaku et al (2015), Alem et al (2013). The willing respondents were also asked to point out their reasons for maximum WTP in birr. The respondents provided different reason for their maximum WTP. About 42.26 % of the respondents reported that they could not afford more than what they stated because of inadequate income. While, the rest 57.73 % reported that the amount they decided to pay was satisfactory (See Table 4).

Table 4: Reason for their maximum WTP in birr

Reason	Frequency	%
Inadequate income to provided more	41	42.26
It is adequate	56	57.73
Total	97	100

However, about 59 (37.8 %) of the sample respondents' were not willing to pay for SWC practice. Specifically, of the 37.8 % unwilling sampled respondents about 8.471 % of the households were categorized as genuine zero bidders. Whereas, about 91.52 % of the respondents stated protest zero1 (See Table 5).

Table 5: Reason for not Willing to Pay

Respondents reasons for zero bid	Frequency	%
We do not believe that the money we pay will actually be used for the proposed change	16	27.11
We believed that the proposed project is unnecessary	38	64.40
Total protest answers	54	91.52
Lack of money	5	8.471
Total non-protest answers	59	100

Determinants of Households' WTP for soil and water conservation practice

Before running the econometric model, the independent variables were tested for the presence of multicollinearity (table 6). The result showed that there were no multicollinearity problems between the variables. The value for Contingency Coefficient(CC) for the dummy variables.The criteria for selecting pr test zero was based on the discussion on NOAA panel guide on Arrow *et al* (1993)

$$VIF = \frac{1}{1 + R_i^2} \quad \text{.......7}$$

Where, Ri 2 is the coefficient of determination in the regression of one explanatory variable (X) on the other explanatory variables (Xj).

were less than 0.75 and the value of Variance Inflation Factor (VIF) for the continuous variables were less than 10; which are obviously the indicators for the absence of multicollinearity.

Table 6:Contingency coefficient and Variance inflating factor of variables used in regression.

The chi-square (χ2) distribution is used as the measure of overall significance of a model in probit mod-

Contingency coefficients for dummy explanatory variables

	sex	Marital status	credit	Land use	fertility	slop	Perception
Sex	1.000						
Marital status	0.421	1.000					
credit	0.059	-0.245	1.000				
Land use type	0.331	0.2327	0.109	1.0000			
fertility	0.113	-0.0761	0.561	0.1372	1.0000		
slop	-0.113	0.1086	0.027	-0.0753	0.2148	1.00	
Perception	0.0481	0.1346	0.072	0.3185	0.1445	0.00	1.0000

Variance Inflating Factor for Continues variable

Variables	Age	Income	Education	HHsize	Livestock unit	Farm size	Distance	Bid
VIF	1.37	1.51	1.55	1.31	1.60	2.49	3.44	3.2

el estimation. The result of the probit model shows that, the probability of the chi-square distributions was 45.678 with 15 degree of freedom less than the tabulated counter factual is 0.0000, which is less than 1%. So, this shows that, the variables included explaining willingness to pay fits the probit model at less than 1% probability level. The estimated result on factors affecting the households' WTP for SWC practice is presented in Table 7 and it shows both the significant and insignificant variables. However, only the significant variables are discussed.

Age of the household head (AGE): Age of the household head had negative and significant effect on households WTP at less than 1% level of significant. This may be older age may shorten planning time horizon and reduce the WTP. On the other hand, young farmers may have a longer planning horizon and, hence, may be more likely to be willing for conservation. Besides, an older aged household heads are more likely to have a money shortage and reduce willingness to pay for SWC practices. Keeping the influence of other factors constant, an increase in household head age by one year the probability of accepting the first bid decreased by 1.41%. The negative relationship between WTP and age is inconsistent with the finding of Mallios and Latinopoulos (2005), Bamlaku *et al* 2015, Tegegne (1999), Alem *et al*, 2013, Solomon (2004).

Table 7:

WTP	Coef.	Std.error	Z	P/z/	Dy/dx
Age	-0.703	0.598	-1.67	0.002	-.014146
HH_hsize	-0.33	0.586	-0.43	0.005	-.0573104
Educ.	3.288	1.670	3.12	0.597	.0319589
Marital st.*	0.384	0.637	0.79	0.215	.1024763
Income	0.000	0.000	2.34	0.008	.0193
Sex*	3.463	1.447	0.43	0.597	.0573104
Farm size	-1.063	1.330	0.28	0.418	-.00493
Distance	-1.865	0.631	-0.95	0.103	-.0000839
Fertility*	-0.017	0.048	-0.06	0.724	-.0091789
Slop*	2.651	0.631	3.13	0.003	.3793325
Land use type*	2.298	0.651	0.07	0.647	.0094057
Credit*	1.30	0.644	1.21	0.021	.0697178
Livestock	1.145	0.177	1.65	0.041	.0102943
Percep*	1.069	0.039	0.12	0.009	.0129797
BID	-0.986	0.289	-1.36	0.001	.01839
constant	0.063	1.512	0.677	0.583	

No. of observation= 150, -2 Log likelihood=-84.03, prob >chi=0.03, R Square= 0.137,LR chi2 (15)=26.78; (*) dy/dx is for discrete change of dummy variable from 0 to 1

Family size of the household (FSIZE): The total family size of households, is negative and significant at 1% level of significant. The estimated marginal effect showed that all other factors kept constant, as the family size increase by one, the probability of accepting the first bid is decreased by 5.73 %. This result is consistent with the findings of Bamlaku et al., 2015 and Alem et al., 2013. In contrary with these finding of (Gebrelibanos*, 2012).*

Education level: The education level of the respondents is positively and insignificantly related to WTP. That is, respondents with more years of schooling are WTP for SWC practice. This might be due to the fact that educated household heads perceive and are willing to pay more than less educated households. The result also revealed that holding other things constant, a unit increase in years of schooling of the respondent increases the probability of accepting the first bid by about 31.95 %.This clearly calls the importance of human capital development for implementation of soil conservation practices. This is consistent with the findings of Tiwari (1998), Whittington et al. (1990), Genanew (1999), Tegegne (1999), Tsegabrihan (1999) and Jonse (2005) Tesfaye *et al,* 2013, Bamlaku et al 2015, Ogunniyi et al 2011. In contrary with these finding of Angella et al 2014.

Annual income: Annual income of the respondent is positive and significant relationship with the households' WTP. One possible reason could be that literate individuals are more concerned about soil and water conservation than illiterate ones. Keeping the influence of other factors constant, when annual income of a household increases by one birr, households' willingness to pay for soil conservation increases by 1.93%. A study by Adugnaw and Desalew, 2013 Genanew (1999), Tsegabrihan (1999), SANREM CRSP (2003), W/Giorgis (2004) and Jonse (2005), recognizes significant association between households income and willingness to pay .

Slop of farm land of the respondents had positive effect on households' WTP for SWC practice 5% level of significant. The implication is that the farmer who has a land with steep slope is more likely to understand soil erosion problem and apply conservation structures than the farmer who has flat sloped land. That is, keeping other things constant, changing the dummy from 0 to 1 will increase probability of accepting the initial bid by about 34%. This is consistent with Bekele, 1998; Wagayehu, and Lars, 2003; and Bett, 2004.

Total Livestock Unit (TLU) has been found to relate to the probability of WTP for SWC practices positively and significantly at 5%. TLU could be a proxy for wealth under Ethiopian farmers condition. When the wealth of a household increases, the WTP will also increase. The marginal factor show that a one unit increase in the livestock increases the probability of accepting the first bid by 10.29 % keeping the other explanatory variables. This is consistent with the findings of Gebrelibanos et al , 2012.

Perception about the existence of problem of soil erosion positive and significant at less than 5% probability level. Holding other things constant, changing the dummy from 0 to 1 will increase the probability of a households WTP for SWC practice by 1.29% for perceived farmers than the other counter factual respectively. The implication is that a farmer who feels that his/her farmlands are prone to soil erosion is more likely to continuously use SWC measures than those who do not perceive the problem of soil erosion. Which is consistent with the result of Abera (2003).

The **initial bid offered (BID1**) has a negative and significant effect on the WTP for SWC practices at less than 1% level of significance. The marginal analysis indicated that as the starting bid price increases by one unit, the probability of household's WTP for SWC by 0.01839.

Mean WTP and Estimation of Consumer Surplus of Soil Conservation Practices

According to Mitchell and Carson (1989) there are four important issues to be considered regarding sample design and execution in order to have a valid aggregation of benefits:

population choice bias, sampling frame bias, sample none response bias and sample selection bias. Random sampling method was used in this study using a list of household. Protest zero responses were not excluded from the analysis and a face to face interview method is used. Hence, none of the above biases was expected in the analysis.

If the probit model is estimated on a dichotomous choice CV question with a follow up and the parameter shows that either the mean, or variance or both differ between the initial bid price and the follow up, the researcher must decide which estimates to use to calculate the WTP measure (Haab and McConnell, 2002). Hence, in order to choose the appropriate WTP among the two probit estimates, we looked into the data and the total amount for the YY and NN responses accounted for about 74.6 % of the total responses. This means that the 2nd bid amount was closer to the unobserved true value of the individual. For example, let the first random bid for the individual be 40 birr per year and let the respondent accept the first bid. Then the 2nd bid becomes 68 birr per year, again, let the respondent accept the second bid. This means that the respondents' true WTP is greater than or equal to 68 birr per year so, the 2nd bid will be a better estimate than the 1st one. The same is true for NN answer. Even for the rest 25.34 % of the NY and YN responses, both the first and the second bid amounts will have equal chances to be closer estimates of the true value. Hence, using the second estimate of the double bounded bivarate probit model the mean willingness to pay for SWC is 36.81 birr per year.

As it is indicated in Table 8, the aggregate WTP was calculated by multiplying the mean WTP by the total number of households who are expected to have a valid response in the study area.

Following this, in this study the aggregate WTP for soil and water conservation practices was computed at 1336873 Birr per.

Table 8:Householdes aggregate willingness to pay

Total HHs Y	Expected HHs to have a protest zero (A^4)	Expected HHs' with Valid Responses (B^5)	Mean WTP (C^6)	Aggregate Benefit (D^7)
38277	1224.864	37052	36.081	1336873

Conclusions

The paper has estimated the total WTP for SWC practices and assessed the determinants of WTP practices in abaro - toga watershed, Ethiopia. The value elicitation method used is a double bounded dichotomous choice with an open ended follow-up question, which is closer to the market scenario respondents are familiar with in Ethiopia. Evidence from the study support that, age, household size, education, income, slop of farm land, perception of soil erosion, total livestock units, are significant factors that explain households' WTP. The mean WTP is found to be 36.08 birr per year with an aggregate benefit of 1336873 birr per year. Therefore, actions to be made towards these socio-economic aspects that significantly influenced households WTP is a first step conserving soil and water to sustain SWC practice to enhance Agricultural production. Policy thrust should focus on enhancing land tenure security through land certification among others.

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Evaluating Performance of SWAT-CN and SWAT-VSA Models for Analysis of Impact of LU/LC Change on Hydrology: A Case Study of Akaki Catchment

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Abstract:

The performances of SWAT-CN and SWAT-VSA were evaluated for analysis of effect of land use land cover change on stream flow of Akaki catchment, Ethiopia. The change of stream flow pattern with respect to land use land cover change was evaluated through change detection analysis of multi-temporal remotely sensed image and hydrological models. The models performances have been evaluated during calibration and validation through performance indicators like RVe, R^2, NSE and RSR. There was a significant and continuous land cover change especially; grass and forest land areas were decreased whereas agriculture and urban areas were increased. Models performance results showed that there was not significance variation over the catchment. However, SWAT-CN model performs slightly better than SWAT-VSA. In this regard, SWAT-CN was selected for further analysis of land use land cover change. The results showed that the mean monthly flow for 2011 land cover map during the wet season had increased by 10.5%, than 1986 land cover map while during dry season mean monthly flow had decreased by 8.5%. Further analysis in selected sub-basins, the mean annual average surface runoff and base flow simulation showed significant change due to similar case.

Key words: Akaki catchment, SAWT-CN and SWAT-VSA models, Stream flow, Land use/ Land cover Change, Remote sensing and GIS.

Introduction

Understanding how Land use and land cover changes (LULCC) influence on the hydrologic condition of the watershed is needed for planners to formulate policies, to minimize the undesirable effects of land cover changes for sustainable management of resources. SWAT model has been successfully applied in Ethiopia example Blue Nile Basin, Central Ethiopia and other part of the country (Kassa, 2009). The finding shows the performance of the model in most cases appears to be reasonable. However, these studies were based on SWAT-CN. It is important first to evaluate the accuracy of this model for area with different geographic and climate condition. Because most of the SWAT-CN model predicts storm runoff using Curve Number (CN) equation assumes run-off is generated only through infiltration-excess (Horton, 1933). However, the CN method should not be used to model the long-term hydrologic response of a catchment (Steenhuis *et al.,* 1995).

Under many situations, surface runoff can be contributed by a portion of a watershed referred to as a variable source area (VSA). It is widely recognized as a primary driver of runoff in watershed where shallow soils with near surface restricting layers generate zones of saturation-excess runoff (Srinivasan *et al.,* 2002). Now day SWAT-VSA (the curve-number-topographic index adjusted version of SWAT) returned hydrologic simulations as modify as original curve number method (SWAT-CN) by improving spatial representation of runoff within the watershed (Collick *et al.,* 2014). For the present study, SWAT -VSA and SWAT-CN models are selected and evaluated the performance for assessing impact of LULCC on hydrological response in semi-urban catchment, in a case study on Akaki catchment.

Objective of the Study:

The main objective of this study is to analyze the impacts of land use land cover change on hydrology of Akaki Catchment.

The specific objectives are;

- To produces land use/land cover map of the Akaki catchment using remote sensing data
- To evaluate the response of a hydrologic models of the catchment to the changes in land cover
- To compute the stream flow alterations in relation to different land use/land cover maps of the catchment developed for different period

Methodology

Description of Study

Akaki catchment is situated at the Northwestern Awash River between $8^0$46'–$9^0$14'latitude and $38^0$34'–$39^0$08'longitude. It is bounded to the North by the Entoto ridge system, to the West by Mountain Menagesha and the Wechecha volcanic range, to the Southwest by Mountain Furi, to the South by Mountain Bilbilo and Mountain Guji, to the Southeast by the Gara Bushu hills and to the east by the Mountain Yerer volcanic center (Figure 1). The total area of the catchment is 1544.7 km^2. The elevation of Akaki catchment varies from 2048 to 3237 m.a.m.s.1. The mean annual rainfall of the study area is range from 973 mm to 1266 mm and the annual average temperature ranges from 13.19°C to 20.01°C. The Akaki catchment mainly covered with cultivated land, reservoir grassland and forest land and urban areas.

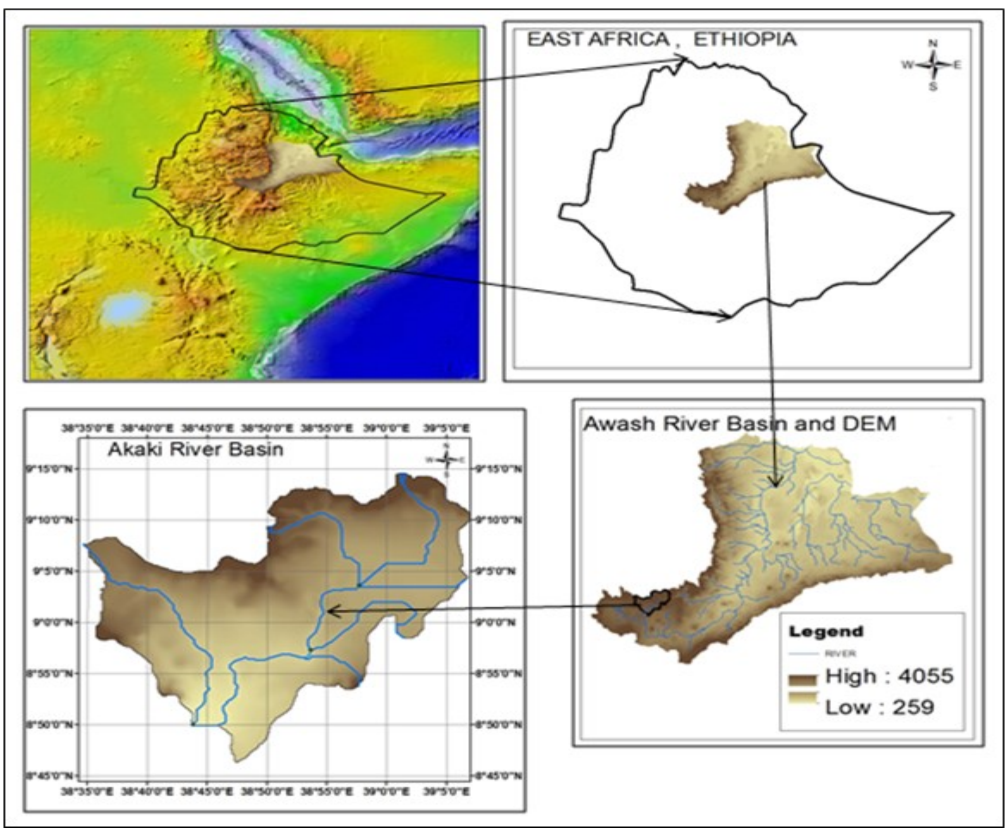


Figure 1: Location map of study Area

For the achievements of this study, it is important to make a strong search for the data and identifying clear and efficient methodology. The methods and procedures used in this research work are presented in the following general methodology (Figure 2).

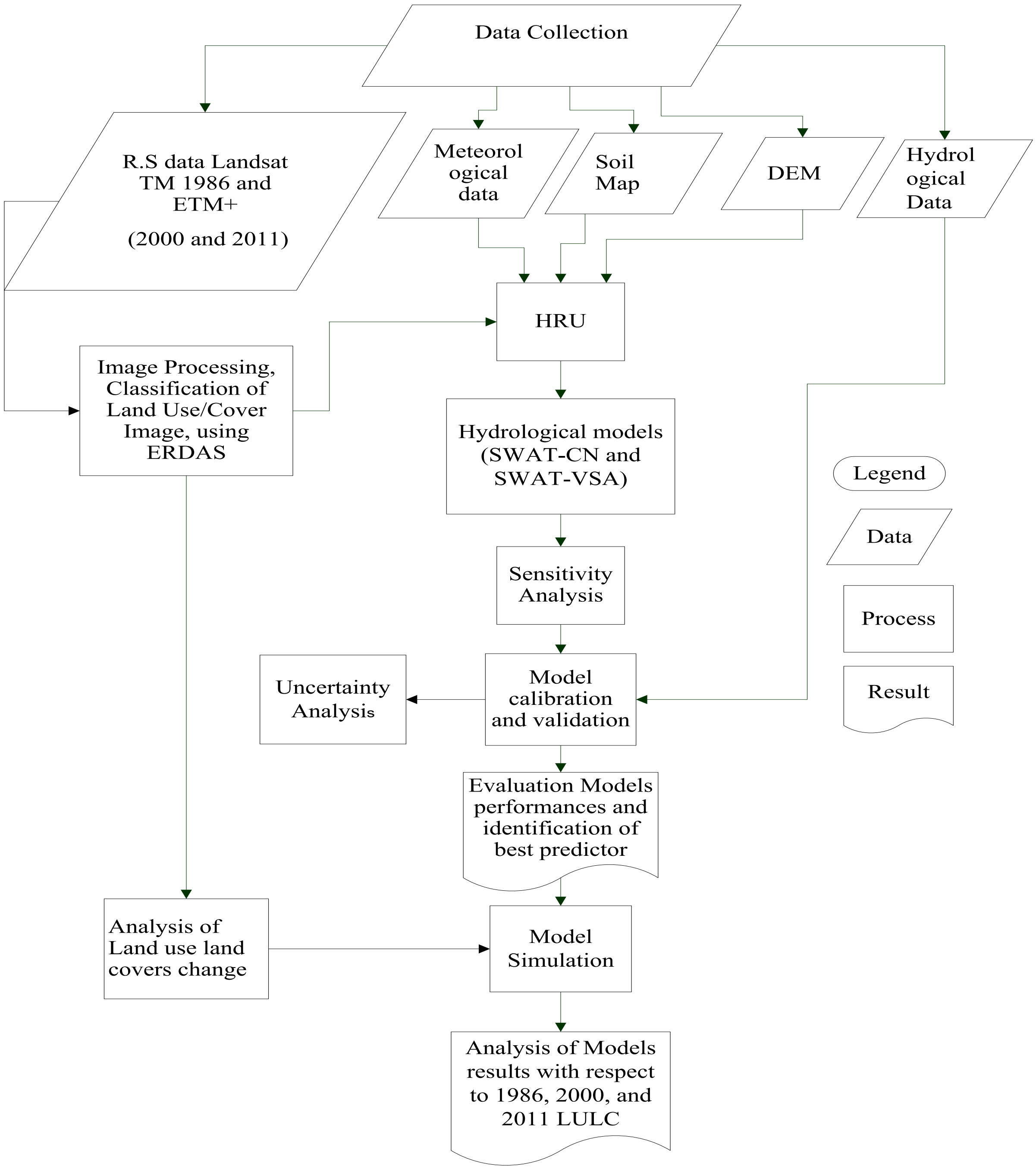


Figure 2: General conceptual framework of the study

SWAT-CN Method: The SCS–CN method estimates total watershed runoff depth Q (mm) for a storm by the SCS runoff equation (*1*) (USDA-SCS, 1972);

$$Q_{sur} = \frac{R_e^2}{R_e + S_e} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where R_e (mm) is the depth of effective rainfall after runoff begins and S_e is the depth of effective available storage (mm). At the beginning of a storm event, an initial abstraction, I_a (mm), of rainfall is retained by the watershed prior to the beginning of runoff generation. R_e, and *Se*, are expressed as the following equation.

$$R_e = R_{day} - I_a \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2a)$$

$$S_e = S - I_a \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2b)$$

Where R_{day} (mm) is the total rainfall for the storm event and S (mm) is the available storage at the onset of rainfall. In the traditional SCS–CN method, I_a is estimated as an empirically derived fraction of available storage:

$$I_a = 0.2 * S_e \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

A curve number is an index that represents the combination of a hydrologic soil group and a land use class. Standard relationship between S_e and *CN* are expressed by equation (*4*).

$$S_e = 25.4\left(\frac{1000}{CN} - 10\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

<u>SWAT-VSA</u> Method: *SWAT-VSA, curve number-topographic index adjusted version of SWAT, allows used to model and predict saturation excess runoff from variable sources areas (VSA) without modifying the original SWAT code base. The rate of runoff generation will be proportional to the fraction of the watershed that is effectively saturated (A_f) which can then be written as:*

$$A_f = \frac{\Delta Q}{\Delta R_e} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5)$$

Where ΔQ is incremental saturation-excess runoff, ΔR_e is the incremental depth of rainfall during the same time period. Runoff *q (mm)* at a point location in the watershed can now also be expressed for the saturated area simply as:

$$q = R_e - \alpha_e \; for \; R_e > \alpha_e \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (6a)$$

$$q = 0 \; for \; R_e < \alpha_e \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (6b)$$

Where α_e is a local effective available storage (mm). Finally the total runoff *Q* of the watershed can be expressed as the integral of *q* over A_f.

$$Q_{sur} = \int_0^{A_S} q(dA_S) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (7)$$

Based on the topographic index map of a watershed is generated by dividing the watershed into a grid of cells and calculating the index for each cell by Equation (*8*).

$$TI = ln\left(\frac{\alpha}{tan_\beta}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (8)$$

Where *TI* is the topographic index, α is the upslope contributing area for the cell per unit of contour line (m), tan_{β} is the topographic slope of the cell. After α_e is determined by above equation for the entire watershed, runoff depth Q_{sur} is the aerially weighted sum of runoff depths *qi* for all discrete contributing areas.

$$Q_{sur} = \sum_{i=1}^{n} qi * \left(A_{s,i+1} - A_{s,i}\right) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (9)$$

Model Performance Evaluation: The models were evaluated through the goodness of fit of the simulated to the observed runoff can be assessed by four different criteria, such as A Relative Volume Error (*RVe*),Coefficient of Determination (R^2), Nash-Sutcliffe Simulation efficiency (*ENS*) and Observation Standard Deviation Ratio (*RSR*)

Results and Discussions

Accuracy Assessment: The overall result of user's accuracy ranges from 77.8% to 100% while the producer's accuracy ranges from 65% to 100% as presented in Table (1,2 and 3) respectively. The lowest values were misclassified due to similar spectral value of different land cover classes. The overall accuracy for the maps of 1986, 2000 and 2011 were 85.2% in Table (1), 87.3% in Table (2) and 86.44% in Table (3) respectively. According to Anderson *et al*.(1976) results for a reliable land cover classification, the minimum overall accuracy value computed from an error matrix should be 85%.Therefore, based the results the present study produced overall accuracies that fulfills the minimum accuracy level defined by (Anderson *et al.*, 1976) for the three land cover maps of Akaki catchment.

Table 1: Confusion matrix's for validation of land use/land cover map 1986

		References Data						User's Accuracy
		CL	GL	U	F	W	Total	
	CL	25	6	0	1	0	32	78.1
	GL	7	45	2	1	1	56	80.4
	U	3	1	40	0	2	46	87.0
	F	3	0	0	32	1	36	88.9
Classified Data	W	0	0	0	0	18	18	100.0
	Total	38	52	42	34	22	188	
Producer's Accuracy		65.8	86.5	95.2	94.1	81.8		Overall Accuracy =85.2

Table 2: Confusion matrixes for validation of land use/land cover map 2000

		References Data						User's Accuracy
		CL	GL	U	F	W	Total	
Classified Data	CL	38	6	4	0	0	48	79.2
	GL	8	47	0	0	2	57	82.5
	UR	5	0	50	0	2	57	87.7
	FR	0	0	0	31	0	31	100.0
	WA	0	0	0	0	22	22	100.0
	Total	51	53	54	31	26	215	
Producer's Accuracy		74.5	88.68	92.6	100	84.6		Overall Accuracy =87.3

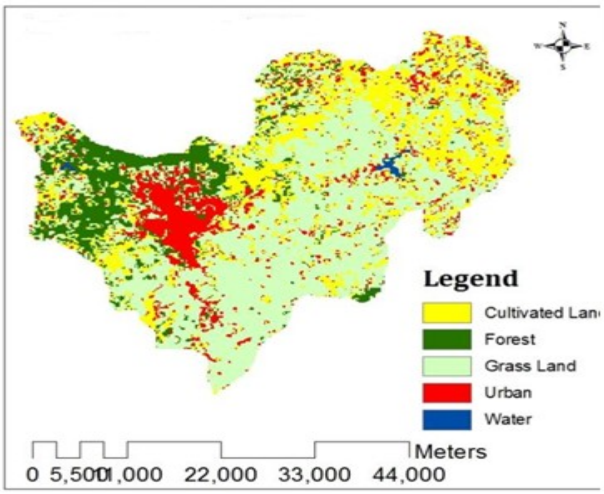
Table 3: Confusion matrix's for validation of land use/land cover map 2011

		References Data						User's Accuracy
		CL	GL	U	F	W	Total	
Classified Data	CL	50	6	3	1	0	60	83.3
	GL	12	49	1	1	0	63	77.8
	U	7	1	59	1	1	69	85.5
	F	3	0	0	36	0	39	92.3
	W	0	0	0	0	42	42	100.0
	Total	72.0	56.0	63.0	39.0	43.0	273	
Producer's Accuracy		69.4	87.5	93.7	92.3	97.7		Overall Accuracy =86.4

Note: CL = Cultivated Land, GL= Grass Land, U=Urban, F= Forest, and W = Water

Land Use/Land Cover Map of 1986, 2000 and 2011

The land cover maps of 1986, 2000 and 2011 are indicated in Figure (3, 4 and 5) respectively.



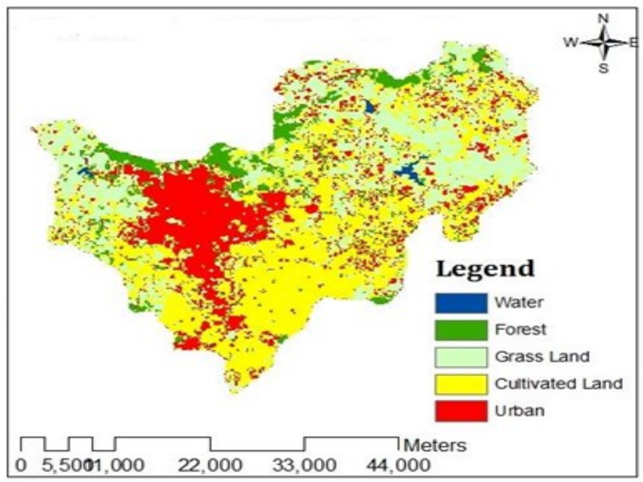


Figure 3: LU/LC map of Akaki catchment (1986) **Figure 4**: LU/LC map of Akaki Catchment (2000)

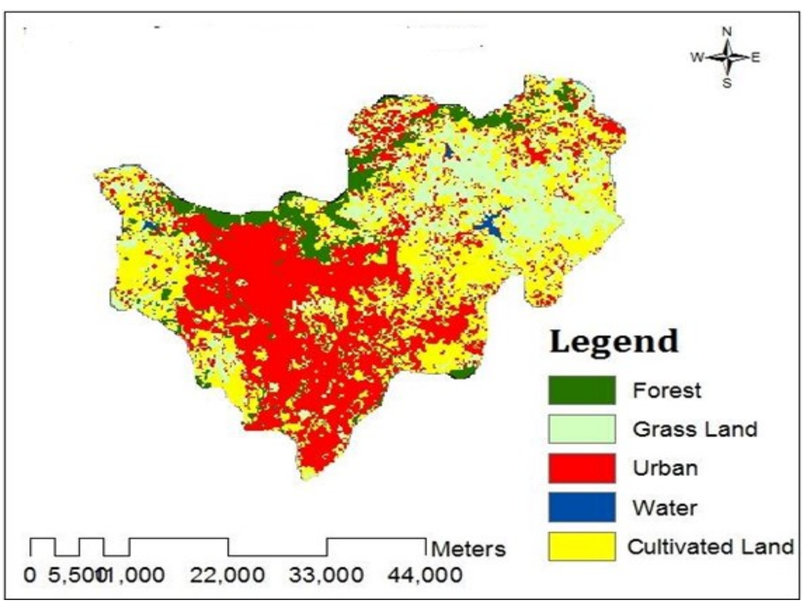


Figure 5: Land use/ land cover map of Akaki catchment (2011)

Summary of Land use/land Covers Class: Generally over the past 23 years, almost all of the urban expansion and cultivated land had resulted from grass land reduction and from deforestation where most grass and forest land are become urban area and cultivated land. The Summary of land use/land covers change in the Akaki catchment are summarized in Table (4)

Table 4: Summary of land use/land covers change in the Akaki catchment

Land Cover Type	1986-2000		2000-2011		1986-2011	
	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%
CL	145.2	9.5	-65.9	-4.3	79.3	5.2
GL	-187.6	-12.1	-132.4	-8.6	-320	-20.8
U	97.8	6.3	202.2	13.1	300	19.4
F	-57.2	-3.6	-2.9	-0.2	-60.1	-3.8
W	1.7	0.2	-1	-0.1	0.7	0.1
CL= cultivated land, GL = grass land, U= urban, F = forest, W = water						

Table (4) negative and positive sign indicates the decrease and increase respectively of land cover class for the specified time of period.

Monthly Calibration and Validation of SWAT-CN Model

The performance efficiencies value in both the calibration and validation phases prove that SWAT-CN predicted measured stream flow best for monthly stream flow time steps as indicated in the Table (5).

Table 5: SWAT-CN performance during the calibration and validation periods

	1986 LULC map		2000 LULC map		2011 LULC map	
	calibration	Validation	calibration	Validation	calibration	Validation
Index	1990-1999	2000 -2004	1990-1999	2000-2004	1990-1999	2000-2004
RV_E	-5.3	0.65	-8.1	5.9	-0.23	9.5
(R^2)	0.90	0.88	0.87	0.88	0.84	0.86
(NSE)	0.88	0.87	0.87	0.86	0.84	0.84
RSR	0.32	0.36	0.36	0.38	0.4	0.4

The performance of the models for both the calibration and validation periods can also be evaluated from the graphical presentations.

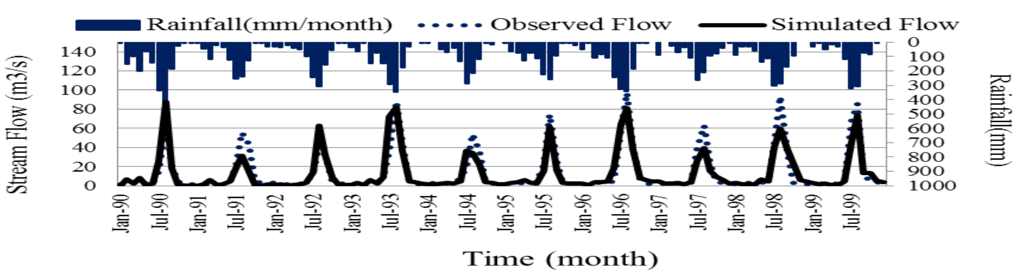


Figure 6: Observed and simulated stream flow hydrograph on a monthly time step during the calibration period using SWAT-CN model (1990-1999)

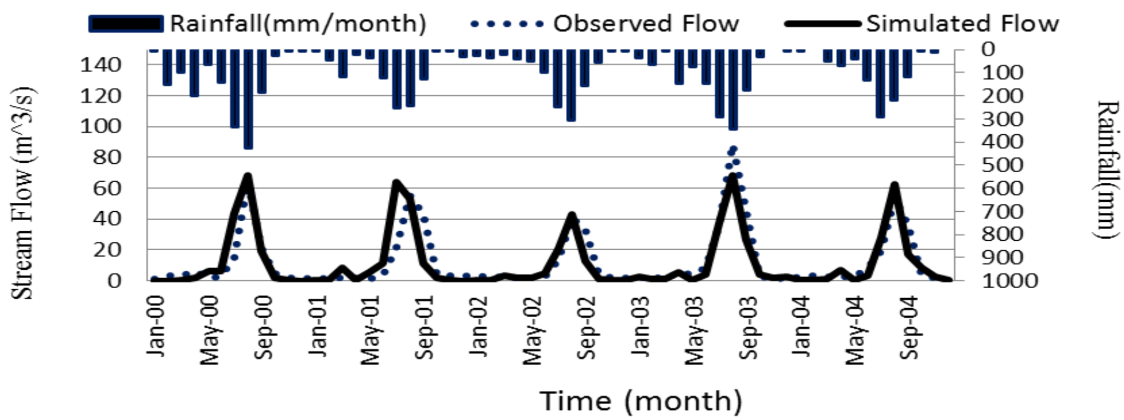


Figure 7: Observed and simulated stream flow hydrograph on a monthly time step during the validation period using SWAT-CN model (2000-2004)

Monthly Calibration and Validation of SWAT-VSA

The relative errors between simulated and observed flows were -14.1% for the calibration period and 14.6% for the validation period; both which are not within the required range of ± 10%. The other performance efficiency values in both the calibration and validation based on *NSE*, *RSR* and R^2 in SWAT-VSA model show that predicted measured streamflow are quite satisfactory for monthly streamflow time steps.

Table 6: SWAT-VSA performance during the calibration and validation periods

Index	1986 LULC map calibration 1990-1999	1986 LULC map Validation 2000-2004	2000 LULC map calibration 1990-1999	2000 LULC map Validation 2000-2004	2011 LULC map calibration 1990-1999	2011 LULC map Validation 2000-2004
RV_E	-2.5	6.28	-14.1	8.6	-5.0	14.6
(R^2)	0.83	0.87	0.84	0.86	0.83	0.85
(NSE)	0.82	0.83	0.83	0.82	0.82	0.79
RSR	0.42	0.41	0.41	0.42	0.42	0.46

The other performances evaluated from the graphical presentations are indicated in Figures (8 and 9) show observed and simulated flow plotted against time at the outlet of Akaki watershed corresponding to calibration and validation periods.

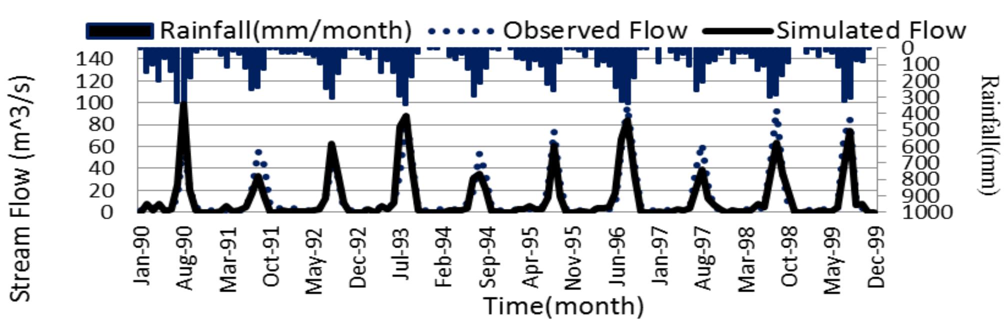


Figure 8: Observed and simulated stream flow hydrograph on a monthly time step during the calibration period using SWAT-VSA model (1990-1999)

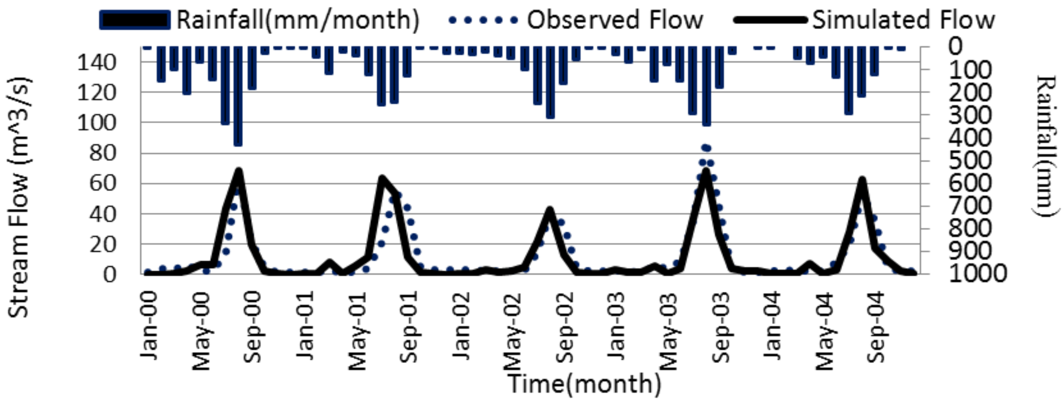


Figure 9: Observed and simulated stream flow hydrograph on a monthly time step during the validation period using SWAT-VSA model (2000-2004)

Comparison of SWAT-CN and SWAT-VSA Models

The calibration and validation value of both models had shown the predicted values have agreed well with the observed data of the watershed. These models are capable to estimate streamflow composition and contributions from the different land use and land cover classes. Although the results of calibration, validation and uncertainty analysis of both SWAT-CN and SWAT-VSA are quite acceptable, the simulated stream flow by SWAT-CN was better than that of SWAT-VSA especially, interims of relative volume error performance criteria (RV_E).

Model Response to Land Use Land Cover Change

The results indicate that the mean annual SURQ for 2011 land cover was increased by 10.7% than 1986 land cover. Similarly the 2000 land cover mean annual SURQ flow was higher by 7.04% than 1986 land cover. The mean annual total aquifer recharge for 2011 land cover was decreased by 8.4% than 1986 land cover, while the 2000 land cover mean annual total aquifer recharge was lower by 5.9% than 1986 land cover. The mean annual WLYD was increased due to the contribution of SURQ from most of the sub-basins.

The result shows dry mean monthly flow was decreased by 8.2%, for land cover map of 2011 and 5.2% for land cover map of 2000 than that of 1986 land cover maps. The mean wet monthly flow for 2011 land cover map was increased by 10.5% than 1986 land cover. Similarly case the 2000 land cover map mean month flow increased by 6.1% than the 1986 land cover map.

The mean annual SURQ (mm) variability in selected sub-basins indicate that mean annual average SURQ had increased by 19.3% while in the base flow simulation decreased by 13.2% during the study periods due to LULCC. In other side, the mean annual base flow (mm) reduces up to 16.4% in (sub-basin 13) was observed.

Conclusions

In the study area, there was a significant and continuous change in grass land and forest/plantation area as caused by most dominantly of agriculture activity next to urban. Therefore, the government administration should focus on regulating un-plan expansion of urban area and also attention should be given on afforestation especially on Northern, Northwestern and Northeastern part of the catchment.

Although the performance results obtained during calibration and validation analysis of SWAT-CN and SWAT-VSA models quite acceptable, the simulated stream flow by SWAT-CN were slightly better than that of SWAT-VSA especially, interims of Relative Volume Error. Consequently, SWAT-CN model was used to further analysis of effect of land use land cover change on the stream flow Akaki catchment.

The mean monthly flow for 2011 land use land cover was increased by 10.5% relative to that of 1986 land cover period while during dry season the mean monthly flow was also decreased by 8.2% than the 1986 land cover. Furthermore, in selected sub-basin the mean annual average SURQ had increased by 19.3% while in the base flow simulation decreased by 13.2% due to the LULCC. Generally, from these results it can be concluded that the effects of changes in land use could potentially change in a significant way the hydrological regime of the whole catchment. Therefore, the results can have an important contribution for water resources managers to be aware of and prepared to deal with the effects of future land use and land cover change on streamflow and related variables.

Recommendations

Since urban areas have complex and heterogonous features, the use of high resolution imageries are important in generating good quality of land cover maps. Moreover the use of more auxiliary ground points as ground truth helps for better accuracy image classification. The model simulation considered only land use land cover change effect by assuming all other thing constant. But change in climate and soil management activities will contribute great effects on hydrological process of the Catchment. Therefore, researcher should consider this factor so as to get further best result. Data quality and availability should be stressed much more while using distributed hydrological models. The use of new data gathering techniques like Automatic weather stations and digital data logger should be applied in order to improve the performance of the model, so that local and respective authorities can be involved in integrated and coordinated data compilation.

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Remote Sensing Based Estimation of Evapo-Transpiration Using Selected Algorithms; the Case of Wonji Shoa Sugar Cane Estate

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Abstract

The goal of every grower is to practice irrigation management to fulfill water needs profitably, safely, and in an environmentally responsible way. For this, accurate knowledge of the amount of evapotranspiration (ET) is critical. The focus of this study was to estimate and compare the actual evapotranspiration (ETa) of the Wonji Shoa Sugarcane Estate using different remote sensing algorithms. The daily ETa of the sugarcane was estimated and thematically mapped pixel-by-pixel using Surface Energy Balance Algorithm for Land (SEBAL), Simplified Surface Energy Balance (SSEB) and Operational Simplified Surface Energy Balance (SSEBop) algorithms on Landsat7 ETM+ images acquired on four days in 2002. The algorithms were based on image processing which uses spatially distributed spectral satellite data (visible, near infrared and thermal infrared) and ground meteorological data to derive the surface energy balance components. The results obtained revealed that the ranges of the daily ETa estimated on January 25, February 26, September 06 and October 08, 2002 using SEBAL were 0.0 - 6.85, 0.0 – 9.36, 0.0 – 3.61, 0.0 – 6.83 mm/day; using SSEB 0.0 - 6.78, 0.0 – 7.81, 0.0 – 3.65, 0.0 – 6.46 mm/day, and SSEBop were 0.05 - 8.25, 0.0 – 8.82, 0.2 – 4.0, 0.0 – 7.40 mm/day, respectively. The Root Mean Square Error (RMSE) values between SSEB and SEBAL, SSEBop and SEBAL, and SSEB and SSEBop were 0.548, 0.548, and 0.99 for January 25, 2002; 0.739, 0.753, and 0.994 for February 26, 2002;0.847, 0.846, and 0.999 for September 06, 2002; 0.573, 0.573, and 1.00 for October 08, 2002, respectively. The standard deviation of ETa over the sugarcane estate showed high spatio-temporal variability perhaps due to soil moisture variability and surface cover. Dry periods exhibit greater variability compared to wetter periods. Generally during the dry season, ET is limited to the well watered sugarcane fields and water storage areas only. During the peak rainy season, ETa was high throughout the entire sugarcane estate. All the three algorithm results showed that generally well watered sugarcane fields in the mid-season growing stage of the crop and water storage areas had higher ETa values compared with the other dry agricultural fields confirming that they consumptively use more water. The evaporation fraction (ETrF) results also followed the same pattern as the daily ETa over the sugarcane estate. The total crop and irrigation water requirement and effective rainfall estimated using the Cropwat model were 2468.8, 2061.6 and 423.8 mm/yr for January 2001 planted and 2281.9, 1851.0 and 437.8 mm/yr for March 2001planted sugarcanes, respectively. The mean annual ETa estimated for the whole estate were 107 Mm3, 140 Mm3, and 178 Mm3 using SEBAL, SSEB, and SSEBop, respectively. Though the algorithms need to be validated through field observation, either of these algorithms tested in this study have potential to be used for effective irrigation water management.

Key Words: CWR, ET, IR, Landsat ETM+, , Remote Sensing, SEBAL, SSEB, SSEBop

Introduction

Water is one of the most important limited natural resources crucial for all socio-economic and environmental needs to be managed in a sustainable way to ensure its long-term availability. Judicious management of precious land and water resources is emerging as one of the biggest challenges of the 21st century. Both water and land resources are finite, but competitive demand from other sectors is increasing. Managing water for multiple benefits and between competing demands is occupying the minds of irrigators, catchment water managers and policy-makers. Agriculture is by far the largest water user sector and the goal of every grower is to practice irrigation management to fulfill water needs profitably, safely, and in an environmentally responsible way. Irrigation depends on reliable supplies of fresh, clean water from surface and/or groundwater sources. Knowing how much water moves through soils and crop canopy can help growers use irrigation water more effectively with less risk to water sources.

As stated by Hemukamara *et al*. (2003), [1], evapotranspiration (ET) which is a process governed by the energy and heat exchanges at the land surface, with the upper bound being constrained and controlled by the amount of available energy and water respectively is also an important factor for evaluating water productivity and monitoring of irrigation performance. Therefore, an estimation of spatially distributed crop water consumption is challenging, but important to determine water balance at different scales to promote efficient management of water resources. Evapotranspiration from irrigated agriculture is an important issue in arid and semi-arid regions where it has large impact on water resources depletion and water management (Tasumi and Allen, 2007), [2]. Accurate determination of crop ET is essential for designing irrigation systems and for irrigation scheduling. Remote sensing data can resolve difficulties in determining water balance due to scientific developments in the calculation of spatially distributed actual evapotranspiration. The use of remote sensing techniques to estimate evaporation is achieved by solving the energy balance of thermodynamics fluxes at the surface of the earth and it is used for calculating the actual evapotranspiration (ET_a) based on the equilibrium between the radiation balance and the energy balance at the surface of the earth.

- The main objectives of this study were:
- To estimate actual ET using Surface Energy Balance Algorithm for Land (SEBAL), Simplified Surface Energy Balance (SSEB), Operational Simplified Surface Energy Balance (SSEBop); and Penman-Monteith Methods;
- To compare the actual ET results of SEBAL, SSEBop and SSEB; and
- To calculate the crop water requirement of the sugarcane plantation at the estate level

Materials and Methods

Description of the Study Area

The Wonji-Shoa Sugarcane Estate lies downstream of the Koka Dam in the Central Rift Valley of Ethiopia in the upper Awash River basin around 114 km from Addis Ababa within the geographical boundaries of 8^0 21' to 8^0 29' N latitudes and 39^0 12' to 39^0 18' E longitudes at an altitude of about 1,540 m above sea level (Melaku, 2009), [3]. Currently the estate is cultivating more than 9352 hectare of irrigated land using furrow irrigation system.

In the estate, generally, the topography of the farm is very gentle slopes with flood prone plains of Awash River. The soils of Wonji-Shoa have been described predominantly as a complex of gray, cracking clays in the topographic depressions and semiarid, brown soils.

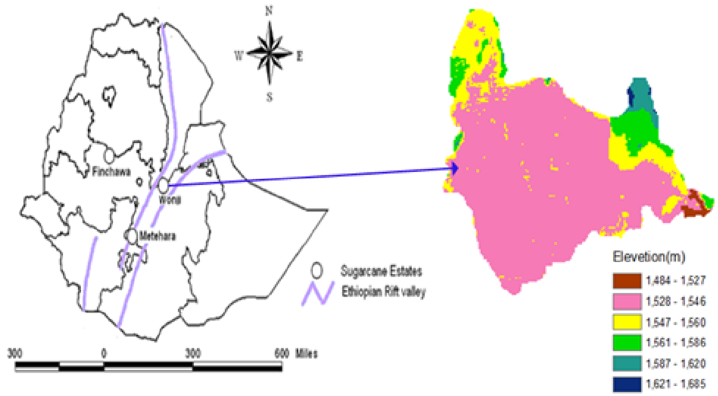


Figure 1: Description of study area

The main crops cultivated are sugarcane, haricot bean and crotalaria. Sugarcane is planted at a rate of 16 -18 t/ha in the estate and it is cultivated as perennial monocrop. The mean annual relative humidity ranges from 43.2 to 68.4%. It is described as tropical wet climate with uniform warmth throughout the year and receives an average annual rainfall of 831.2 mm, average daily evapotranspiration of 4.5 mm/day, mean annual maximum and minimum temperatures of 27.6 ^{0}C and 15.2 ^{0}C, respectively and the average sunshine hour is 9 hours in dry summer and 6.5 hours in August as cited in (Girma and Awulachew, 2007), [4]. At Wonji, in the Upper Valley, the mean annual PET is 1810 mm, over twice the mean annual rainfall (Shimelis, 2004), [5].

Data Collection and Analysis

Data collection

A. Remote sensing data

The main remote sensing input used for this study is Landsat7 ETM+ data having spatial resolution of 30m for visible and near infrared bands (b1 to b5 and b7) and 60m resolution for thermal band (b61 and b62) at satellite nadir provided by the United States Geological Survey (USGS) Earth Observation System (EOS) Data Gateway.

B. Meteorological data

The Meteorological data in daily time steps were collected from Wonji Shoa sugarcane estate research center weather station during the four satellite overpass dates as shown below.

Table 1: Meteorological data for selected months

Dates	Temperature (^{o}C)	Humidity (%)	Wind speed at 2m (m/sec)	Actual sunshine hour (hour)	Precipitation (mm)	ETo Penman (mm)
Jan 25,2002	17.4	43	3.1	10.5	0.0	5.49
Feb 26,2002	20.5	36	2.8	11	0.0	6.31
Sept 6,2002	21.8	58	1.7	0.0	0.0	3.11
Oct 8,2002	19.4	46	2.4	11	0.0	5.39

C. Software packages used

The main software packages used were Earth Resource Data Analysis System (ERDAS) IMAGINE version10, CROPWAT8, ArcGIS 9.3and Saga software.

Data analysis

Image analysis for SEBAL parameter extraction

The original satellite images were properly prepared for use in SEBAL, SSEB and $SSEB_{op}$ algorithms and were applied to Landsat-7 ETM+ data for assessing the actual ET by calculating the ET flux for each pixel of the satellite image as a "residual" of the surface energy balance equation. The Landsat ETM+ seven bands were layered inside ERDAS IMAGINE, in order from band 1 to band 7 to create an image file for use in the image analysis process. After that, a smaller subset image was created for Wonji Shoa sugarcane plantation farm. Having estimated the land surface parameters such as NDVI, reflectance, emissivity and temperature, the selected algorithms were employed to estimate daily actual ET. The first step used in the SEBAL procedure was to compute the net surface radiation flux (R_n) using the surface radiation balance equation.

$$R_n = (1-\alpha)R_{S\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1-\varepsilon)R_{L\downarrow} \qquad (1)$$

Where, $R_{S\downarrow}$ is incoming shortwave radiation (W/m^2), α is broadband surface albedo (dimensionless), $R_{L\downarrow}$ is incoming long wave radiation (W/m^2), $R_{L\uparrow}$ is outgoing long wave radiation (W/m^2), ε is surface thermal emissivity (dimensionless), R_n represents the actual radiant energy available at the surface. This was accomplished in a series of steps using the ERDAS Model Maker tool to compute the terms in equation (1). The land surface temperature (T_s) is computed using the following modified Plank equation and hot and cold pixels were selected.

$$T_s = \frac{K_2}{\ln\left(\frac{\varepsilon \times K_1}{R_c} + 1\right)} \qquad (2)$$

Where; R_c is the corrected thermal radiance from the surface using the spectral radiance of band 6, ε is the "broad-band" surface emissivity (dimensionless). K_1 and K_2 are constants for Landsat images. The SEBAL process utilizes the "hot" and "cold" pixels to fix boundary conditions for the energy balance. The "cold" pixel is selected as a wet, well-irrigated crop surface having full ground cover by vegetation. The "hot" pixel is selected as a dry, bare agricultural field where ET is assumed to be zero (Bastiaanssen *et al.*, 2002), [6].

Estimation of the Fluxes in the Surface Energy Balance Equation: the second step of the SEBAL procedure is to compute the terms soil heat flux(G) and sensible heat flux (H) of the surface energy budget equation as a function of net radiation flux (R_n) as follows:

$$R_n = G + H + \lambda ET \qquad (3)$$

Where; R_n is the net radiation at the surface (W/m^2), G is the soil heat flux (W/m^2), H is the sensible heat flux to the air (W/m^2), and λET is the latent heat flux (W/m^2).

This equation is solved through the following steps using the ERDAS Model Maker tool.

A. Soil Heat Flux (G): SEBAL first computes the ratio G/R_n using the following empirical equation developed by Bastiaanssen (2000), [7] representing values near midday:

$$\frac{G}{R_n} = \frac{(T_s - 273)}{\alpha}(0.0038\alpha + 0.0074\alpha^2)(1 - 0.98\,NDVI^4) \quad (4)$$

Where; Ts is the surface temperature (^oC), α is the surface albedo, and NDVI is the Normalized Difference Vegetation Index. G is then readily calculated by multiplying G/R_n by the value for R_n.

B. Sensible Heat Flux (H): The sensible heat flux (H) is computed as follows for heat transport:

$$H = \frac{\rho \times c_p \times dT}{r_{ah}} \quad (5)$$

Where; ρ is air density (kg/m^3), C_p is air specific heat (1004 J/kg/K), dT (K) is the temperature difference ($T_1 - T_2$) between two heights (z1 and z2), and r_{ah} is the aerodynamic resistance to heat transport (m/s). Equation (5) is difficult to solve because there are two unknowns, r_{ah} and dT. To facilitate this computation, the two "anchor" pixels (where reliable values for H can be predicted and a dT estimated) and the wind speed at a given height were utilized.

C. Latent Heat Flux (λET), Instantaneous ET (ET_{inst}), and Reference ET Fraction (ET_rF): In SEBAL mode latent heat flux is computed as residual variables of the energy balance equation. It can be computed for each pixel using Equation (5):

$$\lambda ET = R_n - G - H \quad (6)$$

Where; λET is an instantaneous value for the time of the satellite overpass (W/m^2). An instantaneous value of ET in equivalent evaporation depth is computed as:

$$ETinst = 3600\ \frac{\lambda ET}{\lambda} \quad (7)$$

Where; is the instantaneous ET (mm/hr), 3600 is the time conversion from seconds to hours, and λ is the latent heat of vaporization or the heat absorbed when a kilogram of water evaporates (J/kg). The reference ET Fraction (ET_rF) is computed using ET_{inst} and weather data.

$$ETrF = \frac{ETinst}{ET_o} \quad (8)$$

Where; ET_{inst} is from Equation 6 (mm/hr) and ET_o is the reference ET at the time of the image from the CROPWAT software (mm/hr). ET_rF is similar to the well-known crop coefficient, K_c and is used to extrapolate ET from the image time to 24-hour or longer periods.

Daily (24-Hour) Evapotranspiration (ET_{24}): SEBAL computes the ET_{24} by assuming that the instantaneous ET_rF computed above is the same as the 24-hour average and ET varies throughout the day while ET_rF is relatively constant. Finally, the ET_{24} (mm/day) can be computed as:

$$ET_{24} = ETrF \times ET_{o-24} \quad (9)$$

Where; ET_{o-24} is the cumulative 24-hour ET_o for the day of the image.

SSEB model overview and parameter estimation

The main concept of the SSEB approach in Senay et al. (2007), [8] is the joint use of reference ET and land surface temperature data. The surface energy balance is first solved for a reference crop condition (assuming full vegetation cover and unlimited water supply) using the standardized Penman–

Monteith equation (Allen et al., 1998), [9]. ET fractions (ETf) account for differences in water availability in the landscape; and are used to adjust the reference ET (ET_o) based on the land surface temperature (T_s) of the pixel (Eq. (2) for ETf). The ET fraction (ETf) is calculated for each pixel "x" by applying Eq. (10) to each of the 4-date Landsat T_s grids.

$$ETf = \frac{TH - Tx}{TH - TC} \tag{10}$$

where TH and TC are the average radiometric surface temperature at hot and cold pixels, respectively; and Tx is the radiometric surface temperature for any given pixel in that image. The basic approach of calculating ETa involves only two steps: ETa is simply a product of the ET fraction (ETf) and ET_o via Eqs. (11) and (12).

$$ETa = ETf \times ETm \tag{11}$$

where ETa is actual ET, ETf is ET fraction, and ETm is maximum ET for the region. When grass reference ETo is calculated from weather data, ETm is estimated as:

$$ETm = \alpha \times ET_o \tag{12}$$

where the multiplier α is recommended to be 1.2 to estimate ET for tall, full cover crops such as alfalfa, corn, sugarcane and wheat which are aerodynamically rougher than the clipped grass reference and have greater leaf area and thus greater canopy conductance (Allen *et al*., 1998), [9].

2.2.2.4 New parameterization approach ($SSEB_{op}$)

The method is developed by Senay *et al*. (2013), [10] and it is based on the Simplified Surface Energy Balance (SSEB) approach which is now parameterized for operational applications, renamed as $SSEB_{op}$. The innovative aspect of the $SSEB_{op}$ parameterization is that it uses pre-defined, boundary conditions that are unique to each pixel for the "hot" and "cold" reference conditions. To estimate ET routinely, the only data needed for this method are T_s, climatology air temperature (T_a) and ET_o. With this simplification, actual ET (ET_a) is estimated using equation 13 as a fraction of the ET_o and the ET fraction (ETf) is calculated using equation 14.

$$ETa = ETf \times \alpha ETo \tag{13}$$

Where ET_o is the grass reference ET; α is a crop coefficient with a recommended value of 1.2.

$$ETf = \frac{T_h - T_s}{T_h - T_c} \tag{14}$$

Where T_s is the satellite observed land surface temperature of the pixel whose ETf is being evaluated on a given time-period. T_h is the estimated Ts at the idealized reference "hot" condition of the pixel, the cold reference value Tc*,* is the estimated *Ts* at the idealized reference "cold" condition of the pixel of the same time period.

T_c determination: T_c boundary condition was determined using correction coefficient as :

$$T_c = c \times T_a \tag{15}$$

Where T_a is the climatology near-surface maximum T_a for the period; c is a correction factor that relates T_a to T_s on a well-watered, fully transpiring vegetation surface.

The correction coefficient c is determined as a seasonal average between T_s and T_a on all pixels where NDVI is greater or equal to 0.8. Preliminary results showed that this coefficient vary little from place to place. However, for localized applications, one is advised to develop local specific ‘c’ values.

$$c = \frac{T_{scold}}{T_a} \quad (16)$$

Where T_{scold} is the satellite-based T_s at the cold pixel where NDVI > 0.8 and T_a is the corresponding air temperature at same location and season. The correction factor for the study area was determined to be 0.989 when both T_s and T_a were processed in Kelvin units which is calculated as the spatially averaged values of available locations and is usually obtained in peak-season irrigated areas and forested regions.

Pre-defined dT and hot boundary condition: Once the T_c is defined as the fraction of the climatological T_a, the hot boundary condition (T_h) can also be defined by a constant difference (dT) that will be added to the T_c of each pixel on a given time period. Thus, the second key component of this method is estimation of dT from energy balance principles for a clear sky condition. The pre-defined dT is solved from the Rn equation solved for a bare, dry soil where ET is assumed to be zero and sensible heat is assumed maximum (Bastiaanssen, 1998), [11]. Since λET and *G* are considered 0.0, the magnitude of the radiation balance for a bare, dry soil with the sensible heat equation can be written as follows:

$$Rn = H = p \times c_p \times dT/r_a \quad (17)$$

Since all Rn is now assumed to be used for sensible heat flux at the hot boundary condition, H will be approximated by the clear-sky net radiation received at an idealized bare and dry surface for a given pixel on a given period. The next step is to estimate the available clear-sky net radiation that is available for a given period so that dT can be solved by rearranging Equation 17. After R_n is estimated for each pixel, the pre-defined dT was solved using R_n, c_p and ρ and r_a as:

$$dT = \frac{R_n \times r_a}{\rho \times c_p} \quad (18)$$

Where c_p is the specific heat of air at constant pressure (1.013 kJ kg^{-1} $^oC^{-1}$); ρ is the density of air which is calculated using Allen *et al.*, 1998 [8]; r_a is the aerodynamic resistance to heat flow from a hypothetical bare and dry surface; it was determined through a quasi-calibration process. Furthermore, comparison with 45 US flux tower ET by Allen *et al.*, 2005, [12] shows that 110 ms^{-1} gives a reasonable agreement and decided in this study to fix the r_a value at 110 ms^{-1}.

Therefore, once the expected dT is determined, Th can be calculated as follows:

$$Th = Tc + dT \quad (19)$$

Estimating potential evapotranspiration (ET_o)

The FAO Penman-Monteith method is used as the sole method for determining ET_o and explicitly incorporates both physiological and aerodynamic parameters.

Methods of crop evapotranspiration (ET_c) estimation

ETc is calculated by multiplying ET_o by K_c, a coefficient expressing the difference in evapotranspiration between the cropped and reference grass surface. In this study the difference were combined into one single coefficient that means the effect of crop transpiration and soil evaporation are combined into a single K_c coefficient. The Crop water requirements (CWR) were calculated on the basis of monthly effective rainfall (P_{eff}) and ET_o, the first being calculated from average rainfall following the Penman-Monteith approach.

$$ET_c = K_c \times ET_o \quad (20)$$

Where ET_c crop evapotranspiration (mm d^{-1}), K_c crop coefficient (dimensionless), ET_o reference crop evapotranspiration (mm d^{-1}).

Results and Discussion

Relationship of Land Surface Temperature (LST) and NDVI in 2002

Figure 4 shows the subset images of the study area created using the ERDAS IMAGINE tool with natural (true) color combination of Band 5, Band 4, and Band 3 correspondingly. This helps to distinguish the distribution of NDVI, LST and ET between different land covers and land features. The figures show Awash River and water storage reservoirs marked with blue color, the sugarcane estate covered by sugarcane crop is marked by dark green color, uncultivated irrigated wet fields are seen as black color and bare agricultural areas are marked by light pink color.

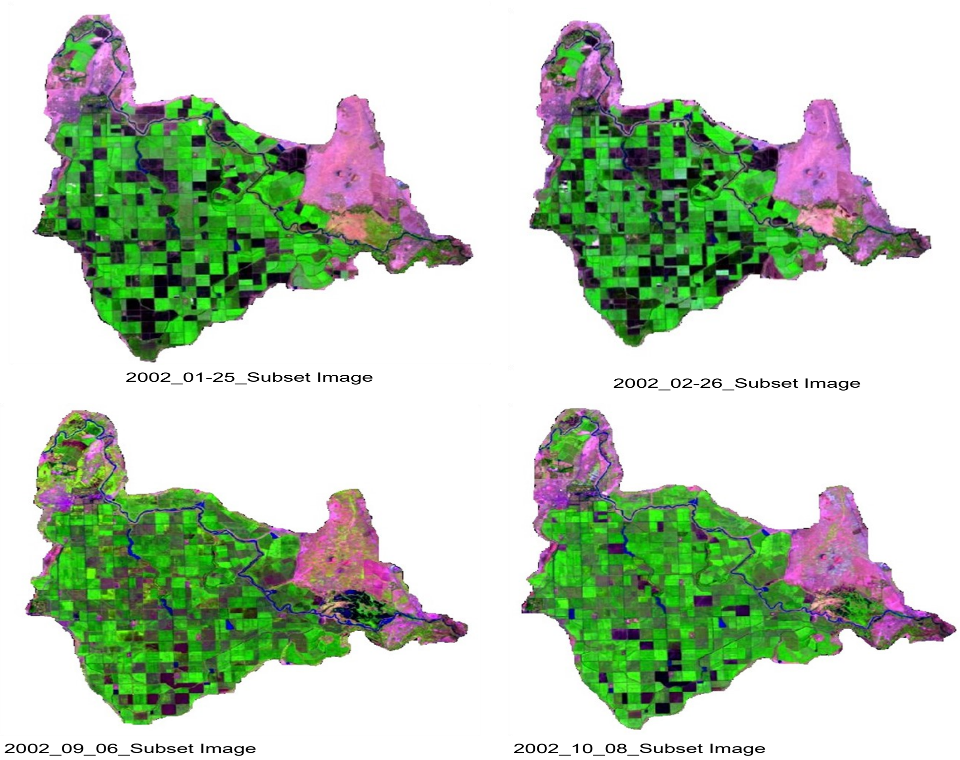


Figure 2. Land cover and features subset images of Wonji Shewa sugarcane estate

The main purpose of this comparison was to show the spatiotemporal variability of land surface temperature which varies with the available moisture on the sugarcane farms, water bodies and vegetation surfaces and it was found to be strongly dependent on the season and moisture availability. Most of the agricultural fields covered by sugarcane plantation and the water storage reservoirs exhibit lower land surface temperature than bare agricultural fields in all images generated and the influence of moisture status was also clearly noted. The images from the predominantly hotter and drier pixels contrast well with the generally cooler and wetter surface covers. There is good linear relationship between NDVI and LST with an r^2 value of Jan, Feb, Sept, and Oct images of 0.72, 0.704, 0.38, and 0.60, respectively.

Table 2. Mean daily temperature and NDVI values of selected days in 2002.

Parame-ters	Statistics	Image dates			
		Jan	Feb	Sept	Oct
LST(K)	Minimum	291	297	297	296
	Maximum	313	325	319	324
	Mean	300	310	304	306
	Standard deviation	4.49	5.89	3.73	4.97
NDVI	Minimum	-0.33	-0.37	-0.23	-0.25
	Maximum	0.77	0.765	0.86	0.81
	Mean	0.314	0.305	0.42	0.37
	Standard deviation	0.16	0.15	0.21	0.20

Spatial and Temporal Distribution of Evapotranspiration

The spatial and temporal variability in the actual evapotranspiration estimated using the SEBAL, SSEB, and $SSEB_{op}$ algorithms are presented and discussed in the following subsections.

Spatial distribution of ET_a during January, 2002

The estimated daily minimum and maximum ET_a values in January using SEBAL, SSEB and $SSEB_{op}$ algorithms were 0.0 and 6.85, 0.0 and 6.78, and 0.05 and 8.25 mm/day respectively with mean and standard deviation values of 2.88 and 1.41, 3.45 and 1.66, and 4.88 and 1.68 respectively. Comparative assessment of standard deviation of ET_a over the sugarcane plantation indicated moderate spatial variability of ET_a due to soil moisture variability which itself is dependent on irrigation application and rainfall availability. Dry periods exhibit greater variability than wetter periods. The SEBAL algorithm ET_a estimation on well irrigated moist sugarcane fields, water storage reservoirs including Awash River was higher than the other cultivated sugarcane plantation fields. It also showed that no moisture was lost by ET in most of bare agricultural fields. SSEB and $SSEB_{op}$ ET_a estimation over moist and cultivated sugarcane fields looked consistent and good. The ET over some bare agricultural fields especially $SSEB_{op}$ contradicted SEBAL results. All the three algorithm results showed that moist surfaces have higher ET_a values. Moreover, dry agricultural fields exhibits generally lower ET_a values. This shows that the remote sensing technique can capture the spatial variability of ET_a . The highest mean ET_a values in the well watered sugarcane fields resulted due to mid-season stage crop developed through irrigation and in swamp of the plain and night water storage reservoirs. Generally higher residual ET_a values were observed over well grown sugarcane fields and water storage areas and lower values were observed over dry agricultural fields. The Root Mean Square Error (RMSE) values between SSEB and SEBAL, $SSEB_{op}$ and SEBAL, and SSEB and $SSEB_{op}$ ET_a estimates were 0.548, 0.548, and 0.99 respectively.

Spatial distribution of ET_a during February 26, 2002

The daily minimum and maximum ET_a values of February 26, 2002 using SEBAL, SSEB and $SSEB_{op}$ algorithms were found to be between 0.0 and 9.36, 0.0 and 7.81, and 0.0 and 8.82 mm/day, respectively. All the three algorithms ET_a estimates on well irrigated and moist sugarcane fields, water storage reservoirs including Awash River were higher than the uncultivated sugarcane plantation fields and bare

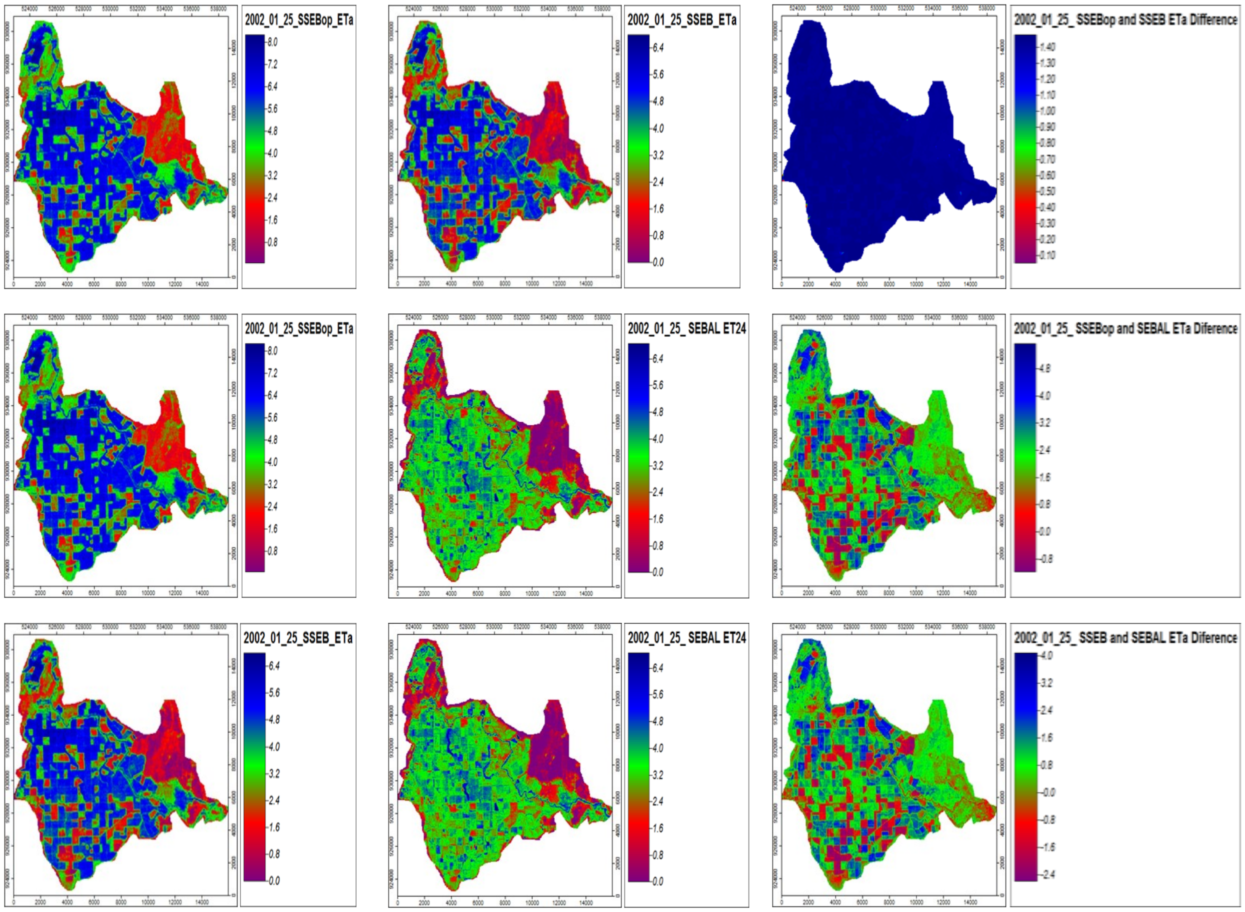


Figure 3. January 25, 2002 actual evapotranspiration (mm/day) at Wonji sugarcane estate

agricultural fields. In summary, it was noted that $SSEB_{op}$ and SSEB ET_a estimates were closer and consistent over fully covered and well grown sugarcane fields, and also were higher than SEBAL ET_a estimates. The SEBAL algorithm ET_a estimates over water storage areas were higher than $SSEB_{op}$ and SSEB ET_a estimates. On the contrary, SEBAL ET_a estimates over uncultivated sugarcane fields were observed to be higher than $SSEB_{op}$ and SSEB ET_a estimates. Over dry agricultural fields, the ET_a estimates of all the three algorithms were close to each other. The Root Mean Square Error (RMSE) values of 0.739 between SSEB and SEBAL, 0.753 between $SSEB_{op}$ and SEBAL, and 0.994 between SSEB and $SSEB_{op}$ ET_a were observed.

Spatial distribution of ET_a during September 06, 2002

The September 06, 2002 minimum and maximum daily ET_a values were 0.0 and 3.61 mm/day for SEBAL, 0.0 and 3.65 mm/day for SSEB and 0.2 and 4.0 mm/day for $SSEB_{op}$ algorithms. All the three algorithms ET_a estimates on well grown and moist sugarcane fields, night storage reservoirs and on the Awash River were higher than other dry agricultural fields. September is end of the rainy month and the soil should contain more moisture for subsequent ET, but generally all of the three algorithms ET_a estimates were lower due to higher humidity and a decreased solar radiation associated with the effect cloud cover at the satellite overpass time. ET_a estimate for $SSEB_{op}$, SSEB and SEBAL during September were close to each other and looked consistent and higher over the entire sugarcane estate. The Root Mean Square Error (RMSE) values were 0.847 for SSEB and SEBAL, 0.846 for $SSEB_{op}$, and SEBAL, and 0.999 for SSEB and $SSEB_{op}$ ETa estimates.

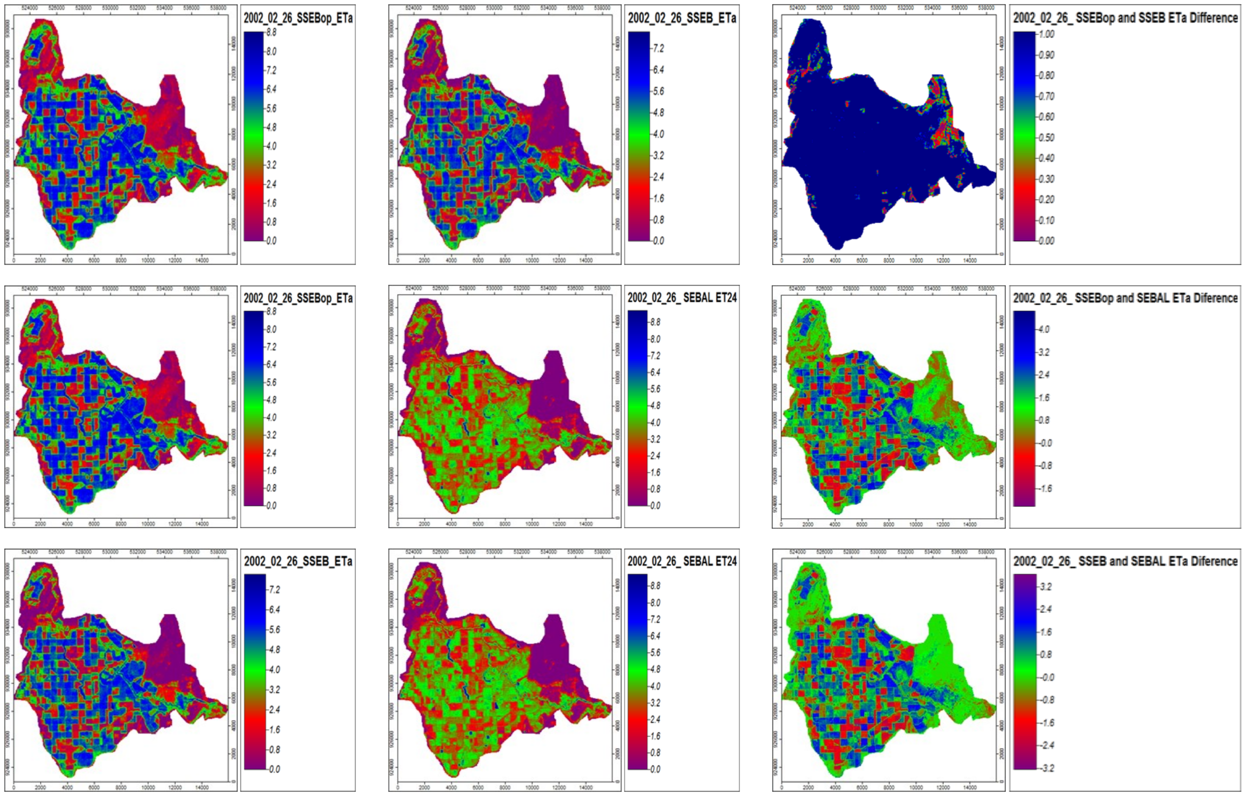


Figure 4. February 26, 2002 actual evapotranspiration (mm/day) at Wonji sugar estate

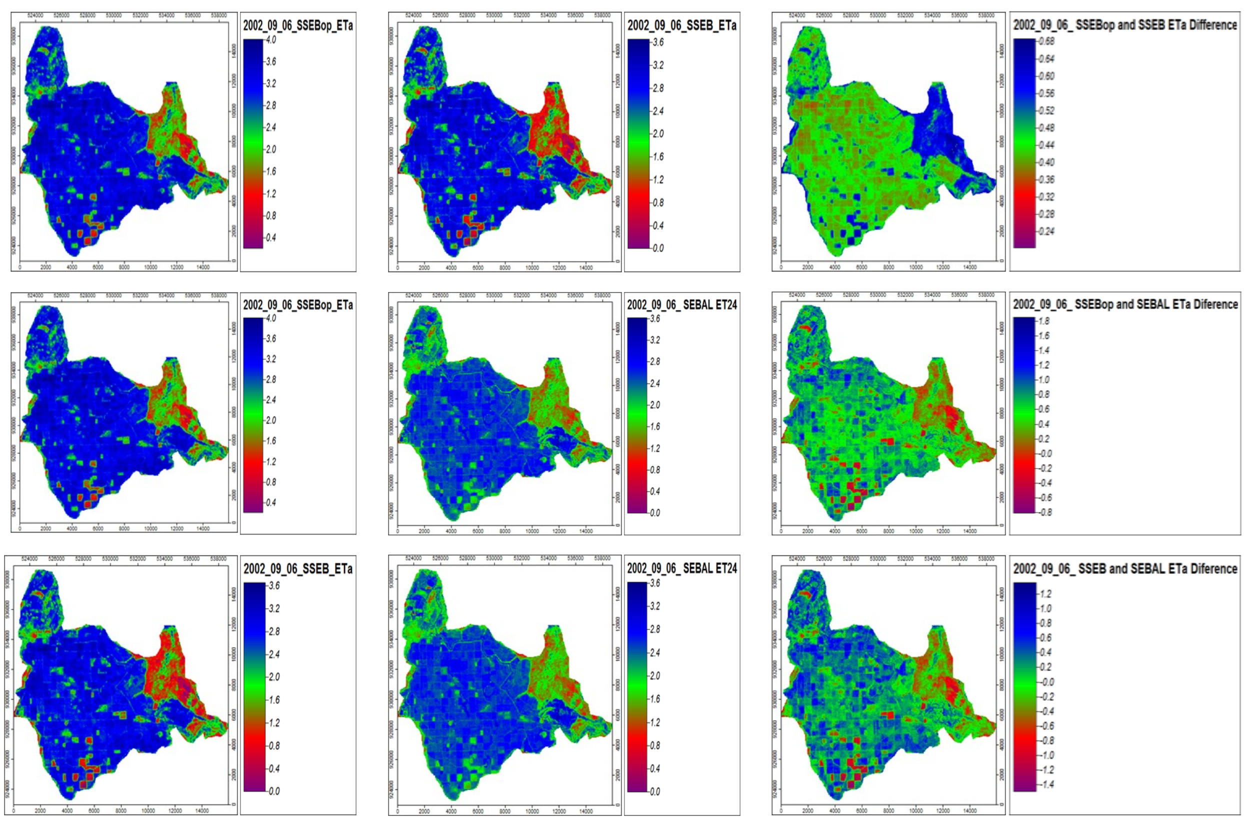
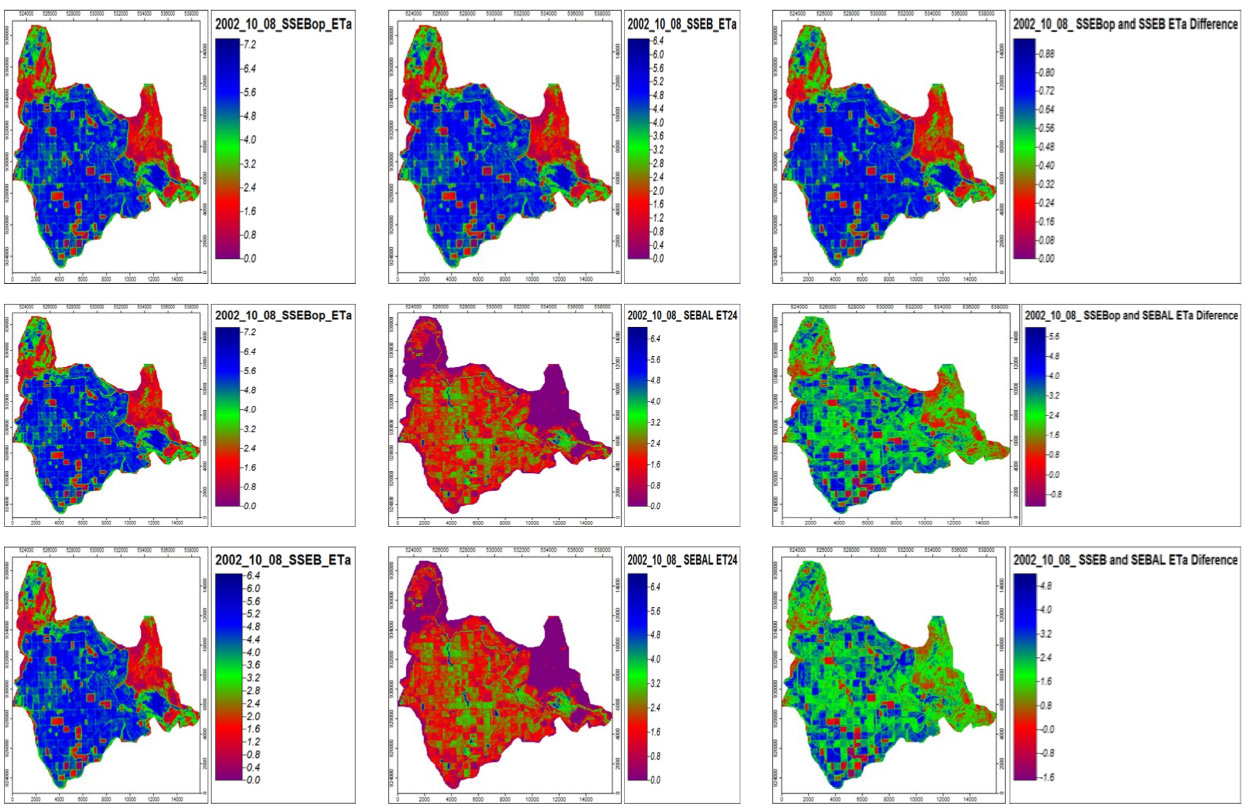


Figure 5. September 6, 2002 actual evapotranspiration (mm/day) at Wonji sugar estate

Spatial distribution of ET_a during October 8, 2002

The estimated daily minimum and maximum ET_a values on October 8,2002 using SEBAL, SSEB and $SSEB_{op}$ algorithms were 0.0 and 6.83, 0.0 and 6.46, and 0.0and 7.4 mm/day, respectively. The corresponding mean and standard deviation values respectively were 1.57 and 1.08 for SEBAL, 3.62 and 1.46 for SSEB, and 4.18 and 1.65 for $SSEB_{op}$. The ET_a values obtained on bare agricultural fields suggested that there were still adequate residual moisture from the preceding rainy months contributing to the overall ET. All the three algorithm results consistently exhibited that moist surfaces have higher ET_a values as compared to dry agricultural fields. During October 2002, the optimum climatic condition to satisfy the evaporative demand of the area were higher and the standard deviation of ET_a over the sugarcane plantation were lower indicating lower spatial variability of ET_a in relation to the soil moisture variability. The residual difference of ET_a estimates between $SSEB_{op}$ and SSEB varied from 0.4 – 0.94 on moist sugarcane fields, and 0.0 – 0.39 mm/day over dry agricultural lands. The ranges of the residual difference of ET_a estimates between $SSEB_{op}$ and SEBAL were -1.29 – 5.98 mm/day, between SSEB and SEBAL were from -1.7 – 5.2 mm/day. The Root Mean Square Error (RMSE) value between SSEB and SEBAL, $SSEB_{op}$ and SEBAL, and SSEB and $SSEB_{op}$ ETa estimation were 0.573, 0.573, and 1.00, respectively.

Figure 6. October 8, 2002 daily evapotranspiration (mm/day) at Wonji sugar estate



Crop and Irrigation Water Requirement (CWR)

As shown in Table 4, estimates of the average annual water consumption by $SSEB_{op}$ were 40 % higher than SEBAL, 21% higher than SSEB and 55 % higher than MOD16. The mean annual ET_a estimated for the whole estate were 107 Mm^3, 140 Mm^3, and 178 Mm^3 using SEBAL, SSEB and $SSEB_{op}$, respectively and the mean annual PET was 219Mm^3.

Table 3. Monthly and annual average actual ET for Wonji Shoa sugar cane Estate using different algorithms

Month	Monthly Average Estates Consumptive Water Use (Mm3)							
	SSEBAL		SSEB		$SSEB_{op}$		MOD16	
	mm/day	mm/month	mm/day	mm/month	mm/day	mm/month	mm/day	mm/month
Jan	2.88	11	3.45	13	4.88	18	1.23	5
Feb	2.82	10	3.01	11	3.95	15	1.26	5
Sept	2.31	8	2.46	9	2.92	11	2.66	10
Oct	1.57	6	3.62	13	4.18	15	1.99	7
Annual Estates Consumptive Use Estimates (Mm3)								
Average	2.39	107	3.14	140	3.98	178	1.79	80

The required timing and amount of applied water for the sugarcane were calculated based upon the prevailing climatic conditions, growing season, growing and harvesting date, root depth, and allowable depletion, soil physical properties, availability of water resources, field water losses and useful rainfall and therefore the CWR and irrigation water requirement (IR) of sugarcane crop were computed by considering the field water balance in the crop root zone. The total CWR, IR and effective rain for January and March planted sugarcane were estimated to be 2468.8, 2061.6 and 423.8 mm/yr and 2281.9, 1851.0 and 437.8 mm/yr respectively.

Conclusions and Recommendations

Conclusions

In this research, ET estimates were made using $SSEB_{op}$, SSEB, and SEBAL algorithms for the Wonji Shoa Sugarcane Estate. Landsat7 ETM+ images of four days in 2002, (i.e. January 25, February, 26, September 6 and October, 8 2002), were used and the actual ET was computed using the three algorithms. The result of this study generally demonstrates that these three algorithms could be used to provide vital information on evaporative loss and moisture condition of the sugarcane estate. It can be considered as operational and feasible methods to predict actual ET and to improve water management and modeling processes in the sugarcane estate. The major findings of the study clearly showed that remote sensing can have a tremendous potential for estimating evapotranspiration and water management at farm and basin level. The simple averaged annual actual evapotranspiration by SEBAL, SSEB and SSEBop showed that the estate losses 107, 140, 178, and 80 Mm^3 of water per year, respectively due to ET and these values are closer to actual evaporation need to be substantiated through field measurement.

The analysis of actual ET in the sugarcane estate estimated by remote sensing method revealed large spatial and temporal variability which closely followed the variability in soil moisture and land use characteristics which otherwise would have been difficult to get it using the indirect methods and the evaporative fraction (parameter determines energy partitioning) in the sugarcane estate, exhibits similar regional distribution patterns as evaporation rate in the sugarcane estate.

Recommendations

As a recommendation, since field measurements were not done in this research, it is not possible to say one method is better than the other. We now have adapted the algorithms and before recommending any of the methods for actual use these results should be tested and validated with field measurements in different environments. The integration of remote sensing techniques and distributed hydrological models can produce better results and rerunning the model using fine spatial resolution product is recommended.

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THEME TWO

RENEWABLE ENERGY

Water Balance and Reservoir operation Analysis for Optimal Power production for Cascaded Hydropower plants

(A case of Upper Omo-gibe River Basin, Ethiopia)

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Abstract

Increasing competition for water across sectors (agriculture, industries, domestic, and power generation) increases the importance of the river basin as the appropriate unit of analysis to address the challenges facing in water resources management. As per the national level statistics of power production and distribution, Ethiiopian has been facing an acute shortage of power. Hence, this study mainly focuses on water balance and reservoir operation analysis for optimal power production for cascaded hydropower plants in the upper Omo-Gibe river basin. SWAT model was used to simulate the current inflow to the cascade reservoirs. The performance of the model has been evaluated through calibration and validation process. Model sensitivity analysis at Abelti gauging station shows ESCO, Soil_Z and Alpha_Bf as the most sensitive parameters. The overall evaluation indicated that SWAT model satisfactorily simulates river flows in the study area with R^2 of 0.84 and NSE of 0.81 during calibration. During validation, R^2 of 0.79 and NSE of 0.69 were obtained.HEC-ResSim was used to simulate reservoir operation of existing cascaded hydropower plants in Upper Omo-Gibe basin. Three water resources development scenarios were applied to analyze reservoir operation of the basin (Scenario T, Scenario A and Scenario B). Scenario-A result shows that an average annual energy output of 786.97 and 1806.40 GWh/year for Gibe I and Gibe II respectively. The mean maximum pool level in Gilgel Gibe-I and Gibe-III was estimated to be 1671 m.a.s.l and 891.9m.a.s.l.in October whereas the minimum mean pool level was estimated to be 1658.5 m.a.s.l. in May and 859.6m.a.s.l.in June respectively. In scenario B, the annual power production in Gibe III 6514.00 GWh/year. The mean maximum pool level in Gibe-III was 895m.a.s.l.in September whereas the minimum mean pool level in Gibe-III pool was 860 m.a.s.l. in July.

Key words-Water balance, Reservoir operation, SWAT model, HEC-ResSim, Omo-Gibe basin

Introduction

Ethiopia is a prosperous country endowed with abundant water resources having 12 river basins. However, they have yet to contribute more than a fraction of their potential to achieve the national economic and social development goals. Very little has been done still in harnessing the country's water resources as engines to propel national economic and social development.

Increasing competition for water across sectors (agriculture, industries, domestic, and power generation) increases the importance of the river basin as the appropriate unit of analysis to address the challenges facing in water resources management; and to provide essential information for policy makers in their resource allocation decisions.

With a view to derive the maximum possible benefit from the available water resources, the Ethiopian government ratified water resources management policies which aimed at utilizing the available water resources of the country for socioeconomic development of on sustainable basis[1].

Water shortages and poor water management leads to loss of agricultural production, lack of energy, increase in malnutrition and disease, reduced economic growth, social instability, and conflict [2]. A large share of water to meet new demands must come from water saved from existing uses through a comprehensive reform of water policy. Hence, this study is aimed to estimate the water balance components of the basin and analyze the reservoir operation of the basin for optimal production of the cascaded hydro power plants of the basin. In this study, SWAT model was used for estimating Water balance components and HEC-ResSiM model for reservoir operation analysis for cascaded hydro power plants in the Upper Omo-Gibe basin.

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. 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. The western watershed of Omo-Gibe basin is the range of hills and mountains that separate it from the Baro-AkoboBasin (fig.1).

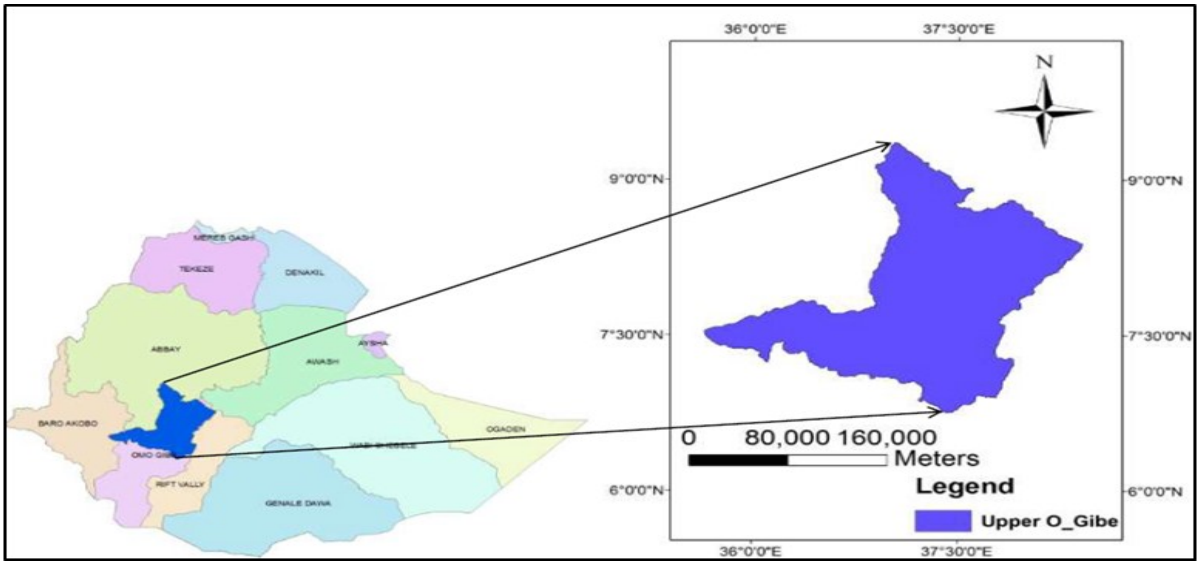


Figure 1: Location map of Omo-Gibe Basin

Annual rainfall varies from 400 mm in the extreme south lowland to 1900 mm in the highland with the average being 1140 mm. The mean annual temperature in the basin varies from less than 17°C in the west highlands to over 29°C in the south lowlands [3].Omo-Gibe basin is characterized by its physical variation. The northern two-thirds of the basin has mountainous to hilly terrain cut by deeply incised gorges of the Omo, Gojeb, Gilgel-Gibe Rivers, while the southern one-third of the basin is a flat alluvial plain punctuated by hilly areas. The northern and central half of the basin lies at an altitude greater than 1500ma.s.l with maximum elevation of 3360m.a.s.l and the plains of the lower Omo lies between 400-500m a.s.l [4].Land use pattern of northern catchment is characterized by extensive cultivation with increased land pressure. The dominant soils in the basin are Chromic Luvisols and calcic Xerosols.

Materials and Methods

Meteorological data was collected from the National Meteorological Agency (NMA). A request for daily rainfall, maximum and minimum temperature of 18 years period from1987-2004 data of nine rainfall stations was collected. The methodology includes data collection from institutions such as Ministry of water resources, Irrigation and Electricity and National Meteorological Agency. After collecting the necessary data for the research, filling of missed data and consistent checking have been made. Input data were prepared, watershed was delineated, HRU was analyzed , write input table was carried out and simulation of the model was done by SWAT model whereas watershed setup, reservoir network and simulation module were done by HEC-ResSim model.

Muskingum flood routing method was applied for determination of inflow into Gibe III reservoir. SWAT model is calibrated validated against the observed discharge to determine best parameters that represents the physical processes of the basin. Next, the mode was used for estimating water balance components of the basin.

Data analysis

In this study, normal ratio method was used to complete missing data of all stations. Double mass curve was used to check the homogeneity and consistency of rainfall as well for adjustment of inconsistent data. According to the double mass curves all the stations were found to be consistent and no need of correction. There are number of methods to estimate potential evapotranspiration. The Penman-Monteith method is recommended as the sole method for determining reference evapotranspiration (ETo) when the standard meteorological variables including air temperature, relative humidity and sunshine hours data are available [5].

Result and discussions

Sensitive analysis of model parameter

The sensitivity analysis was done in two steps. Initially the sensitivity of 27 SWAT - input parameters was tested by trial and error, and it was found that ESCO,Soil_Z, Alpha_Bf, Revapmn and Soil_Awc parameters have a significant effect on the stream flow. As this manual Sensitivity analysis turned out to be too tedious and not exhaustive enough, the automatic sensitivity analysis implemented in SWAT by means of the SWAT-CUP interface [6] was considered in the second round.

Model calibration result

Model parameters were calibrated manually followed by SWAT-Cup until satisfactory agreement between simulated and observed flow was obtained. Flow calibration was made by using sixteen years (1985-2000) hydro-meteorological data the simulated monthly flow matched well with the observed monthly flow (R^2=0.84, Nash-Sutcliffe coefficient of (NSE) =0.81 and mean deviation of D= -12%. Hence, SWAT has the ability to predict the water potential of the basin.

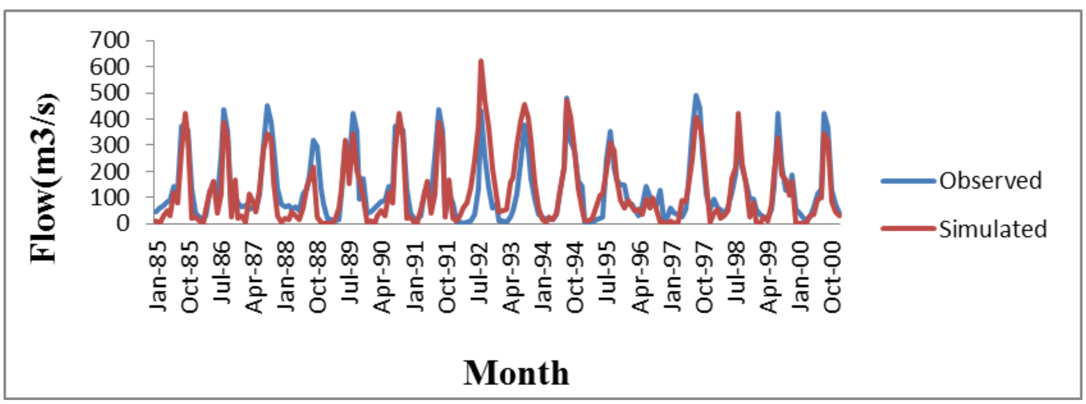


Figure 2: Mean monthly simulated and observed flow for Abelti station during calibration period

Flow validation at Abelti station

The model performance in validation was carried out from 2001-2006.Accordingly, good match between measured and simulated flow was obtained in validation period (R2=0.79 and NSE=0.69).The model captures the peak flow and simulated flow follows the pattern of observed flow.

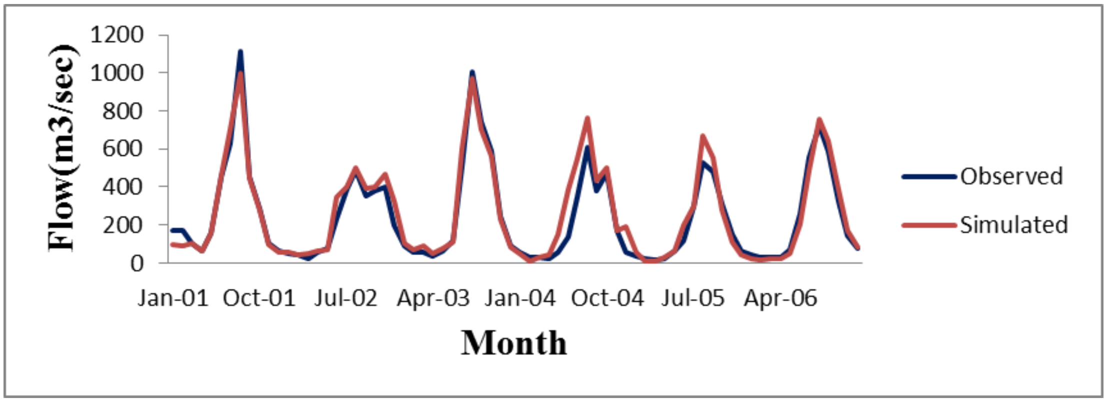
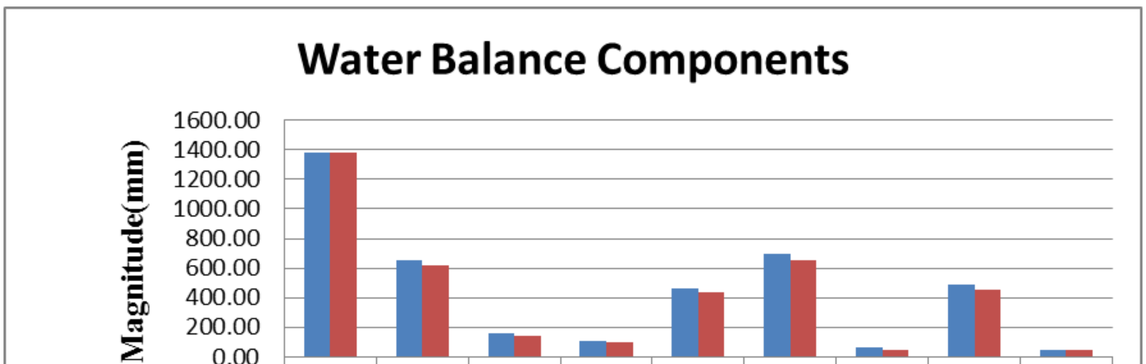


Figure 3: Mean monthly simulated and observed flow for Abelti gauging station during validation period

Water Balance Components of the Basin

Water balance components before and after calibration period in upper Omo-Gibe basin is shown in figure 6below. Therefore, water potential of the basin for different water resource development can be quantified once knowing the water balance components of the basin.



	RF	ET	SUR-Q	LAT-Q	GW-Q	WYLD	SW	PERC	LOSS
Before Calibration	1380.90	650.24	155.90	110.24	466.82	700.53	67.78	491.67	50.23
Aftre Calibration	1380.90	620.23	141.56	99.12	434.90	650.95	49.67	450.17	45.73

Figure 4: Water balance components of Upper Omo-Gibe basin

HEC-ResSim Simulation Results of Gibe Cascade Reservoirs System

Simulation for testing the model

In this scenario, there was no any water resource development in the basin. The performance of the model was evaluated at Gibe III by Nash-Sutcliffe efficiency (0.76), which is acceptable.

Simulation for scenario A

In this scenario, Gilgel Gibe I and Gibe II Cascaded Reservoir operation were analyzed. Operation of these reservoirs have been driven by an operating rule called Tandem rule which seek to produce continuous power in each day without having the reservoir drop below minimum operating level (MOL) and seek to minimize spillage in any day.

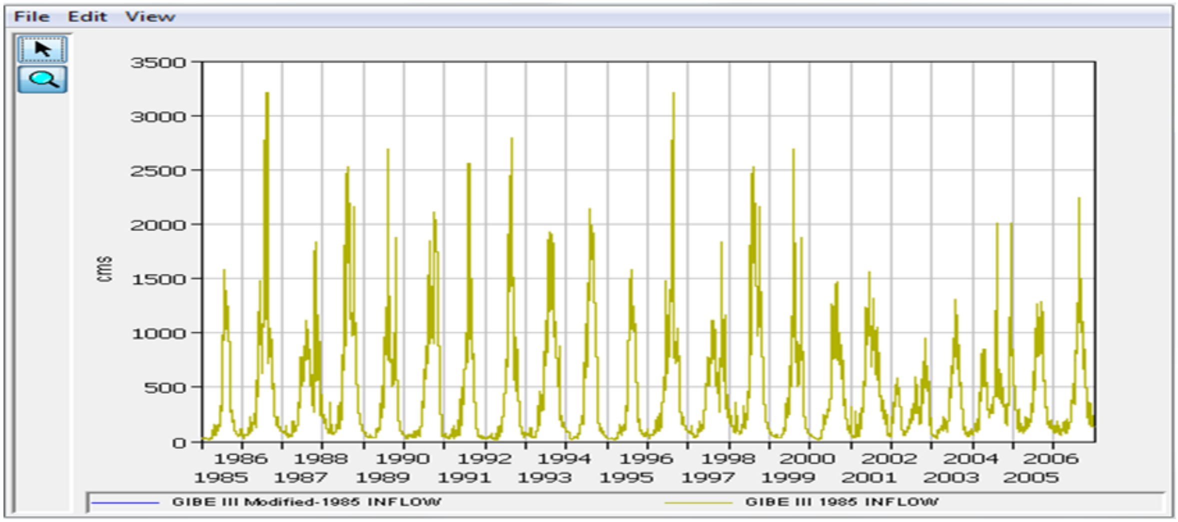


Figure 5: Simulation of Gibe III at natural condition

Simulation for scenario A

In this scenario, Gilgel Gibe I and Gibe II Cascaded Reservoir operation were analyzed. Operation of these reservoirs have been driven by an operating rule called Tandem rule which seek to produce continuous power in each day without having the reservoir drop below minimum operating level (MOL) and seek to minimize spillage in any day.

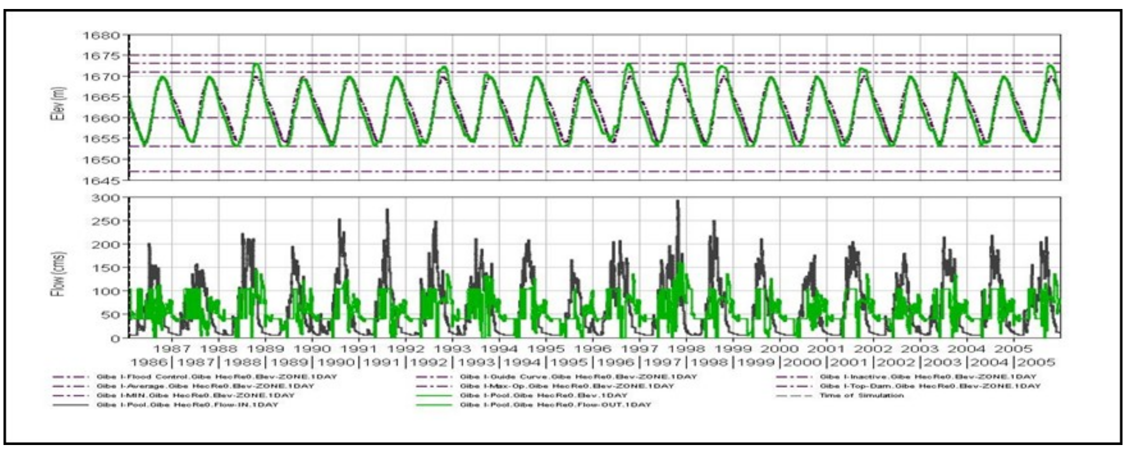


Fig-ure 6: HEC-ReSism simulated Gibe-I pool level, inflows and out flow for scenario A

From figure 6, the upper plot region shows the computed reservoir pool level, guide curve and operating zone. The lower region shows the computed pool inflows and outflow. Here, the reservoir guide curve fall above conservation zone throughout the simulation period and hence the reservoir releases more water than entering into the pool.

Simulation in Scenario B

In this scenario, water resource developments of Gibe –I, Gibe –II and Gibe –III were analyzed. Regulatedwater ws released into Gibe III due to Gibe I and Gibe II reservoirs

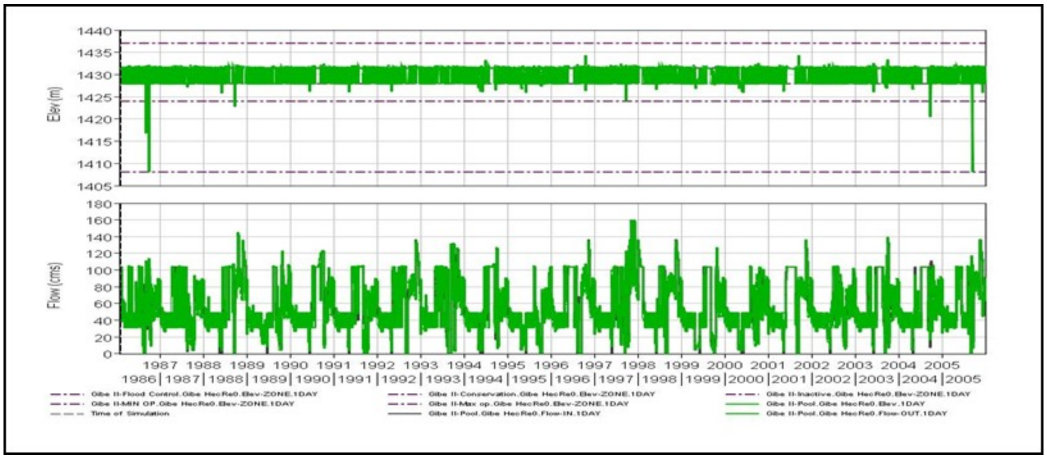


Figure 7: HEC-ReSism simulated Gibe-II pool level, inflows and out flow for scenario A

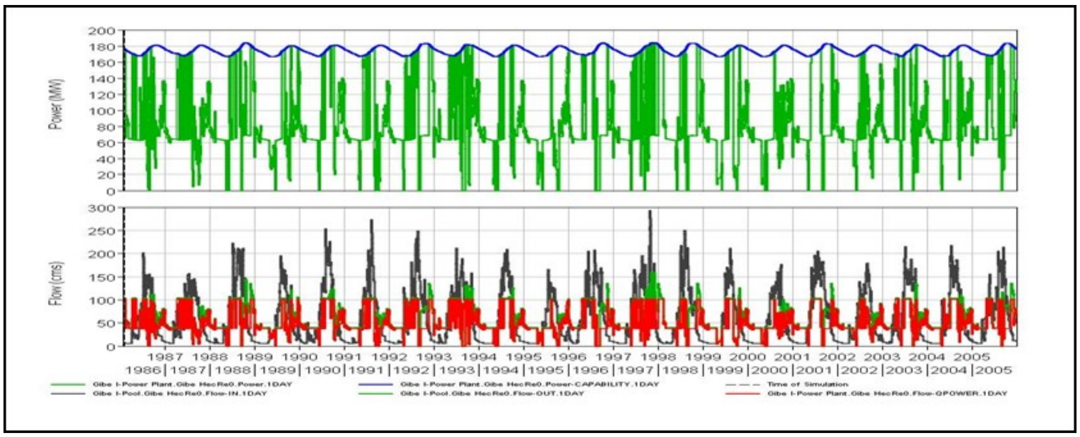


Figure 8: Simulated Gilgel Gibe-I power plant operation

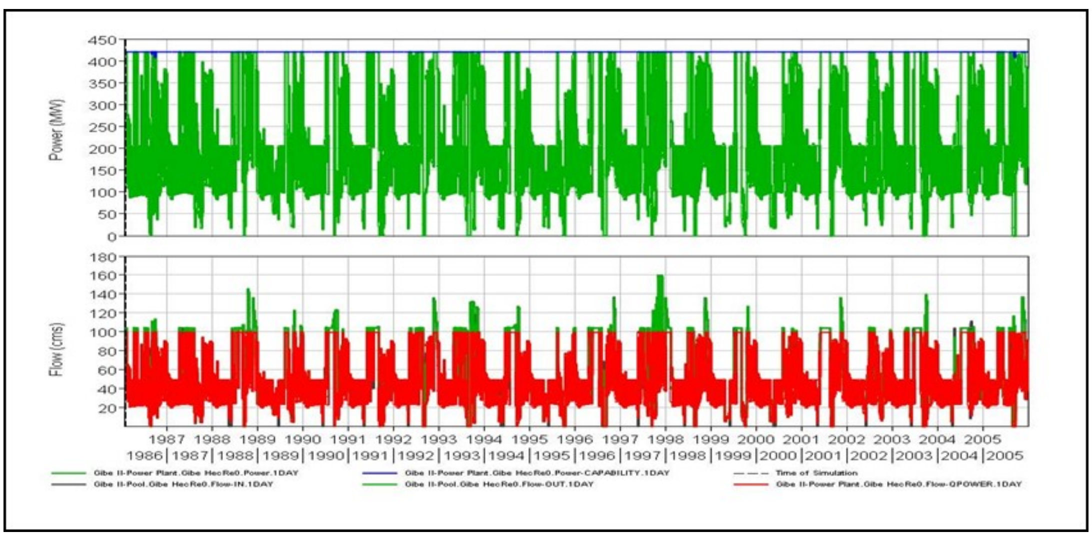


Figure 9: Simulated Gilgel Gibe-II power plant operation

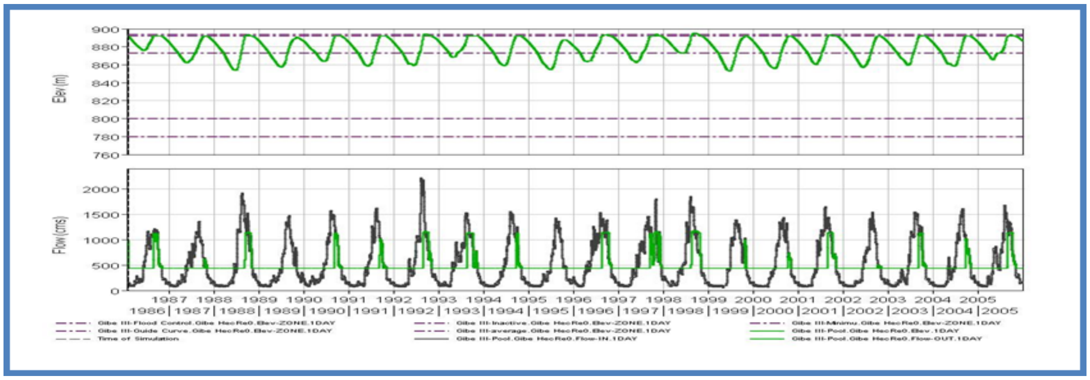


Figure 10: HEC-ReSism simulated Gibe-III pool level, inflows and out flow for scenario B

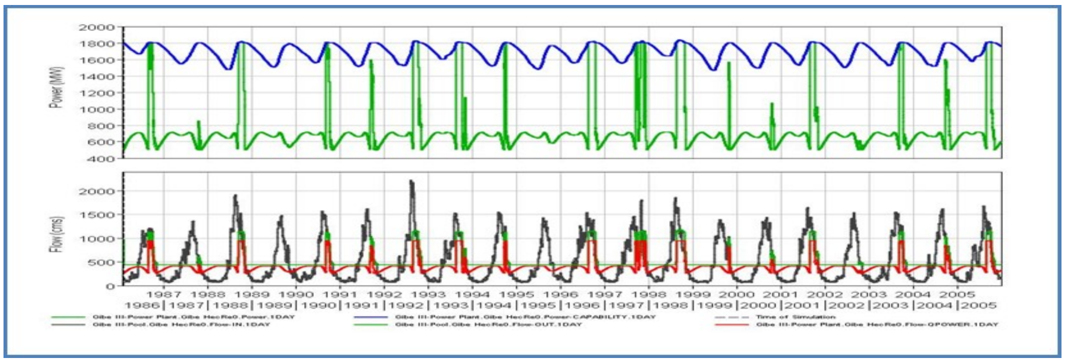


Figure 11: HEC-ReSism simulated Gibe-III power production for scenario B

Conclusion

The SWAT model was adequately reasonable to adopt for estimation of water balance components at the cascade reservoirs in the semi-ungagedOmo-Gibe river basin. Gibe III reservoir inflow was estimated by using the Muskingum routing method SWAT model was calibrated, validated and sensitivity analysis was done in basin. The sensitivity analysis shows that ESCO, Soil_Z, Alpha_Bf, Revapmm and Soil_Awc were the five most sensitive parameters. SWAT model was adequately reasonable to adopt for semi-ungauged Omo river basin even though it slightly overestimates the flow with the model performance criteria of R2=0.84, NSE=0.81 for calibration, and R2=0.79, NSE=0.69 for validation. HEC-ResSim model was applied for the analysis of reservoir operation and optimal power production in Upper Omo-Gibe basin. The results of annual average hydropower energy generated by the model for each reservoirs system is nearly the same as the EEPCO’s study results. The annual average hydropower energy generated in scenario A in Gilgel Gibe I and II and are 786.97GWh/year and 1806.40GWh/year and respectively by HEC-ResSim model whereas in scenario B, 865.7, 1987.0, 7090.6 and 1787.1, GWh/year in Gibe I, II and III respectively.

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Biogas Production Potential of Brewers Spent Grain: The Case of St. George Brewery

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Abstract

The production of biogas from brewers spent grains and cow dung mixtures were studied. Physico-chemical characteristics of brewer's spent grain and cow dung: total solids, volatile solids and carbon to nitrogen ratio were determined. The amount and quality of biogas production was measured by water displacement method. It was found that spent grain has a total and volatile solid content of 94.95 and 90.04 % respectively. Four treatments of brewer's spent grain (BSG) mixed with cow dung (CD) in different proportions as: T_1 (75% BSG: 25% CD), T_2 (50% BSG: 50% CD), T_3 (25 BSG: 75% CD) and T_4 (100% CD) were studied in bench scale anaerobic digestion to select optimum combination that produced the highest amount of biogas. On batch experiments of 72 days retention time, and room temperature, the combination of spent grain and cow dung in the ratio 1:1 produced maximum biogas of 69.6 ml g^{-1} total solid added with the highest (69%) biogas quality. The biogas quality obtained for the treatments were in the range of 60.8-69%. Experimental findings further showed the effluent slurry is in a suitable pH range and has necessary nutrients which can be used as bio fertilizer.

***Keywords**:* Brewers spent grain, cow dung, anaerobic digestion, biogas.

Introduction:

A driving force in the field of renewable energy is to develop systems which minimize dangerous emissions to the environment, yet deliver the opportunity to create energy options and minimize ecological footprint. In this respect, bioenergetics represents a practically ideal case as compared to the combustion of fossil fuels, because combustion of biofuels does not disturb the planet-wide CO_2 balance[1].

During the past decades, anaerobic digestion (AD) of organic matter has been used as a suitable method for treatment of organic biodegradable waste and production of energy from combustion of biogas.

The brewing industry generates relatively large amounts of by-products and wastes: spent grain, spent hops and yeast being the most common. Brewery spent grain is the major byproduct, corresponding to around 85% of total by-products generated in the brewing process[2].

Spent grains are the by-products of mashing process; which is one of the initial operations in brewery in order to solubilize the malt and cereal grains to ensure adequate extraction of the wort: water with extracted matter. The filtered wort is subsequently brewed to beer, whereas the BSG is traditionally used as a relatively low value cattle feed.

Production of methane rich biogas through anaerobic digestion of organic material provides versatile career of renewable energy as methane can be used as a substitute for fossil fuels and reduces its environmental impact. This calls for widening the scope of anaerobic digestion technology by tapping organic material like BSG and other industrial wastes that produce huge amount of residues which can be used as feedstock for biogas production.

Methology

General procedures

Sample BSG was sun dried, grinded and mixed with cow dung in different proportions to modulate C/N ratio. The effect of substrate on gas yield was monitored in the laboratory on batch digestion.

Total solids and volatile solids determination

The total solid and volatile solid content of the feedstocks was calculated according to American Public Health Association Standard[3].

Organic Carbon determination

Estimate of the amount of Carbon in a feed stock component was calculated from the volatile solids (VS) content of the dried material[4] by applying the equation

$$\% \text{ Carbon} = \frac{\% VS}{1.8} * 100 \qquad \ldots\ldots 1$$

Nitrogen determination

The total nitrogen content of BSG and cow dung was determined by Kjeldahl procedure.

Preparation of feed stock composition of the digesters

The amount of TS in the digesters was fixed to be 100 g by taking the digesters volume in to consideration. Feed stocks were mixed with tap water to get about 8% TS solution for better bio gas production[5]. This was the basis for the determination of the amount of water to be added for any given mass of total solid.

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This was the basis for the determination of the amount of water to be added for any given mass of total solid.

Experimental set up

The study was conducted by varying the proportion of feed stock to be co-digested while the amount of total solid was kept constant. The batch experiment was performed in a series of 2.5L amber glass bottles. Twelve anaerobic digesters were constructed in bench-scale experimental set up.

Figure 1: Bio gas Digestors set up

Gas production and quality of biogas

Gas production and quality was measured by downward water displacement method. The gas produced was bubbled through a 15% Sodium hydroxide solution to estimate the quality of gas.

Macro plant nutrient analysis of the slurry

Total nitrogen, Available potassium and phosphorous were analyzed by Kjeldahl procedure. Phosphorous was determined by Olsen method while potassium was determined using flame photometric method.

Result and Discussions

Table 1: Characteristics of the feed stock

Parameter	Spent Grain (%)	Cow Dung (%)
TS	94.95	16.4
VS	89.04	88.67
MC	5.05	83.6
Ash	10.96	11.33

High volatile solid content in BSG shows that its large fraction is biodegradable. This reveals, BSG has high potential for utilization as biodegradable substrate for biogas production. Organic substances containing more than 60 % of volatile solid are considered as good substrates for anaerobic digestion[6].

Table 2 :Carbon and Nitrogen content of the feed stocks

Parameter	**Spent Grain (%)**	**Cow Dung (%)**
C	53	49.3
N	3.81	1.81
C:N	13.91	27.2

Optimum C/N ratios in anaerobic digesters are between 10 and 30[9]. BSG has a lower Carbon to nitrogen ratio of 13.91 %. It is important to mix materials of lower C: N ratio with higher ones for optimum gas production[7]. Cow dung which was used to act as inoculums in this study has a better C: N ratio than BSG. Cow dung was also used as a material that can modulate the C: N ratio of brewer's spent grain.

Temperature situation of the room

The ambient temperature of the room where digestion took place was monitored three times a day throughout the digestion period and the result is shown in figure 2.

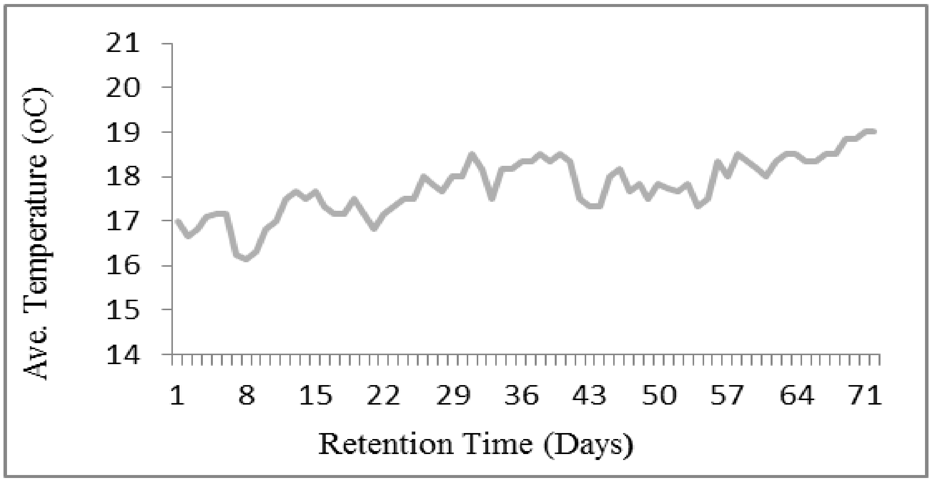

Figure 2: Ambient temperature situation of the digesters

The daily mean minimum and maximum temperature reading of the room during the digestion period was 16.1 and 19 ^{o}C respectively. It can be concluded from this experiment that, the anaerobic digestion of brewers spent grain with co-substrate; cow dung, is feasible at the sycrophilic temperature range.

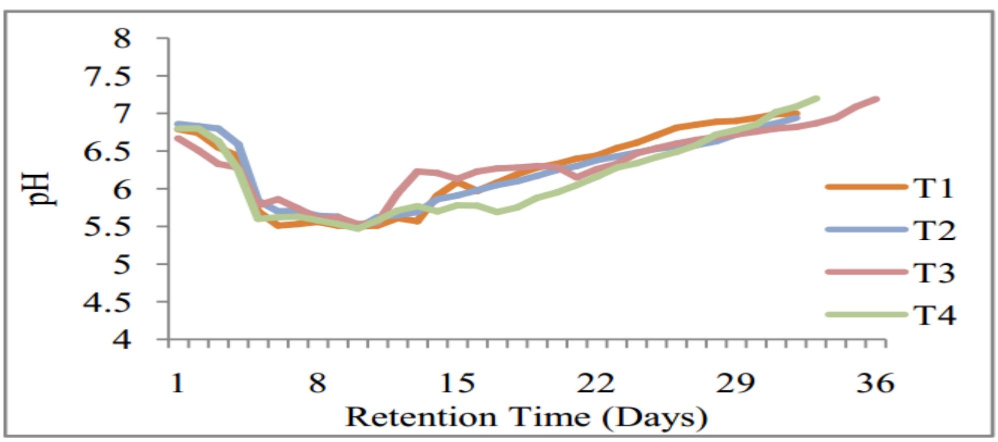

Figure 3: pH value of the digesters throughout the digestion period

The pH in a biogas digester is a function of retention time. A decrease in the process pH was observed in the initial period of digestion and this is due to organic acid formation by acid forming bacteria[8]. After a period of three weeks the pH started increasing back from a pH of about 5.5. After six weeks of the digestion period, pH of the slurry was above 6.3 where ammonia production by methanogenic bacteria resulted an increase in pH. Overall, pH of the treatments was between 5.5 and 7.2 throughout the digestion period. This experiment proves the feasibility of producing biogas in a pH range of 5.5 to 7.2.

Total biogas and methane production

Total biogas and its quality were monitored for about 72 days in batch experimental set up.

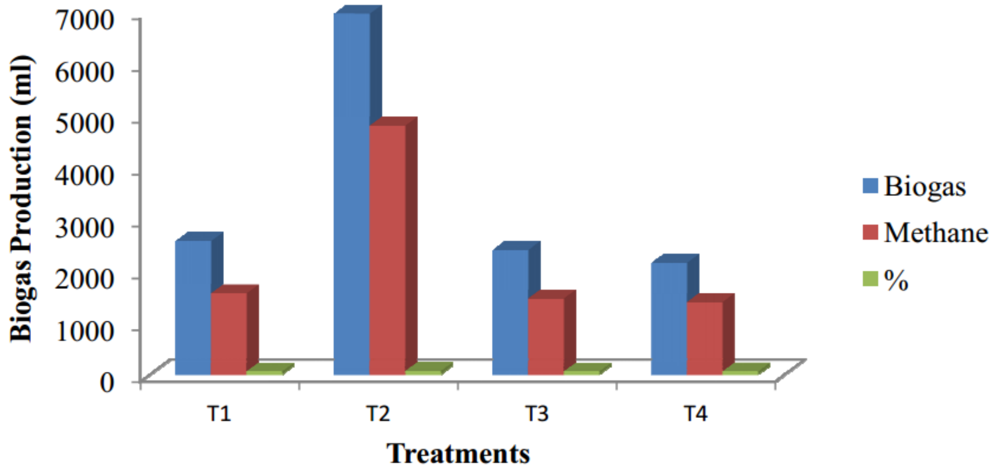

Figure 4: Total biogas Production

The total biogas production of the four treatments is shown in figure 4. It was found that, the highest (6961.7 ml) amount of biogas production was observed for T_2 with a 1:1 ratio of BSG to cow dung. Other treatments produced lower volume of biogas. The treatment with 3:1 ratio produced 2579.7 ml, where as T_3 and T_4 produced 2409 and 2159.7 ml of biogas respectively.

Mixing BSG with cow dung in the 50: 50 proportion resulted an increase in total biogas yield of 222.3 % when compared to biogas produced from the conventional feed stock.

The best combination of BSG with cow dung for optimum biogas production was found to be 50: 50 ratio where, a total solid mass of 50g BSG was mixed with a total solid mass of 50g cow dung. This shows that the biogas yield of BSG could be maximized by combining BSG with cow dung in the 1:1 ratio on total solid basis.

Quality of the gas produced

Biogas quality is an important economic factor in anaerobic digestion, since it is the methane (biogas quality) that makes an efficient energy source.

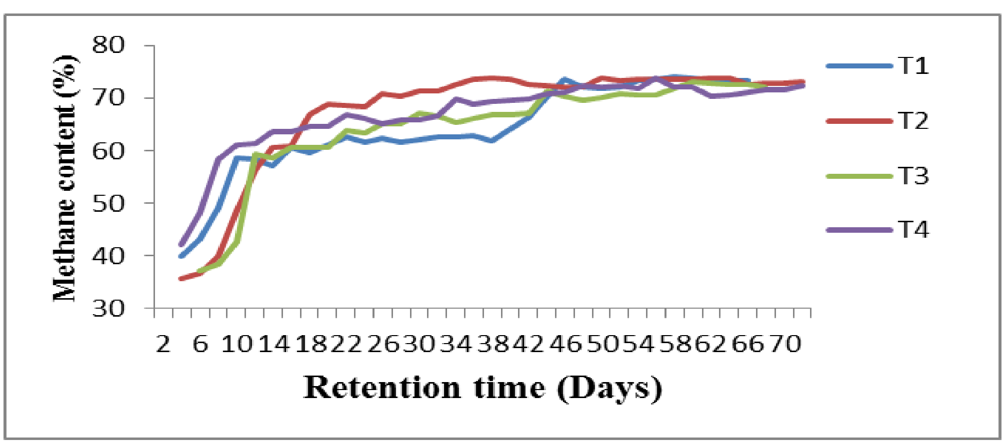

Figure 5: Bio gas quality of the treatments

It can be deducted from figure 5 that, the quality of biogas was below 48 % in the first week of the digestion period. The biggest differences in biogas quality were observed in the first two weeks of the retention time. Percentage of methane showed an increasing trend and stability as retention time goes. In the last four weeks of the retention time percentage of methane increased and became stable in the range 65 to 73%. This shows that quality of biogas increases with retention time. Methane content and hence its calorific value increases with increasing retention time[9]. Percentage composition of methane for all treatments was between 60 and 69. This value is in par with the theoretical methane value of 55 – 80%[9].

The supplementation of BSG to cow dung can be advantageously used for economic biogas generation. This shows that mixing of these two materials in different proportions enhanced the gas production by utilizing more of the complex substrates than when used alone.

The effect may be due to the synergistic action of a variety of cellulolytic and hydrolytic bacterial species in the breakdown of the feed stock[10].

Nutrient status of the effluent slurry

Fertilizer value of effluent slurry was determined on the basis of contents of total nitrogen, available phosphorus and potassium contents.

Table 5: Nutrient status of the slurry

Treatment	TN (%)	Av. P (%)	Av. K (%)
T_1	4.15	0.42	0.54
T_2	3.73	0.39	0.82
T_3	3.64	0.38	1.55
T_4	2.92	0.39	2.73

Total nitrogen and available phosphorous percentage of the treatments showed a decrease when the percentage of CD mixed with BSG increases. This is due to higher nitrogen and phosphorus content in the feed stock. This makes the feed stock preferable for bio-fertilizer application through anaerobic digestion. Whereas available potassium increased when the percentage of CD mixed with BSG increases and this may be due to mineralization of potassium by anaerobic micro-organisms initially present in the cow dung. It can be deducted from figure 5 that, the quality of biogas was below 48 % in the first week of the digestion period. The biggest differences in biogas quality were observed in the first two weeks of the retention time. Percentage of methane showed an increasing trend and stability as retention time goes. In the last four weeks of the retention time percentage of methane increased and became stable in the range 65 to 73%. This shows that quality of biogas increases with retention time. Methane content and hence its calorific value increases with increasing retention time[9]. Percentage composition of methane for all treatments was between 60 and 69. This value is in par with the theoretical methane value of 55 – 80%[9].

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The total nitrogen value obtained for the four treatments was beyond the range 1.4 to 1.8[11]. Lower phosphorous and comparable potassium content was observed in the range of 1.1 to 2 and 0.8 to 1.2 respectively. This gives the potential to fill the deficiency of Potassium and Phosphorous in artificial fertilizers. Generally, the effluent slurry is comparable to nutrient content of bio-slurry from freshly digested cow manure.

Conclusion

Physicochemical analysis of the feedstocks revealed higher total solid and volatile solid amount in the feedstocks. Among the various combinations of BSG and cow dung used in this study, a mixture containing a TS of 50:50 ratio produced maximum (6961.7 ml) biogas yield with highest quality (69 % CH_4). The anaerobic digestion processes lasted for 72 days of retention time. Anaerobic digestion of cow dung produced the least amount 2159.7 ml of biogas compared to other treatments, but with 64.9 % methane.

BSG and cow dung combination in the 50: 50 ratio which produced maximum biogas also has the maximum value of m^3 of biogas produced per kg of TS added as 0.07 m^3/kg total solid.

The supplementation of BSG to cow dung can be advantageously used for economic biogas generation.

Generally, it is shown that BSG is a biodegradable organic industrial waste with high total solid and volatile solid content and has shown to have the potential to produce biogas with high methane content. Co digestion of BSG with cattle dung was found to be a more feasible biogas production option in the generation of methane thereby reducing its environmental impacts.

This study recommends a BSG – cow dung mixing ratio of 50: 50 % by total solids which should be tried in pilot study.

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THEME THREE

IRRIGATION AND DRAINAGE

Evaluating irrigation application efficiency and scheduling: baseline to revitalize Meki-Ziway Irrigation Scheme, Ethiopia

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Abstract

It costs the Meki-Ziway irrigation scheme about 40,000 birr per month to pump water from Lake Ziway for irrigation, yet no irrigation performance assessment has not been carried out for this scheme since its commencement in 1986. In this study, we evaluate irrigation application efficiency and scheduling to provide inputs to revitalize the scheme. Our experiment covered four farm plots with three replicas in each plot. Field capacity, permanent wilting point and bulk density of the plots were determined in laboratory. We monitored furrow inflow rate, cutoff time and soil moisture content in the plots over a period of about four weeks. We conducted the monitoring in two periods; one representing good water availability and the other when water was scarce. Our results show that only 42% to 77% (58% on average) of the applied irrigation water amount can be considered beneficial while the remaining is lost by deep percolation, evaporation or runoff. The irrigation application efficiencies significantly vary across farm plots, replicas and irrigation events. Soil moisture level of farm plots at the canal head is always between the soil saturation level and permanent wilting point. However, it drops below the permanent wilting point for many days in farm plots which are located at middle and tail ends of main canal. This is mainly caused by absence of appropriate water allocation system that would ensure equity and by the unlined main canal which is contributing to large water loss. Interventions to improve the current irrigation efficiencies are therefore needed across the scheme. Although rehabilitating the physical infrastructure of the scheme in isolation from on farm efficiency improvements will not necessarily lead to improved overall performance of the scheme, rehabilitation of the infrastructure can increase farmer's confidence and commitment to improve on-farm irrigation water application.

Key words: On-farm water management, irrigation, soil moisture, application efficiency, Ziway Lake

Introduction

Agricultural water development is one of the main priority for Ethiopia to meet the demand of its ever-increasing population (presently ~ 90 million) (CSA, 2013). Ethiopia has made huge investments in irrigation over recent decades, however recent estimates indicate that the total irrigated area in Ethiopia is 2.1 million ha which is only 21 % of its irrigation potential (MoANR, 2016). Much of the increase in irrigated area came as a result of expansion of traditional small-scale irrigation. However, poorly designed, planned and managed irrigation schemes undermine actual achievements.

The attainable application efficiency for surface irrigation according to the United States Soil Conservation Service (USSCS) ranges between 55 and 70%. Research results by Lesley (2002) showed that the application efficiency could be in the range of 50 to 80%. Surface irrigation efficiencies in schemes in Ethiopia are reported to vary between 25 to 50% (Beshir and Bekele, 2006). However, the field application efficiency of Tendaho sugar state farm of Ethiopia studied by Shonka (2015) showed 57% efficiency. This suggests the need for additional research to be undertaken across schemes in Ethiopia to evaluate and improve irrigation efficiencies in the country.

Meki-Ziway pump irrigation scheme was constructed in 1986 with technical and financial support from North Korean government. It was planned to irrigate 3000 ha land (Meki-Ziway irrigation project design document, 1985). However, the currently total irrigated area is only 221.54 ha is irrigated currently. Generally, the physical, financial, and social performance of the scheme is unsatisfactory (Haile and Anteneh, 2015). The scheme has deteriorated over the past 30 years.

Revitalization of existing schemes is important before investing on construction of new schemes. The costs of such interventions are lower than constructing new systems (IWMI, 2010). There is great potential for revitalizing existing irrigation systems in Ethiopia. Meki- Ziway irrigation scheme is one of such systems. The main objective in this study is to evaluate irrigation application efficiency and scheduling in the Meki- Ziway irrigation scheme to support future revitalization of the scheme.

Material and Methods

Descriptions of the Study Areas

Meki-Ziway irrigation scheme is situated in Dugeda Bora woreda of Oromia region, Ethiopia. It is located on the north eastern side of Lake Ziway and about 5km south east of Meki town as shown in Figure 1. The scheme lies within 8°06'13" and 8°08'43"N latitude and 38°47'49" and 38°50'31"E longitude. Lake Ziway is the source of water for irrigation for the Meki-Ziway irrigation scheme.

The farm plots are fairly plain and the main canal is aligned along a ridge. Individual farm hold sizes mostly range from 0.125 to 1 ha with an average farm size of 0.25 ha.

Site selection and field measurement

Four farms were selected to measure the variables needed to estimate the application efficiency of the scheme. The selection was based on farm location relative to the main canal and the cooperation, education and communication skill of farmers. Level of access to water for the three of the four farms is rated very high, high, and medium depending on their location which is head, middle and tail end of the main canal. The remaining one farm has high access to water. We had three replicas (experimental furrows) in each farm plot.

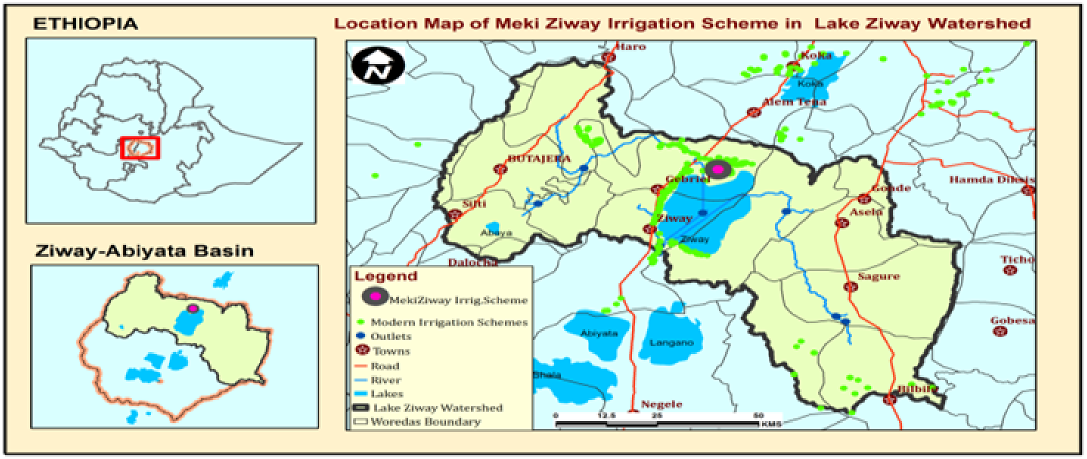


Figure 1: Location of Meki-Ziway irrigation scheme

Soil samples were collected from the four farms and relevant parameters were analyzed in laboratory. At each farm, soil samples were taken at 30 cm interval for the top 120 cm depth. Field capacity, permanent wilting point and bulk density were then determined in Ethiopian Construction Design and Supervision Works Corporation laboratory.

Furrow length, depth, width, and slope of the three replicas of each selected farm were also measured. Furrow inflow rate was measured through filling a bucket of known volume and measuring the time it took to fill that bucket. The furrow inflow rate was measured at 3 irrigation events at each replica (except for few). Measurements were carried out once per event for each replica and during a relatively ample water availability period (October) in farm blocks 6A and 11C and during water scarcity period (February) in farm blocks 7A and 9B. The scarcity was caused by the below average rainfall amounts received in the area during the previous Kiremt rainfall season which led to reduced water levels of Lake Ziway; the main pump at the scheme was thus only turned on for few hours during this period.

Irrigation cutoff time (the time taken for diverted water to reach the furrow end) was recorded by a stop watch. Soil moisture content in the root zone of crops was also monitored. The soil moisture content in the root zone of crops was measured just before and immediately after irrigation by using a soil moisture profiler that measures soil moisture content at various depths up to 1 m depth. The soil profiler was calibrated with soil samples from the farms whose moisture contents were determined gravimetrically in the laboratory. Each measurement with the soil moisture profiler in the three replicas in the selected four farm plots was repeated three times. The soil moisture was monitored at daily time intervals over a period of 25 days. On rare occasions the measured volumetric moisture content was above the recommended saturation level. In this instance, the maximum saturation level of the soil as recommended by literature was adopted for further analysis. However, note that since some of the measurements were done immediately after irrigation, it is expected for the soil moisture content especially of the soil surface layers to be above the maximum level of soil saturation since water redistribution takes place immediately irrigation stops.

Application efficiency relates to the actual storage of water in the root zone to meet the crop water needs in relation to the water applied to the field (Howell, 2003). In this study, the field application efficiency of the four experimental farm blocks was estimated by the measured application depth and soil moisture content. The applied irrigation water amount which was stored in the crop root zone was measured by using Delta T soil moisture instrument by taking a reading before and after irrigation.

Result and discussion

Soil characteristics

Field capacity (FC), permanent wilting point (PWP), available water content (AWC) and bulk density of the soils in the experimental farm blocks is shown in Table 1. FC slightly decreases with depth in the four experimental farm plots. The average FC of the top 120 cm depth is 21.42% (Block 6A) and 20.06% (Block 7A) for loamy sand soil of the study area, while its average value is slightly higher for sandy loam soil. PWP also slightly decreases with the soil depth in the four farm plots. The average value of PWP for the top 120cm is 11.8% (Block 6A) and 12.32% (Block 7A) for loamy sand soil while it is slightly increases for the sandy loam soil. The estimated PWP values of sandy loam soil agree with literature reported values but those of the loamy sand soil are only slightly higher than literature reported values (FAO, 1995; Martin, 2014). This is may be due to the effect of cropping practice and environmental conditions (Martin et al., 2014) but the deviation is too small to question the laboratory results.

For the top 120 cm, the average bulk density of loamy sand soil is 1.63 g cm^{-3} (both in Block 6A and 7A) while it is 1.60 g cm^{-3} (Block 9B) and 1.70 g cm^{-3} (Block 11C) for sandy loam soil of the study area. Porosity ranged from 35.8 to 39.6 %.

Table 1: Laboratory results of soil water field capacity, permanent wilting point, available water content and bulk density. Values refer to averages over the top 120 cm of the soil.

Farm Blocks	**6A**	**7A**	**9B**	**11C**
Soil Type	Loamy sand	Loamy sand	Sandy loam	Sandy loam
FC (gravimetric) %	21.42	20.06	22.70	25.97
PWP (gravimetric) %	11.48	12.32	12.16	13.54
AWC (gravimetric) %	9.95	7.74	10.54	12.43
Bulk density(g/cm^3)	1.63	1.63	1.60	1.70
Porosity (%)	38.5	38.5	39.6	35.8

Furrow Dimensions

The furrow slope in the study area is fairly gentle (0.002 to 0.014 m/m). Such slopes provide relatively extended opportunity time for the applied water to infiltrate into the root zone of the crops. The furrow depth varies from 0.085m to 0.15m which is in the range of what is recommended in literature for sandy soil (FAO, 1989).

Considering the high infiltration rate, local farmers use short furrow lengths for better irrigation and crop management. The furrow length of the test plots varies from 3.93m to 6.83m. Furrow spacing is influenced by soil and crop type. The recommended furrow spacing is between 0.30 and 0.60 m for sandy soils (FAO, 2001). The furrow spacing adopted by the farmers in our study area is mostly within the recommended range. However, furrow interconnection problems were observed in some farms which may contribute to irrigation water loss and uneven water distribution. Furrow dimensions of the selected farm plots are shown in Table 2.

Table 3: Summary of inflow rate and cut off time in each of the selected farm blocks

Farm Blocks	min discharge (l/s)	max discharge (l/s)	Mean discharge (l/s)	Max cut off time (s)	Min cut off time (s)	mean cut off time (s)
Farm Block 6A	4.08	5.59	4.74	31.09	44.74	37.36
Farm Block 7A	2.37	3.37	2.92	50.09	65.26	40.36
Farm Block 9B	2.37	3.87	2.92	25.30	49.30	40.36
Farm Block 11C	4.30	5.45	5.09	44.22	50.18	46.16
Mean of mean			3.73			45.77
Std Dev			1.16			10.96
CV (%)			31.10			23.94

Gross Application Depth

The mean of the gross applied depth for the study area is 13.97 mm/day and varies between 9.58 mm/day to 22.73 mm/day (Table 4). The highest gross water depth is applied in farm block 6A which has good access to canal water. In addition, water application in this farm was measured when there was sufficient water.

Applied water in farm blocks 7A and 9B was measured in a time when there was water scarcity in the scheme. The applied water depth in farm block 7A is slightly higher than that of farm block 9B. This difference in water application between these two farm blocks occurred due to their position from the main canal. The former is situated relatively close to the canal head than the later.

Even if farm block 11C was measured in a time when there was a better water availability in the scheme, the water diverted to the irrigation scheme was the lowest (9.89 mm/day). This is mainly due to the fact that irrigation water rarely reaches to this block.

Table 4: Applied and estimated depth of irrigation in each of the selected farm blocks

Farm block	Applied water depth (mm/day)			mean
	Rep 1	Rep 2	Rep 3	
B6A	21.9	23.7	22.6	22.7
B7A	11.7	10.6	10.7	11.0
B9B	9.4	8.7	10.7	9.6
B11C	10.4	9.4	10.1	9.9

Temporal variation of soil moisture

The moisture content of farm block 6A was below PWP for some consecutive days (Figure 2). It was brought to above the management allowable depletion (MAD) level afterwards by irrigation. Farm block 6A was irrigated 7 times during the 25 days monitoring period. Irrigation application was not triggered based on specific criteria since Figure 2 shows that irrigation is applied at different soil moisture levels. However, moisture level is always kept above MAD level except for the first week. In the first week there was a water scarcity due to the 2015/16 drought. The average irrigation interval over the monitored period was 3 days for the initial 7 days. The farmer then started to apply water every other day or daily afterwards. However, the farmer did not apply irrigation to replica 2 for the last 7 days. For each irrigation application, moisture content exceeded the FC level and reached saturation level.

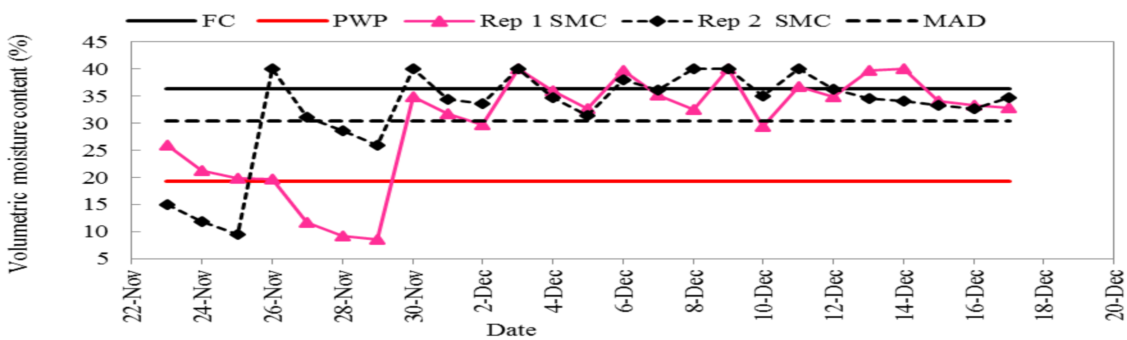
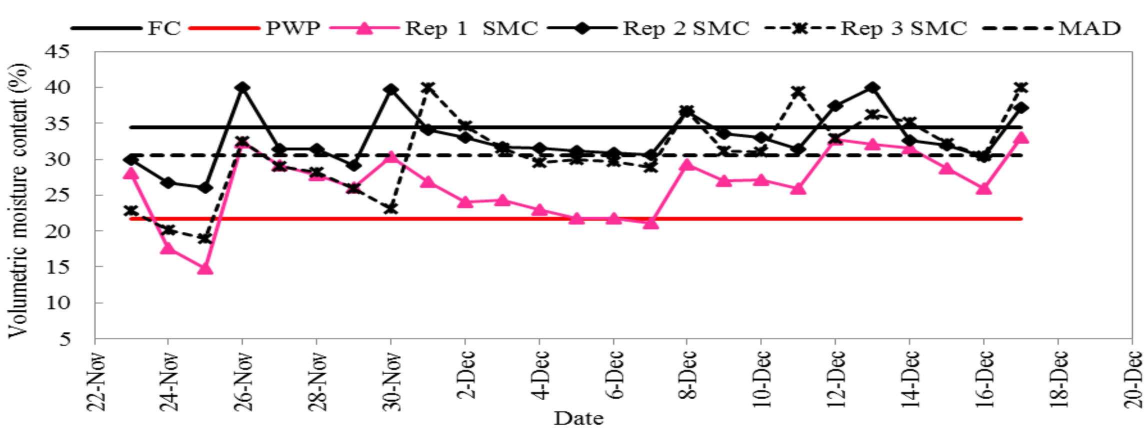


Figure 2: Temporal variation of soil moisture content in farm block 6A (Refer to Table 2 for furrow dimensions and crop type grown)

Temporal variation of soil moisture content is shown in Figure 3 for the three replica of farm block 7A. All replicas first received irrigation water on day 3 while water is applied 6 times over the entire data recording period. Irrigation interval is not consistent and varies between 1 day and 8 days with the longest interval occurring in the second week. After the first week, the soil moisture content of replicas 2 and 3 slightly exceeded MAD level and reached FC occasionally during irrigation application. Moisture content in replica 1 is mostly below MAD showing moisture stress. Moisture content even dropped below PWP on the second and third monitoring days for two of the three replicas.

Figure 3: Temporal variation of moisture content in farm block 7A



Farm block 9B received irrigation water only 4 times over the course of the 25 days (Figure 4). The applied water was not sufficient enough to bring the soil moisture content to FC. The mean irrigation interval was 6 days varying between 4 to 9 days. With exception of few days, the moisture content of the farm block was below the recommended MAD level. However, the moisture content did not fall below PWP. This implies that the plant was under moisture stress which is expected to negatively impact its productivity.

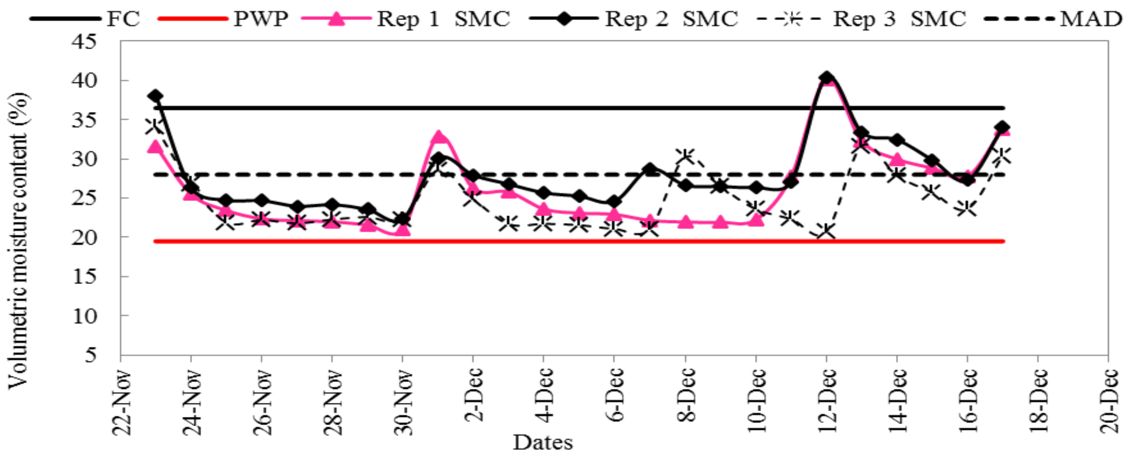


Figure 4: Temporal variation of soil moisture content in farm block 9B

The soil moisture content of farm block 11C was significantly lower than the PWP for an extended period covering the first 11 days and 16 days for replicas 1 and 2 and for the entire monitoring period for replica 1 (Figure 5). Farm block 11C received irrigation water only for 4 times for the two replicas while one of the replicas was not irrigated at all. The irrigation interval varied between 2 and 11 days for replica 2 while it varied between 1 and 16 days for replica 1. The applied water amount was not sufficient at all to increase the moisture content to FC level. Moisture content in the farm block was mostly below the management MAD which led to crop failure with the farmer harvesting nothing.

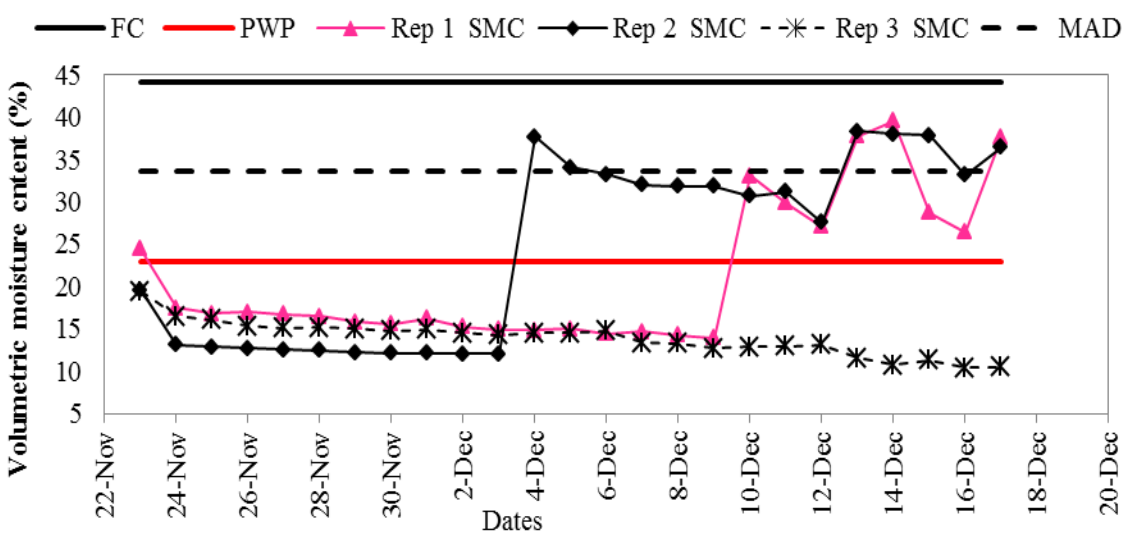


Figure 5: Soil moisture content pattern of farm block 11C

Field Application efficiency

The overall mean application efficiency of the scheme is estimated as 58.17% and varies between 42.14% and 77.3 % (Table 5). The result varies with irrigation events and replicas. Application efficiency is highest in farm block 7A. The lowest mean application efficiency was recorded on farm Block 11C. The values obtained in this study were close to the lower limit of the literature recommended value of surface irrigation.

In this study, the reported differences in application efficiencies were possibly caused by variations in inflow rate and cut-off time (generally called decision variables) and furrow parameters mainly soil infiltration characteristics. The application efficiency of the sandy loam soil fields was (farm block 6A and 7A) better than the loam sand soil fields (farm block 9B & 11C). The application efficiency likely depended on farmer's experience in recognizing flow resistance, required depth of irrigation, and soil moisture depletion prior to irrigation.

Table 5: Field application efficiency of the scheme

Field	**Replica**	**Irrigation event 1**		**Irrigation event 2**		**Irrigation event 3**		**Mean Discharge (l/s)**	**Mean Ea (%)**
		Discharge (l/s)	Ea (%)	Discharge (l/s)	Ea (%)	Discharge (l/s)	Ea (%)		
B6A	Rep 1	4.081	77.31	4.780	54.78	4.240	66.59	4.37	66.22
	Rep 2	4.780	51.19	5.547	51.66	4.281	53.09	4.87	51.98
	mean							4.62	59.10
B7A	Rep 1	3.369	53.04	2.983	60.70	2.751	64.37	3.03	59.37
	Rep 2	2.463	67.62	2.488	59.18	2.425	69.10	2.46	65.30
	Rep 3	2.447	53.09	2.373	72.25	2.475	64.90	2.43	63.41
	mean							2.45	62.69
B9B	Rep 1	3.87	46.03	3.08	63.94	3.01	56.04	3.32	55.34
	Rep 2	2.98	50.09	2.72	50.85	2.93	68.29	2.88	56.41
	Rep 3	2.54	42.14	2.37	65.49	2.74	60.19	2.55	55.94
	mean							2.92	55.90
B11C	Rep 1	5.32	52.58	5.35	50.68	4.75	58.57	5.14	53.94
	Rep 2	5.45	64.35	5.37	57.65	4.30	46.19	5.04	56.06
	mean							5.09	55.00
Mean of mean								3.82	58.17
Std Dev								1.22	3.49
CV,%								31.92	6.00

Conclusion

Meki-Ziway Irrigation scheme has been benefiting several smallholder farmers over the last 30 years without major maintenance. Irrigation performance evaluation showed that the scheme's performance was far from satisfactory. Currently, there is no water allocation strategy in the scheme that would ensure equity and reliability across the reaches. Excess water is applied in the water accessible reaches while inadequate or no water is being supplied to many farmers who are being forced to decrease their irrigated area or seek alternative source of water for irrigation.

The following main conclusions can be drawn based on our experimental results:

- Crops are facing critical water stress to the extent that leads to yield loss or failure. In the scheme, soil moisture frequently drops below MAD and occasionally below PWP.
- Many farmers are increasing unhappy by the observed inequality in access to water. Soil moisture level of farm plots at the canal head is always between the soil saturation level and permanent wilting point. However, it drops below the permanent wilting point for many days in farm plots which are located at middle and tail end of main canal.
- Irrigation application efficiency is within literature reported values for Ethiopia but in the lower limit of application efficiency in many other countries. Application efficiency in the scheme varies over large range of values. Within a single plot irrigation interval shows large variation.
- Since irrigation water delivery is not reliable in the scheme, farmers do not know when they will receive the next irrigation water. They irrigate whenever water is made available in the main canal. As a result, they could not apply a specific and consistent criteria to trigger irrigation application. Irrigation interval is also inconsistent.

Overall, rehabilitating the infrastructure of the scheme in isolation from on farm interventions does not necessarily lead to improved overall performance of the scheme. There is a strong need to enhance farmer's knowledge of crop yield response to water application. Future interventions should provide incentives to farmers to improve the current irrigation efficiency levels. Rehabilitation of the physical infrastructure may also increase farmer's confidence and their willingness to improve on-farm irrigation water application.

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IMPACTS OF IRRIGATION PRACTICES ON SELECTED SOIL PHYSICO-CHEMICAL PROPERTIES OF DUBTI/TENDAHO STATE FARM, NORTH EASTERN ETHIOIPIA

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Abstract

Physicochemical properties of soils could be damaged through irrigation due to inappropriate irrigation practices with poor quality of irrigation water. In Ethiopia, particularly in Afar region information about the effects of irrigation on soil properties is lacking. Thus, this study was conducted at Dubti/Tendaho state farm to investigate the impacts of irrigation on selected physicochemical properties of soils. Six composite soil samples were taken from each irrigated and non- irrigated lands with sampling depths of 0 - 30 and 30 – 60 cm. Data were analyzed using descriptive statistics and regression analysis of variance. The results showed that clay and silt clay loam soils were dominant in irrigated and non-irrigated lands, respectively. Relatively higher bulk density (Bd) but lower total porosity was recorded in irrigated than non-irrigated soils both at the surface and subsurface soils. Clay content was positively and significantly ($P \leq 0.001$) correlated with field capacity (FC) and permanent wilting point (PWP) in irrigated soils while correlated but non-significant ($P > 0.05$) in non-irrigated soils. Infiltration rate was also higher in non-irrigated land and then decreased steadily with time. Soil OC and TN contents were higher in irrigated land both on the surface and subsurface soils. Soil pH of in irrigated land was strongly alkaline (>8.5) while it was moderately alkaline (8.08 – 8.20) in non-irrigated soil which was also significantly ($P < 0.01$) affected by soil depth. The concentration of ECe, Na^+, ESP and SAR were relatively higher in irrigated land and decreased with increasing soil depth in both land uses. Generally, the results revealed that the physical and chemical properties of irrigated soils have been degraded due to salinity problems. Hence, it is possible to infer that long periods of irrigation practices have negative impacts on soil properties which urge to take measure for maintaining its productivity in the study area.

Keywords: Bulk density, irrigated and non-irrigated lands, irrigation water quality

Introduction

The problem of food security is exacerbated by the rapid growth of population and hence of the increasing demand for food. To alleviate this problem, irrigation can and should play an important role in rasing and stabilizing food production, especially in the less developed countries like Ethiopia (FAO, 1987). However, due to inappropriate irrigation practices, environmental problems like rising of ground water, increasing soil salinity and deterioration of soil physicochemical properties have been observed in many irrigated lands of arid and semi-arid regions (Schuler and Satter, 2010, and Mustafa, 2011). Even good quality irrigation water with EC of 0.15 dS m^{-1} (100 mg salt L^{-1}) Even good quality irrigation water with EC of 0.15 dS m^{-1} (100 mg salt L^{-1}) adds one tone of salt ha^{-1} of soil after an application of 1 m depth of water (Mirza *et al*., 2012). Thus, long periods of irrigation practice may lead to the gradual development of salt-affected soils (saline, saline-sodic and sodic) in irrigated lands (Qadir *et al*., 2006). For instance, Postel (1999) stated that worldwide, one in five ha of irrigated land suffers from a build-up of salts in the soil.

Poor quality irrigation water applied to the soil result in soil dispersion, aggregate breakdown, surface sealing and crust formation (Emdad *et al*., 2006). Consequently, accumulation of salts in the form of sodic and saline sodic categories may show unique structural problems (Quirk and Schofield, 2005; Qadir *et al*., 2006; Quarashi *et al*., 2007; Raue, 2008). Soils having those physical properties could affect water and air movement, available water holding capacity (AWHC), root penetration, seedling emergence and tillage operations (Oster *et al.,* 1999; Rehman *et al*., 2002). Moreover, it may also lead to osmotic effect and specific ion toxicity together with imbalances in plant nutrition which may range from deficiencies of several nutrients to high levels of Na^+ (Liang *et al*., 2005; Tajada *et al*., 2006). Soil characteristics such as organic matter (OM), EC, pH, and CEC can be changed with irrigation practices through time (Lado *et al*., 2004; Presley *et al*., 2004).

Soil degradation due to salinity problems appears mainly in developing countries of arid and semi-arid areas where precipitation is insufficient and irrigation is a common practice (Caitlin, 2003; Ziad *et al.,* 2004). For instance, in irrigated soils of Kenya, about 26,000 ha of land are considered degraded through salinity development due to poor quality water, poor drainage and lack of proper irrigation management systems especially in areas with high or increasing ground water tables (Mugwanja *et al*.,1995).

Similarly, soils in Ethiopia are physically and chemically degraded through compaction and structural breakdown due to the continuous removal of nutrients and the development of salt affected soils particularly in arid and semi- arid areas of irrigated lands (World Bank, 1994). Over 11 million ha of salt affected soils are known to occur in the arid and semi arid parts of Ethiopia, mostly in areas where irrigation is a common practice (Kidane *et al.,* 2006). At present, due to long periods of irrigation practice, most of the irrigated large state farms in Afar National Regional State (ANRS) are being converted into saline and sodic soils annually at an alarming rate (Fentaw, 2007). For instance, in the Middle Awash Valley of the Ethiopian Rift Valley System, over 1,600 ha of the Melka Sedi-Amibara irrigated state farm that was irrigated for about 18 years (1971 - 1988) had gone out of cultivation due to the soil physical and chemical degradation through salinity and sodicity/alkalinity problems (Heluf,1995). Therefore, timely monitoring the impacts of irrigation practice on soil physicochemical properties is crucial for sustainable crop production and productivity (Henry and Hogg, 2003).

At Dubti/Tendaho state farm, irrigation has been practiced for about 54 years. As a result, white crusts, dark oily damp nature of the soils and surface soil sealing have been observed in some irrigated plots but not that much pronounced in non-irrigated adjacent lands. The difference in physical appearance of soils in this two land uses (irrigated and non-irrigated lands) indicated that soil properties have been impacted through long periods of irrigation practices. Hence, knowledge on the physicochemical properties of soils is critical to make decision with respect to soil management and crop production (FAO, 1988; Heluf, 1995). However, in the study area until now there was no any research done about the impacts of irrigation practice on soil physical and chemical properties. Therefore, the objective of this study was to investigate the impacts of irrigation practice on selected soil physicochemical properties at Dubti/ Tendaho state farm

Materials and Method

Description of the Study Area

The study was conducted at Dubti/Tendaho state farm, which is located in Afar National Regional State (ANRS), northern part of the Ethiopian Rift Valley system at the lower portion of the Awash basin (Figure 1). Geographically, it is located between 11°39'0'' - 11°48'0''N Latitudes and 041°6'0'' - 041° 12'0''E Longitudes with an altitude that ranges from 339 - 381(m. a. s. l.) and its slope ranges between 0.03 and 0.3%. The area is characterized by bimodal rainfall pattern with mean annual precipitation of 222 mm. The annual mean minimum and maximum temperatures are 22.6 and 48.8 ^{0}C, respectively (Figure 2) with an average of 35.7 ^{0}C and the mean annual evapo-transpiration (ET) was 2854.1 mm (Dubti meteorological station). Soils of the study area fall into five main soil units of Solonetz (39.35%),Calcisols (28.34%), Solonchak (14.55%),Vertisols (13.89%) and Fluvisols (3.88%) with most of them characterized by massive soil structure which is attributed to the dominance of exchangeable sodium (WWDSE, 2004; Sileshi *et al*., 2015). A brief description about the area is indicated under section 1.1.

Sample Site Selection and Soil Sampling

Two land use types (irrigated and non- irrigated) were selected for evaluation. The irrigated land has been continuously cultivated for 54 years through furrow irrigation system. Accordingly, sampling sites from irrigated land has been selected purposefully from the area in which irrigation has been continuously practiced for about 54 years. On other hand, non- irrigated land refers to the land that has not yet been cultivated either through irrigation or rainfed system.

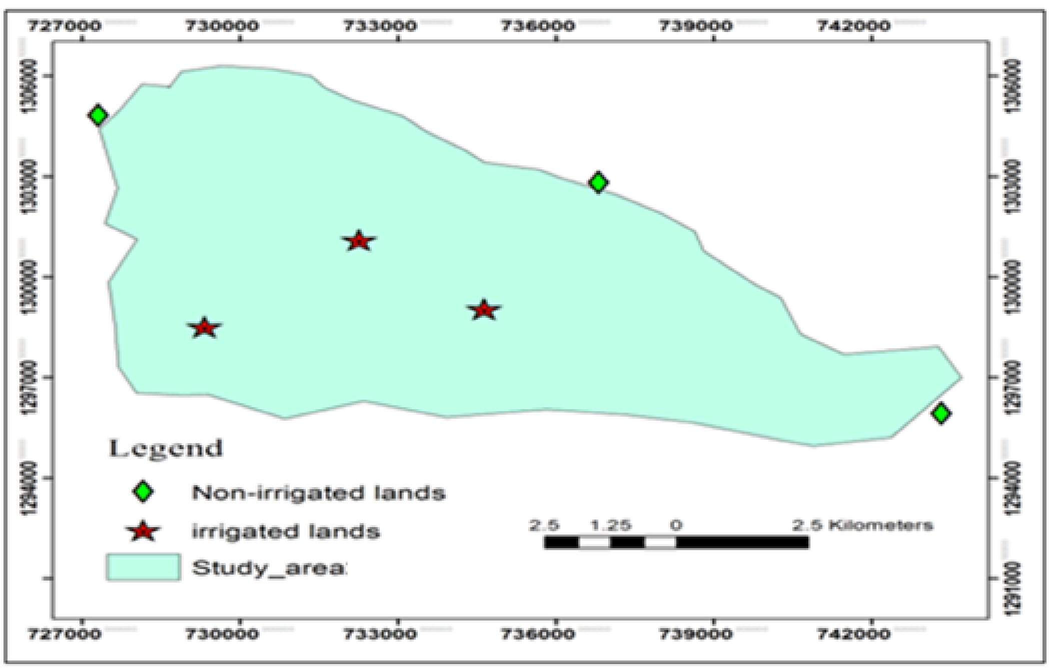

Figure 1: Location of soil sampling from irrigated and non-irrigated lands

The locations of soil sampling in non-irrigated lands were also deliberately selected from the adjacent area of the irrigated lands (Figure 4.1) assuming that the two land uses have similar soil properties with similar genetical factor, topography and micro climatic condition but may show differences due to different management systems. Then, six composite soil samples for each land use types were collected from twelve soil sub-samples within two depths of 0 - 30, 30 – 60 cm using an auger

Soil Water Analysis

The moisture content at filed capacity (FC) and permanent wilting point (PWP) was measured at soil water potential of -1/3 bar and -15 bars, respectively, using the pressure plate apparatus.; whereas the available water holding capacity (AWC) between FC and PWP was calculated using Equation 1 (Kalute and Dirksen, 1986).

$$AWHC = \Theta_{FC} - \Theta_{PWP} \qquad (1)$$

Where:

Θ_{FC} = water content at FC (v/v)

Θ_{PWP} = water content at PWP (v/v)

For a given soil depth (D, in mm), the available water was calculated as:

$$AW = AWC \times D \qquad (2)$$

Field Infiltration Measurement

Soil infiltration rate was measured using the double ring infiltrometer with three replications in each representative site following the procedures outlined by Reynolds *et al*. (2002). Two concentric rings were used with diameter of 30 cm for inner ring and 60 cm for outer ring. The rings were driven to about 15 cm deep in soil using falling weight type hammer striking on a wooden plank placed on top of ring uniformly without disturbing the soil surface. The observations for infiltration rate were carried out on inner ring with field type point gauge and stop watch for a period of at least 300 minutes (5 hours) to 420 minutes (7 hours) to ensure that the steady state was achieved. This was based on the fact that it usually takes 2 - 6 hours for the soil infiltration process to reach steady state as reported by Lili *et al.* (2008).

Soil Analysis

The soil samples were air dried, ground and passed through 2 mm sieve for analysis. Particle size distribution was analyzed by the Bouyoucos hydrometer method after oxidation with H_2O_2 and dispersing with sodium hexamethaphosphate (Day, 1965). Bulk density (Bd) was determined from undisturbed (core) soil samples collected using core sampler (Rowell, 1997) while particle density (pd) was measured using psychnometer as described by Sahlemedhin and Taye (2000). Total porosity (f) was then calculated from the values of Bd and pd as:-

$$\text{Total porosity (\%)} = 100(Bd/PD) \qquad (3)$$

Soil reaction (pH) and electrical conductivity of the saturated paste extract (ECe) were measured in 1:2.5 soils: water suspension using pH meter and conductivity meter, respectively (Sahlemedhin and Taye, 2000). Organic carbon content was determined by the wet combustion or dichromate oxidation method (Walkely and Black, 1934). Total nitrogen (TN) was determined using macro-Kjeldhal method (Jackson, 1958) and available phosphorus (P) was analyzed using the Olsen method (Olsen *et al*., 1954). Cation exchange capacity and exchangeable cations were determined from neutral 1.0 molar (M) ammonium acetate (NH_4OAc) extracts. Exchangeable calcium (Ca) and magnesium (Mg) in extracts were analyzed using Atomic Absorption Spectrophotometer (AAS), while sodium (Na) and potassium (K) were analyzed by flame photometer (Chapman, 1965; Rowell, 1994). Water soluble cations (Na^+, K^+, Mg^{2+} and Ca^{2+}) were determined from the saturated soil paste extract by flame photometry for Na and K, while Mg and Ca ions were determined by AAS. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) concentrations were determined from the saturated soil paste extract by simple acidimetric titration using phenolphthalein indicator for CO_3^{2-} (pH > 8.5), and methyl orange for HCO_3^- (pH < 6.0). The extract with a mixture of these indicators was titrated by standard 0.01N H_2SO_4 to phenolphthalein and methyl orange end points for CO_3^{2-} and HCO_3^- contents, respectively (Hesse, 1971).

Chloride ion (Cl^-) was determined by titrating the aliquot used for CO_3^{2-} and HCO_3^- determinations using silver nitrate to potassium chromate end point as described by Hesse (1971). In addition, sulphate ions in soil samples were determined gravimetrically by precipitating as barium sulphate ($BaSO_4$) as described by FAO (1984). Exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR), and percent base saturation (PBS) were computed from the data of chemical analysis (Baruah and Barthakur, 1997).

$$ESP = \frac{Na^+}{CEC}(100)......................................Eq.4$$

$$\text{PBS (\%)} = \frac{Ca + Mg + Na + K}{CEC} \times 100.......................Eq.5$$

And

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}..................................Eq.\ 6$$

Statistical Analysis

Data were analyzed using descriptive statistics to compare the selected soil physicochemical properties from irrigated land against non-irrigated areas. Accordingly, mean values of soil physicochemical properties were computed and employed to compare the results with relevant findings. Correlation and regression analysis were also conducted with Minitab 15 English Ink soft ware to check the validity of some parameters.

Result and Discussions

Soil Physical Properties

Particle size distribution

Soils of irrigated lands have clay texture whereas non-irrigated lands were dominated by silt clay loam texture (Table 1). This variation might be due to the sedimentation of silts in non-irrigated lands through flooding from River Awash although not in irrigated lands which is a state farm and well protected from being flooded. This result was contradictory with that of Jibrin *et al*. (2008) who found that soils of irrigated land contain high amount of sand with little silt and clay while non-irrigated lands contain more of clay particles.

Under both land use types, the clay content at the surface layer (0 – 30 cm) is slightly lower than that in subsurface layer (30 – 60 cm) (Table 4.1). This could be due to the fact that there was a translocation of clay down the profile and subsequent accumulation in the sub surface layers. Similarly, IUSS (2006) Working Group also noted that the textural differentiation within depth of soils might be caused by an illuvial accumulation of clay or/and upward movement of coarser particles due to swelling and shrinking.

Table 1. Mean values of selected soil physical parameters in the study area

Land use	**Sampling depth(cm)**	**Particle size (%)**			**Textural Class**	**Bd gcm^{-3}**	**Pd g cm^{-3}**	**Total porosity (%)**	**FC (v/v)**	**PWP (v/v)**	**AWHC (mm/m)**
		Sand	Silt	Clay							
Irrigated	0 - 30	14	37	49	C	1.54	2.48	38	39.10	21.03	180.7
Irrigated	30 - 60	11	35	54	C	1.48	2.50	41	44.41	24.05	203.6
Non-irrigated	0 - 30	19	48	33	SCL	1.33	2.45	46	33.52	16.11	174.1
Non-irrigated	30 - 60	9	57	34	SCL	1.41	2.36	40	39.68	19.59	200.9

* Bd= bulk density, Pb= particle density, C= clay, LCL= silt clay loam

Bulk density, particle density and total porosity

Bulk density of the irrigated surface layer (0 – 30 cm) was increased by 15.8% as compared to to the non -irrigated soil of similar layer. The increment of Bd in the upper surface of irrigated land might be due to the impacts of irrigation that led to the rearrangement of soil particles and reorientation of soil pores coupled with the compaction of soils with high traffic machines at the time of plowing. Similar studies by Arocena (2000) and Berli *et al*. (2004) noted that compaction by heavy wheeled tractors reduces total porosity and increases Bd of soils in agricultural cultivated fields. Mamedov *et al*. (2001) and Levy and Mamedov (2002), Abdelaty and Gamal (2009) also reported that Bd of the soil increased under irrigation due to applied irrigation water resulting in soil swelling and dispersion that lead to pores clogging and surface sealing.

According to Hazelton and Murphy (2007), if the Bd of clay texture soil is greater than1.4 g cm^{-3} it cause root restriction and surface soil sealing. Accordingly, Bd of soils under irrigated land may limit root growth, air circulation and availability of less mobile essential plant nutrients. In non-irrigated lands, average Bd values of soils ranged between 1.1 - 1.4 g cm^{-3} which may not limit root penetration (Miller, 1997). Similar studies by Guruprasad and Veena (2014) also Bulk density, particle density and total porosity

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revealed that Bd increased in cultivated/irrigated lands due to its susceptibility to damage caused by water to fill the pore space and reduce the porosity of soils. The Bd in non-irrigated lands has shown an increasing trend with depth. This might be due to less pore space and aggregation as a result of low OM content and compaction caused by the weight of the overlying layers. In agreement with this, Guruprasad and Veena (2014) and Rawls *et al*. (2003) reported increase in Bd with soil depth due to overburden pressure, reduced OM and less aggregation compared to the surface layers.

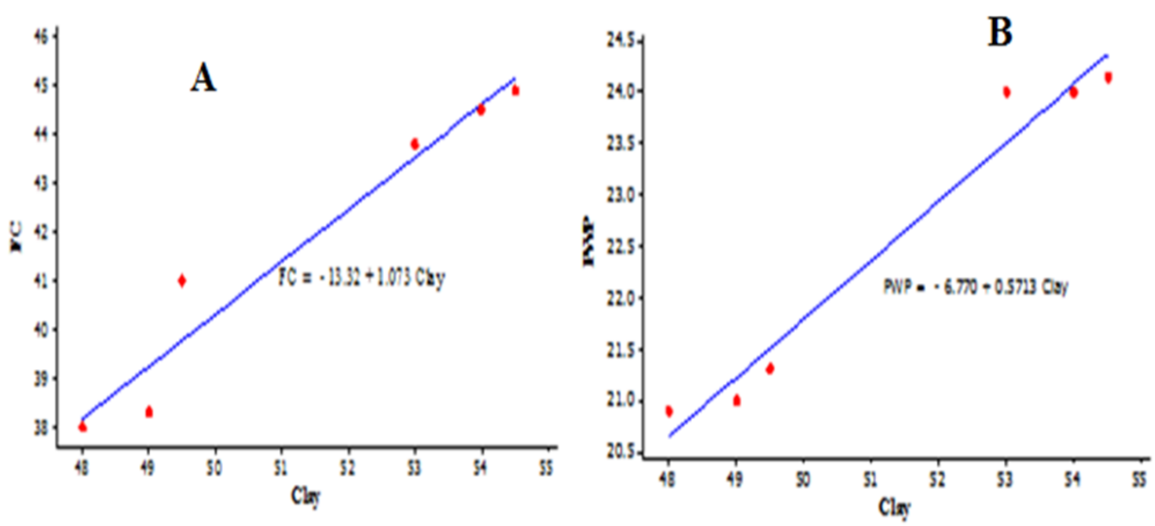
The particle density (Pd) of soils in the study area is generally low (< 2.65g cm^{-3}) in both land uses which might be due to the original mineral composition of the soils and relatively high clay content in the study area. In accord with this, Ahmed (2002) notified particle density of the soil might be varying due to its mineral composition and higher clay content of the soil.

Data regarding total porosity in both land uses have shown lower porosity on surface than in subsurface layer (Table 1). However, the value on irrigated lands were lower compared to non-irrigated lands. This is due to the fact that Bd of irrigated surface soil was relatively higher than that non- irrigated surface soil and in sub surface soil the value of Bd was vice versal. In accord with this, Gebhardt *et al*. (2009) and Rawls *et al*. (2003) noted that low Bd in non-irrigated lands is an indicator of high soil porosity due to less disperssion and swelling of soils.

Soil water characteristics

In both irrigated and non-irrigated lands, FC, PWP and AWHC values were relatively lower on the surface (0 - 30 cm) than the subsurface (30 – 60 cm) soils (Table 1). The increase in these three components in the subsurface soil could be due to the relatively higher clay content in the subsurface layers. These results were similar to the findings of Wakene (2001), Ahmed (2002) and Gizaw (2008) who reported that as a result of high clay content in the subsoil, water contents at FC, PWP and AWHC were found to increase with soil depth for soils under different management practices.

Figure 2. Regression analysis of soil clay content with FC (A) and PWP (B) in irrigated lands



The regression analysis further revealed higher soil contents of irrigated lands than the non-irrigated lands (figures 2 and 3). This might be linked with the presence of high clay content in irrigated than non-irrigated land. Similar reason was given by Dadgari (2005) and Adamu and Aliyu (2012) who confirmed that soils with high amount of clay retain higher amount of water both at FC and PWP than soils with low amount of clay content.

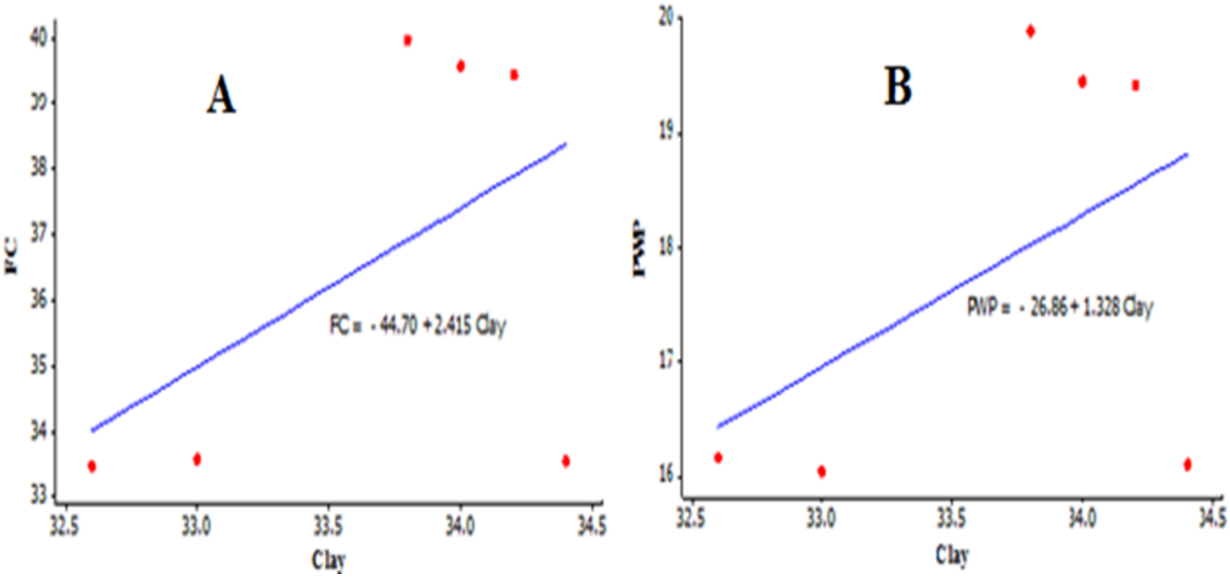


Figure 3. Regression analysis of soil clay content with FC (A) and PWP (B) in non- irrigated lands

Investigation through regression analysis of variance also indicated that clay content was positively and significantly ($P \leq 0.001$) correlated with FC and PWP in irrigated soils while correlated but it was non-significant ($P > 0.05$) in non-irrigated soils. The comparison between total porosity values with water retention at FC also showed that the water maintained at FC was greater than total porosity for the clay-ey soils of the irrigated land while it was slightly lower than the total porosity in case of the non-irrigated soils. This indicated that the soils of irrigated lands will be under anaerobic condition when they are at FC and even those of the non-irrigated land soils will not be adequately aerated.

On the other hand, infiltration rate of irrigated soils showed lower trends compared to non-irrigated lands (Figure 4). The impact of initial soil moisture content was considered as non significant since all the experiments were done when soils were dry. The reason for the lower values in irrigated soils can be ascribed to poor quality of irrigation water such as high Na% and RSC (Sileshi *et al*., 2015).

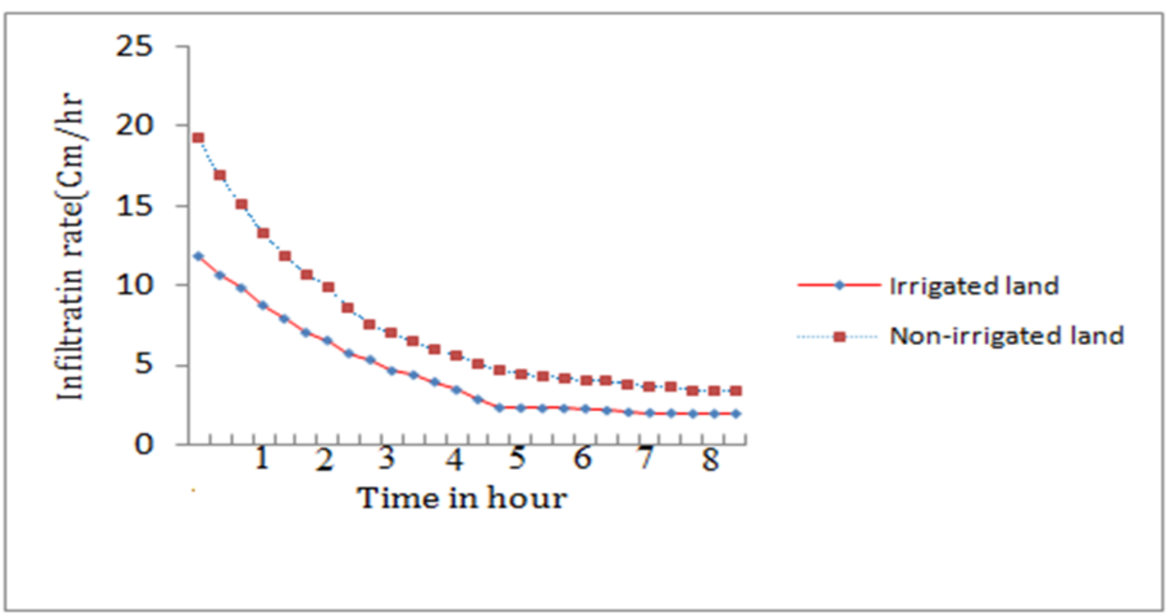


Figure 4. Infiltration rates (cm hr^{-1}) of irrigated and non-irrigated soils

Furthermore, the higher ESP (>15%) and SAR (>13) value (Tables 4.3 and 4. 4) might have caused the reduced infiltration rates of irrigated lands. In conformition with this finding, SAI (2010) revealed that the presence of high HCO_3^- ions in irrigation water may precipitate Ca and/or Mg as carbonates and open the room for the dominance of Na resulting in permeability problems in irrigated fields. Suarez *et al*. (2006) also found that high SAR in irrigation water reduced infiltration rate especially in clay and loam soils.

The other reason might be due to higher clay and lower silt contents in irrigated land resulting from the migration of pore-blocking swelling and dispersed clay particles. In accordance with this, ISWM (2008), Gregory *et al.* (2005) and Hillel (2004) noted that the infiltration rates of the fine soil group is much lower than the medium to high soil group due to the migration of dispersed clay particles, which result in the formation of surface crust.

Soil Chemical Properties

Organic carbon, total nitrogen and available phosphorus

Even though in both land uses, the OC content was very low (< 0.50%) (Tekalign, 1991) at the surface layer (0 – 30 cm), irrigation has improved the OC content by 133%, and at the lower layer (30 – 60 cm) the improvement is about 90%. However, the increase of OC on the surface layer of irrigated lands didn't result in lower Bd and higher total porosity indicating the relatively higher ESP and compaction by heavy machinery have exceeded the effects of the higher OC. Relatively higher OC of irrigated land both at the surface and subsurface layers could be attributed to the residual effects of cultivated crops in irrigated lands, while almost no vegetation cover is present on non-irrigated lands. Similarly, Omar (2011) reported that the high level of OC in the irrigated fields of Bauchi and Dass LGAs were due to high return of agricultural residues to the soils. Oriola (2004) also stated that high OM in the irrigated fields may be the result of plant residues after harvest.

Table 2.: Soil organic carbon, total nitrogen, carbon nitrogen ratio and available phosphorous

Land use	Sampling depth (cm)	OC (%)	TN (%)	C/N ratio	Avail.P (ppm)
Irrigated	0 – 30	0.49	0.070	7.0:1	2.91
Irrigated	30 – 60	0.38	0.067	5.7:1	2.43
Non-irrigated	0 – 30	0.21	0.048	4.4:1	3.91
Non-irrigated	30 – 60	0.20	0.042	4.8:1	3.80

As shown in Table 2, the values of OC decreased from the surface to subsurface layers in both land uses. The reason might be due to the decrease of root biomass with increasing soil depth. In accord with this, Gebayaw (2007) stated that the substantial amount of organic materials added on the surface soil from root biomass after the crop is harvested remain in the upper surface of the soil until the processes of mineralization is completed. Generally, the very low soil OC content in the soils of the study area could be related to the warmer climate, which enhances rapid rate of mineralization (Abayneh, 2005; Teshome *et al.*, 2013).

The values of TN content showed similar trends with soil OC content both in irrigated and non-irrigated lands i.e. it showed very low values and decreased from the surface to subsurface layers in both land uses. Since the study area is arid, the reason might be due to the presence of low organic matter (OM) content.

The result was in agreement with that of Gebayaw (2007) who reported that changes in soil OM could lead to changes in total N because OM generally account for more than 95% of soil N. Although irrigated land has better TN content both on the surface and in the subsurface soil than the non-irrigated land, as per the rating proposed by Havlin *et al*. (1999), the values in both land uses were in the low range (< 0.15%).

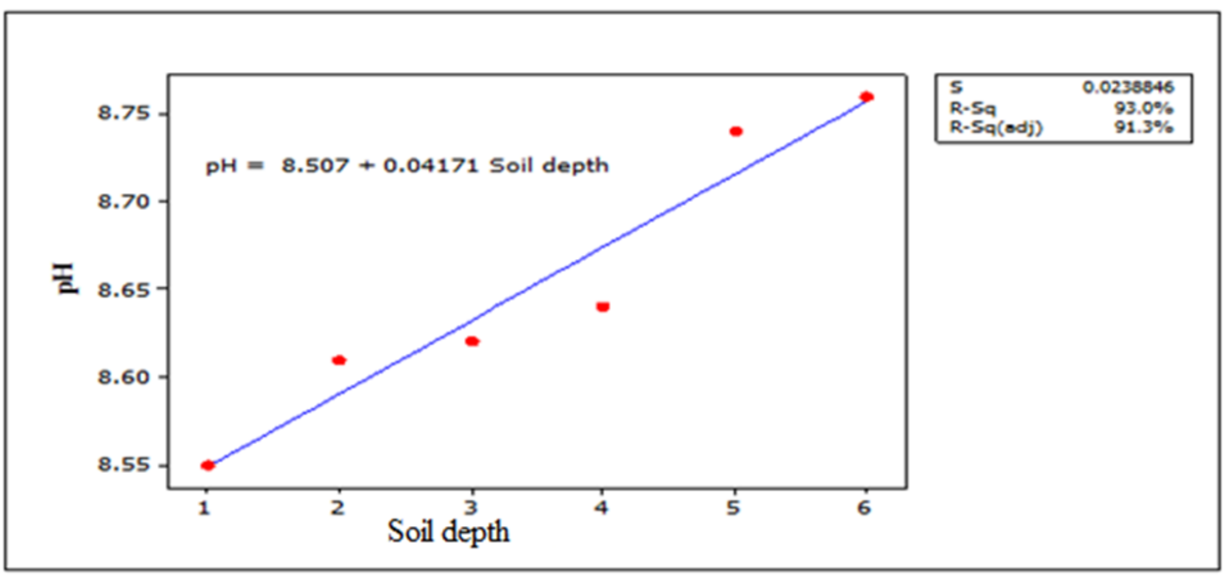
The carbon to nitrogen (C/N) ratio of soils in irrigated land was relatively higher than the non-irrigated land both on the surface and subsurface soils. This could be due to the residual impact of OM and less mineralization resulting from restricted microbial activities in highly saline soils of irrigated lands (Table 2). Similar findings by Sardinha *et al.* (2003) revealed that if the concentration of salt increases in the soil, the microbial activity will be decreased due to osmotic pressure and toxicity of specific ions.

The concentration of available P decreased with increasing soil depth in both land uses (Table 2). This could be due to the presence of relatively higher clay content in the subsurface soils which may cause P fixation. In line with this, Havlin *et al*. (1999) stated that P fixation tends to be more pronounced and ease of P release tends to be lowest in soils with higher clay contents. The result showed that the concentration of P was relatively lower in irrigated lands indicating that no P containing fertilizer application, loss of P through crop uptake due to continuous crop production and P fixation with high clay content (Akhter *et al*., 2010). Generally, as per the rating suggested by Olson (1954), the soil available P in both land uses was in the range of very low (<5 ppm).

Soil pH and electrical conductivity

The pH of the soils increased with increasing depth both in irrigated and non-irrigated lands (Table 3). Statistically, it was also significantly ($P < 0.01$) affected by soil depth (Figure 5). This could be due to the dominance of Na^+ among the cations and HCO_3^- among the anions. These results confirmed that the concentrations of HCO_3^- and exchangeable bases are apparently the sources of slight variability of pH in soils (Heluf, 1995).

Figure 5: Regression analysis between pH and soil depths



Moreover, soil pH was relatively higher in irrigated than non-irrigated lands. This could be due to the effects of irrigation water (pH > 8.4 with high Na and HCO_3^-) (Sileshi *et al*., 2015). Similar studies by Rodolfo *et al*. (2007) indicated that irrigation water with high concentration of Na increases the soil pH, thereby elevating exchangeable sodium percentage (ESP). Based on the ratings set by Murphy (1968), soils on the irrigated land qualified under strongly alkaline (pH>8.5) while the non-irrigated land fall in the range of moderately alkaline (7.9 - 8.4) (Table 3)

The values of ECe were greater in irrigated lands, and the results in both land uses decreased consistently with soil depth (Table 3). Sileshi *et al*. (2015) confirmed that about 51% of Dubti/Tendaho irrigated land was dominated by shallow (<2m) ground water. Hence, the increments of ECe at the surface soils could be due to the dominance of upward (capillary) movement of salts from shallow saline ground water than its downward (leaching) movement with irrigation water (Gizaw, 2008).

Soluble cations and anions

Highest concentrations of soluble cations and anions under irrigated lands than non-irrigated lands were recorded (Table 3). This might be due to the impact of irrigation practices with poor quality water and redistribution of salt constituting minerals from the underlying rocks with water. In accordance with this, Qureshi *et al.* (2007) reported that deteriorated water quality had a major effect on the development of salinity and sodicity in the irrigated land of Iran located in the lower reaches of the basin. Heluf (1995) also reported that continuous use of irrigation water with high level of dissolved salts without leaching are the most common cause of soil salinity and sodicity hazards.

Table 3: Soil pH, electrical conductivity, soluble cations, soluble anions and sodium adsorption ratio

Land use	Depth (cm)	pH (1:2.5)	ECe dS m^{-1}	Soluble Cations (meql^{-1})				Soluble Anions (meql^{-1})				SAR
				Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	
Irrigated	0 - 30	8.61	17.47	48.73	0.63	11.51	8.40	5.00	5.60	36.0	27.17	15.4
Irrigated	30 - 60	8.75	10.74	36.41	0.95	8.50	6.00	3.60	4.00	28.0	16.25	13.7
Non-irrigated	0 - 30	8.08	4.97	22.80	0.09	4.40	2.30	4.40	4.60	10.0	7.72	12.5
Non-irrigated	30 - 60	8.20	4.49	20.53	0.08	2.80	4.40	2.00	5.56	8.20	6.86	10.8

As indicated in Table 3, similar to the values of ECe, almost all soluble cations and anions decreased with soil depth. This could be due to the higher upward capillary movements from shallow saline ground water than leaching of soluble salts to the subsurface horizons. In agreement with this, Gizaw (2008) reported that in Melka-Sedi Amibara plain and Bisidimo areas, higher salt accumulation was observed on the surface layers than at lower depths of the profile due to upward capillary movement of salty ground water than removal of soluble salts to the lower horizons.

Exchangeable cations and exchange properties

All exchangeable cations (Ca, Mg, Na and K) and CEC of soils in irrigated lands were relatively higher than those in non- irrigated lands indicating the presence of high smectite and/or vermiculite type of clay minerals in irrigated lands. In line with this, Lambooy (2013) confirmed that clay soils with high contents of 'smectite, vermiculite and illite have higher exchangeable cations and CEC values than soils with high contents of kaolinite and hapoysite, irrespective of actual clay content. Similar studies by FAO (2000) also reported that higher CEC in Iran has been mostly the consequence of naturally occurring phenomena due to geological composition of the parent material of the soils.

The other reason might be due to the fact that relatively better OM content (which act as colloidal sites) was found in irrigated land than non-irrigated land resulting in significantly contributing to the CEC of soils (Brady and Weil ,2002). However, as per the rating proposed by Hazelton and Murphy (2007), in both land uses the values of CEC were very high (> 40 meq/100g of soil) which decreased from the surface to the subsurface soils (Table 4).

Table 4: Exchangeable cations, cation exchange capacity, percent base saturation and exchangeable sodium percentage in the study area

Land use	Sampling depth(cm)	Exchangeable Cation (meq/100g)				CEC (meq/100g)	PBS (%)	ESP (%)
		Na^+	K^+	Ca^{2+}	Mg^{2+}			
Irrigated	0 – 30	9.53	1.43	35.00	7.00	53.60	98.81	17.78
Irrigated	30 – 60	7.18	0.98	32.00	5.00	45.80	98.60	15.68
Non-irrigated	0 – 30	3.25	0.86	30.00	4.00	41.00	92.95	7.93
Non-irrigated	30 – 60	2.91	0.83	31.00	4.00	42.00	92.24	6.77

Exchangeable sodium percentage of irrigated lands was higher than non-irrigated land; and it decreased with depth in both land uses. It followed the trend of exchangeable Na (Table 4). The higher concentration of exchangeable cations and ESP in irrigated land could be due to impacts of irrigation water quality. In accordance with this, Rodolfo *et al*. (2007) confirmed that irrigation water increased the Na content and other exchangeable cations in soils. According to Gonzalez *et al*., (2004), soils in irrigated lands were neither saline nor sodic (pH > 8.5, ESP > 15%, SAR > 13 and EC > $4dSm^{1-}$). However, it has the characteristics of both saline and sodic. Based on the guideline of salt affected soil categories set by Richards (1954), this soil falls under saline-sodic class. Saline-sodic soil has a pH value less than 8.5. However, pH values of soils collected from all sites of irrigated lands were greater than 8.5. Eventhough the pH value of saline-sodic soil are seldom higher than 8.5 due to high exchangeable sodium and SAR (Ann and Clain, 2005), generally, this value indicates that the characteristics of sodic soils rather than saline-sodic soils (Conway 2001; Gonzalez *et al.,* 2004; Qadir and Schubert, 2002). On the other hand, soils under non-irrigated land were classified as saline (pH < 8.5, ESP < 15%, SAR < 13 and EC > $4dSm^{1-}$) soils. The concentrations of ESP and exchangeable cations were high on the surface soils due to the capillary rise of the ground water and its high evapotranspiration loss leaving the salts on the surface of the soil.

Percentage base saturation (PBS) was also relatively higher in irrigated than non-irrigated land (Table 4) which might be due to relatively high OM and clay contents (soil colloidal sites and storehouse of exchangeable bases) in the irrigated lands. The other reason might be due to the presence of greater basic cations through the application of irrigation water on the irrigated land. Similarly, Mamo (2011) elucidated that the processes that affect the extent of basic cations also affect PBS. As per the ratings proposed by Hazelton and Murphy (2007), the PBS of both irrigated and non-irrigated soils were in the range of high (>80%) which were >98% and > 92%, respectively. Based on the ratings set by Metson (1961), PBS as a criterion of leaching, those soils are rated as very weakly leached (70-100%).

Dominant salts formed in irrigated and non-irrigated lands

The dominant salt types in both land uses were different because the concentration of ions (cations and anions) which were involved in salt formation was different in each soil type. The dominant anion in soil from both irrigated and non-irrigated lands was Cl^- followed by SO_4^{2-}, HCO_3^- and CO_3^{2-} in a decreasing order (Table 3). On the other hand, from the cations, there was more concentration of Na followed by Ca, Mg and K in irrigated land while it was Ca followed by Mg, Na and K in non-irrigated land. Thus, by taking both the anions and cations concentrations, it was possible to suggest that there was more sodium chloride (NaCl) salt concentration in irrigated land followed by sodium sulfate (Na_2SO_4) with the least expected salt type of potassium carbonate (K_2CO_3).while in non-irrigated land the dominant salt type is calcium chloride ($CaCl_2$) followed by calcium sulfate ($CaSO_4$) with the least expected salt type of potassium carbonate (K_2CO_3). Sodium containing salt dominance in irrigated land could be due to high concentration of Na, Cl, HCO_3^- and CO_3^{2-} ions in irrigation water caused the precipitation of Ca and Mg by HCO_3^- and CO_3^{2-} ions and facilitate the dominance of Na in the soil. In confirmation to this findings, Salliah and Pathmarajah (2003) cited by Meron (2007) noted that long periods of frequently irrigation practices with marginal or worse irrigation water quality leads to the accumulation of high salt contents in the irrigated lands

Cconclusions

Irrigation has significant impact on soil physicochemical properties at Dubti/Tendaho state farm. In non-irrigated lands, the dominant soil texture was silt clay loam with high soil porosity, available P, and low Bd, pH, ECe, soluble and exchangeable Na^+, ESP, SAR and soil water contents at different conditions while in irrigated soils, clay soil fraction was dominant with high surface crusted soils, Bd, pH, ECe, soluble and exchangeable Na^+, ESP and SAR. Based on this study, irrigation lands were highly affected by soil salinity that leads to the deterioration and severely degraded of soil physicochemical properties due to long periods of inappropriate irrigation practices, poor irrigation water quality and inadequate drainage systems that leads to shallow ground water. Therefore, there is a great need for the improving irrigation practices, drainage systems to rehabilitate degraded lands and restore to a normal productive state.

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Improving irrigation efficiency and water productivity of furrow irrigation in central zone of Tigray region, Ethiopia

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Abstract

The study was conducted in Laeelay Maichew District Mai Nigus micro dam irrigation scheme with the objective of evaluating the effect of surge flow irrigation under alternate and every furrow on irrigation efficiency, water use efficiency and crop yield. The experiment has eight treatments replicated three times and arranged with factorial randomised complete block design (RCBD). The first factor was irrigation systems (alternate furrow and conventional furrow) and the second factor irrigation flow methods (continuous, surge 1, surge 2, and surge 3). The results showed that the performance indicators (application efficiency, distribution uniformity, deep percolation, and run off) were not significantly affected ($p<0.05$) by the interaction of irrigation systems and irrigation flow methods however; these performance indices were significantly different with the main effects of irrigation system and irrigation flow methods. Similarly, the interaction of irrigation systems and irrigation flow methods had no significant effect on yield and water use efficiency. On the other hand, yield and water use efficiency were significantly different with main effects of irrigation flow methods (continuous, surge 1, surge 2 and surge 3) and irrigation systems (alternate furrow and conventional furrow) also has significant effect on water use efficiency but not on yield. In this study, better water use efficiency, application efficiency and distribution uniformity was attained from surge and alternate treatment. It can be concluded that alternate irrigation and surge flow irrigation seems to be better irrigation system and irrigation flow method for dry land area of Ethiopia with water scarcity and poor water management practices. Adopting those methods for such areas could be good option to improve the water productivity and yield of irrigated agriculture.

Keywords: alternate irrigation, surge flow, performance indicators, water use efficiency, crop yield

Introduction

Irrigation development can meet its objectives if it is managed properly. Improper on-farm irrigation management practices lead to erosion and sedimentation of reservoirs, poor water distribution, non-uniform crop growth, excessive leaching in some areas (leading to water logging), and insufficient leaching in others (leading to salinity build up), all of which decrease the yield per unit of land area and per unit of water applied (Umali, 1993, Ritzema, *et al.,* 1996, Strelkoff *et al*., 1999 and 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 (Kifle and Gebretsadikan, 2016; Mintesinot, 2002 and Horst *et al.,* 2007).

Now a days, small scale farmers in the country especially in Tigray regional state adopt traditional way of surface irrigation method application. Unfortunately these methods often have lower application efficiency and distribution uniformity. High runoff and deep percolation losses are cited as the main problems. Minimizing deep percolation and runoff while meeting irrigation requirements of crops can increase irrigation performance. For these reasons, several management techniques have been developed to reduce water losses during the irrigation event. Some of these are the cutback stream method, the run-off recovery system, and the intermittent application of water (surge flow) and drip irrigation systems. Studies conducted in Ethiopia, Egypt and Pakistan under cropped condition has indicated that, surge irrigation improves irrigation performance and irrigation water use efficiency (Kifle *et al*., 2008, Ismail *et al.,* 2004; Mahmood *et al*., 2003; Amer, 1998; Zaghloul, 1988), however, most of the researchs conducted on surge flow irrigation were on furrow lengths $\geq$ 70 m, with every furrow irrigation application system. Moreover, in Ethiopia development oriented researches on surge flow irrigation under very short furrow length and different irrigation method of application were not conducted.

The region mainly focused on increasing crop productivity currently more than any time through improving irrigation performance and water productivity. Maize crop was used as an indicator in the experiment because it is an integral part of Ethiopian dish. The crop is produced under furrow and irrigation in arid and semiarid parts of the country. Hence this experiment was proposed to improve irrigation efficiency and water productivity of conventional furrow irrigation system thereby to formulate irrigation improvement strategies that enhances irrigation efficiency, water productivity and production with the specific objective of evaluating the effect of surge flow irrigation under alternate and every furrow on irrigation efficiency, water use efficiency and yield.

Materials and Methods

Description of the study area

The experiment was conducted in the central zone of Tigray regional state Laeelay Maichew District Mai Nigus micro dam irrigation scheme. It is located at 38.4^o East and 14.1^o North with the altitude of 2080 masl in *'Weina Dega'* agro ecology. The soil type the experiment site was clay texture.

Experimental design and treatments setting

The experiment was conducted with the indicator crops maize on 30 m long and 75cm center-center / ridge–ridge spacing and 30 cm plant spacing. The experiment was conducted with two factors. The first factor was composed of two levels of irrigation application systems (alternate and every furrow) and the second factor with four levels of irrigation flow method (CF, S_1, S_2 and S_3) one case with continuous flow and three cases with surge flow. The treatments were replicated three times and the arrangement was in a factorial Randomized Complete Block Design (see the treatment details in Table 1 and Figure 1).

Treatment detail

Irrigation systems

Cf – Conventional furrow system

Af – Alternate furrow system

Irrigation flow method

CF - Continuous flow;

S_1 - Surge flow by which the water will be allowed to advance over the furrow length in two equal pulses;

S_2 - Water will be allowed to advance over the furrow length in three equal pulses and

S_3 - Water will be allowed to advance over the furrow length in four equal pulses.

Table 1: Treatments and their combinations

Irrigation systems	Irrigation flow method	Treatment combinations	Symbols of treatments
Cf	CF	CfCF	T1
	S_1	CfS_1	T2
	S_2	Cf S_2	T3
	S_3	Cf S_3	T4
Af	CF	AfCF	T5
	S_1	AfS_1	T6
	S_2	AfS_2	T7
	S_3	AfS_3	T8

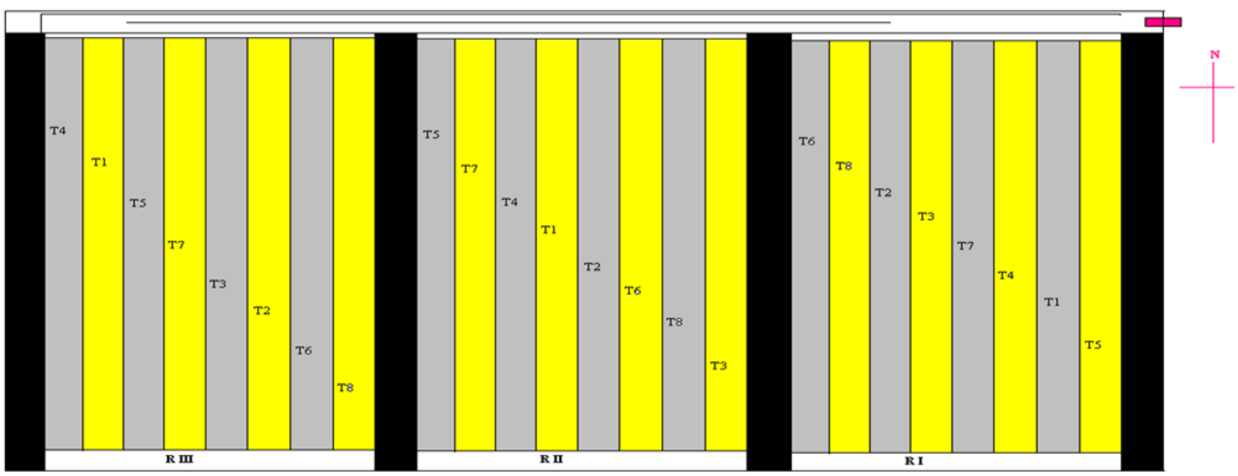

Figure 1: Lay out for the experiment on Maize at Mai Nigus micro dam irrigation site

Soil sampling and laboratory analysis

Composite soil samples at three soil depths, 0-30 and 30-60, 60-90 cm was taken from five random spots of the experimental plot. The soil texture and the soil chemical characteristics such as: pH, EC, and Organic matter were analysed from the composite samples using standard procedures (Taye and Sahilemedihin, 1998). Disturbed and undisturbed soil samples were taken for field capacity (FC), permanent wilting point (PWP) and soil bulk density (BD) analysis using soil core sampler. The sampled soils were analysed at Mekelle soil laboratory and Mekelle University soil lab.

Crop water requirement and irrigation scheduling

Meteorological data (minimum and maximum temperature, relative humidity, wind speed and daily sunshine hours) was taken from nearby station. Reference evapotranspiration was determined using Modified FAO Penman Monteith method. Crop water requirement was determined from the inputs reference evapotranspiration and respective crop coefficients of the crop stages (Allen *et al.,* 1998). Irrigation requirement was computed by subtracting effective rain fall from the estimated crop water requirement.

Fixed interval and variable depth (refill to field capacity) irrigation scheduling criteria was adopted.

Soil moisture determination

Soil moisture content before and after irrigation was taken from five points (0L, 1/4L, ½ L, 3/4L and L) along the furrow length (L) from each plot at three depths 0-30, 30-60 and 60-90 cm once at the mid-season stage of the crop for the purpose of soil moisture determination. Aquater meter moisture sensor was used for soil moisture measurement. Before taking the actual measurements calibration test for the instrument aquater meter was done.

Discharge measurement and water application duration

The discharge was measured using Parshal flumes installed at the entrance of the supply ditch channel and the upstream inlet of experimental furrows. Finally, water application duration was computed as:

$$t = \frac{D_{ap} * l * w}{60Q}$$

Where, t = Water application time (min), D_{ap} = Gross water application depth (mm),

l = Furrow length (m), w = Furrow width (m), and Q = Discharge (l/s)

Determination of performance indicators

Irrigation performance for the furrow was performed using the water balance of the root zone from the measurement of irrigation water applied, water stored in the root zone, and tail water runoff loss. The depth of water retained in root zone of the soil was computed based on the moisture contents of the soil taken using Aquater meter before irrigation and after irrigation (48 hr). Moisture status of the soil was measured at the five (0L, 1/4L, 2/4L, 3/4L, and L) points along the furrow at three depths (0–30 cm), (30 – 60 cm) and (60–90 cm).

The following performance indices were used to evaluate the effect of surge flow irrigation under alternate and every furrow method of irrigation application:

(a) Application efficiency (Ea)

$$E_a = \frac{D_{ad}}{D_{ap}} \times 100$$

Where, E_a = Application efficiency (%), D_{ad} = Depth of water added to the root zone (mm), and D_{ap}= Depth of water applied to the furrow (mm)

(b) Distribution uniformity (DU)

$$DU = \frac{Z_{\min}}{Z_{av}} \times 100$$

Where, DU = Distribution uniformity (%), Z_{min}= the minimum infiltrated depth (mm), and

Z_{av}= t`he mean of depths infiltrated over the furrow length (mm)

(c) Deep percolation loss (DPR)

$$DPR = \frac{D_{dp}}{D_{ap}} \times 100$$

Where, DPR = Deep percolation ratio (%), D_{dp} = Depth of deep percolated water (mm), and

D_{ap} = Depth of applied water to the furrow (mm)

(d) Irrigation water use efficiency

It is the ratio of crop yield to the total amount of water applied to the field (Michael, 1978).

Therefore, irrigation water use efficiency for all the experiments was computed as:

$$IWUE = \frac{Y}{D_{ap}}$$

Where, $IWUE$ = Irrigation water use efficiency (kg/m^3), Y = Crop yield (kg/ha),

D_{ap} = Irrigation water applied (m^3/ha)

Statistical Analysis

Analysis of variance was performed for the experiment and analysed using Genstat 13th edition statistical software (Alvey et al., 1982). ANOVA showing a significant treatment was subjected to fishers protected least significant test for mean separation.

Results and Discussion

Soil analysis results

As presented in the Table 2, soil physical and chemical property analysis of the experimental plot revealed that it has a clay texture with percentage of sand, silt and clay as 16.3, 41 and 42.7%, respectively. The soil has an average moisture content of 35.50% at field capacity (FC) and 15.20% at permanent wilting point (PWP) on volume basis. Average Organic matter of the soil is 0.81. Bulk density of the soil is 1.16g/cm^3 at a depth of 0 – 20 cm, 1.22 at a depth of 20 – 40 cm and 1.24g/cm^3 at a depth of 40 – 60 cm. The total available water holding capacity of the soil was found to be 171.2mm/m.

Table 2: soil characteristics of Mai Nigus maize experiment

	Type of analysis										
Depth (cm)	% sand	% silt	% clay	Texture	EC (ds/m)	pH	OM	Bulk density	FC Vol (%)	PWP Vol (%)	TAW (mm/m)
0-30	15	53	32	clay	0.07	7.91	0.99	1.16	34.56	14.07	182.4
30-60	17	37	46	silt clay loam	0.06	7.7	0.74	1.22	36.25	15.44	174.2
60-90	17	33	50	clay	0.06	8	0.69	1.24	35.67	16.10	157.1
Average	16.3	41	42.7	Clay	0.063	7.87	0.81	1.21	35.50	15.20	171.2

Irrigation Water Requirement of Maize

The water requirement of maize at Mainigus micro dam was computed for 90 days using the CROP-WAT computer program with the above mentioned procedures. The water requirement of maize at Mai Nigus micro dam experimental site is presented in Table 3.

Table 3: Crop water requirement of maize at Mai Nigus site

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)
13/1	42.89	100.00	0.30	12.87	0.00	0.00	12.87
23/1	45.64	100.00	0.35	16.18	0.00	0.00	16.18
2/2	46.37	100.00	0.68	31.45	0.00	0.00	31.45
12/2	47.32	100.00	1.04	49.16	0.00	0.00	49.16
22/2	49.14	100.00	1.20	58.96	0.00	0.00	58.96
4/3	51.53	100.00	1.20	61.83	0.00	0.00	61.83
14/3	53.86	100.00	1.20	64.64	0.00	0.00	64.64
24/3	55.58	100.00	1.01	55.96	0.00	0.00	55.96
3/4	56.42	100.00	0.66	37.09	0.00	0.00	37.09
Total	448.75			388.14	0.00	0.00	388.14

Performance indicators

Irrigation performance indices from the experimental plot were measured at middle growth stages of maize crop and performance indicators was analysed. All performance indicators (application efficiency, distribution uniformity, deep percolation, and run off) were not significantly affected by the interaction effects of irrigation systems and irrigation flow methods however these performance indices were significantly different with the main effects irrigation system and irrigation flow method (Table 4 and 5).

Table 4: The effect of irrigation system on performance indices, IWUE and Yield of maize

Treatment	DU %	Dp %	Ea %	RO%	IWUE (kg/hamm)	Yield (kg/ha)
Cf	79.34	37.5	51.7	10.9	3.88	3010.1
Af	85.09	35.4	55	9.7	7.12	2898.4
LSD (0.05)	2.989	1.6	1.44	0.79	0.456	ns
CV%	4.2	5	3.3	8.7	9.5	6.5

Yield and water use efficiency of maize

Yield and water use efficiency was analysed similar in this study. Yield was collected from the central three furrows. The interaction effects of irrigation systems and irrigation flow method had no significant on maize yield and irrigation water use efficiency. On the other hand, as presented in Table 4, yield and water use efficiency were significantly different with main effects irrigation flow method (C, S1, S2 and S3). Irrigation system (Af and CF) had significant effect on irrigation water use efficiency but there was no significant difference on yield of maize as indicated in Table 5.

Table 5: The effect of irrigation flow methods on performance indices and yield of maize

Treatment	DU %	Dp %	Ea %	RO%	IWUE (kg/ hamm)	Yield (kg/ha)
C	68.9c	41a	45.6c	13.3a	4.78c	2628c
S1	83.1b	35.1b	54.1b	10.8b	5.41ab	2888.9b
S2	86.4ab	36a	54.8b	9.2c	5.9a	3140.4a
S3	90.4a	33.6c	58.7a	7.8d	5.92a	3160a
LSD (0.05)	4.23	2.26	2.04	1.11	0.65	238.3
CV%	4.2	5	3.3	8.7	9.5	6.5

Conclusion

The interaction effect of irrigation system and irrigation flow methods were not significantly affected the performance indicators (application efficiency, distribution uniformity, deep percolation and run off loss). Yield of maize was not significantly influenced by the main effect of irrigation system (Af and Cf). The alternate and conventional every furrow have almost similar yield with less irrigation water for the alternate treatment. In contrary to yield, irrigation system had significant effect on performance indicators and water use efficiency. On the other hand, the main effect of irrigation system has significant effect on the performance indices and irrigation water use efficiency. Similarly, irrigation flow methods (C, S1, S2 and S3) were significantly affected the performance indices (application efficiency, distribution uniformity, deep percolation and runoff), irrigation water use efficiency and yield. It can be concluded that alternate irrigation and surge flow irrigation seems to be better irrigation system and irrigation flow method for dry land area of Ethiopia with water scarcity and poor water management practices. Adopting those methods for such areas could be good option to improve the water productivity and yield of irrigated agriculture.

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Acknowledgments

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THEME FOUR

WATER SUPPLY AND SANITATION

Rehabilitation of the Water Supply System of Arba Minch University, Ethiopia

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Abstract

The water supply system of Arba Minch University main campus is a standalone system composed of three tube wells mounted with submersible pumps, three service reservoirs and a branched gravity distribution system. The system suffers from lack of comprehensive design, which causes non optimal utilization of system capacity, pressure and discharge bottle necks, water losses and lack of adequate supervision, operation and maintenance. There are no adequate records of the components, maintenance and expansion works. The work presented in this paper established the existing system through comprehensive survey, modeled the distribution system using USEPA, EPANET 2.0 to ascertain the technical problems and solved them by applying modifications to the distribution system. The human resource requirements needed to implement these changes, the activity lists and responsibility matrix was developed along with technical solution for the effective implementation of the results.

Keywords: *Pressure. Losses, Discharge, Distribution systems, reservoirs*

Introduction

The existing water supply system in Arba Minch University main campus is a standalone water supply system. It comprises of tube wells as water sources within the compound boosted by submersible pumps via galvanized iron water mains to reservoirs constructed on nearby hills. Water reaches consumers through a mixed network of galvanized iron and polyvinyl chloride pipes by gravity. It serves approximately 13,000 residents in the campus.

The system was not constructed in one phase, rather it is expanded from the initial borehole-reservoir-distribution system constructed in 1979 E.C. to its current state along with the expansion of the institute at various times. Initially it had 360m^3 circular concrete storage tank (Reservoir 1) constructed at the mountainous side of the university. When the university was established in 1994 E.C. two new water reservoirs (reservoirs 2 and 3) were constructed with a capacity of 500m^3 each by the south water works construction enterprise.

The distribution system is composed of two distinct systems constructed at different times with little inter connection. It can be characterized as a branched distribution system composed of twelve boreholes, of which only three are operational, with three inch and two inch galvanized Iron pipe-pumping mains, three reservoirs on two separate hills, four supply mains and a network of pipes ranging between half to six inches in diameter. Large proportion of the pipe network, especially in the old distribution system, is galvanized iron pipe. The new distribution system from 1994E.C. expansion works has significant number PVC pipes. The total length of the pipe network is estimated to be 18.5 km. A system is shown in figure 1.Iron pipe-pumping mains, three reservoirs on two separate hills, four supply mains and a network of pipes ranging between half to six inches in diameter. Large proportion of the pipe network, especially in the old distribution system, is galvanized iron pipe. The new distribution system from 1994E.C. expansion works has significant number PVC pipes. The total length of the pipe network is estimated to be 18.5 km. A system is shown in figure 1.

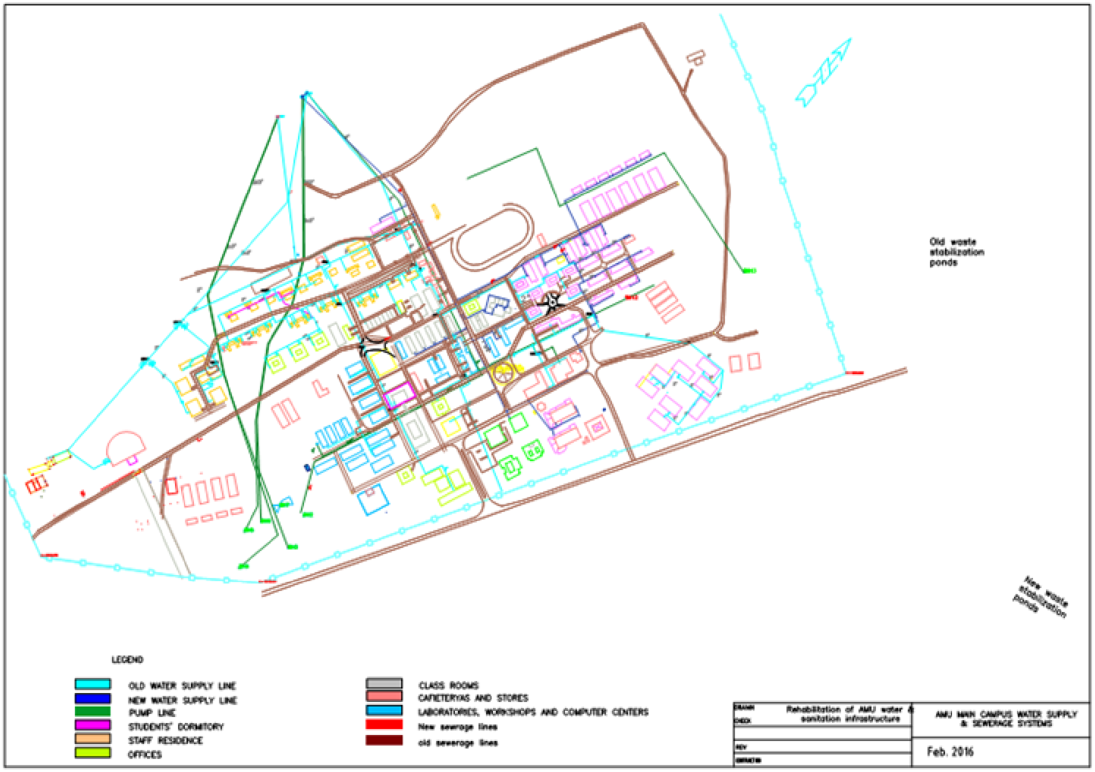

Figure 1 : AutoCAD representation AMU water supply system

Historically the water supply was complemented by the municipal water supply of Arba Minch town for special purposes like, laboratories, due to its higher quality to protect equipments. In addition, water was siphoned from the irrigation canal of the nearby Amibara state farm for gardening purposes. However, currently these water sources are no longer in use. In addition Hare River was used to irrigate the University small irrigation farm located in the campus. The submersible pumps are powered by 24 hours power supply from the national grid with no auxiliary power supply is available except to one of the pumps.

Problem Statement

Assuming a moderate 70 liters per capital per day, the total amount of water produced is barely adequate for the existing consumers. If one accounts for losses in the system and also consider other important demand types like fire fighting and gardening the available water falls short of the demand by 35%.

At this juncture in time water reaches buildings only 8-12 hrs. a day. This is possible when there is no power interruption; available pumps are working and are operated satisfactorily. A number of buildings in the compound are either not connected or the existing links cannot be established. Consequently, they do not get the water service. Lack of integration of the distinct systems constructed at different times has caused improper utilization of available storage capacity. The pipe size and length are not optimal. Furthermore, it reduces the overall flexibility of the system to supply demand nodes in the event of a pump failure. constructed at different times has caused improper utilization of available storage capacity. The pipe size and length are not optimal. Furthermore, it reduces the overall flexibility of the system to supply demand nodes in the event of a pump failure. Frequent mechanical and electrical failures of pumps and pipes in the distribution system have been observed and hence dented the reliability of the water supply system reliability of the water supply system .

The water quality of Arba Minch University main campus has been frequently tested in Arba Minch institute of technology water quality laboratory and found to satisfy all the minimum criteria for potable water. However, it has a high percentage value of total dissolved solid as compared to the municipal water supply. Hence it is not uncommon to see some people who work and live in the campus bring drinking water from Arba Minch town.

There is no water metering anywhere in the system. This makes it difficult to account for water losses, consumer behavior (trends in water demand) and overall efficiency of the system and has adversely affected consumer behavior.

The lack of automated switching system to turn pumps off when the reservoirs are full requires manual observation of reservoir levels, which are not easily accessible for frequent visits by pump operators. As a result, significant amount of water is lost as overflow from the reservoirs. The problem is especially pronounced in reservoir 3, where distinct green vegetation on the hill side during the dry season is observed indicating the magnitude of water released from the reservoir as overflow.

Despite the significant water loss through the distribution system, the largest loss is attributed to consumer wastage. The wasteful behavior of the consumer is expressed in student dormitories and staff residences, where no one bothers to close a running faucet or report lose fittings and pipe breakages. In addition lack of regular monitoring and preventive maintenance of house connections and fixtures is causing significant losses.

The design characteristics of the wells in AMU, i.e. the specific yield, depth, type of screens and gravel packing, pumping test results should have been available. Furthermore, the performance records of the wells on daily, monthly and yearly basis should have been available to establish the performance of the wells.

Water quality data from the sources shall be recorded .This will help establish weather contaminations of the water is from the source or from the distribution system. The pump type, capacity, characteristic curve i.e. head and flow combination that yields the highest efficiency, should have been available to guide the operation of pumps.

Proper record of operational decisions, capacity expansions, extension of connections, change of components of distributions system, addition of operational and/or control valves and other components shall be kept and put forward for use in current operation and future planning.

Improvement of system performance can only be achieved their adequate monitoring and recording of operational data. Operational data will help recognize how much percentage of the system capacity is in used, assess the unaccounted water loss and other inefficiencies in the system, assess water use patterns, get realistic design parameters for future expansions and help estimate operational cost.

Objective of the works

The objectives of the works include:

- To review the existing water supply system, identify prevalent problems of pressure. discharge, water loss and other operation and maintenance issues
- To design the water supply systems and its components to solve the identified technical and management problems
- To design an organizational framework to address the maintenance and operation of water supply system

- To develop a geographic information system based interactive data base for the designed systems

Materials and Methods

A number of methods were used to establish the existing water sources, storage and distribution system components. These include literature review of available documentation and previous studies, field visits, interviews with key informants, household and dormitory survey and focus group discussions. Furthermore, the system components were surveyed using state of the art total station equipment to determine their location and elevations.

Formal and informal interviews were conducted to collect data on present water supply and sanitation situation of the campus. This method was also used to elicit information regarding people's feeling about the current water supply service and their attitudes towards the planned intervention to improve the water supply system. Thus, interviews and discussion were held with different categories of people and relevant institute officials in the community. Officials of the campus are also involved in one way or another.

AutoCad 2007 was used to develop a graphic representation of the water supply in a geo-referenced manner using the data acquired by total station. USEPA's hydraulic analysis tool, EPANET 2.0, is used to undertake the hydraulic computations. The yield of the pumps and water loss estimation were measured using ultrasonic flow measurement equipment in collaboration with the Arba Minch town water supply experts.

Analysis of the data collected and hydraulic simulations have identified a number of technical and operation and maintenance problems. Alternative solutions to solve these technical problems were introduced to hydraulic models until satisfactory results were achieved.

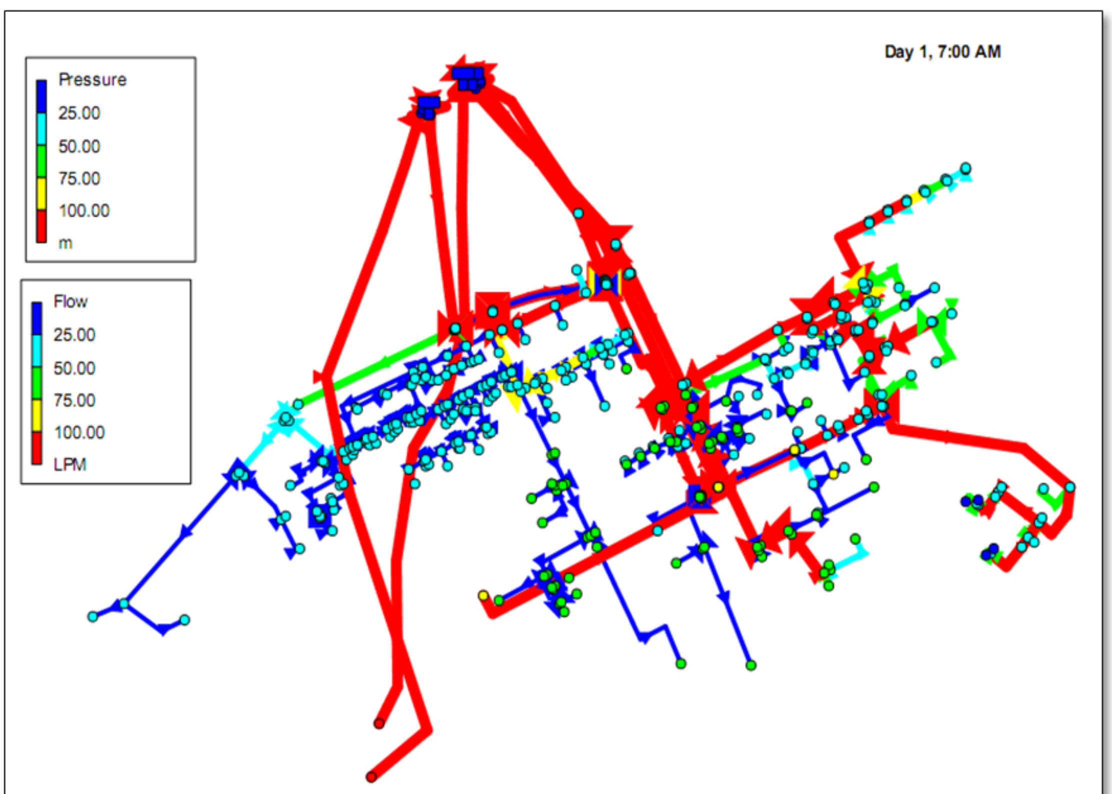

Figure 2 :EPANET 2.0 Model of AMU distributions system

Results and Discussions

The following problems are identified as major problems of the various components of the water supply system.

- The overall water supply system can only support basic domestic demand. If one accounts for conventional demand elements of fire demand and gardening and consider loss, the system can only support 65% of total current demand.
- The well field in AMU campus is delivering yields at design level, as verified by ultrasonic flow meters, however the readings may be biased by high seasonal recharge providing high piezometric head
- The possibility of well interference is high given the close location of the wells with each other, hence the level of interference is not known
- The pumping main to the reservoirs indicate (specially to reservoir 1) high unit head loss due to small diameter pipes and unnecessary long route
- The pumps are operating at very high head based on the pump characteristics curve provided(only one pump characteristics curve is provided) this greatly reduces the efficiency of the pumps and also causes pump deterioration leading to mechanical and electrical failure
- The pumps are working long duty cycles
- The available storage is adequate to support total current demand over a 24Hrs supply cycle. However, the pipe connection at the reservoir need simplification and the reservoirs need to be clean and chlorinated at least twice a year
- The reservoirs do not have automatic switching system hence overflow losses are significant
- The gravity mains from the two old reservoirs are adequate however the third reservoir is not supplying the system adequately due to poor connection to the old system
- The distribution system suffers from comprehensive design. It consists of two separate (little interconnection) hence in the event of failure of one component some areas will not get water.
- The available storage is not utilized evenly; one of the reservoirs is barely used by the system due to poor connection to the network.
- EPANET simulations of the system indicate many demand nodes have negative pressure implying they do not receive water hence the pipe have improper connections that need to be corrected
- The distribution system lacks fire hydrants
- The distribution system does not show visible breakage and water losses except some water stored in junction boxes. Although this physical observation does not rule out water loss in the distribution system, the water stored in junction boxes can well be a source of contamination when negative pressure sucks in the water into the distributions system
- House connection losses are largely attributed to consumer wastage, old and poor quality water fixtures, water closets etc.
- There are so many unconventional pipe connections in the pipe main which lead to avoidable head losses

There are no built in monitoring mechanisms in the water supply system to monitor water quantity, quality and head losses

- There is no water metering which denies the opportunity to study consumer trends and also affecting consumer behavior adversely
- There is no documentation of the system and alterations are not properly reported and documented
- The water quality is not regularly sampled and tested from various sources to monitor the quality status
- There are no operation and maintenance guidelines for the M&O crew
- There is no quick and effective mechanism of reporting system component failures from the consumers such as students dormitories and residential units
- The reliability of the system is dented by lack of backup power supply, reserve capacity in the event of pump failure and slow and inefficient maintenance and operation response capacity

Conclusion and Recommendations

The following remedial measures were taken to alleviate the problems listed above.

- The existing water supply system can only support 65% of the overall current water demand i.e. assuming reasonable pump duty hours. Currently, the pumps are working long duty-hour, which is causing short service lives. The operation is not sustainable. All in all, additional water sources must be sought to supply the deficit i.e. 1,176,586.5 liters per day. Significant amount of this deficiency i.e. 1,050,000.00 liters per day is for gardening purposes and the rest is for fire demand and losses
  - Increasing pump duty hours
  - Sinking additional bore holes
  - Roof top water harvesting
  - Surface water from Kulfo/Hare
- The submersible pumps deployed in tube wells are working long duty hours very close to their shut-off load according to head-flow characteristic curve provided, EPANET simulation of the existing system and operator’s report. This leads to low efficiency of performance, short service life and high operation cost. The pumps need to be replaced by a higher capacity pumps based on requirements of the improved network. Another alternative is to replace the pumping mains with a higher diameter pipe and reduce the load on the pumps. Existing and Design Pumping Curves are shown in figure 3 for the improved pipe network.
- The current total storage is adequate to support the overall water demand over a 24Hr supply cycle. However, the reservoirs need to be equipped with an automated reservoir level and pump control rely system.
- EPANET simulation of the system discloses the distribution system does not utilize the available storage capacity. Reservoir 1 and 3 maintain a high water level over extended period simulation. Reservoir 2 on the other hand is never filled to maximum water level as shown in figure 4. Hence, the following major changes are made to optimize the distribution network.
  - ◊ All demand nodes to the south of the road connecting Water quality lab and Swimming pool are connected to reservoir 3.

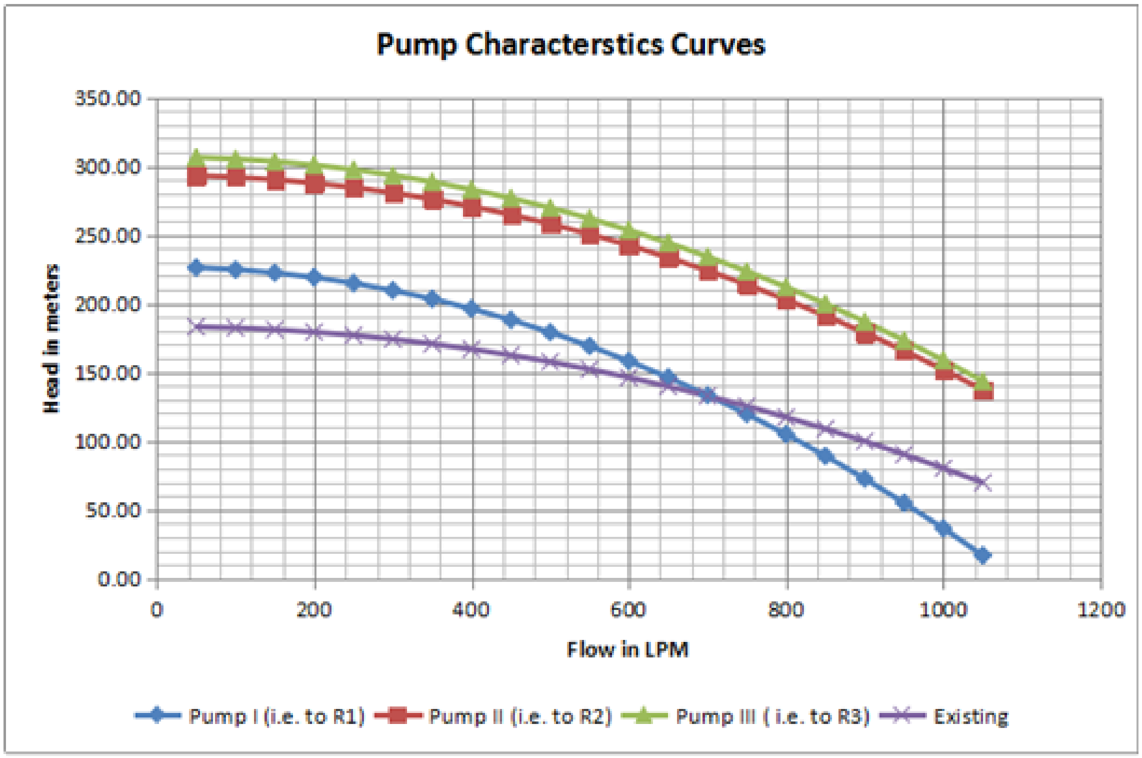

Figure 3: Pump Characteristic curves of Existing and proposed pumps

- The gravity main connecting reservoir 1 and staff residential apartments is disconnected and the apartments are connected to reservoir 3
- The water main connecting reservoir 2 to the students' canteen and its surrounding is disconnected and made to focus on high demand node concentration of newly built student dormitories
- All three reservoirs are connected to each other at a junction box near kindergarten to improve the flexibility of the system.

A number of pipe diameters are changed diameter and additional pipes included in the modified network.

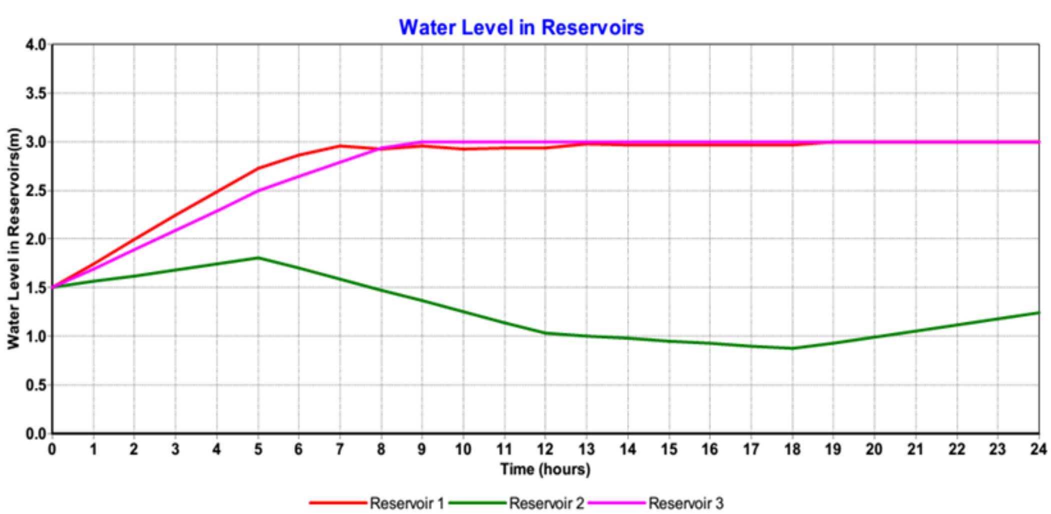

Figure 4: reservoir water level variation over 24Hrs simulation of existing distribution system

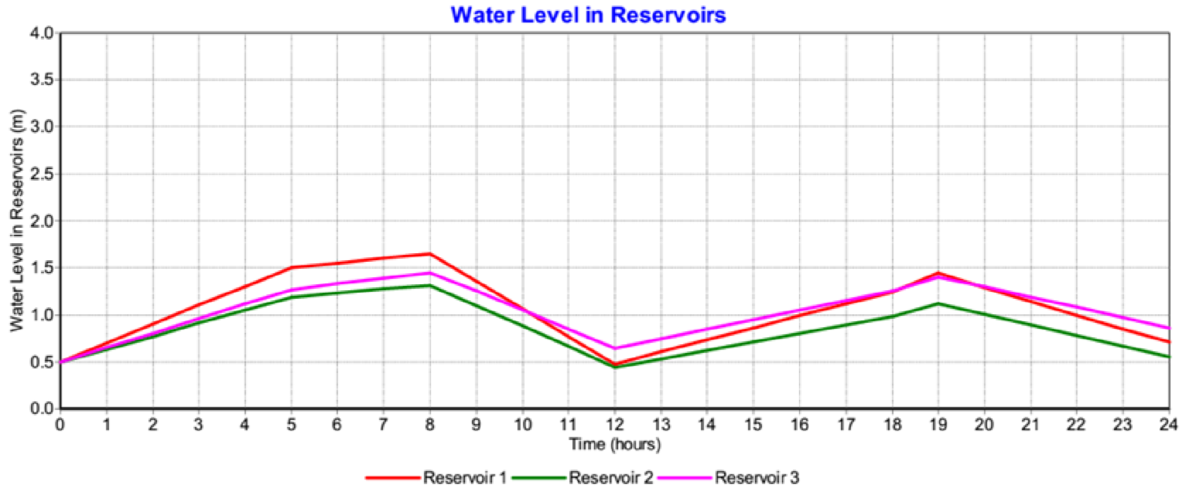

Figure 5: Reservoir water level variations over 24Hrs simulation of modified distribution system

- There were a number of buildings, which are disconnected from the network. Due to the optimization work done on the storage facilities, these demand nodes can now be connected to the network at the nearest distribution main
- With this changes a 24Hrs continuous water supply with due account for 37% loss on base demand is achieved through 16 hours of pumping per day
- The automatic pump controlled system proposed in this report is expected to avoid overflow water loss at reservoirs. The consumer water wastage can only be controlled through sound operation and management practices. To this end water user contracts are proposed to influence consumer behavior
- The water supply system is mapped in geo-referenced manner using UTM coordinates of demand nodes, junctions, connection pipes, and borehole and pump locations.GIS based record of the system is developed.

Organizational frame work of the human resources required to implement these changes, the actability list to achieve these changes along with a responsibility martix is developed

Limitations

- The bulk of the distribution system is buried underground and hence the full picture of the pipe network cannot be ascertained with high degree of confidence. The effort to establish the existing system was not helped by the lack of maintenance and expansion work records
- The pipe diameters are not optimized with respect to cost against pressure and flow constraints.
- The well yield assume in the supply is verified only through indirect measurement of flow through pumping mains, hence the performance of the wells over a complete seasonal cycle is not known
- The possibility of well interference is a credible cause of concern
- Water losses due to pipe breakage cannot be identified and accounted for.

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Rehabilitation of the Sewerage Line and Sewage Treatment System of Arba Minch Institute of Technology, Arba Minch University, Ethiopia

Negesa Yadesa, Kinfe Kassa, Abdella Kemal, Bereket Bezabih, Yegelilew Yesus

Abstract

The Arba Minch University main campus, with the current population of about 13000 has a sewerage system, which is directed indiscriminately towards set of waste stabilization ponds (WSP). There were reports from the users and operators that the sewer and treatment are not functioning properly indicated by overflow, regular block-age of sewers and some buildings are not connected at all. Therefore the main objectives of this research were to identify the hydraulic and other operational physical problems of the system and propose a possible solution using SewerCAD software. Information regarding the system was collected from interview of senior operators and plumbers, exhaustive field visit, and surveying of the campus. The comprehensive analysis of the performance of the system with SewerCAD has shown that the existing sewer network is not completely efficient in transporting sewage from the campus, and the WSP are not functioning properly. The main findings were the system lacks regular operation, correct and sustainable maintenance, theft of the part of sewer system and disposal of solid waste in the sewer system. Based on the findings, a new network is designed with SewerCAD and unconnected part of the campus joined with the network to amend the draw backs identified. The human resource requirements needed to implement the changes, the activity lists was developed along with technical solution for the effective implementation of the results and the regular user behavior change education is also proposed.

Keywords: *behavior change; operation and maintenance; SewerCAD; sewer system; Waste stabilization ponds*

Introduction

Arba Minch is administrative capital of Gamo-Gofa zone of the Southern Nations, Nationalities and People's Regional State. It has a geographical position of 6°2'N and 37°33'E and is situated about 500 km from the capital Addis Ababa. Arba Minch University has five campuses. Among those, Arba Minch Institute of Technology is the one which is surrounded by governmental and private farmlands and bush land.

The Institute has currently about 11,272 students and more than 2000 academic staff and family. This Institute enjoys relatively modern sanitation facilities compared to the town and the surrounding regions. It has stand-alone water supply and sewerage systems. The Institute uses water based modern toilet in its entire compound, except some dry pit latrines are there for use during shortage of water and non-connected buildings to the sewer line. However, there are places in the compound where open defecation is practiced especially next to bushes where access to toilet is not possible

This Institute enjoys relatively modern sanitation facilities compared to the town and the surrounding regions. It has stand-alone water supply and sewerage systems. The Institute uses water based modern toilet in its entire compound, except some dry pit latrines are there for use during shortage of water and non-connected buildings to the sewer line. However, there are places in the compound where open defecation is practiced especially next to bushes where access to toilet is not possible

The sewage is indiscriminately sewered to two separate set of waste stabilization ponds. One set of the pond was constructed in 1986 to treat sewage generated from very old buildings, and currently it is filled with sludge, and not functional. The old sewer connections are still draining the sewage to this waste stabilization pond but the flow is not reaching the pond due to illegal diversion from the line by farmers merely. The other two parallel set of ponds were constructed in 2003 when the university changed from water technology institute to university. This waste stabilization pond is designed to receive sewage generated from most of students dormitories. Currently, these ponds are receiving no sewage and covered with weeds.

While water carriage sanitation system is a good system of wastewater disposal, consistent and thorough maintenance of the sewerage system is equally important to serve its stated life. The campus's sewer system lack this inspection activities and maintenance of sewers takes place after worsening of the problem. In addition to late repairing and maintaining sewer lines, the maintenance schedule is not consistent and maintenance itself is not long lasting.

Currently, more than half of manholes especially downstream manholes have no cover or not covered properly. Different solid wastes [pieces of sponge from mattress, stones, food waste, emptied can, jerry can, plastic waste, papers, clothes, artificial and human hair and so on] have ended up in to open manholes and clog the outlet pipe. Generally, no wastewater is reaching the waste stabilization ponds. Sewage is flowing out of manholes on the field in the campus's compound and outside of the campus too.

Therefore, a scientific analysis of the system and provision of a solution is required. therefore, the objective of the study was:

- To identify the problems associated with existing sewer line
- To model the existing sewerage system and modify the sewer line using sewerCAD in order to solve the identified technical and management problems.
- To assess the sufficiency of treatment unit, waste stabilization pond

Materials and Method

Literature review of available on previous studies, intensive field visits, interviews with operators, focus group discussions with different stakeholders and laboratory and engineering surveying was conducted to study the situation of the compound.

A Field survey was conducted in the entire campus where sewerage system components exist. The system components were resurveyed using state of the art total station equipment to determine their location and elevations.

During the field visit, all potential areas of official waste disposal sites, illegal dumping and open defecation areas, future plan of disposal sites, major sewerage system problem areas, and storm water hazard areas of the main campus were visited. The GPS readings and pictures of the sites were taken.

Formal and informal interviews were conducted to collect data on present sanitation situation of the campus. Interviews and discussion were held with operators, users and with relevant officials in the university.

Focus group discussions were conducted with janitors of the university with relevance to toilet and solid waste collection and with plumbers who are operating and maintaining the sewer line.

AutoCAD 2007 was used to develop a graphic representation of sewage components in a geo-referenced manner using the data acquired by total station. The AutoCAD drawing was imported to Bentley's SewerCAD for hydraulic analysis. The existing and the new design of sewerage system was modeled and analyzed via Bentley's SewerCAD.

Results and Discussion

The findings of the study are presented in three sub-sections:

Observation and Field Visit

Manholes

The manholes have a lot of problems such as: lack of cover and improperly sealed, some manholes are buried under solid waste and soil.

Currently, more than half of manholes especially downstream manholes located out of the campus have no cover at all. Some manholes are partially covered. Different solid wastes [pieces of sponge from mattress, stones, food waste, emptied can, jerry can, plastic waste, papers, clothes, artificial and human hair and so on] have ended up in uncovered manholes and are a reason for clogging.

The over flow of manholes occurs due solid waste, and is observed at different places such as manhole next to abandoned dormitories [North of the campus]. These areas are vulnerable to pipe clogging due to plenty of solid waste generation and intensive human activity around there.

A number of manhole structures are buried under dumped solid waste or soil, because of they are constructed 30 years ago. Therefore, it is difficult to find the exact location of such manholes and the manholes' structure is also damaged with the weight of the materials. Obviously, the cost of maintenance and the frequency of maintenance for such manhole are expensive due to the aforementioned problem. The vulnerable manholes to such problem are located between ECAFCO, DH Geda dormitories and different part of the compound.

Unconnected Buildings

A lot of buildings are not connected to the sewer line. Cafeteria 3 and, cafeteria 4, new registrar building, school of graduate study, new laboratories, students' resource center, meeting hall, Sinetta buildings, libraries are not connected to any of branch or main sewer line of the campus. The sewage generated from these buildings is disposed using on site sanitation facility mainly septic tanks or releasing openly over ground surface.

Septic Tank

Less capacity septic tank is receiving high quantity of flow. Initially, this septic tank was designed to receive sewage from the main library, later from three sources: one library and a students' cafeteria. Currently, the tank is receiving additional sewage from residential apartments [R04, R05, R10, R11, R12], some offices [former AMIT building, continuity building, new AMIT building], some workshops and laboratories [hydraulic laboratory, electrical and mechanical workshops], which resulted in overflow and contamination of the area. The tank is over loaded a thousand times than its design capacity. For additional sewage from different buildings, it is not enough and releasing sewage to this septic tank is nothing different from releasing sewage over the field.

SewerCAD Output

Velocity and Slope

The existing sewer system of the campus is shown in figure 1. As sewage flowing through sewer contains organic and inorganic solid matter which should remain in suspension, there should be minimum velocity which can avoid the deposition of these solid matters.

The recommended minimum velocity at peak flow in sewer should be 0.6m/sec (Department of public work 2008). Analysis shows a number of sewers have developed velocity less than the recommended minimum velocity, Figure 2. In other words, the slope at which sewer line designed is not sufficient to develop enough velocity in the sewer.

At higher velocity the flow becomes turbulent, resulting in continuous abrasion of the interior surface of the sewers by the suspended particles. The recommended maximum velocity in cement concrete pipe is 3m/s (Department of public work 2008). Analysis shows, a number of sewers have developed the velocity beyond this maximum velocity that is the slope at which sewer designed and constructed is more than sufficient.

As shown in Figure 2, the maximum average velocity detected in sewer is 14.5m/s and the minimum is 0m/s [P-181 from figure 3]. The sewer, in which 0 m /s velocity produced, was re-laid with no slope via road culvert Addis Ababa-Arba Minch road construction, P-181, Figure 3.

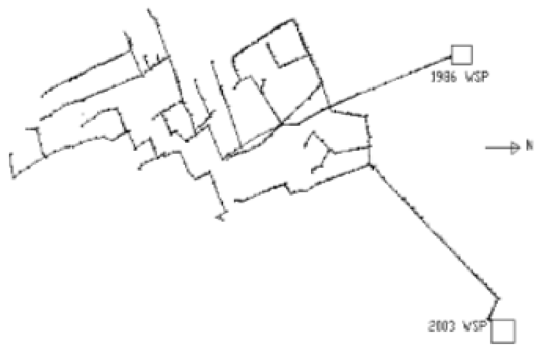


Figure 1: Skeleton of existing sewer line of the campus

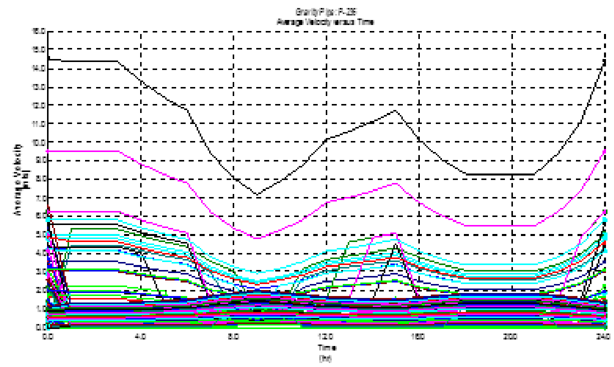


Figure 2: Velocity versus time of all existing sewer

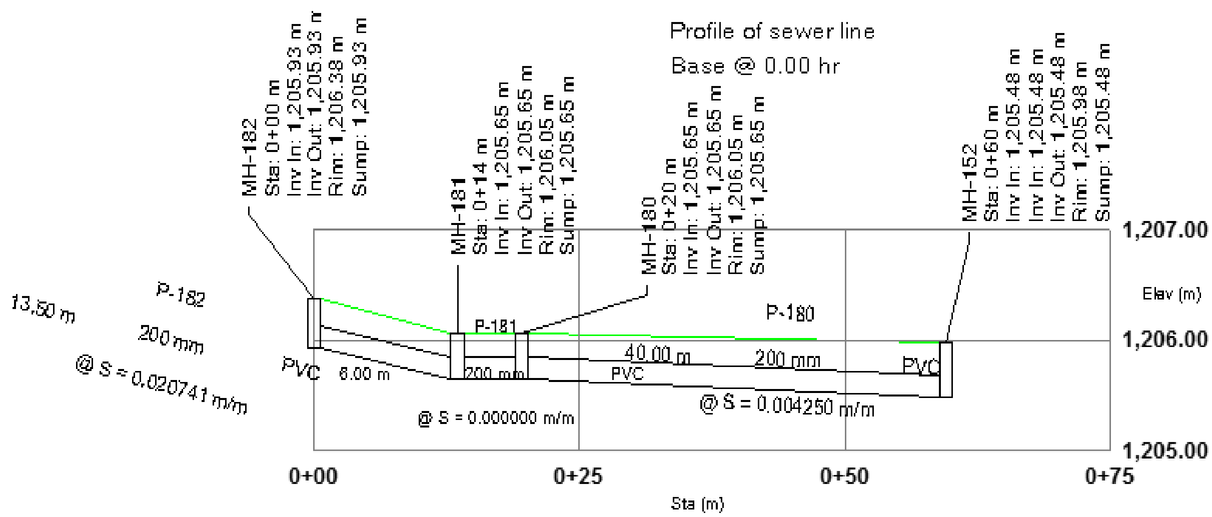
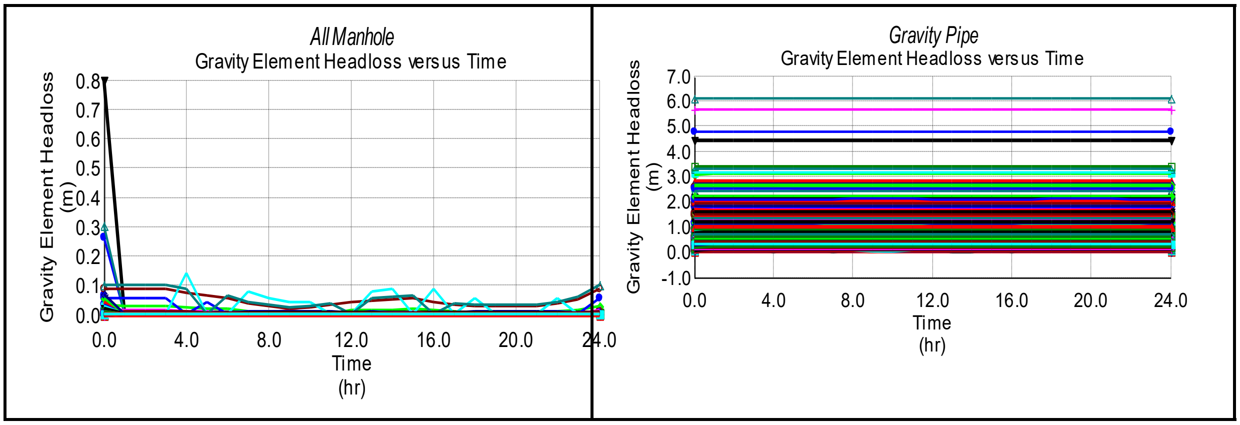


Figure 3: Profile of existing sewer line

Head loss in gravity element

The maximum gravity head loss in manhole structures was 0.8m and the minimum value was 0m. In gravity sewer pipe maximum head loss is 6m and the minimum value was detected as 0m.



Friction losses are generally based on the relationships between fluid velocity, section roughness, depth of

Figure 4: Gravity element Head loss

There are many equations that approximate friction losses associated with the flow of liquid through a given section. In this study Manning's formula was used to calculate the friction loss.

$$Q = \frac{K}{n} AR^{2/3} S^{1/2}$$

where: Q =Discharge(m³/s, cfs), k =Constant(1.00m$^{1/3}$/m/$^{1/3}$, 1.49 ft1/3/m1/3), n = Manning's roughness (s/m$^{1/3}$), A = Flow area (m², ft²), R = Hydraulic radius (m, ft), S = Friction slope (m/

flow, and the friction slope (head loss per unit length of conduit).

Redesigning the Sewer

The new design of sewerage system covers the entire area of the university, including newly expanded areas specifically to south of the campus. In this design, the proposed sewer line covers all those unconnected areas with length of 1600m and about 80m length of sewer line modification.

The modified sewer lines are:

1. Near library septic tanks is abandoned and buildings have to be connected to other branch of sewer lines.

2. Outside university compound, between main roads the direction of one sewer line is changed and connected to other manhole P-115, refer Figure 6b). Friction losses are generally based on the relationships between fluid velocity, section roughness, depth of flow, and the friction slope (head loss per unit length of conduit).

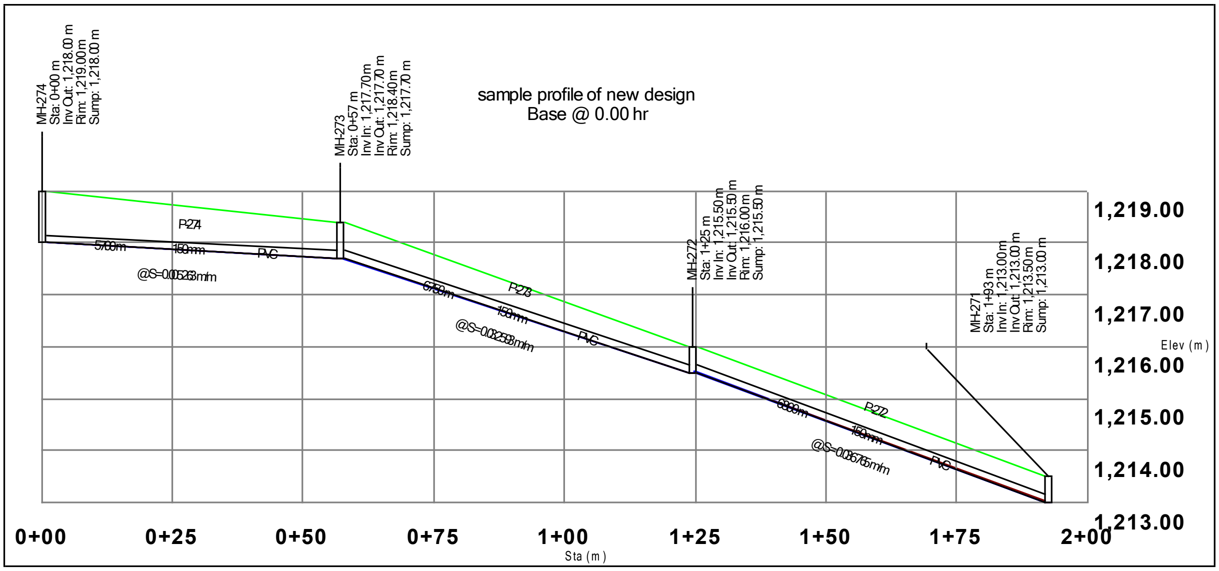
Figure 5: Location of the new design and modification of the sewer line

However, it is not possible to install sewer network for small portion of the university sites owing to their relative altitudes. Key areas that were not possible to be served with the system are the staff resource center and main hall. For these buildings Septic tank were proposed.

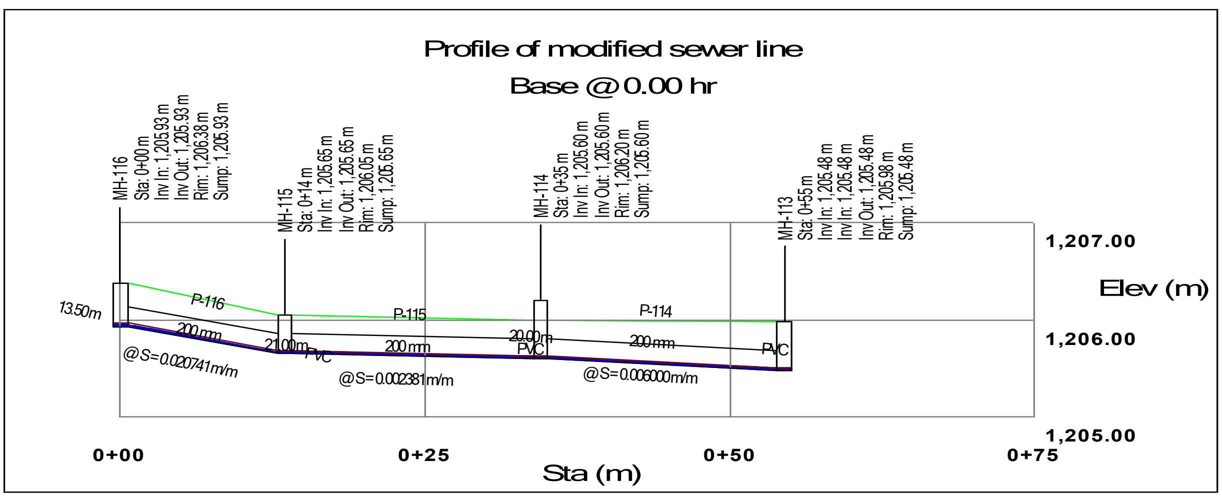
The detailed hydraulic analysis has indicated that the proposed branch sewer reticulation network would require sewers of 150mm diameter for lateral and branch sewer, respectively. Cheaply available, flexible and easily handle able sewer material, UPVC, is preferred than the other sewer materials.

Most of the existing manhole's shape is rectangular and few are circular. The maximum depth of existing manhole is 3.94m and the minimum depth is 0.47m. The width and length rectangular manholes vary from manhole to manhole. The maximum size of rectangular manhole is 1.00m by 1.82m and minimum size of 0.65m by 0.65m. The maximum diameter of circular manholes is 0.80m and minimum diameter of 0.68m.

The shape of all newly designed manholes is rectangular because of its simplicity for construction. The maximum depth of this manhole is 2m, with minimum depth of 0.5m. The width and length of these is designed to be 0.80m by 0.80m to offer enough space during construction, operation and maintenance.



[a]



[b]

Figure 6: profile of (a) newly designed sewer line and (b) modified sewer line

Waste Stabilization Pond size

After new design and modification of sewer lines, the 1986 waste stabilization pond treat an average sewage flow of 170m^3/d. And the 2003 waste stabilization pond treat an average sewage flow of 527.5m^3/d

From waste stabilization pond physical measurement, the actual volume of the ponds was estimated for all anaerobic, facultative and maturation ponds for both 2003 and 1986 waste stabilization ponds, Table 1 and 2. The actual volume of these ponds is greater than the minimum volume required to treat the sewage. So, the waste stabilization pond has enough size to treat all sewage generated from university community.

Table 1: Summary of 2003 waste stabilization pond's hydraulic elements

Pond type	Minimum volume required [m^3]	Actual volume [m^3]	Actual Depth [m]	Standard depth [m]	Hydraulic residence time [day]
Anaerobic	1243	1858	1.55	2 -5	3.7
Facultative	1539	1738	1.3	1- 2.5	3.5
Maturation	1500	1579	1.2	0.5 - 1.5	3.2

Table 2: 1986 waste **stabilization ponds' hydraulic elements**

Pond type	Minimum volume required [m^3]	Actual volume [m^3]	Depth [m]	Hydraulic residence time [day]
Pond1 [anaerobic]	643	723.5	4	4.3
Pond2 [facultative]	426	452	2.5	2.7
Pond3 [maturation]	204	217	1.2	1.3

Operation and Maintenance

The operation and maintenance of the sewer's system main problems are the behavior of users emanated either they are not exposed or used water based sanitation system or some are negligent and damage public common property. So awareness raising during students 'entry and regular updating should be given to make the system functional.

Operators have to do regular maintenance to make the system functional. The surroundings of the waste stabilization ponds should be maintained regularly by cutting grass and weeds mechanically and removing solid waste from internal connections.

Operating persons have to be assigned to take care of the ponds and the external pipe systems.
With new design and modification, over 274 manholes found along sewer line, among these, 42 manholes are newly designed and modified. Most of the existing manholes have no cover as mentioned in introduction part of sewerage system. Knowing each size of coverless manholes, in this design report, manhole cover is recommended to be constructed for those manholes and cost estimation is done.
Some sewer lines needs frequent operation and maintenance due to lack of sufficient slope implying that lack of self-cleansing velocity at peak flow. It is obvious that where self-cleansing velocity is not maintained in the sewer, there is deposition of suspended solids which result in clogging of sewer. From newly designed sewer line, P-266, P-263, P-262, P-261, and P-260 need frequent operation and maintenance. From the existing sewer line, P-117, P-116, P-115, P-114 needs frequent operation and maintenance. All these sewers could not maintain self-cleansing velocity as they pass through road culvert.

As anaerobic ponds designed to settle down solid particles, gradual accumulation of sludge is observable after months/years which reduce the capacity of the pond. So, it is recommendable to desludge the anaerobic waste stabilization pond regularly.

Conclusions and Recommendations

Even though, hydraulically the system is not designed properly, majority of the sewerage system is functional, but it lacks proper operation and maintenance. The behavior of users, careless solid waste disposal, disposal of construction materials on manholes, and lack of scheduled operation and maintenance have significant influence on the proper operation and construction of the sewerage system. The university spends a lot of money and manpower every year for the maintenance of the sewer system, toilets and water system but it can be improved by educating the students and the workers.

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Reuse Potential of Treated Tannery Effluent for Irrigation of Vegetables: Encouraging water efficiency and sustainable development in Ethiopia

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Abstract

Wastewaters from tanneries are characterized by high level of organic and inorganic matter, chromium, suspended and dissolved solids. Due to the high conductivity and toxicity of tannery industry effluents, wastewater reuse can be possible only by implementing integrated process of sustainable wastewater treatment. The objective of the present study was to investigate the influence of irrigation of treated tannery effluent on growth and heavy metal accumulation in the edible part of the selected vegetables. An innovative integrated treatment technology [hydrolysis-anaerobic-Sequence Batch Reactor (SBR) integrated with a constructed wetland] was used for the treatment of tannery wastewater. Randomized block design with three replications in both control and treatments was used for field experiment. Field and pot experiment was used to see Cr source and its effect on the vegetable growth and absorption. Ground water for control and treated tannery wastewater for treatments was irrigated. Wastewater vegetable samples were analyzed for nutrient, Cr and microbial quality. Soil and edible vegetable samples were analyzed for heavy metal using standard methods (APHA). The removal efficiencies of the treatment system show 98% for BOD, 97% for COD, 82% for total nitrogen, 99% for NH_3-N, 85% for SO_4^{2-}, 99% for S^{2-}, 96% of total Cr, 99% total Colin forms and 86% for EC. Significant variations in growth were no observed between the control and treatment of vegetables for 83 % of the test vegetables. Cr, Pb, Cd, and Ni concentrations in Vegetables and fruits were lower than the toxic threshold. Therefore, the study concluded that the integrated treatment processes was efficient to treat the tannery wastewater below the limit of EEPA standards and irrigation water quality, possibly reuse the effluent.

Keywords: *Tannery wastewater treatment,* Irrigation of *Vegetables, Chromium, Health risk estimation,*

Introduction

Due to scarcity of fresh water, in developing countries, wastewater is used to irrigate land and can provide highest productivity that the added nutrients (reduce fertilizer use) and organic matter enables farmers to sow all year round vegetables (Chaw and Reves, 2001; Murtaza, *et al.,* 2003; Palese *et al*., 2009; Mani & Kumar, 2014). The agro-processing sector, in Ethiopia, generates a large quantity of highly loaded effluents, which if managed appropriately, can result in a perpetual source of energy and organic fertilizer. However, the uses of untreated tannery wastewater for irrigation contaminate the soil, vegetables and crops, which when consumed causes serious health hazards to the consumer (Warner, 2000; Vol, 2006; Bahri, 2009; Alebele, 2010).

Tannery wastes are ranked as the highest pollutants among all the industrial wastes due to high level of Cr, sulfide, other organic and inorganic pollutants which causes the highest toxic intensity per unit of output (Khan, 2001; Cooman *et al.* 2003; Tadesse and seyoum, 2015). The presence of Cr and S^{2-} in tannery wastewater has become a major threat to plant, animal and human life due to their toxic effect and/or non-biodegradable in living organisms which leading to unwanted effects (Nabulo et al., 2011).

Therefore, pollutants must be removed from the effluent before reusing for irrigation or discharging in to water bodies. Therefore, objective of the present study is to evaluate the suitability of treated tannery wastewater for safe reuse for irrigation of vegetable crops with particular emphasis on the detection of chromium from irrigated vegetables.

Materials and Methods

Study area

The study was conducted on a pilot-scale integrated biological wastewater treatment plant (WWTP) which was installed in the premises of a privately owned tannery in Modjo Town, 70 km south of Addis Ababa, Ethiopia.

Experimental Design

Suitability assessment of treated tannery WW, for irrigation of vegetables experiment, was carried out both in pot and field experiment (Completely Randomized Block Design (CRBD) with a total of 36 treatment plots). Both the pot and field experiment were irrigated with treated tannery WW (treatments) and underground water (controls) each in triplicates. Each block has an area of one meter square plots. The pots and plots were seeded with seeds of vegetables (Cabbage (*B. oleracea capitata),* onion (*Allium cepa*), Swiss chard (*Beta vulgaries*), Tomato (*Lycopersicum esculentum*) and Beet root (*Beat vulgaris*)).

Collection and Analysis of Sample

Samples of vegetables, soil, wastewater and treated effluents were collected from mojo tannery premises, prepared and preserved in the laboratory until analysis was done. A liter of effluents were collected at the end of CWs using cleaned plastic bottles every week for 3-day of hydraulic retention time (HRT). The influents and effluents were characterized for Total Colin forms (TCF), Fecal Colin forms (FCF), BOD, COD, TN, nutrients (NO_3-N, PO_4, S^{2-} and SO_4^{2-}), pH, TDS, conductivity, chlorides and heavy metals (Cr, Cd, Ni and Pb) following standard methods. WW samples, edible parts of each vegetable and soil samples were digested and analyzed for Cr and other heavy metals (Cd, Ni, and Pb) using flame following standard methods (APHA, 1998). The growth inhibition percentage was calculated using the following formula (Harlapur *et al.,* 2007):

$$I\% = \frac{100x(C-T)}{C} \qquad \text{...1}$$

where I% is inhibition percentage of vegetable growth, C is average growth in control, T is average growth in the treatments.

A target hazard quotient (THQs) is calculated based on the following equation (USEPA, 2002:

$$THQ = \frac{EFxEDxFIxMC}{RfDxBWxAT} x10^{-3} \qquad \text{...2}$$

where, EF is the exposure frequency (365 days/year), ED is the exposure duration (64.7 years), FI is the food ingestion (g/person/day), MC is the metal concentration in vegetables (mg/kg, on fresh weight basis), RfD is the oral reference dose (mg/kg/day), BW is the average adult body weight (60 kg), AT is the averaging exposure time for non-carcinogens (365 days/year × number of exposure years, assuming 64.7 years in this study).

Statistical analysis

The nutrient and elemental concentration of water, soil and vegetable samples were statistically analyzed using the statistical software SPSS 16.0 (SPSS, USA), origion8 and Microsoft excel.

Result and Discussion

Characterization of treated effluents

The average raw tannery wastewater in terms of BOD, COD, TN, NH_4^+-N, NO_3^--N, SO_4^{2-} and S^{2-} were 3120.6±172 mgO_2/L, 7,273±536.97 mgO_2/L; 545±12.7 mg/L; 261.5±68.51 mg/L; 112.2±24.36 mg/L; 583.7±170 mg/L and 148.5±6.18 mg/L, respectively. The mean influent concentration of TDS, TSS, EC and pH were 7,035±42.52 mg/L, 2,215.38±61mg/L, 15.5±1.99 ms/cm and 8.67±3.56, respectively. The removal efficiency of pilot biological treatment system integrated with CWs in the removal of priority pollutants of tannery wastewater was high (ranges between 81- 99.9 %) (Fig.1 A).

The final effluent concentration for BOD and COD were 56±18 and 217±26 g/l, with removal efficiencies of 98% and 96.6%, respectively. The average concentrations of TN, NO^{3-}-N and NH_3-N in the final effluent were 49 mg/l, 22.7mg/l and 7.1mg/l, respectively and their removal efficiencies were 90.37%, 95.98%, and 97%, respectively. The concentrations of S^{-2} and $SO4^{-2}$ in the effluent were 0.4 and 88mg/l with a removal efficiency of 99.8 and 81.8% respectively (Fig. 1A). The value of PH, COD, TN, S^{2-}, SO_4^{2-} and chloride were within the acceptable national provisional discharge limit (Fig. 1B, C). There was a 99.9% removal of total coliforms but fecal coliform was not detected in the effluent. The results showed that the treated wastewater can be used as irrigation water for vegetable production.

Effluent Effects on Vegetable growth

There was no significant difference in shoot length between the control and treatments (at $p < 0.05$). The inhibition of treated tannery effluent on Carrot, Tomato, Cabbage, Onion, Swiss chard and Root Beet was 0%, 7.3%, -0.36%, 15%, 4.2% and 2.3% respectively. The treated tannery effluent imposed inhibitory effect on both shoot growth of onion (15%) while stimulates shoot growth in cabbage (-0.36%)(Fig. 2).

Heavy metal in vegetables

Vegetables analysis grown using treated tannery effluents showed that Cr has detectable concentrations in the analyzed sample while Cd, Pb and Ni were found below minimum detection limit of flame AAS (< 0.005mg/L). In the field experiment the mean total Cr values (mg kg^{-1}) in the edible portion of vegetables were in the following order: tomato (0.197±0.005) > carrot (0.122±0.002) > cabbage (0.113±0.004) > onion (0.098±0.002) > swiss chard (0.088±0.001) > beet root (0.05±0.001) (Table 1).

Pot and field experiment results, with different Cr soil content, revealed that the Cr in the vegetables is mainly translocation of from the soil to the vegetables. This can also be showed by the lower level of Cr in the treatments in pot experiment, where the soil has no detectable Cr concentration (<0.005mgkg^{-1}) before the experiment.

According to WHO/FAO (2001), the maximum allowable concentrations Cr and Cd were 0.1 and 0.2 mg kg^{-1}, respectively for leaf vegetables. About 50 % of the average treatment vegetables from field samples were above the WHO/FAO standards for Cr. Fissha (2002) reported that Cr levels in vegetables varying from 1.25 to 2.81 mg kg^{-1}in cabbage, onion, potato, red bet and swiss chard which was almost ten times higher than those in the present study. Thus, treated tannery wastewater irrigation was

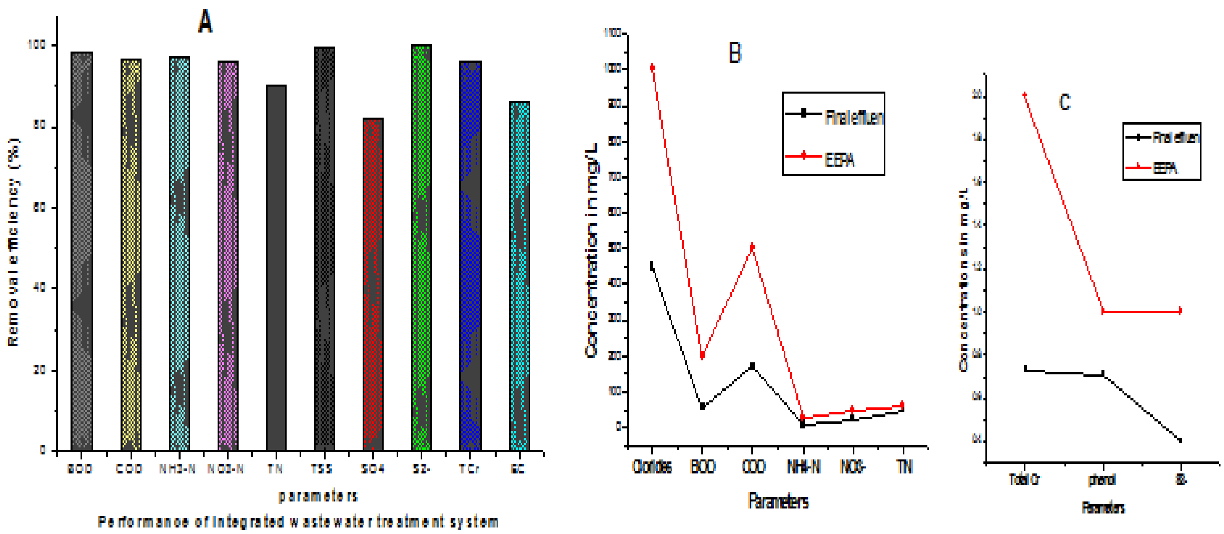
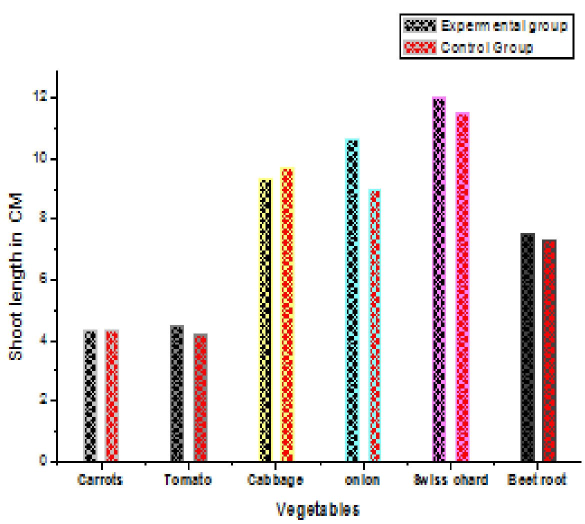
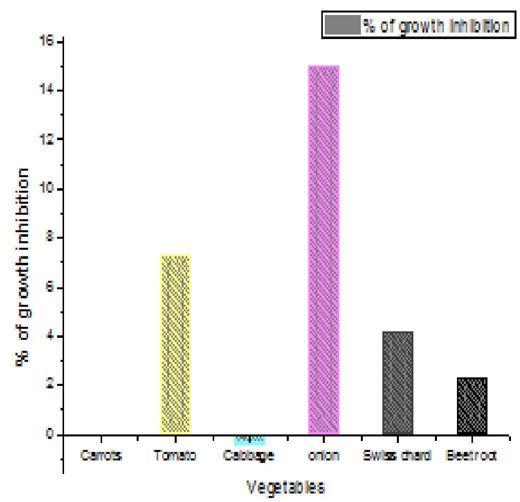


Fig. 1. Performance of integrated biological treatment system (A), comparison of effluent quality with





EPA discharge limits (B, C)

safer than using polluted Akaki river. Before and after experiment soil analysis showed that the tannery effluent (0.73 mg Cr kg^{-1}) in irrigated soil showed increase its average Cr concentration from 0.129 to 0.166 mg kg^{-1} in three months interval both in the pot and field experiment. The mean total Cr value in the treatment soils from the field experiment (0.166 mg kg^{-1}) was higher than those of pot experiment (0.298 mg kg^{-1}).

As shown in table 1, the soils used for irrigation of field vegetables were already contaminated with Cr before the experiment. In addition, considerable amounts of heavy metals were found in soil irrigated with wastewater as compared with control soil irrigated with ground water.

Therefore, irrigation with tannery effluent was believed to be responsible for soil enrichment with Cr. The magnitude of Cr in soils irrigated with tannery effluent was below the maximum permissible limit (3 mg kg^{-1}) as indicated by Kabata- Pendias and Pendias (2001).

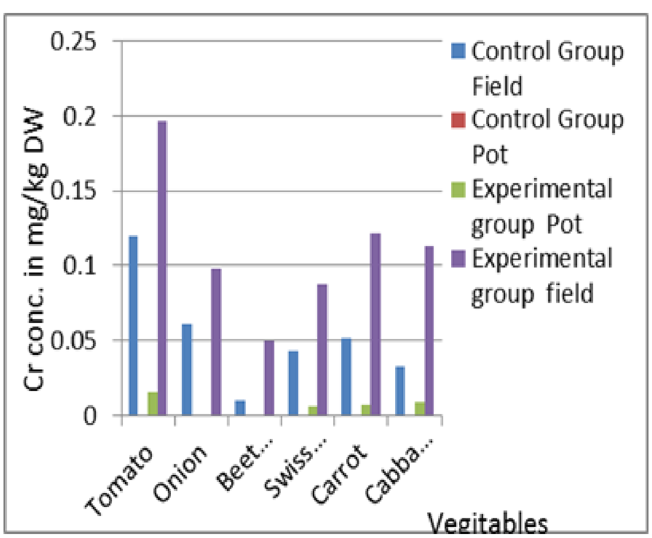
Table 1.: Heavy metal conc. (mgkg^{-1}, except Cd (µg/kg)) in edible part of vegetable and soil Cr concentrations (mgkg^{-1} soil) (0–15 cm depth)

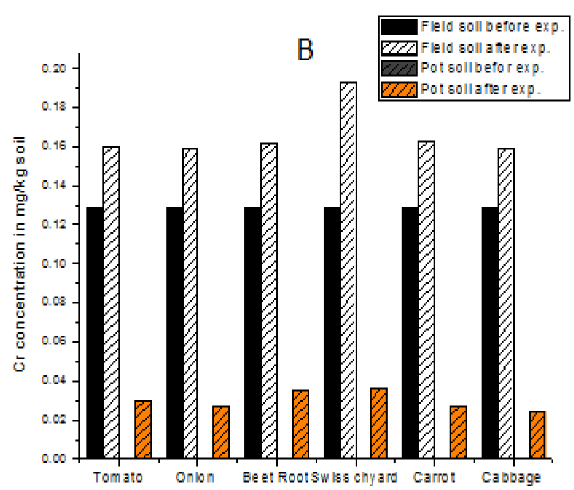
Vegetable Samples	Control group		Treatments group					Soil Cr Concentration			
	Field	Pot	Pot Experiment		Field experiment			Field experm.		Pot expert.	
	Cr	Cr	Cr	BTF	Cr	BTF	Cd µg/kg	Before	After	Before	After
Tomato	0.120	ND	0.016	1.23	0.197	0.53	0.017	0.129	0.160	ND	0.030
Onion	0.061	ND	ND	0.62	0.098	-	0.001	0.129	0.159	ND	0.027
Beet Root	0.010	ND	ND	0.31	0.05	0.023	0.011	0.129	0.162	ND	0.035
Swiss chard	0.043	ND	0.0061	0.46	0.088	-	0.018	0.129	0.193	ND	0.036
Carrot	0.052	ND	0.007	0.75	0.122	-	0.021	0.129	0.163	ND	0.027
Cabbage	0.033	ND	0.009	0.71	0.113	0.29	0.023	0.129	0.159	ND	0.024
WHO/FAO	0.1	0.1	0.1		0.1		0.2	3	3	3	3

WHO: World Health Organization and FAO: Food and Agriculture Organization; BTF: Bio-transferable factor; ND: note detected (<0.005 mgkg-1)

Potential health risk estimation

Health risks associated with Cr and Cd through vegetable consumption were assessed based on the target hazard quotients (THQs) (USEPA, 1998). Oral reference doses (OfD) were taken 0.003 and 0.005, mg kg^{-1} day^{-1} for Cr and Cd respectively (USEPA, 2002; Islam MS, Hoque, MF, 2014). The THQ <1 means the exposed population is assumed to be safe and 1 < THQ < 5 means the exposed population is in the level of concern interval. The average amount of Vegetable consumption in Ethiopia is 25.4 kg/person/year (Marie, 2005); which is much less than the WHO/FAO recommended intake (86 kg per capita per year).





In the present study Cd, Pb and Ni contamination in plants had lowest potential to pose health risk to the consumers due to low concentrations. The target hazard quotients (THQs) for Cr was less than 1 (0.073) in all the vegetables. Since the THQs for Cr is 0.073, the potential health risks posed by Cr from treated tannery effluent were considered negligible. Similar study by Cui et al. (2004) have also reported that local residents of an area near Modjo river have been exposed to Cr through consumption of vegetables, but no risk was found.

Conclusion

The results show that the technical performance of the pilot integrated treatment processes were efficient to treat high strength tannery wastewater and the treated wastewater meets the acceptable minimum national and international environmental discharge standards. The treated wastewater has a potential for reuse for irrigation. Highest heavy metal (Cr and Cd) concentrations in field experiment compared to pot experiment reflect that the major source of Cr in vegetable was the soil. THQs analysis showed that consuming vegetables, grown using treated tannery effluent and considering the current consumption pattern, has no health risk. The study proved that the integrated treatment technology can turn industrial wastes in to value added products such as clean water for use in domestic purposes and irrigation.

Recommendation

The study also recommends that contentious tannery wastewater irrigation might led to accumulation of Cr in the soil which can uptake by vegetables and fruits and might cause potential health hazard to consumers.

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THEME FIVE

EMERGING CHALLENGES

Lessons from evaluation of TRMM based rainfall estimates over selected hydrological basins of Africa

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ABSTRACT

Satellite rainfall estimates (SRE) provide reliable rainfall data with "continuous" spatial coverage. However, accuracy of these estimates needs to be evaluated before receiving any application. Several researchers evaluated SREs though such evaluations in Africa are concentrated over few basins. As we entered in to the end of Tropical Rainfall Measuring Mission (TRMM) era and started a new era of satellite rainfall mission by Global Precipitation Measurement (GPM), it is necessary to draw lessons from past evaluation efforts of TRMM based SREs. In this study, a review is presented on the accuracy of SRE from the real time (RT) and post-real-time (PRT) (bias adjusted) versions of TRMM and other sources product known as TRMM-3B42 and the National Oceanographic and Atmospheric Administration Climate Prediction Center (NOAA-CPC) product which is based on the CPC morphing technique (CMORPH). The review will be limited to studies which were carried out over selected African basins. We assess detection and estimation capability of SRE, strength and limitation of the accuracy measures, reference data sets, and factors that are proved to affect SRE accuracy. SRE have been evaluated in literature across a range of spatial and temporal scales, though only few studies are documented at fine (sub-daily) temporal scales. Some authors used a national meteorological network while others set-up their own observation network to collect rainfall data as ground truth. There is inconsistency in literature in the use accuracy measures making it difficult but not impossible to synthesis findings. It is suggested that systematic (bias) and random errors should be differentiated and total bias should be decompose into three components: hit, miss, false rain biases. Overall, this review is expected to provide a platform for future evaluation of GPM based SRE with potential benefit to data users and algorithm developers.

Keywords: *satellite rainfall estimates, TRMM, 3B42, CMORPH, GPM, Africa*

Introduction

Tropical Rainfall Measuring Mission (TRMM) was a satellite mission which was designed to survey the rain structure, rate and distribution in tropical and subtropical regions. The satellite was launched in November 27, 1997 and underwent an orbital boost in August 2001 in order to increase its lifetime. It had non-synchronous orbit and an orbital period of 92.5 minutes. The main strength of a non-synchronous orbiting satellite is that it revisits a place at different local times. This makes assessment of diurnal rainfall cycle possible.

Geographic coverage of TRMM was extended between 38°S - 38°N latitudes. It orbited at an altitude of 350 km (before August 2001) and 400 km (after August 2001) with an inclination of 35°. TRMM satellite was shut down on April 8th, 2015 after providing several years of data which was utilized to enhance our understanding of tropical rainfall which accounts for two-third of the global rainfall.

Currently, the Global Precipitation Measurement (GPM) mission has continued space based precipitation measurement. The advantage of GPM over TRMM includes greater global coverage (68°S - 68°N) at an inclination of 65^o, reduced revisit time, extension of measurement range to light rain intensity (<0.5 mm/h) and more frequent availability of data in real time (within 3 hours). Light rain detection capability is important to monitor rainfall over mountainous and mid-latitude areas.

NASA and JAXA deployed the GPM core observatory on 28 February 2014. The satellite has an expected 3 years design life with its fuel expected to last for at least 5 years. The observatory carries the first space-borne dual-frequency precipitation radar (DPR) and GMI instrument which has 13 channels.

A number of algorithms have been developed to estimate rainfall from satellite data during TRMM era. The algorithms mostly merge microwave and infrared based observations from multiple satellites. TRMM The National Oceanographic and Atmospheric Administration Climate Prediction Center (NOAA-CPC) product which is based on the CPC morphing technique (CMORPH) and the real time (RT) and post-real-time (PRT) (bias adjusted) versions of Tropical Rainfall Measuring Mission (TRMM) are among these algorithms. CMORPH combines rainfall estimates from micro wave (MW) sensors, fills space-time gap in the MW-based estimates using cloud motion and then morphs the shape and intensity of the rainfall patterns (Joyce et al., 2004). The finest resolution of CMORPH data is 30 minutes, 8km X 8 km. TRMM 3B42 product is primarily MW-based estimates but fill gaps in MW coverage using MW-calibrated infrared (IR) data (Huffman et al., 2007). In the post real time TRMM-3B42, a systematic error (bias) of the rainfall estimates is adjusted using the Global Precipitation Climatology Centre (GPCC) rainfall data. The finest resolution of TRMM-3B42 data is 3-hour, 0.25^{o}X0.25^o.

Several studies have evaluated TRMM based rainfall estimates. In this manuscript, the focus is to understand the methods, findings and suggestions of these studies to facilitate evaluation and use of the new GPM rainfall estimates. The objective in this study is therefore to review studies that evaluated SRE in selected African basins where ground based rainfall data is scarce.

Reference data sources to evaluate SREs

The traditional source of rainfall data is rain gauge network which is operated by national meteorological agencies. Rain gauges provide long term rainfall data which can be used to evaluate SRE. However, the inter-station distance of national rain gauge networks is larger than the grid pixel size of satellite rainfall products. As a result, there will be no or only one station within each pixel limiting validation of satellite data at its finest resolution. Data from operational rain gauge networks may also be unreliable, inconsistent and incomplete.

There are a number of spatially gridded rainfall products which are produced by interpolating rain gauge data from national meteorological agencies. Various interpolation techniques are used and additional variables such as elevation are utilized in the interpolation. These data sets offer the opportunity to avoid the limitation of rain gauges which is area-point comparison and make the comparison based on area estimates from two data sources. However, gridded data sets still have limitation as interpolation introduces smoothing and accuracy is low in developing countries with poor rain gauge network.

Experimental rain gauge networks are established to monitor rainfall at high space and time resolutions. The experimental networks usually cover small area and often run for pre-specified period as determined by project duration. In these networks, data is collected from multiple rain gauges within a single grid pixel which enables to capture sub-pixel rainfall variation.

Ground based radar is often preferred as the source of reference data to evaluate SRE since it provides spatially averaged data (e.g. Habib et al., 2012). However, radar observation networks are not common in African countries due to cost and beam blockage in mountainous areas.

The most common sources of reference data in previous SRE evaluation studies in African basins are rain gauge networks which are operated by the national meteorological agencies (e.g. Haile et al., 2016). Some researchers, also utilized grid based rainfall products (e.g. Dinku et al., 2007) with few using data from experimental networks (e.g. Haile et al.; 2013).

Measures of SRE accuracy

Many studies evaluated SRE with regard to rain detection capability and accuracy in capturing rainfall amount or rate. Rain detection capability can be evaluated using Hit (HIT), Miss (MISS), False alarm (FA) and Non-Event (NE). If both the observed and estimated rainfall of a particular day exceed the specified threshold, then the estimate is considered as HIT. If the estimated rainfall is smaller than its threshold while the observed flow exceeds its threshold, then it is called as missed event (MISS). If the estimated rainfall exceeds the threshold while the observed rainfall is below the threshold, then the estimate is considered as false alarm (FA). NE refers to events where both rainfall estimates are below their respective thresholds. The rainfall threshold is often specified based on the purpose of the evaluation and measurement range of the reference data source.

The categorical statistics which measure the detection capability of SRE read as follows:

$$POD = \frac{HIT}{HIT + MISS} \qquad \text{range}[0,\ 1],\ \text{best: } 1$$

$$FOH = \frac{HIT}{HIT + FA} \qquad \text{range}[0,\ 1],\ \text{best : } 1$$

$$FOM = \frac{MISS}{HIT + MISS} \qquad \text{range}[0,\ 1],\ \text{best : } 0$$

POD

measures how accurately the SRE detects actual rainfall events. Frequency of hit (FOH) is the ratio of the number of correctly estimated rainfall events and the total number of estimated rainfall events. Frequency of miss (FOM) measures the observed rainfall events that are missed by the SRE. Values of the three categorical statistics range between 0.0 and 1.0. POD and FOH values of 1.0 and FOM=0 indicate perfect forecast skill.

Systematic error of SRE is estimated in literature using various forms of bias which makes comparison across regions challenging. The various forms of bias in literature read:

$$Bias1 = \frac{\sum(R_S - R_R)}{N}$$

$$Bias2 = \frac{\sum(R_S - R_R)}{\sum R_R}$$

$$Bias3 = \frac{\sum R_S}{\sum R_R}$$

where R_s and R_R refer to the SRE and the reference rainfall amount, respectively. N represents the total number of data pairs.

Bias1 does not allow comparison of accuracy across regions since it is affected by rainfall amount. Here, it is strongly suggested to use the second form of bias which is presented by *Bias2* as it expresses bias as a ratio of the reference rainfall amount. *Bias2* can be compared across regions or basins.

Decomposition of bias into its various components is essential to provide inputs to algorithm developers, bias correction efforts and inform data users. The total bias can be decomposed in to three components: (i) Hit bias which represents rainfall depths difference between satellite and reference data when both detect rainfall, (ii) Missed bias represents total rainfall amount reported by reference when satellite does not report rainfall, and (iii) False bias refers to the total amount of falsely detected rainfall amount by satellite. The equation for the three bias components is presented as follows:

$$\text{Hit bias} = \sum (R_S - R_G) | (R_S > 0 \& R_G > 0)$$

$$\text{Missed rain bias} = \sum R_G | (R_S = 0 \& R_G > 0)$$

$$\text{False rain bias} = \sum R_S | (R_S > 0 \& R_G = 0)$$

where R_S and R_R refer as defined previously.

Other measures of accuracy include correlation coefficient which measures the linear relationship between SRE and reference rainfall amounts, root mean square error (RMSE) and standard deviation of differences (R_S-R_R).

Performance of SRE in African basins

Rainfall detection

In this section, the rain detection capability as evaluated by various studies is presented. For the Nile basin, Haile et al. (2012) reported that rainfall events are better detected by satellite products for areas closer to the equator than those far away from the equator. For high latitudes, rainfall occurrence is overestimated by CMORPH and underestimated by TRMM-3B42. The authors reported insignificant difference between the products' rain detection capability over low latitude areas.

Gumindoga et al. (2017) evaluated CMORPH rain detection capability in Zambezi basin. Their finding indicates CMORPH capability is better for areas closer to the equator than those far away and for highlands than lowlands. CMORPH also better detected rain events in the wet season than the dry season. The detection capability deteriorated for thresholds corresponding to high rainfall intensity.

Correlation

In Gilgel Abbay watershed of Upper Blue Nile basin, hourly - 8km X 8 km SRE from CMORPH has extremely weak linear relationship with gauge rainfall amounts with correlation coefficient less than 0.27 (Haile et al., 2013). The correlation increased (up to 0.52) when the hourly rainfall was aggregated to daily (Bhatti et al., 2016). Further space-time aggregation of the SRE is shown to increase the correlation.

Strong correlation (0.74 for CMORPH and 0.55 for post real time (PRT) TRMM-3B42) is reported by Dinku et al. (2010) for 10 day, 0.25^{o}X0.25^{o} resolutions over the Ethiopian highlands. Gosset et al. (2013) reported correlation coefficient values of 0.79 (CMORPH); 0.73 (PRT 3B42) and 0.69 (Real time (RT) TRMM-3B42) for Benin and 0.75 (CMORPH); and 0.67 (RT 3B42) for Niger basin at daily, 1^{o}X1^{o} resolution. The relationship between daily rainfall depths from CMORPH and rain gauges is stronger in wet season than dry in Lake Tana basin (Haile et al., 2014).

Strong correlation for coarse spatial resolution is good news for hydrological modelers of large basins. However, strong correlation does not necessarily mean that the error is zero or no relation exists. Perfect correlation only implies that the relation between satellite and gauge rainfall estimates can be perfectly expressed by a linear relationship.

Systematic error

Large systematic errors can be amplified when SRE is used for runoff modeling (Habib et al., 2014). CMORPH overestimates annual rainfall amount over most parts of the Nile basin, except for the equatorial region and the most eastern part of the basin over the Ethiopian Plateau (Habib et al., 2012). The overestimation is completely reversed toward the eastern boundary of the basin with an underestimation. TRMM-3B42 underestimates the annual rainfall amount over most parts of Nile basin with better performance in southern part (Lake Victoria basin) and worst performance over the Ethiopian highlands (Upper Blue Nile basin).

For 8kmX8km grid element, the systematic error of CMORPH varies between -0.11 to -0.65 mm/h in Gilgel Abbay watershed (Haile et al., 2013). The error is within -1.66 to 1.57 mm/d in Zambezi basin (Gumindoga et al., 2017). Over $1^{o}X1^{o}$ grid pixel, CMORPH error is 1.8 mm/d in Benin and 2.0 mm/d in Niger basin (Gosset et al., 2013). Overall, mean error is less than 2.0 mm per day for Nile, Zambezi and Niger basins. However, the rainfall threshold used by various studies is expected to affect comparison results. For instance, Haile et al. (2013) used a threshold of 0.2 mm/h, which is the minimum rate that their rain gauge can record, to differentiate between rainy and non-rainy hours while many other studies used zero as threshold.

In Lake Tana sub-basin of Upper Blue Nile, SRE biases are characterized by seasonal and topographic variation. Smaller biases are estimated in the wet season than the dry season (Haile et al., 2014). Biases of CMORPH are within -7% to -52% in Gilgel Abbay watershed in Lake Tana sub-basin (Haile et al., 2013). In Benue sub-basin of Niger, biases of 3B42 PRT are -42 to 21 % though the values are within 10% for most parts of the basin (Haile et al., 2016). In Zambezi basin, overestimation by CMORPH is the main

concern with some underestimation (Gumindoga et al., 2017). CMORPH bias is largest for low rainfall amounts (<2.5 mm/d) in Zambezi basin.

In Gilgel Abbay watershed, hit bias is larger over lowlands (suggesting bias is larger during successful detection of rain events) while missed bias is larger over the highlands (Haile et al., 2013). The spatial difference in false rain bias is not significant. The total bias and its three components in the watershed are much larger than those reported in the flat terrain in southern Louisiana state in the United States (Habib et al., 2011).

Conclusion

The archived TRMM based rainfall products are useful for hydrological applications due to their long observation period. It is therefore important to understand the accuracy of such products and draw lessons to benefit evaluation and use of the GPM based rainfall products. The following lessons are drawn from past evaluation efforts of rainfall products across basins in Africa.

Evaluation of SRE in African basins is hampered by poor density of rain gauges. Attention should be given to establishing experimental rain gauge networks in small watershed at key locations of the main African basins.

Rainfall events are better detected by satellite products for areas closer to the equator than those far away from the equator. The rainfall threshold which is specified to separate raining and non-raining days/hours should always be reported. Accuracy of detecting light rainfall intensities can be considered low for TRMM based SRE products.

The linear relationship between SRE and gauge rainfall data is weak at daily and sub-daily time scales and at the native spatial resolution. However, the relation becomes stronger for coarse resolutions. The mean error of SRE is less than 2.0 mm per day in Nile, Zambezi, Benin and Niger basins.

There is inconsistency in the use of bias equations in literature making comparisons of findings for various basins difficult. Here, bias estimated as (SRE minus reference rainfall)/reference rainfall) is strongly suggested for use as it is comparable across basins. SRE algorithm developers and users also benefit from bias decomposed in to its components which are hit, missed and false biases.

SRE biases are significantly affected by many factors including latitude, topographic, climate season and rainfall rate. SRE performance also varies with the satellite rainfall product. Over all, satellite products have contradicting bias directions across medium and large size basins. This indicates that more evaluation studies are needed to better understand accuracy of SREs across various African basins and eventually utilize these estimates for various applications.

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Assessment of Future Climate Change Impact on Temperature and Precipitation in the Upper Awash River Basin, Ethiopia, Using Statistical Downscaling Approach

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Abstract

Climate change is considered as one of the development challenges of many developing countries. This paper aims to quantify changes in precipitation and temperature in the Upper Awash River Basin due to climate change. The investigation encompasses the calibration of the statistical downscaling model (SDSM) by using large-scale atmospheric variables including NCEP/NCAR reanalysis data, the validation of the model using independent period of the NCEP/NCAR reanalysis data and the general circulation model (GCM) outputs of A2 and B2 scenarios of HadCM3 model, and the prediction of future minimum and maximum temperatures and precipitation scenarios. The future climate conditions of the river basin were predicted by downscaling the outputs of A2 and B2 scenarios for three time periods: 2015 – 2039, 2040 – 2069 and 2070 – 2099 (2020s, 2050s and 2080s, respectively). The daily precipitation, minimum and maximum temperatures data for thirty years (1981 – 2010) from twenty-three weather stations in and around the river basin were used for the process. The significant change in temperature was predicted for 2080s for the A2 scenario. The maximum and minimum temperatures were predicted to increase by 2.1 ^{0}C and 5.3 ^{0}C respectively in the 2080s for the A2 scenario. The change in minimum temperature is highly pronounced as compared to the maximum temperature. The average precipitation, in general terms, is expected to increase in 2020s and 2080s, while a slight decrease is predicted in the 2050s for both A2 and B2 scenarios. The precipitation experiences a mean annul increase by 17.1%, 26% and 22% for A2a scenario in 2020s, 2050s and 2080 respectively. But, the precipitation exhibits a mean annual increase in amount by 1.8% and 6.0% for B2a scenario in 2020s and 2080s; but shows a slight decrease of 0.3% in 2050s.

Keywords: Climate change; SDSM; Scenario; Precipitation; Temperature; Upper Awash

Introduction

An increase of greenhouse gases in the atmosphere, resulting from the burning of fossil fuels by human is considered nowadays to be the main cause for the unusual change of climate (Huang et al., 2011). In particular, carbon dioxide gas is emitted from year to year and boosts the magnitude of the carbon already present in the atmosphere. It is estimated that every year about seven thousand million tonnes carbon is added, of which the larger proportion is very likely to remain in the atmosphere for a century or more. The increase in temperature leads to the increase in the amount of another important greenhouse gas, atmospheric water vapour. The water vapour provides more blanketing effect, causing the surface to be even warmer (Houghton, 2004).

The Intergovernmental Panel on Climate Change (IPCC) has reported in the fifth assessment report (AR5) that the globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C, over the period 1880 to 2012 (IPCC, 2013). According to the IPCC fourth assessment report, the likely range of global average surface air temperature would reach 1.1 – 6.4 ^{0}C depending on the scenarios (IPCC, 2007).

The change in temperature and precipitation forces the world community in general and the climate change experts in particular to device ways to make the necessary qualitative and quantitative estimation of the climate change on water resources. General Circulation Models (GCMs) are the essential methods by which the future climate change can be studied and predicted. Many improvements have been made in the spatial resolution of GCMs in recent years. The resolution has been improved from as coarse as 50,000 km^2 to about as fine as 2500 km^2. In fact this is a great improvement. Yet more effort is required to further increase the resolution. Therefore the uses of some methods are still mandatory to link the relatively coarse-scale GCM with the final scale required for realistic impact assessment.

In a general sense, downscaling methods can be divided into two types: dynamical downscaling and statistical downscaling. Dynamical downscaling consists of increasing the spatial resolution of a GCM using a physical model which solves the governing equations with a higher resolution. Unfortunately it is difficult to run a GCM at the fine resolution needed to obtain the local detail required for impact assessment. Statistical downscaling technique involves the use of a strong observed empirical relationship between large-scale predictors and a climate variable at the local scale, the predictands. Statistical downscaling model (SDSM) is one of the various models available tools offered to the broader climate change impacts study (Wilbi et al., 2007). The application of SDSM in climate change impact assessments have been verified by studies made on river basins of Ethiopia (e.g., Kassa, 2010, Yemsrach, 2012). The objective of this paper is to generate maximum and minimum temperatures and precipitation in the future in the Upper Awash River Basin, Ethiopia. Even though there are emerging studies in some of the Ethiopian river basins, still more have to be made and it is believed that the study may provide valuable information for future climate change scenarios for the river basin. In this study statistical downscaling method is employed.

Study area and data

Study area

The geographical location of the Upper Awash River Basin (UARB) is between $8^0$16' and $9^0$18' N latitude, and $37^0$57' and $39^0$17' E longitude. The River Basin has an area of about 11,140 km^2. Topographically it is characterized by highlands in the north-west and lowlands in the south-east. Elevation ranges from 1545 to 3554 meters above sea level. In plain areas of the basin, annual rainfall ranges from 800 mm to 1000 mm, and reaches about 1200 mm in peaks. The mean annual temperature of Awash Basin is about 15^0 C in the highlands and around 20^0 C in the lowlands. The lowest temperature occurs during the main rainy season. Seasonal temperature variation is not pronounced. The variation of rainfall with altitude is very strong.

Available data

The digital elevation model (DEM) for Upper Awash River Basin was derived from Ethio-dem with 90 x 90 meter resolution, the source being the former Ministry of Irrigation, Water and Energy (MoIWE). Daily precipitation, maximum and minimum temperature, wind speed, relative humidity and sunshine hours data for the period 1981 – 2010 were collected from National Meteorology Agency (NMA).

For this study future climate data from the SRES A2 and B2 scenarios of the HadCM3, that couples Atmosphere – Ocean General Circulation Model were used for the prediction of rate of change of future climate. This model was selected because of the availability of a state-of-the-art downscaling model with sufficient details on predictor files representing the study area. The model used for this purpose was the Statistical Downscaling Model (SDSM) version 4.2 (Wilby et al., 2007), a decision support tool for

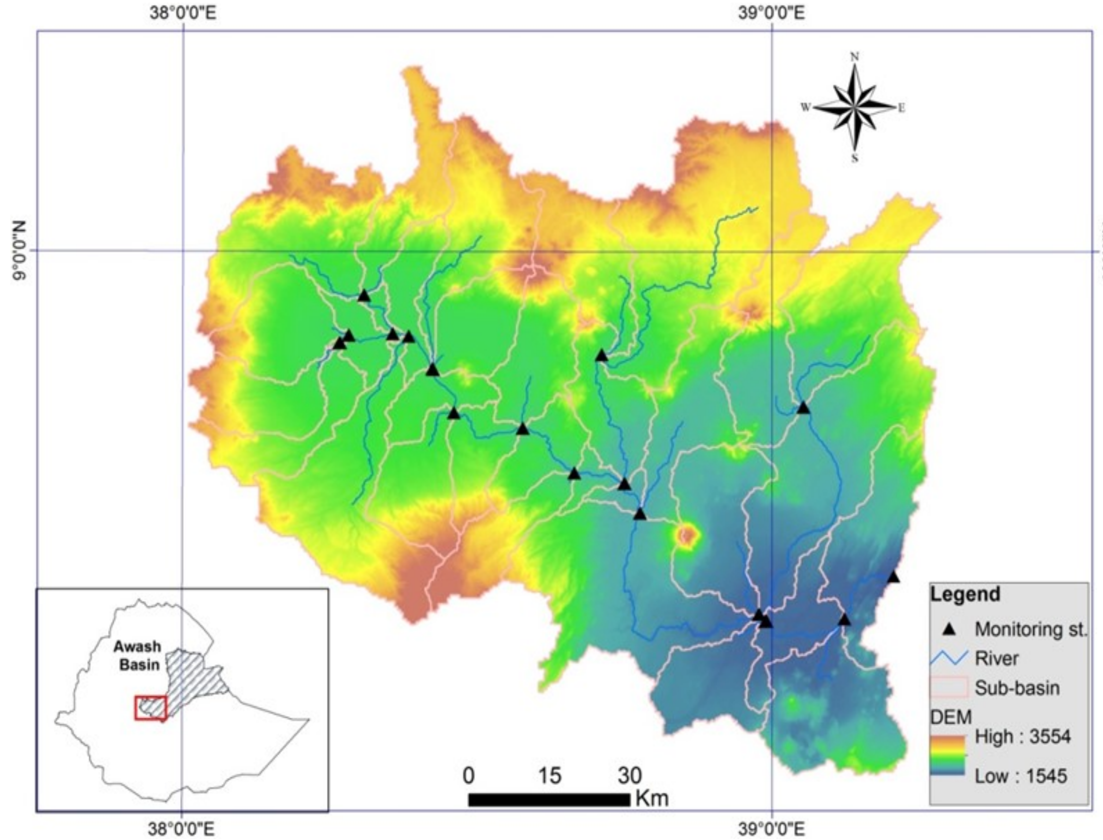


Figure 1: Map of Upper Awash River Basin

the assessment of regional climate impacts. The climate change future scenarios for the period 2015 – 2099 were projected using the A1 and B2 storylines. From this period of eighty five years, three representative time scales, namely the 2020s, the 2050s and the 2080s, were selected and the respective precipitation and maximum and minimum temperatures from the GCM were downscaled to suit to the local meteorological stations of the study area.

Methodology

Temperature and precipitation were downscaled using the Statistical Downscaling Model (SDSM) (Wilbi et al., 2007). The downscaling of the climate variables for the study area were carried out by multiple regressions of the observed data obtained from the National Canter for Environmental Prediction (NCEP) reanalysis data and the GCM outputs from HadCM3 for A2 and B2 emission scenarios. Climate data were collected from twenty three meteorological stations in and around the UARB, of which fifteen are found within the boundary of the sub-basin. Even though the downscaling was done for all the stations, five stations that can best represent the basin in all directions were selected for simulation of future climate.

The selection of appropriate predictors from the large-scale atmospheric circulation is one of the most important steps in downscaling activity. Three main factors constrain the choice of predictors. Data should be (1) reliably simulated by GCMs, (2) readily available from archives of GCM output, and (3) strongly correlated with surface variables under consideration (Wilby, 1999). The best correlated predictor variables selected for precipitation, maximum temperature and minimum temperature are listed in table 1.

Table 1: Summary of predictor variables and their respective predictands

Predictors	
Maximum and Minimum Temp.	Precipitation
Surface relative humidity (rhum)	Mean sea level pressure (mslp)
Mean temperature at 2 m height (temp)	Surface airflow strength (p_f)
500 hPa zonal velocity (p5_u)	Surface specific humidity (shum)
500 hPa geopotential height (p500)	Relative humidity at 850 hPa (r850)
	500 hPa geopotential height (p500)
	Surface vorticity (p_z)

Results and discussion

Calibration and validation of SDSM

The calibration was carried out from 1991 – 2000 and the withheld data from 2000 – 2010 were used for model validation. The model developed a better multiple regression equation parameters for the maximum and minimum temperature than the precipitation. This result is mainly due to the conditional nature of precipitation

Performance of SDSM

Table 2 provides values for both R^2 and root mean square error (RMSE) for assessing model performance for monthly minimum and maximum temperature for the five stations. The R^2 values above **0.5** and RMSE less than **1.22 °C** were accepted to calibrate and validate the SDSM model for downscaling temperature. In a similar way for downscaling precipitation, the SDSM model was calibrated and validated with acceptance of R^2 values exceeding **0.5** and RMSE below **13.34** mm.

Table 2: Performance of SDSM during calibration and validation period

Predictands	**Stations**	**Calibration**			**Validation**		
		Year	R^2	RMSE	Year	R^2	RMSE
Precipitation	Addis Ababa	1991-2000	0.53	12.91	2001-2010	0.52	11.98
	Debrezeit	1991-2000	0.51	13.34	2001-2010	0.50	13.41
	Guranda Meta	1991-2000	0.52	11.06	2001-2010	0.50	10.89
	Hombole	1991-2000	0.52	9.08	2001-2010	0.51	10.21
	Tulubolo	1991-2000	0.53	10.87	2001-2010	0.53	10.37
Temperature	Addis Ababa	1981-1995	0.68	0.8	1996-2010	0.67	1.0
	Debrezeit	1981-1995	0.59	1.12	1996-2010	0.60	1.03
	Guranda Meta	1981-1995	0.56	0.92	1996-2010	0.57	0.97
	Hombole	1981-1995	0.61	1.19	1996-2010	0.60	1.21
	Tulubolo	1981-1995	0.60	1.13	1996-2010	0.60	1.14

As can be seen from the table, the performance of SDSM is relatively acceptable in downscaling both temperature and precipitation. Figure 2 shows the comparison of observed and simulated minimum temperature at Hombole station.

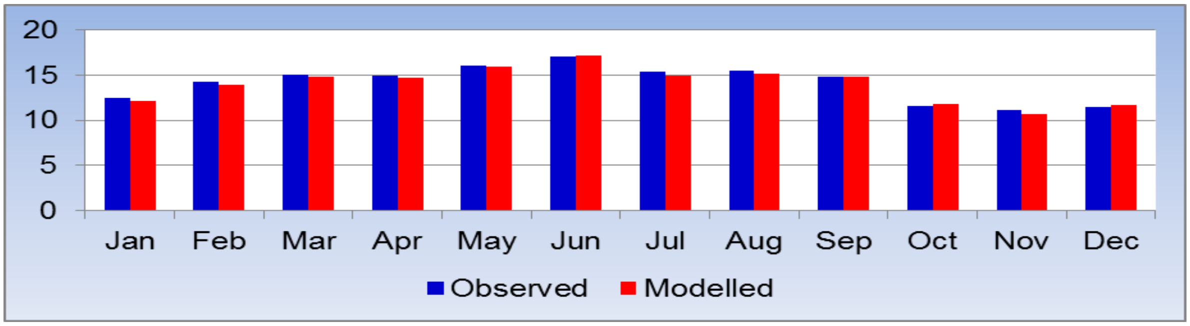


Figure 2 Comparison of observed and predicted mean minimum monthly temperatures (^{0}C) for the period 1981-2001 at Hombole station

Projection of future temperature and precipitation

Minimum temperature

The downscaled minimum temperature in 2020s indicated that the minimum temperature will rise by 1.7 ^{0}C for A2a and by1.2 ^{0}C for B2 scenarios. For 2050s the increment will be 2.3 ^{0}C for A2a and 1.8 ^{0}C for B2a scenarios respectively. Finally, for 2080s, the increment will be 5.3 ^{0}C for A2a and 2.0 ^{0}C for B2a scenario.

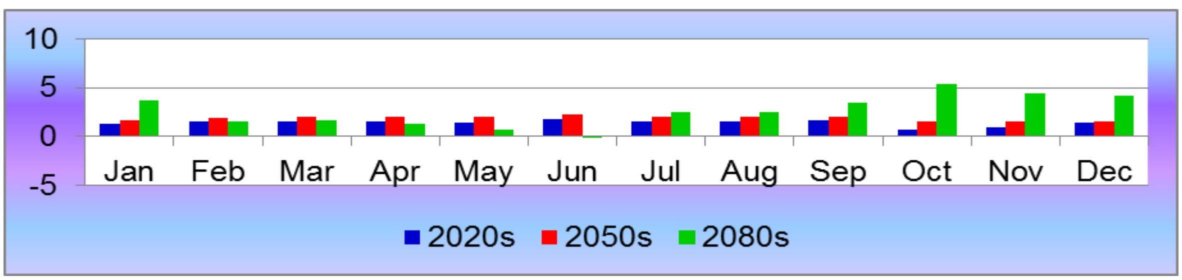


Figure 3: Change of downscaled monthly minimum temperature from the baseline period (A2 Scenario)

Maximum temperature

Similar to projected average monthly minimum temperature, maximum temperature also reflects increasing trend in future climate periods.

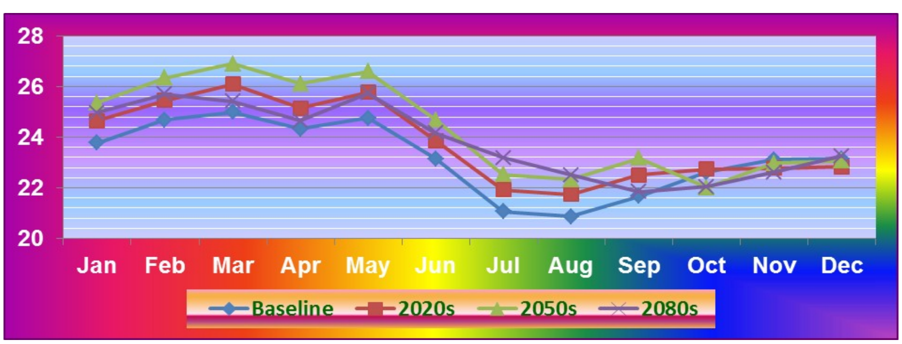


Figure 4: Projected future mean monthly maximum temperature (^{0}C) for A2 scenario against the baseline period of 1981 – 2010 for Addis Ababa

The projected maximum temperature in 2020s indicated that maximum temperature will rise by 1.1^{0}C and 0.8^{0}C for A2a and B2a scenarios. In 2050s the increment will be 1.9^{0}C and 1.7^{0}C for A2a and B2a scenarios respectively, whereas in 2080s, the maximum temperature will be rise by 2.1^{0}C and 2.0^{0}C for A2a and B2a scenarios, respectively. The increments will be less for B2a scenario compared to A2a scenario. This is due to the fact that HadCM3A2a represents medium high scenario which produces more CO_2 as compared to HadCM3B2a scenario which is medium low scenario.

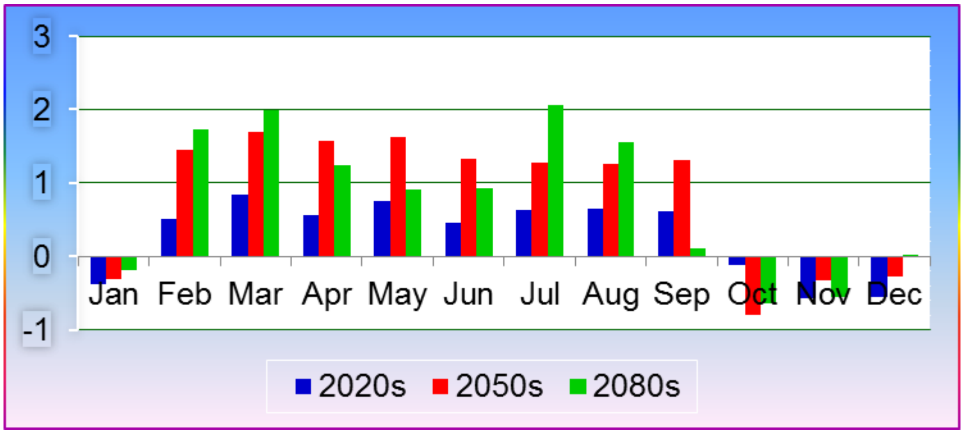
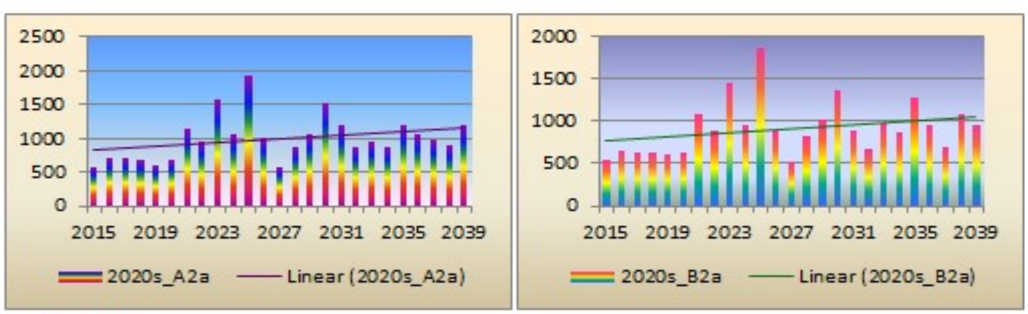


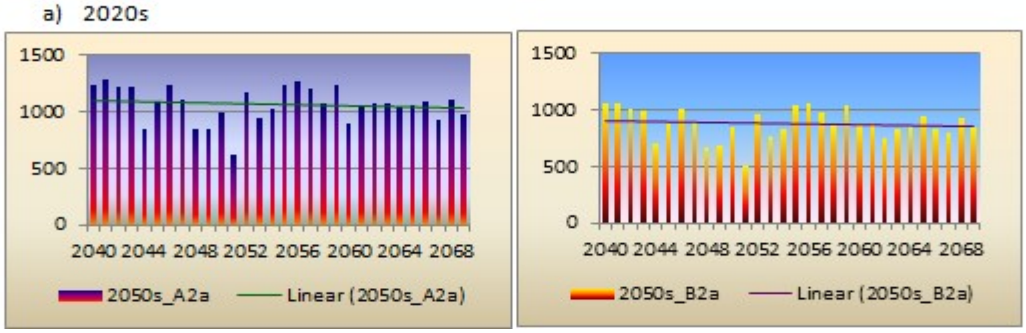
Figure 5: Change of downscaled monthly maximum temperature (^{0}C) from the baseline period for B2 Scenario

Precipitation

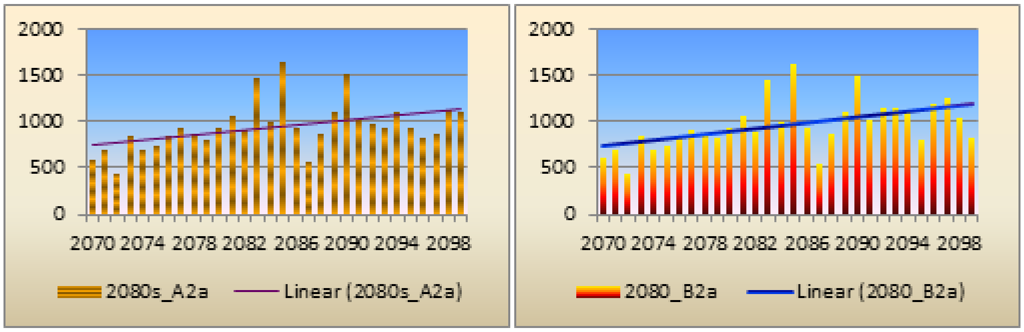
The precipitation experiences a mean annul increase amount by 17.1%, 26% and 22% for A2a scenario in 2020s, 2050s and 2080 respectively. But, the precipitation exhibits a mean annual slight increase in amount by 1.8% and 6.0% for B2a scenario in 2020s and 2080s; but shows a slight decrease of 0.3% in 2050s. In general terms, for both A2a and B2a scenario the precipitation shows an increasing trend. Figure 5 illustrates the predicted annual rainfall with A2a and B2a scenarios for the future period.



a) 2020s



b) 2050s



c) 2080s

Figure 7: Predicted annual rainfall with A2a and B2a scenarios for the future period for a) 2020s b) 2050s and c) 2080s

Conclusion

* Statistical Downscaling Model was employed to simulate and project temperature and precipitation in the UARB, Ethiopia, and some conclusions could be drawn.
* The performance of SDSM was relatively acceptable in downscaling both temperature and precipitation, with R^2 of up to 0.68 and 0.53 for temperature and precipitation respectively. Also the RMSE was found to be relatively reasonable with values 0.9 and 9.08 for temperature and precipitation respectively.
* Temperature showed an increasing trend in all the three future time periods of 2020s, 2080s and 2080s for both scenarios, except that the increase is pronounced more in the A2 scenario. Regarding precipitation, increasing trend was observed for 2020s and 2080s, but a slight decreasing trend, in general terms, was observed for the 2050s, for both A2 and B2 scenarios.
* Comparing maximum and minimum temperature, the increment is more in the minimum temperature in almost all the cases. The largest change in maximum temperature, for instance was 2.1 ^{0}C in 2080s for A2 scenario, whereas the change could reach to as large as 5.3 ^{0}C for minimum temperature, again in 2080s for the A2 scenario.
* The precipitation experiences a mean annul increase amount by 17.1%, 26% and 22% for A2a scenario in 2020s, 2050s and 2080 respectively. But, the precipitation exhibits a mean annual increase in amount by 1.8% and 6.0% for B2a scenario in 2020s and 2080s; but shows a slight decrease of 0.3% in 2050s. In general terms, for both A2a and B2a scenario the precipitation shows an increasing trend.
* The result may provide some insight for water resource planning in the basin. Yet the projection of future temperature and precipitation here was statistical in nature, and thus, some more methods should be employed for more fine results in the future.

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ANALYSIS OF THE IMPACT OF CLIMATE CHANGE ON MAIZE(*Zea mays*) YIELD IN CENTRAL ETHIOPIA

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Abstract

Climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or variance of its properties and that persists for an extended period, typically decades or longer. In Ethiopia; Maize production in relation to climate change at regional and sub- regional scales have not been studied in detail. Thus, this study was aimed to analyse impact of climate change on maize yield in Bako and Ambo Districts, Central Ethiopia. To this effect, weather data, soil data and maize experimental data for BH660 hybrid were used. APSIM software was used to investigate the response of maize (*Zea mays*) yield to different agronomic management practices using current and future (2020s–2080s) climate data. The climate change projections data which were downscaled using SDSM were used as input of climate data for the impact analysis. Compared to agronomic practices the impact of climate change on BH660 in Central Ethiopia is minute. However, within 2020s-2080s in Ambo area; the yield of BH660 hybrid is projected to reduce by 0.88% to 1.4%. While in Bako area; it is projected to increase by 1.3% to 3.5% in 2050s and 2080s. Thus, to adapt to the changing climate; farmers should consider to increase plant density and fertilizer rate per hectare.

Key words; APSIM, calibration, Sensitivity, Downscaling and SDSM

Introduction

Climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or variance of its properties and that persists for an extended period, typically for decades or longer (IPCC, 2007).Ethiopia is already experiencing change in its climate. Between 1951 and 2006, annual minimum temperature in Ethiopia has increased by about 0.37^{O}C every decade. Furthermore, climate change projections to Ethiopia depicts that mean annual temperature in the country would increase by 1.1 to 3.1^{O}C by the 2060s, and 1.5 to 5.1^{O}C by the 2090s and could reduce GDP by 3-10% by 2025 (McSweeney *et al*., 2010).

Crop productivity in the tropical regions which is characterized by low levels of technological interventions is highly dependent on both expected climate and season-to- season variability of weather patterns (Challinor *et al*.,2004). Ethiopian agriculture is mostly characterized by its extreme dependence on rained system (Woldeamlak, 2009). The amount and temporal distribution of rainfall is generally the single most important determinant of inter-annual fluctuations in national crop production levels (Mulat *et al.*2004). Inter-annual and seasonal rainfall variability is high and droughts are frequent in many parts of the country in which crop production suffers the most. The intra-seasonal variations in rainfall distribution during crop growing periods, without a change in total seasonal amount, can also cause substantial reductions in yields of cereals, including maize. This means that the number of rainy days during the growing period is as important, as that of the total seasonal rainfall. However, all agro-ecologies are not likely to be affected by climate change and variability with the same magnitude. In addition, all crops and crop cultivars are not expected to respond to the threat of climate change and variability in a similar manner(Araya et al., 2015).

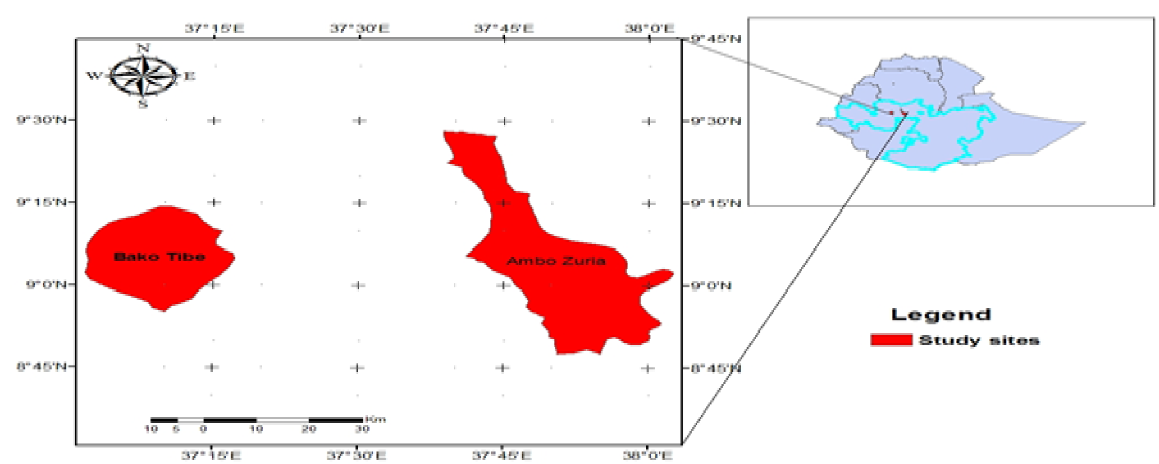
In Ethiopia maize is the second important commodity crop only exceeded by Teff in area coverage. Maize is first in production and yield per unit area. It grows up to 2400m above sea level. The major producing zone lies between 1000- 2000m above sea level. Maize grows in four agro-ecological zones in Ethiopia. (1) Mid altitude sub-humid zone 1500-1800m, maturity day of 140-180 days, annual precipitation of 1000-1250mm. (2) mid altitude moisture stress zone 1000-1500m. (3) high altitude sub-humid zone 1800-2400m, annual rainfall of 1500mm and maturity day of 180-200 day. (4) low-altitude sub-humid zone below 1000m, annual precipitation of 1250mm and maturity days of 130-140 day (MoARD 2010).

In the process, climate change will make the challenge harder on every front: reducing crop yields, and placing more pressure on food security (Alex, 2012). However, this national level information does not necessarily hold true for specific localities like Central Ethiopia which is the strategic geographic region in the national food security assurance efforts. Hence, this study intended to calibrate APSIM and in sequence, to analyze the impact of climate change on maize yield in central Ethiopia. Bako and Ambo districts were selected for this particular study because of their strategic contribution to maize production in the country. Moreover, both sites are located in in different agro-ecology and closer proximity to Agricultural Research Centers. Despite the challenges in climate risks, presently the maize research program in the central highland of Ethiopia mainly depends on multi-location field trials in its variety development–demonstration-release continuum. While, the application of crop-climate modeling that could optimize the number of multi-location research has received minor attention resulting an increased coast of research and widened knowledge gaps (Girma e*t al*., 2011).

Materials and Methods

Description of the Study Area

Figure 1: Map of the study area



The study area covers Ambo and Bako Tibe districts of West Showa Zone, Oromia Regional State. The study sites are located in different altitudes and agro ecology. They are the strategic contributors to maize production in the country. Besides, they have agricultural research centers and climate data archives from where point data of selected maize hybrid and meteorological data were collected.

Table 1 Important characteristics of Ambo and Bako study sites

	Ambo	**Bako**
Location	8°57'N and 38° 07' E	09°6'N and 37°09'E
Altitude	2185 m. a.s.l	1650 m.a.s.l
Seasonal rainfall	Bimodal	Bimodal
Mean Annual rainfall	875 mm	1220 mm
Median start of season	19th May	28th April
Median length of season (days)	197	181
Max Temperature (°C)	26	28
Minimum Temperature (°C)	11	14
Soil type	Vertisols	Nitosols
Crops	Teff, Maize, wheat, Barley, and Sorghum	Teff, Maize, wheat, Barley, and Sorghum, Bean, Pea

Climate, Crop, soil and management data for calibration

Climate data

The climate data required for preparing the APSIM 7.4 climate files (daily rainfall, Tmax, Tmin, Solar radiation) was obtained from the Ambo Agricultural Research Centre and Bako Agricultural Research Centre.

Crop and management data for model calibration

For both Bako and Ambo stations the 160 days growth cycle maize hybrid-BH660 which is mid-altitude maize was chosen because of its long track of release in the production system. And, its production has been treated scientifically in research centers (Table 2).

Table 2 Agro-ecological, phenological and yield characteristics of BH660 maize hybrid

Property	**BH660**
Year of release	1993
Altitude	1600-2200
Rainfall (mm)	1000-1500
Temperature	17-23°C
Plant height(cm)	255-290
Ear Placement(cm)	145-165
Days to maturity	160
Yield(t/ha) at Research station	9-12
Yield(t/ha) on Farmers field	7-8

Source MoARD 2010

Field management practices of maize hybrid

Data of historical yields (kg/ha) of BH660 from 2002-2011 were collected from Ambo Agricultural Research Center and from National Maize Research Project for the Ambo and Bako sites respectively. Experimental data on maize sowing date, days to flowering, days to maturity, plant density, fertilizer rate, sowing depth and row spacing for the same years were collected.

Crop Model Calibration

For the present study APSIM 7.4 crop modeling software was used to simulate productivity of BH660 maize hybrid that have been grown at Ambo and Bako stations for years 2002-2011 and 2000-2010 respectively. The maize genotype BH660 has not been calibrated before it was necessary to build its module within APSIM. We selected hybred614 maize variety since it has similar genetic coefficients, have nearly similar days to maturity and its module is available in APSIM 7.4. We then adjusted its coefficients to fit the heat unit requirement at different critical growth stages of BH660.

Management practices like plant population, row spacing, plant population, planting depth and fertilizer rate which were kept constant for all years of simulation. The planting dates varied from year to year according to the records. Next, the red clay loam of the Australia-mid North was chosen from the International Toolbox, as a basis for building the soil file at Ambo. Similarly, the York Peninsula's sandy clay loam was used to represent Bako soil. These soil profiles were then edited based on the soil profile information from Ambo and Bako. The missing values were filled based on 'a protocol for the development of appropriate soil parameters for use in APSIM (Neal *et al* 2012). Then, days to flowering, days to maturity and yield (kg/ha) were simulated. While running the model, varied soil parameters (initial water, plant available water capacity, soil organic matter) and genetic coefficients were adjusted iteratively until the best result was obtained. Finally, the outputs of the model (days to flowering, days to maturity, grain yield) were compared with observed measurements using statistical parameters.

Downscaling of future climate scenario

The Statistical downscaling model (SDSM) was used to downscale the global climate information to the selected study sites to understand if the global information could reflect the impact at localized level. As a result, SDSM outputs of the Hadley Centre Coupled Model (HadCM3) with A2a and B2a scenarios were used to develop climate change scenarios in the study areas for 100 years based on the mean of 20 ensembles. And, analyses was done based on three time horizons centered on the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071- 2099).

Analysis of the impact of climate change on maize under Ambo and Bako climate

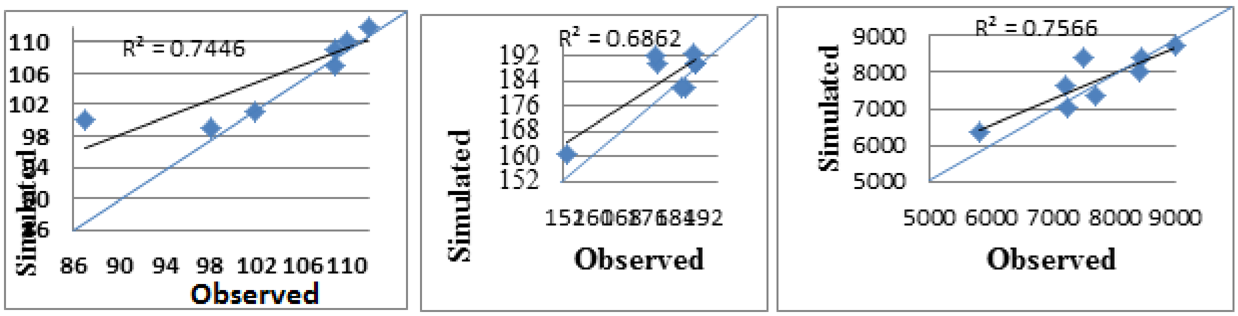
APSIM 7.4 was used to analyze the potential impact of the future climate change on grain yield of BH660 under Ambo and Bako farming zones. The input climate data for the impact analyses were the outputs of HadCM3 coupled atmosphere-ocean GCM model for the A2a and B2a SRES emission scenarios which were downscaled to the project site. For rainfall and temrature; the change during the current growing season of the area was used. Subsequently, the generated climate data was submitted to APSIM 7.4 software to simulate the potential of future maize /BH660/ yield within 2020s, 2050s and 2080s under the assumption of current farming practices. To compare the yield for each scenario with the baseline (1980-2010); descriptive statstics were used.

RESULTS

Crop Model Caliberation

BH660 grown under Ambo climate

The simulated model results for BH660 at Ambo indicates that the model has over estimated yield compared to the actually observed yield during years 2002, 2004, and 2010 (Figure 2). On the other hand, in all the other years, there was an under estimation of yield by the model compared to the actual yield data; which can be explained by the associated uncertainty. As shown in Figure (2) the 1:1 plot and R^2 values of observed vs simulated days to flowering, days to maturity and yield shows convincing result about the fitness of the model in Ambo area. The R^2 value for observed and simulated result for crop parameters such as days to flowering, days to maturity and yield were 74.4%, 68.6% and 75.7 respectively. Besides; the mean, standard deviation and c.v of the respective simulated vs observed days to flowering, days to maturity and yield were 104.8:106.4, ±8.65: ±5.6, 8.3%:5.3% for days to flowering, 185.5:185, ±12.43: ±10.57 and 6.8%: 5.7% for days to maturity and 7730.7: 7661.3, ±808 : ±988.6 and 10.4%:12.9% for yield, respectively.

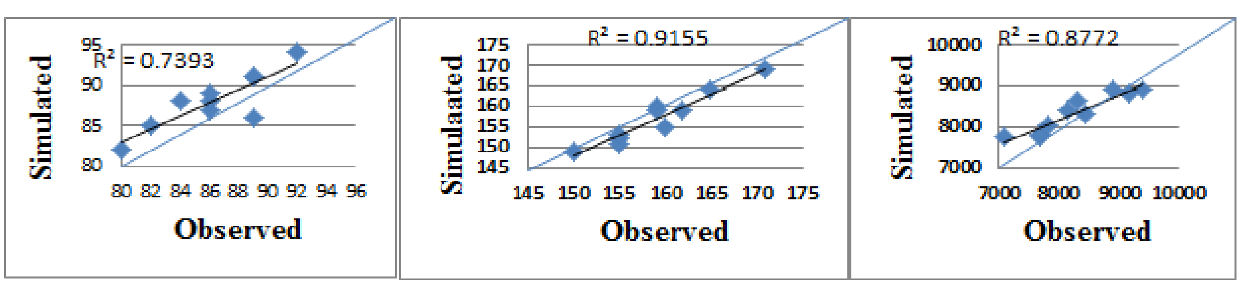


A) Days to flowering B) Days to maturity C)Yield

Figure 2: Relationship between observed and simulated days to flowering (A), days to maturity (B) and yield (Kg/ha)(C) for BH660 at Ambo

BH660 grown under Bako climate

The model simulated yield for BH660 hybrid that was grown under Bako climate was partly underestimated and partly overestimated, compared to the observed yield. On the other hand, days to flowering and days to maturity nearly agreed with the observed data. As shown in Figure (3) the 1:1 plot and R^2 values of observed vs simulated days to flowering, days to maturity and yield shows convincing result about the fitness of the model. Accordingly, the R^2 value which explains the extent of agreement between observed and simulated results for days to flowering, days to maturity and yield were 73.9%, 91.5%, and 87.7% respectively. Furthermore, the mean, standard deviation and c.v of respective simulated vs observed days to flowering, days to maturity and yield were 88.1:86.3, ±3.41: ±3.622, 3.9%:4.2% for days to flowering, 159.1:157.1, ±5.953: ±6.27 and 3.7%: 4% for days to maturity and 8251.43: 8332.7, ±730.9 : ±477.13 and 8.9%:5.7% for yield respectively.



A) Day to flowering B) Days to maturity C) Yield

Figure 3: Relationship between observed and simulated days to flowering (A), days to maturity (B) and yield (Kg/ha)(C) for BH660 at Bako

Downscaled future Climate change scenarios

The projected climate for the three scenarios downscaled for Ambo and Bako sites were used as input to APSIM crop model. The statistics of the climate parameters is summarized in Table 3.

Table 3 Future (2020s-2080s) summary statistics for absolute maximum temperature change (^{O}C) at Bako and Ambo stations

Scenario	**Bako**			**Ambo**		
	2020s	2050s	2080s	2020s	2050s	2080s
		Tmax Absolute change (^{O}C)				
HadCM3A2a	0.24	0.47	0.9	0.55	1.17	2.24
HadCM3B2a	0.24	0.38	0.67	0.58	0.95	1.67
Tmin Absolute change (^{O}C)						
HadCM3A2a	0.46	1.09	1.97	0.14	0.28	0.52
HadCM3B2a	0.51	0.96	1.53	0.12	0.24	0.39
Rainfall Percentage change in mm						
HadCM3A2a	-0.019%	0.824%	0.0031%	-3.63%	-2.364%	14.69%
HadCM3B2a	0.104%	0.008%	1.29%	-11.31%	-7.84%	2.262%

Impact of future climate change on maize productivity

Impact of climate change on BH660 hybrid under Bako climate

As indicated in Table (4), Due to climate change the percentage change in yield within each scenario shows the likely minute decrease by 2.1% and 1.32% within 2020s A2a and B2a

emission scenarios, respectively. And, it could probably increase by 1.62% and 0.85% within 2050s A2a and B2a scenarios respectively. In 2080s, A2a and B2a emission scenarios it could probably increase by 3.48% and 3.46% respectively. Further, descriptive statistics like mean, standard deviation and c.v of the corresponding scenarios are respectively, 8309.2, ±1090.7 and 13.1% for baseline, 8134.4, ±1227.7 and 15.1% for 2020s A2a, 8199.2, ±1251.3 and 15.3% for 2020s B2a, 8444.1, ±1134.5 and 13.4% for 2050s A2a, 8379.7, ±1158.1 and 13.8% for 2050s B2a, 8598.1, ±1177 and 13.7% for 2080s A2a, 8596.4, ±1202.2 and 14% for 2080s B2a scenarios (Table 4).

Impact of climate change on BH660 hybrid under Ambo climate

Grain yield of BH660 in Kg/ha will probably shows slightly declining trend in both scenarios of 2020s, whereas slight increase under both scenarios in 2050s and 2080s. As shown in Table (4), the yield/ha within each scenario compared to the baseline, could probably decrease by 1.38% and by 2.36% within 2020s A2a and B2a, respectively. In2050s A2a and B2a scenarios it shows likely increase by 0.74% and the likely decrease by 2.43% respectively. While, within 2080sA2a and B2a scenarios, it could probably increase by 0.23% and could probably decrease by 0.88% respectively. On the other hand, the mean, standard deviation and CV of the scenarios are respectively, 9319.1, ±1186.8 and 12.7% for baseline, 9190.5, ±1228.4 and 13.4% for 2020s A2a, 9099.4, ±1218.7 and 13.4% for 2020s B2a, 9387.9, ±1303.8 and 13.9% for 2050s A2a, 9092.6, ±1266 and 13.9% for 2050B2a, 9340.6, ±1319.5 and 14.1% for 2080s A2a and 9236.7, ±1302.1 and 14.1% for 2080sB2a scenarios (Table 4).

Table 4 Statistical summary of yield for BH660 hybrid from 1980-2099

BH660 under Bako climate							
	Baseline	2020sA2a	2020sB2a	2050sA2a	2050sB2a	2080sA2a	2080sB2a
Mean	8309.2	8134.4	8199.2	8444.1	8379.7	8598.1	8596.4
s.d	1090.7	1227.7	1251.3	1134.5	1158.1	1177	1202.2
c.v (%)	13.1	15.1	15.3	13.4	13.8	13.7	14
change (%)		-2.1	1.32	1.62	0.85	3.48	3.46
BH660 under Ambo climate							
Mean	9319.1	9190.5	9099.4	9387.9	9092.6	9340.6	9236.7
s/d	1186.8	1228.4	1218.7	1303.8	1266	1319.5	1302.1
c/v (%)	12.7	13.4	13.4	13.9	13.9	14.1	14.1
change (%)		-1.38	-2.36	0.74	-2.43	0.23	-0.88

Discussion

Getting complete data for maize phenology at all growth stages for crop modeling was a great problem. Besides, access to all soil profile data was also difficult. Thus, for those missing values, the international soil list of APSIM 7.4 similar soil type was chosen and fitted based on ‘A protocol for the development of appropriate soil parameters values for use in APSIM’(Neal *et al*., 2012). During Calibration of APSIM model the 1:1 plot and R^2 values of observed vs simulated days to flowering, days to maturity and yield showed best result about the fitness of the model at both Ambo and Bako stations. As a result, we can use APSIM for further studies like sensitivity testing and analysis of the impact of climate change on BH660 hybrid.

During sensitivity testing, compared to the baseline (farming under the current climate and agronomic practices) the grain yield of BH660 hybrid at both stations could probably decrease in the condition of delay in planting date by 7 days, rise in temperature by $2^{O}C$ -$3^{O}C$ and rise in temperature by $2^{O}C$ coinciding with reduction in rainfall by 20%. And is likely increase if the plant population is increased to 6/m^2. whereas, at a baseline +10, 20, 30kg nitrogen/ha at Bako if the plant population is increased to 6/m^2 Ambo. In agreement with this result Camilo *et al.(*2011) revealed for the APSIM model, an increase in temperature led to a decrease in grain yield and the grain yield decline was more than 50% with an increase by $9^{O}C$ from the current levels. And delayed planting resulted in reduced grain yield by 24%.

Compared to the agronomic management practices, the projected climate change could have minute impact on BH660 yield within the three time horizons in both Ambo and Bako areas. However, its impact could probably positive in Bako area in 2050s and 2080s. Girma *et al*. (2011), also revealed that for Bako, the amount of rainfall available per growing season will be reduced due to climate change through 2030 and will also result in a reduction of yield of BH660 at the rate of 65 kg/ha.

In contrast, Jones and Thornton (2003) suggested that the maize crop benefits from climate change in the areas like the Ethiopian highlands, where substantial localized yield increases are predicted, sometimes up to 100%. Besides, Araya *etal*.,(2015) reveled that, climate change may not have severe negative impacts on BH540 in Bako and Melkasa-1 in Melkasa area. Moreover, it might be possible to bring more positive yield change easily by introducing some climate smart agronomic practices. Hence, the present study agrees with these findings because, even though a single GCM was used, there will be reduction of rainfall from 2.4% to 11.31% in 2020s in both Ambo and Bako areas, and also slight reduction at Ambo in 2050s during the growing season. And, results in minute reduction of maize yield. Moreover, since the model projected the temperature well; the temperature of the area will probably increase in the three time horizons within both HadCM3A2a and HadCM3B2a emission scenarios. However, the crop model simulations considered only future climate change scenarios assuming all other things constant. But, change in agronomic practices, soil, management activities and other climate variables might contribute some impacts on crop production.

Conclusion

During calibration of APSIM, the model simulated result showed good agreement with observed days to flowering, days to maturity and yield. This shows the fitness of the model in both Ambo and Bako farming localities. Hence, it is possible to use APSIM for further study like sensitivity test and analysis of the impact of climate change on BH660 hybrid.

Under Ambo climate, the sensetivity test revealed that the yield could probably increase if the plant population is increased to $6/m^2$.whereas, in other conditions it could decrease. Furthermore, under Bako climate it shows the likely yield increase in kg/ha under 6plants/m^2 of planting density, within baseline +10, 20 and 30 kg nitrogen/ha, baseline +1^{O}C temperature and baseline +2^{O}C temperature.

In general, the present study revealed that the projected climate change could have minute impact on BH660 within the three time horizons in Ambo area. On the other hand, the impact on the production BH660 hybrid in 2050s and 2080s in Bako area is likely positive.

The present study has opened the window to re-imagine maize research and production from climate risk management perspectives within the country.

Recommendations

Further, to mainstream climate information to the farming localities, it would be effective if the crop breeders, agronomists and environmentalists cooperate to improve the research on concept of Genotype by management by environment (G *M * E) interaction. Besides, there should be a bridge among the stakeholders (researchers, policy makers, government, NGOs, farmers and etc.) to share up to date information on climate change to cope and adapt to its adverse impact.

To secure crop-climate modeling, agricultural research Institutes and researchers should record crop data including management practices and its phenology data at necessary growth stages. On top of this, soil profile data for crop research areas like Agricultural research centers of the Country has to be available.

Management practices like increasing plant population per unit area and agricultural inputs should be improved. Accordingly, to increase the productivity of BH660 under Ambo climate, increasing plant population to greater than $6/m^2$ would be better. Whereas, under Bako climate; increasing nitrogen rate from 10-30kg per hectare and increasing plant population to greater $6/m^2$ on the current recommended management practices would be better.Management practices like increasing plant population per unit area and agricultural inputs should be improved. Accordingly, to increase the productivity of BH660 under Ambo climate, increasing plant population to greater than $6/m^2$ would be better. Whereas, under Bako climate; increasing nitrogen rate from 10-30kg per hectare and increasing plant population to greater than 6/m^2 would be better. Whereas, under Bako climate; increasing nitrogen rate from 10-30kg per hectare and increasing plant population to greater 6/m^2 on the current recommended management practices would be better.

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Design Development of Spate Irrigation Structures in the Raya Valley, Ethiopia

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Abstract

Spate irrigation is a resource system, whereby flood water is emitted through normally dry wadi and conveyed to irrigable fields. Modernization of spate structures has been taking place in Raya valley since 1998 even though the efficiencies are not as intended. Initially the design standard was directly adopted from the conventional irrigation systems. Farmers were complaining that the implemented design standard was not appropriate with regards to their experiences. According to the professional's perception, the reason for schemes failure could be poor management and lack of maintenance. Spate irrigation design development in Raya valley shows significant changes through time; like widening of intake, increasing of deflection angle, excluding of rain fall during design and reduction of irrigation time. The spate schemes with relatively best performance still have problems like; sedimentation around intakes, less spate flow and low performances. Therefore, understanding of the experience, wisdom and tradition of farmers is necessary during design and construction of spate irrigation.

Keywords: Spate irrigation, design development, intake, diversion structure, Raya valley

Introduction

According to FAO and UNDP, (1987) spate irrigation define as "an ancient irrigation practice that involves the diversion of flashy spate floods running off from mountainous catchments where flood flows, usually flowing for only a few hours with appreciable discharges and with recession flows lasting for only one to a few days, are channeled through short steep canals to bunded basins, which are flooded to a certain depth". Mehari et al. (2007) also defines spate irrigation in the simple way as "a resource system, whereby flood water is emitted through normally dry wadi and conveyed to irrigable fields". Moisture stress resistant crops, often sorghum and maize are grown in the spate irrigated agricultures and planted after the first flood irrigation water has occurred. In many areas crops can get matured and give reasonable yield using two or more floods depending on the water holding capacity of the soil.

According to Van Steenbergen et al. (2010) rough estimates, global spate irrigation coverage extends up to 3.3 million hectares even though uncertainty is there. According to the research conducted by Mehari et al. (2011) spate irrigation is frequently practiced in the Middle East, North Africa, West Asia, East Africa and parts of Latin America. Although spate irrigation is uncertain type of investment, economically it is very important practice in countries such as Yemen, Pakistan, economically it is very important practice in countries such as Yemen, Pakistan, Eritrea and Ethiopia where agriculture is a vital component of their economy (Ratsey, 2011). Even though spate irrigation contributes a lot for food security enhancement in the drought prone areas little concern and emphasis had been given in its developments.

In Ethiopia spate irrigation is a common practice in midlands as supplementary and in lowland area used as dominantly full irrigation. According to Van Steenbergen et al. (2011) in Ethiopia both farmer's initiative and public investments are the driving forces for spate irrigation development. Currently the cultivated areas under spate irrigation estimates to be 140,000 ha of which 20,000 ha is modern spate irrigation and 70,000 ha still need improvements and other 50,000 ha are under design and construction phases (Van Steenbergen et al., 2011).

Spate irrigation system in Ethiopia is increasing in arid areas particularly; south Tigray (Raya valley), Oromia (Bale, Arusi, West and east Hararghe), Dire Dawa Administrative Region, Southern Nations, Nationalities and Peoples Region (Konso), Afar and Amhara (Mehari et al., 2011)

Raya valley is one of the areas where spate irrigation is being practiced for long times. Farmers were diverting flood water to their farm land using traditional spate irrigation system. During the past decades many governmental and non-governmental organizations were trying to improve and modernize the traditional spate irrigation systems. Many traditional spate schemes were modernized while they did not perform as expected due to several problems. Among this problems are over sedimentation in diversion and canal, failure of structures, inappropriate design and poor participation of farmers during design and construction.

Methodology

Study area

The Raya Valley is located in the south-east part of the Tigray Regional State between $39^0 22'$ to $39^0 25'$ east longitude and $12^0 17'$ to $12^0 15'$ north latitude. It is bordered by Hintalo Wajerat Woreda to the north, Afar Region to the east, Endamekoni and Ofla woredas to the west and Amhara Region to the south. It comprises the total area of Raya Azebo and Alamata Woredas and some eastern high lands of Endamekoni and Ofla Woredas (REST, 1996). Figure 1 shows the location map of Raya valley. The total population of the Raya Valley Area is about 227,431 (136,039 for Raya Azebo and 85,359 for Alamata woreda) (CSA, 2007).

Topographically the Raya Valley is divided in to two major agro ecological zones: low land areas with an altitude less than 1500 m.a.s.l. which mostly covers large part of the central part of the valley; and the high land areas having altitude above 1500 m.a.s.l. which covers the western and eastern edges of the valley. According to the moisture index criteria provided by REST, (1996) the Raya Valley area is classified as dry climates of semi-arid and arid types.

Data collection

Secondary data mainly study design report, design specification and scheme locations were collected from relevant organizations of Tigray Water Resources, Mines and Energy Bureau, Mekelle University, Raya Alamata and Raya Azebo weredas or districts. After having this secondary data rough evaluation on the design development in time was made and seven schemes namely Hara, Tirke, Fokissa, Beyru, Tengago, Dayu and Oda were selected for field observation and assessment. Hara, Tirke and Oda modern spate irrigation schemes did not have any report. Therefore analysis was made to this sites based on the current condition in the field and farmers perceptions.

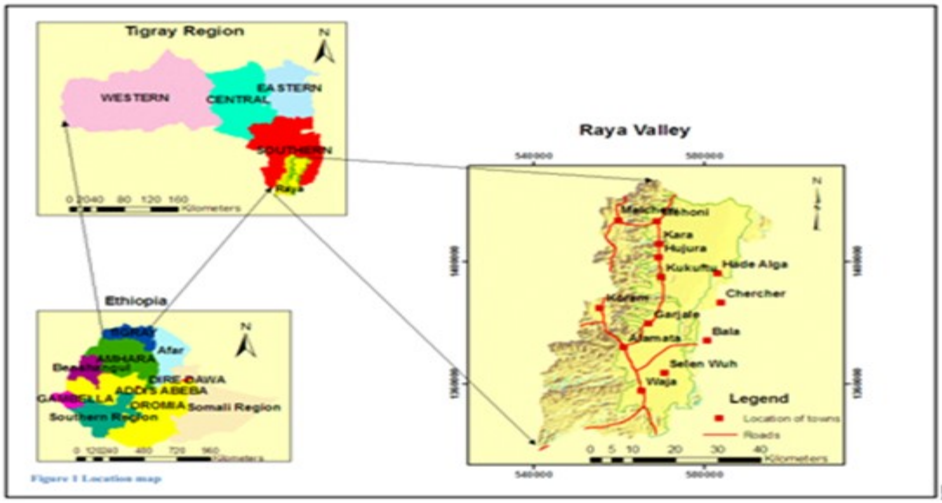

Figure 1. Location map of Raya valley (source Gebreezgi A.H., 2010)

An intensive scheme visit and observation was made for the seven selected schemes so as to envision the current situations in the ground. Headwork structures measurement was also made to Hara, Tirke, Fokissa, Beyru, Tengago, Dayu and Oda modern spate irrigation schemes. The field observation was aimed to measure the headwork structures and to observe the practical problems in the field. Structures like intake size, weir dimensions, sluice gates and main canals were measured. This data are used for comparison of design development with other scheme designs. Discussion with local farmers and experts were held in all visited schemes to determine the perception of the beneficiaries.

Result and Descussion

Modernization of spate irrigation schemes in Raya valley starts in 1998. Hara was the first modernized spate irrigation scheme in the area and that leads to many improvements in the designing and constructions of modern schemes in Tigray. Tirke spate irrigation scheme was also modernized in 2004 following to Hara scheme. In 2005 four schemes namely Fokissa, Beyru, Utu and Burka was designed and constructed while Ula-ula, Buffie, Tengago and Dayu schemes were constructed in 2006.

The design standard of Hara and Tirke was directly adopted from the conventional irrigation schemes which have low sediment concentration. The headwork of this two spate schemes has gated off take or intake with broad crested weir and all the structures were made up of concrete masonry. According to the farmers response both Hara and Tirke spate schemes were failed in one rainy season due to the problem of sediment in both intakes and canal systems. Figure 2 shows the modernized headwork structures of Hara and Tirke spate irrigations.

According to the farmers perception the main reason for failure of these schemes was the inappropriate design structure of intakes. During construction the farmers were complaining about the size, shape and deflation angle of the gate. According to field observation the intakes of Hara and Tirke has 90^0 deflection angles from the river flow direction and less than one meter diameter of gate.

In 2005 when Fokissa, Beyru, Utu and Burka was designed and constructed the design engineers took key lesson from the failure of Hara and Tirke. They came to realize that the incoming sediment or bed material load was too high. Hence, they decided that gated intake, narrow canal and siphons cannot work as structures of spate scheme. At that time the designers tried to know the indigenous knowledge of farmers for sediment managements and they observed some traditional irrigation schemes in the valley.

The major findings of farmer's knowledge were wide open gate intake with an angle of deflection greater than 90^0 and wide size of canals. To some extent experts tried to understand and incorporate farmers traditional knowledge during design and construction. They took good lesson on size and deflection angle of intake and they tried to give attention for sediment problems.

- The major changes of the design includes;
- To change the gated intakes to open gate
- To increase the width of the intakes and canals
- Improving of diversion angle from 90^0 to 120^0
- Avoiding of crossing structures
- The main problems or limitations during these designs were:
- The crop water requirement (CWR) was calculated for 24 hours while flood occurrence is too short
- Effective rainfall was considered during irrigation water requirement calculation (IWR) which leads to underestimation of net irrigation water requirement (NIWR) but rain fall is not reliable.
- As the width of the gates ranges from 1 to 3 meter depending on size of irrigable area but the farmers were still complaining as they were thinking even 3 meter gate is small.

Intake structure of Hara scheme

Under sluice gate in Hara scheme

Crossing structure, Hara spate scheme

Orifice intake, Tirke scheme

Figure 2. Headwork structures of Hara and Tirke schemes

In 2006 four spate schemes were designed and constructed namely Ula-ula, Buffie, Tengago and Dayu schemes. In addition to the design improvement takes place in 2005 some improvements were made based on recommendations of supervision. These improvements try to solve the limitations and problems occurred in the design of schemes made in 2005Figure 3 presents the headwork structures of

Tengago and Dayu modern spate irrigation scheme. The main design improvements for Ula-ula, Buffie, Tengago and Dayu schemes are;

- The calculation of crop water requirement was minimized to 4 hours
- Effective rainfall was neglected during net irrigation water requirement calculation
- The schemes design was limited to headwork and main canals.

In 2011 Oda spate irrigation was designed with some improvements to traditional spate system, it was designed as a simple intake using gabion and only cut offs built to reduce the risk of bed level lowering around the river bed and intake (Embaye et al., 2012).

During the field visit to Oda spate irrigation it was found that the weir or cut off structure was completely destroyed by flood hazard. According to the farmers response Oda scheme was failed before handed over to users just during completion of construction work. Now farmers are using in traditional way using forest and shrub embankment Figure 4 shows the failed weir axis and reconstruction of scheme in traditional systems.

Diversion structure of Tengago scheme

Sluice gate blocked by gabion, Tengago

Diversion weir in Dayu spate

Silted intake, Dayu

Figure 3 Headwork structures of Tengago and Dayu schemes

From 2011 to 2013 there was no sound change in design development of spate irrigation schemes. Few schemes were constructing by the wereda or district of Raya Azebo and Raya Alamata bureau of water resources, mines and energy. Most of these schemes are simple and small structures and they are exposed to flood hazards. In 2014 two spate irrigation schemes were designed by Mekelle University. The headwork of these schemes was designed to have 50 centimeter high slant barrage across the river. This design was aimed to convey limited amount of water and during medium and high flood occurrences the flood will over flow above the barrage and sediments will flashed away. This spate scheme is still under construction and its performance and applicability was not assessed.

The major design development made for spate irrigation system in Raya valley are summarized as shown in Table 1.

The relatively best performed modern spate irrigation system in Raya valley was the one designed and constructed in 2006 namely Ula-ula, Buffie, Tengago and Dayu schemes. Renovations have been taking for these schemes to minimize the structural damages and sedimentation problems. Among this schemes Dayu spate irrigation scheme were found relatively best performing scheme. Therefore, this scheme was selected for further study.

Comparing Tengago and Dayu spate irrigation schemes Dayu is relatively best performing. The reason for this could be the difference in river flood discharge. As we can see from Table 2 the design flood discharge for Tengago is 50.0m^3/s while 358.89m^3/s is flood discharge of Dayu. Even though the river discharge is small but Tengago was designed to irrigate 500 ha with two intakes in one diversion structure.

Broken diversion structure, Oda   Embankment using forest and shrub, Oda   **Figure 4**

Headwork structure of Oda spate irrigation scheme

The structures of Tengago are still in good conditions while there are accumulations of sediments around both intakes. Therefore designing of 500 ha to a river which has 50m3/s is not optimum and this could be the reason for poor performance.

Current problems of schemes in relation to sediment management and spate flow

Dayu spate irrigation scheme is the relatively best performed scheme in Raya valley while it is irrigating about half of the designed area.

The main structural problem of Dayu in relation to sediment management and spate flow are;

- Siltation problems both in intakes and main canal
- Diverted amount of water through in intake is small
- In small flood it is difficult to convey water through intake as too much sediments are accumulated in the intake than in weir.

Causes of the problems

Farmer's perception

According to the farmer's perception the main cause of the structural failure to modern spate irrigation systems are;

- Narrow intake and canal width
- Angle of intake deflection
- Existence of sluice gate; it is not good because it can lost many floods.

Designers and experts perception

According to the discussion held with designers and professional experts of spate irrigation system the main cause could be lack of good operation and maintenance in addition to lack of inappropriate design. As there is no known standard for spate irrigation system most the decisions for all structural design are by trial and errors. The experts are still not confident on the size and angle of intakes which they have been designing for years. In the other way round the experts are not convinced by the farmers complaining about the existence and functionality of sluice gate. Sluice gate is important parameter for sediment control. Opening of sluice gate during high flood helps to erode the accumulated sediments around intake (Ratsey, 2011) and (Van Steenbergen *et al*., 2010). In low flood it must be closed so as to rise the water level and divert more water. Therefore the existence of intake could not be a problem but it needs care full management and frequent supervision.

Remedial solutions for the problems

From farmers point of view

Based on the farmers indigenous knowledge most of traditional irrigation system are characterized as wide intake width up to 6 meter wide, the angle of deflection are greater than 120^0 in some area they can make it near to 180^0 which is parallel to the river flow and mostly they use temporary and small solid weir or barrage to clot the flow along the river and divert to earthen canal. For the modernized schemes the farmers put the following remedial actions;

- Width of intake have to be up to 5 meter
- Angle of deflection have to be more than 120^0 deflected
- The weir must be without sluice gate

From expert point of view

The design experts of spate irrigation system are keen to know the impact of different deflection angle and width length on sediment management and spate flow. Therefore the possible remedial solution in relation to sediment management and spate flow could be;

- Width of intake 3m or 5m
- Deflection angle 120^0 or 150^0

Conclusions

Modernization of spate irrigation was started in 1998. Hara and Tirke schemes were the first to modernize. The design parameter of these schemes was directly adopted from the conventional design system without consideration of the sediment income and extreme flood events. Nevertheless, these schemes were failed in one rain season and went out of use due to high sedimentations. Based on this study the following conclusions were given.

- Inappropriate design parameters of intakes and canals are the main cause of failure.

Table 1 Summary of spate structures design development

Parameters	**Name of schemes**					
	Hara	**Tirke**	**Fokissa**	**Tengago**	**Dayu**	**Mersa**
Year of construction	1998	2004	2005	2006	2006	2014
Design flood discharge	-	-	220.5	50.0	358.89	-
Weir length	35	34	35	23	29	-
Intake type	Closed gate	Closed gate	Open gate	Open gate	Open	Open gate
Gate size	0.8X0.8 both sides	0.9m diameter	3 m	2.5m right & 2m left side	3 m	3 m
Deflection angle	90^0	90^0	120^0	120^0	120^0	120^0
Main canal system	Concrete	Concrete	Concrete	Concrete	Concrete	Concrete
Crossing structures	Available		Avoided	Avoided	Avoided	Avoided
Assumed irrigation time	24 hrs	24 hrs	24 hrs	4 hrs	4hrs	4hrs
Effect of rainfall	Considered	Considered	Considered	Neglected	Neglected	Neglected
Designed area (ha)	400	380	500	500	320	420
Current area (ha)	0	0	100-150	<50	150	-
%ge of current area (%)	0	0	20-30	<10	47	-
Over all status	Failed	Failed	Poor	Poor	Good	In construction

- Sedimentation and less spate flow are still the major problem in spate irrigation schemes.
- Farmers are complaining to experts for not considering their willing and construction of inappropriate designs. Experts were also complaining to farmers for their poor management and lack of maintenance.
- The design of main intakes has significantly improved over the past years. The intake dimensions were changed from closed intake, 90^0 deflection angles and narrow (90 cm wide) gates to 3 meters wide open intake with 120^0 deflection angle and this improvement gives relatively good performance for modern spate irrigation schemes.
- The latest design of diversion structure is however, far below optimum. This design is irrigating about 47% of the intended area. The main reason for the poor performance could be lack of optimum intake designs
- Understanding the experience, wisdom and tradition is necessary during design and construction of spate irrigation.

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New Development in the Ethio-Egypt Relations over the Hydro-Politics of Nile: Questioning Its True Prospects

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Abstract

The central objective of this study is to examine the true prospects of the recently established amicable relations between Ethiopia and Egypt. To this end, the researcher employed qualitative methodology. Accordingly, data were gathered from secondary sources mainly from books, journal articles, unpublished materials and websites. Based on the data analyzed, the study came up with findings which show a great suspicion on the sustainability of the newly established cordial relations following the coming into power of president El-Sisi in Egypt. The study outlined the following basic reasons: the still persisting mistrust among Egyptians, the existence of anti-Ethiopia forces, absolute dependence of Egypt on Nile, the possibility of using visits for spying purpose, the possibility of buying a time and the inherent worry on the development of Ethiopia. Thus, the paper concludes that the new friendly approach of El-Sisi may be a new tactic to pursue the old objective. Following this conclusion, the study suggests that there is a need, on the part of Ethiopia, to be skeptical and keep a watchful eye on the development while keeping ahead the friendly relations.

Keywords: *Ethiopia, Egypt, Nile, amicable relations, downstream countries, upstream countries, El-Sisi.*

ETHIO-EGYPT HISTORICAL RELATIONS

The politics of Nile has greatly influenced the Ethio-Egyptian relations since very long time ago. The Nile River has served as the source of tension and mistrust in the two countries' rel tions. It is rightly outlined that "deep distrust, suspicion, misunderstanding and even political and military confrontations have characterized their relations throughout history" (Ibrahim, 2012). As history reveals, Egypt under the leadership of Khedive Ismail Pasha had encroached into northern Ethiopia so as to control the source of Blue Nile (Abay) as a colony in 1875 and 1876. However, Emperor Yohannes IV, the then emperor of Ethiopia, had successfully taken victories on such invasions at Gundet and Gura respectively.

The whole effect is it created "shadow of mutual suspicions, hostile perceptions, conspiracy theories, and deeply entrenched emotions" between the peoples of Egypt and Ethiopia (ibid). The point at the heart of such hostilities is Egypt has been all in all dependent on Nile which emanates, mainly, from Ethiopia. As a result of this fact, the foreign policies of Egypt have centered on the objective of securing the continuous consumption of Nile waters. This reality has made the issue of sharing of Nile waters intolerable phenomenon and compelled Egypt to secure its hegemony over Nile.

The colonial agreements have been the main legal basis for Egypt in an attempt to perpetuate its hegemony over the Nile waters. The 1929 agreement was made between Egypt and Great Britain (which had colonized most of upper riparian countries) and it prohibited any kind of activities on the Nile River and its branches that may affect the interest of Egypt (Oestigaard, 2012). This agreement offered Egypt the upper hand on the Nile waters. The 1959 agreement was also concluded between Egypt and Sudan for the full utilization of the Nile waters (ibid). Accordingly, the agreement allocated 55.5 and 18.5 billion cubic meters to Egypt and Sudan respectively (Tedros, 2014). This agreement neither involved upstream countries during the negotiation nor allowed them to use water in any amount. Generally, these segregating colonial agreements put upstream countries out of the game of Nile waters' utilization, without giving concern to where the waters originate.

Upstream countries benefited very minimal from Nile waters. Most importantly, Ethiopia which is the contributor of 86% of Nile waters has used very little, if not nothing, thereon. Conversely, Egypt successfully utilized the Nile waters for long using such discriminatory colonial agreements as a legal ground. Put differently, it advanced the 'historical' and 'natural' rights that colonial powers gave her over the Nile waters (Yacob, 2012). Egypt has contributed nothing to the total volume of Nile, but it has taken the lion's share from Nile's benefit and firmly convinced of monopolizing it (ibid). To this end, it has developed a strict commitment to the 1929 and 1959 colonial agreements and its historical status quo. However, in the recent time, it has encountered great challenges on the part of upstream countries. Climate change, population growth, and poor water management, among others, are the factors that compelled upstream countries to come together to discuss on how to use Nile for sustainable development of the area (Tedros, 2014).

In view of that, the upper riparian countries appear to be highly concerned with the fair and equitable utilization of Nile waters challenging the firm position of Egypt to unilaterally enjoy as well as administer the river. Here comes the clear contention between the need to maintain the status quo by Egypt and the need for cooperation on the river by upstream countries. In 1999, Nile Basin Initiative (NBI) was established by 10 riparian countries (including Eritrea as an observer) with the aim to bring sustainable development of riparian countries using Nile equitably by signing an agreement which includes upstream countries (Yacob, 2012; Michel *et al*., 2012). Accordingly, riparian countries came up with the Comprehensive Framework Agreement (CFA) in 2009 and majority of upstream countries signed it, namely Ethiopia, Rwanda, Tanzania, Uganda, Kenya, and Burundi while Egypt and Sudan strongly oppose (Yacob, 2012; Michel *et al*., 2012; Nicoll, 2014). Following the disagreement of downstream countries and the failure of other upstream countries to sign it, Yacob (2012) noted that "countries continue to resort to unilateral measures within their jurisdiction". Most notable example in this respect is the inauguration of Grand Ethiopian Renaissance Dam (GERD). This new development by upstream countries goes against Egyptians' interest of unilateral utilization of the Nile waters. Egyptian hegemony over the Nile waters put at risk as the upstream countries began to take measures on Nile waters on their territories.

THE COMMENCEMENT OF "GERD" AND THE HASTENING OF HOSTILITIES

Ethiopian government showed great commitment to meet the overriding energy demand of the country as well as neighboring countries by commencing to aggressively harness its hydropower potential. GERD was commenced in 2011 and planned to be completed in 2017. After the completion, the dam is expected to generate 6000MW hydroelectric power. This aggressive plan of the country has created great worry on the part of Egypt which is 97 percent dependent on the Nile waters. Egyptians consider the dam as a serious threat to their national interest as they believe that it will reduce the amount of water flow. As a result, Egyptians continuously released propagandas as to the measures they may take unless Ethiopia stops its project on Nile. In this regard, Pohl *et al*. (2014) unequivocally noted that "Egypt's government responded with belligerent rhetoric, raising the possibility of violent conflict and serious doubts about future cooperation in the basin". Most importantly, former president Mohammad Morsi went to express the possibility of even bombing the dam (The Reporter, 2015). This shows the truth that the announcement of the beginning of the dam added fuel on the existing hostile relations of the two countries.

In response, Ethiopia reiterated that the dam has a lot to contribute to the downstream countries such as providing regular flow of water, resolving problem of siltation, significantly reducing evaporation and providing cheaper electricity export (Tedros, 2014). Above all, it is attested that there exists neither irrigation plan nor irrigable land on the area thereby imposing no significant harm on the downstream countries. Despite such argument, Egyptians have not been convinced instead continue to put pressure to deter the undergoing project.

By the mid-2011, Egypt sent a 48 person delegation named “Egyptian People’s Diplomatic Delegation” comprised of different important figures of the society being headed by Moustafa El Gendy (Getnet, 2014; Simon, N.D). By welcoming the delegation, Ethiopia’s late prime minister reiterated that the dam is helpful for downstream countries. And, to assure them Ethiopia accepted the establishment of an International Panel of Experts (IPE) led by Ethiopia, Sudan and Egypt with the support of consultants from international bodies and individual experts (Yacob, 2012; Kidane, 2012; Simon, N.D). This group was established to study the possible impact of GERD on the downstream countries. After their investigation, experts came up with the conclusion that the dam will pose no significant harm on the downstream countries instead it benefits all the three countries (Getnet, 2014; Simon, N.D). The result of experts was unwelcomed event for Egyptians and heightened the prevailing friction (Simon, N.D). Misunderstandings, hostilities and psychological warfare continued to be the order of the days.

THE COMING INTO POWER OF EL-SISI AND THE CHANGE IN ETHIO-EGYPT RELATIONS

After the overthrow of the Islamist government of Mohammad Morsi, Abdel Fattah El-Sisi came to hold the post of the presidency. Subsequently, the new president of Egypt pronounced that “Egypt’s relations with Ethiopia must be informed by cooperation and love, not hatred and belligerence” (The Reporter, 2015). Following this premise, Egypt has changed its foreign policy orientation to have friendly relations with Ethiopia (Ghelawdewos, 2015). The new president recognized negotiation and cooperation as a means for resolving the issue of Nile.

3.1. The Meeting of the Two Leaders

Following the coming into power of Abdel Fattah El-Sisi in Egypt, the two countries’ relations seem turning into a better direction. Discussions on issues of common concern between governments of the two countries have come to be more regular and more frequent compared to what had been in the previous times (MoFA, 2015).

By the month of June 2014, both countries' leaders could met together at the African Union summit in Malabo and discussed bilateral, regional and continental issues thereby showing an important shift in the two countries' relations on the Nile issue (Getnet, 2014). This meeting is considered to be a springboard for a new step in the two countries' friendly relations and mutual understanding (Daily News, 2014). In their discussion, prime minister Hailemariam assured El-Sisi the fact that the dam is crucial for his country too. El-Sisi, on his part, being optimistic of the value of the project, denounced the anti-Ethiopia activities used by his predecessors and promised that his country will oppose any act of destabilizing Ethiopia (ibid). It is crystal clear that the stance of the new president of Egypt shows a dramatic shift from the past leaders of Egypt as regards the hydro-politics of Nile. This is because the past leaders of Egypt had no room for compromise on the issues of Nile with other riparian countries.

3.2. Ethiopian Public Diplomacy Delegation

As part of the efforts to build confidence of Egyptians on Ethiopia's intension, the Ethiopian public diplomacy delegation, the first of its kind, had a tour in Egypt (ibid). The tour was aimed at consolidating the newly established amicable relations following the meeting of the two countries' leaders (Getnet, 2014; MoFA, 2014). The team was anticipated to express the intention of Ethiopian government for mutual progress thereby narrowing the gap created due to the inaugural of GERD (ibid). The delegation was comprised of prominent academicians, former Ambassadors, religious leaders, artists and other prominent personalities drawn from various sectors with the headship of Speaker of the House of Peoples' Representative, Aba Dulla Gemeda (Getnet, 2014). In their meeting with Egyptians, the team time and again reaffirmed the fact that the sole objective of the dam is eradicating poverty and nothing else. It is true that the discussions made in Egypt by these important personalities have a paramount importance in well articulating the beliefs of their country to the host country thereby promoting trust and confidence between the two countries. At the top of all, different activities undertaken by the delegates, most importantly by artists are instrumental in fostering people to people relations.

The response of Egyptians for this public diplomacy delegation was a promising to future amicable relations of the two countries. Interestingly, Egyptian Prime Minister Ibrahim Mahleab expressed, on behalf of Egyptian government, to the Ethiopian public diplomacy team the need for cooperation of the two countries in all areas including education, trade, tourism and investment surpassing the commonly raised and overwhelming issues of Nile (MoFA, 2014).

President El-Sisi further confirmed that Egypt under the new government will not repudiate the construction of GERD and the development of Ethiopia at large (ibid). From this standpoint it is possible to safely conclude that the current government of Egypt has showed a major departure from the preceding leaders as to the issue of Nile which had for long been the bone of contentions between Ethiopia and Egypt. It is a common knowledge that there was a propagation that Egypt will go to war if any act is to be done which meddles with the waters of Nile (Daniel, 1999). But, this is reversed by the current government.

The Visit of the Patriarch

The other significant manifestation of the Ethio-Egypt renewed relations is underscored by the visit of His Holiness Abune Mathias, Patriarch of the Ethiopian Orthodox Church, in Cairo. Abune Mathias visited Egypt for six-days. In his visit, he got His Holiness Tawadros II, Patrriarch of Egypt's Coptic Church and visited several churches and monasteries thereby negotiating the need to consolidate the two churches' relation which was interrupted during the Derg regime (MoFA, 2015).

At the top of all, Abune Mathias met El-Sisi and made discussion on the issue of GERD besides the talk to strengthen the two countries' historical, cultural and religious relations (ibid). In the discussion they made, His Holiness reiterated the fact that GERD is so helpful for downstream countries and will not cause significant harm to them, adducing the outcomes of the experts and other studies (ibid). Also, His Holiness insisted that GERD should serve as a source of cooperation and negotiation than conflict and mistrust (ibid) as also been expressed by Ethiopian Public Diplomacy Delegation (MoFA, 2014). President El-Sisi was in affirmative as he affirmed that Egypt will not be a bottleneck for Ethiopian development and thereby promised the two countries' future better relations. This is a major breakthrough compared to the past Egyptian leaders who were highly worried with the development and growing hegemony of Ethiopia as well as other Nile basin countries in the area (Daniel, 1999). Generally, the coming into power of president El-Sisi has showed unpredicted change in the Egypt's position in the hydro-politics of Nile which tends to more cooperation and negotiation than confrontation and animosity.

STILL WORRYING ISSUES

4.1 Still Persisting Mistrust

Even though El-Sisi reengineered Egyptians' approach towards Ethiopia in a right direction, the hostility has not been removed completely.

In this connection, it is rightly noted that "such an encouraging development, however, does not mean that animosity and mistrust have been rooted out. Some politicians and elites still spew out hatred and threats against Ethiopia. And, a sizeable portion of the people of Egypt continues to distrust Ethiopia" (The Reporter, 2015). It is beyond doubt that even though there are Egyptians who have positive outlook towards Ethiopia, there are still individuals with misconceptions and manifest extreme nationalism (ibid), which could have the potential of dragging the current developments to the opposite direction. The public diplomacy delegation was sent to overcome such still persisting doubts and mistrusts. However, the researcher believes that even though it is significant, the possibility of utterly converting the deeply rooted pessimistic outlook of Egyptians towards Ethiopia is less likely. To root out the deeply rooted mistrust, hatred and animosity and create full trust and confidence among all Egyptians is not something to be achieved easily.

4.2. The Existence of Anti-Ethiopia Forces

It has been a common practice in the Horn of Africa countries to use the principle of "the enemy of my enemy is my friend". Following this premise, countries supported the available enemies of their enemy to secure their national interest. Most commonly, the tactic is using the enemy's neighboring rivals and internal dissident groups. In this respect, Egypt has for long used all the available means to put pressure on Ethiopia and thereby to maintain its hegemonic position on the Nile waters. The Reporter (2015) affirmed that Egypt has used until recently both directly and indirectly all the possibilities to destabilize Ethiopia internally which is considered to be instrumental for their continued full enjoyment of the Nile waters.

Egypt was the mastermind behind the preparation, consolidation, and perpetration of the Eritrean Liberation Front (ELF) (Daniel, 1999; Ibrahim, 2012). It gave office in Cairo for ELF and facilitated the insurrection eventually leading to political instability, economic decline, and social turmoil in Ethiopia (Daniel, 1999). The whole purpose was to weaken Ethiopia internally and divert its attention and scarce resources to fight insurgents so that Egypt can secure uninterrupted flow of Nile waters. Indeed, as hinted above, Egypt had successfully devastated Ethiopia by backing Eritrean insurgents militarily, ideologically, politically, and diplomatically and secured its hegemonic position on Nile (ibid).

Besides, Ibrahim (2012) clearly noted that "….the war with Somalia, the Ethio-Eritrean conflict and the current threat by the Islamist Al-Shebab movement have all been fanned by Egyptian support". It was supporting Somalia and Eritrea while they were in war with Ethiopia. And it has also backed insurgents in Somalia to prevent the establishment of pro-Ethiopia government. These show that Egypt has never passed any opportunity to undermine Ethiopia. In fact, in response to such conspiracy there was a less comparable reaction by Ethiopian foreign policy too.

The researcher highly convinced that there may be the possibility for the continuance of such practice of proxy wars. One reason for this conviction is that Ethiopia is still in hostile relations with Eritrea. Though the two countries ended the war, they are standing on uncompromising positions and the condition remains to be no peace no war. Though no direct military confrontation, it is noted that Eritrea still poses a security threat on Ethiopia (Habtamu, 2015). Thus, using such condition Egypt may perpetuate its act of creating threat and turmoil in Ethiopia. The fact that Eritrea supports the "historical rights" of Egypt on Nile (Memar, 2013) may encourage Egypt to further consolidate its relations with Eritrea and operate on the land of the latter to destabilize Ethiopia. Therefore, Egypt may use this opportunity as an instrument to coerce Ethiopia to come to its term. Another reason is the fact that the threat from Somalia is not utterly resolved. Al-Shabab of Somalia is still a security threat to Ethiopia (Habtamu, 2015). Thus, as usual, Egypt may continue to back anti-Ethiopia insurgent groups operating in Somalia. Above all, Ethiopia is not still free from the danger posed by internal dissident groups. Here again, the opportunity is open for Egypt to destabilize the internal situation of Ethiopia and once again to turn her face with all its scarce resources to react insurrections putting aside of the whole development processes.

The researcher strongly believes that Egypt may not miss such chances. This is because Egypt well knows what it has benefited from its previous proxy wars on Ethiopia. The bottom line is Egypt may take supporting Ethiopian enemies as a better option to the already started renewed amicable relations. It may not hesitate to support all the available anti-Ethiopia forces. In this regard, Memar (2013) rightly argued that "I don't think that Egypt will keep its hand away from Ethiopia as long as there are political forces that are willing to attack Ethiopia". In a nutshell, there exist ample opportunities to facilitate Egyptian longstanding motive of undermining Ethiopia.

Egypt's Absolute Dependence on Nile

Egypt has for long extremely been dependent on the waters of Nile. Herodotus attested this fact stating that "Egypt is the gift of the Nile". Nile means everything for Egyptians. Nile is not only the source of ancient Egyptian civilization but also the very existence of today's Egypt. Egyptians are 97 percent dependent on the Nile waters. They used Nile waters for millennia for agriculture, drinking, washing, transportation, energy, and other purposes. Egypt's absolute dependence on Nile emanated mainly from its geographical location and climatic conditions.

Egypt is located in the northeastern Africa. The country forms part of the Saharan desert. It is characterized by the climatic conditions of hot dry summers and mild winters and it received very low, irregular and unpredictable rainfall (Khalil *et al*., 2011). Egyptians' maximum average rainfall is only 120mm per year which is the least in the riparian countries (Hassan and Al Rasheedy, 2007). Also, 96 percent of the country is unpopulated desert thus the whole population of the country is gathered in the 15,000 sq km along the narrow green belt of the river (known as the Nile Valley), and in the exceptionally fertile delta altogether constituting 4 percent of the country's total area (Yohannes, 2008). This fact forced Egyptians to be absolutely dependent on Nile and to develop a deep sense of entitlement to the river (**ibid**). Without Nile one cannot think of the existence of Egypt. It is for this reason, successive Egyptian leaders strongly committed to safeguard the continuous flow of Nile waters to their land.

The aforementioned fact compelled the researcher to doubt the possibility of the current renewed relationship of the two countries to come to a good end. The fact that Egyptians are still without possible alternative to the waters of Nile blurs the prospects of the two countries' viable future relationship. To meet the overriding needs of its population, Egypt has entirely dependent on overexploitation of Nile waters instead of finding alternative solutions (ibid). President Mohamed Morsi rhetorically pronounced that "… If it diminishes by one drop, then our blood is the alternative" (Verhoeven, 2013). It is also expressed by El-Sisi that Nile is "the source of life" for Egyptians not merely for Egyptian development (Ahram Online, 2015). These expressions show their absolute dependence on Nile and the non-existence of another viable alternative. To complicate the matter, studies revealed that the water demand of the country will continue to increase steadily in all economic sectors (Hassan and Al Rasheedy, 2007) which puts doubt on the continuation of newly established amicable relations which allow Ethiopia to harness its river.

Spying the Realities in Ethiopia

The researcher also believes that the positive approach of Egypt may be to consolidate its relations with Ethiopia and pay a regular visit to the latter to investigate the prevailing conditions. They may gather the realities in Ethiopia to report back to home. The possibility of using such visits and subsequently acquired facts for another purpose is immense. It is clear that an attack based on knowledge is more likely for success. The act of spying has already been attempted and thus not a new thing. In view of this, it has been reported that very few days before El-Sisi's presidential inauguration, Egypt sent three individuals to spy dam projects in Ethiopia and south Sudan (Middle East Online, 2014). Hence, though allowing them to visit the dam is instrumental in creating confidence and trust which have been the main sources of hostilities, there is still a need to take into account the possibility of delegates/visitors to serve as a formal spy group. Put differently, the idea is not to prohibit a visit to the site of the dam which in its turn creates another serious danger of mistrust on the issue, but to stress the care be taken as they may have mysteries missions. Thinking the other way around is very vital while acting in good faith is still normal.

May be Buying a Time?

The El-Sisi approach appears to be surprising in a sense that it deviates from what had been experienced by his predecessors. He positively looked the development of Ethiopia and the under construction dam which were great concerns of Egypt previously. He completely reversed Egypt's zero-sum game calculation almost overnight. Why he preferred so? May be buying a time? There is a belief that "in political struggles peace is only a way to buy time and prepare for war" (Gorfu, N.D). In this connection, Habtamu (2015) best articulated that "…. it can be rightly argued that if the right time comes, he will show his true self by inciting hyper-nationalist views at home in pressuring and if need be in forcing Ethiopia". It is noted that after averting the ISIL forces which committed a sudden attack in Egypt, Egypt may turn its face to Ethiopia using the sophisticated weapons which are obtained from external support. It is further argued that "Sisi is not foolish to confront the sophisticated Israel and Iran. Rather, his first target in this case will be Ethiopia" (ibid). Zerihun (2014) further noted that "….what we have seeing and listening is no more than a mere change of tactic to buy time and appear cooperative while continuing the divide and rule policy". The researcher supports these arguments because Egypt may be using a new tactic while pursuing the usual goal. It may be waiting the right time to resume the commonly known act of creating threat and turmoil in Ethiopia thereby to ensure the constant and undiminished flow of Nile waters into its land.

The message is the new development should not give Ethiopia a relief instead it should make it skeptical of the change on the part of Egypt. It needs to keep a watchful eye on the development because when the circumstances allow Egypt may turn back to its real ultimate goal.

Egypt's Inherent Worry on the Development of Ethiopia

Ethiopia is said to be one of the fastest growing countries in Africa and the world at large while anticipated to continue in the same pace (Addis Ababa, 2011). It has showed a remarkable economic growth for the past decade. It is also a relatively politically stable country in Africa which contributes for the overall development of the country. In this regard, the realization of GERD is supposed to be one significant engine of the overall development of the country, which has been a headache for Egyptians since long time ago. Pragmatically looking, having cognizant of this truth letting Ethiopia to further develop and consolidate seems less conceivable unless Egypt has calculated some other project having the goal of undermining Ethiopia. This is because if it allows the progress of Ethiopia, what would be its guarantee for the uninterrupted flow of Nile into its land in the future, unless it is going to opt military attack which is an outdated weapon in this modern time.

The above outlined points are reasons why suspicion is to be made on the unexpected development in the Ethio-Egypt relations. Accordingly, the whole idea of the above discussion is that there are a number of factors which pose question on the healthiness of the new development on the two countries' relations. After all, how one can easily (free of doubt) think of positive from the country which has constantly and without rest strived for the failure of Ethiopia. Hence, a critical look on the true intension of Egypt to convert its entrenched zero-sum mentality is very crucial.

CONCLUDING REMARKS

Ethio-Egypt relations have for long been characterized by hostilities and mistrust. However, the coming into power of president El-Sisi has showed unexpected departure from the past leaders through changing the two countries' relations into a positive direction. In this study, the researcher questioned the true prospects of the renewed amicable relations. The fact to be noted is that the analysis given in this study does not show the pessimistic outlook of the researcher on the two countries' future positive prospects. It does not also mean that normalizing the two countries' hostile relations and consolidating amicable relations have no importance. Instead, the very idea of this paper is to insight the fact that there is a need to critically scrutinize the true motive behind the new and friendly approach of the current government of Egypt.

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