



**PERFORMANCE EVALUATION OF SMALL SCALE IRRIGATION
SCHEME IN ADDIS-ALEM, SEHARTI SAMRE WOREDA, TIGRAY,
ETHIOPIA.**

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HAWASSA UNIVERSITY

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**A THESIS SUBMITTED TO HAWASSA UNIVERSITY, SCHOOL OF
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DEDICATION

I dedicate this thesis manuscript to my mother, Tiblets Ftwi, my brother Adane Fentaw, my sister Tsge Fentaw, for their affection, love and their moral support during my studies and to my late elder brother Kassahun Fentaw who passed away while I was conducted the research work for this thesis.

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ACRONYMS AND ABBREVIATIONS

ADLI	Agricultural Development Led Industrialization
Ai	Area Cover by Irrigated Crop
AR	Advance Ratio
Bd	Bulk Density
cm	Centimeter
CROPWAT8	Crop Water Requirement Estimation model window8
°C	Degree celcious
Co-SAERAR	Commission for Susitainable Agriculture and Environmental Rehabilitation of Amhara Region
D	Average Depth of Water Applied to the Field
d	Average Depth of Water Infiltrated
DEM	Digital Elevation Model
DPR	Deep Percolation Ratio
Dsr	Water Stored in the Root Zone
DU	Distribution Uniformity
Ea	Aplication Efficiency
Ec	Conveyance Efficiency
Ed	Distribution Efficiency
Ef	Field Canal Efficiency
Er	Storage Efficiency
Es	Secondary Canal Efficiency
Et	Tertiary Canal Efficiency
ETc	Actual Evapotranspiration
ETo	Refferance Evapotranspiration
ETp	Potential Evapotranspiration
Em	Conveyance Efficiency of Main canal
FAO	Food and Agricultural organization
Fc	Field Capacity
H	Height of Water in the Canal

ha	Hectar
hr	Hour
H1, H2, H3	Head water users
IWMI	International Water Management Institute
IWR	Irrigation Water Requirement
Kc	Crop Coefficient
LGP	length of Growing Period
m	Meter
M1, M2 ,M3	Middle Water users
MAD	Management Allowed Deficiency
mm	Millimeter
MoAFS	Minister of Agricultueral and food security
MoWR	Minister of Water Resource
NGO	Non Governmental Organization
pwp	Permanent Wilting Point
RR	Runoff Ratio
RIS	Relative Irrigation Supply
RWS	Relative Water Supply
SRTM	Shuttle Radar Topography Mission
t	Time
T1,T2,T3	Tail Water Users
TAW	Total Available Water
TWS	Total Water Supply
UCC	Christianson's Uniformity Cofficient
US\$	United State Dollar
USDA	United State Department of Agriculture
V	Velocity of Water in the Canal
W	Width in Canal
Wd	Dry Weight of the Soil
Wf	Depth of Water Applied to the Field
Wn	Water Desired to be Stored in the Root Zone

W_s	Depth of Water Diverted from the Source
W_θ	Gravimetric Soil Moisture Content
W_w	Wet Weight of the Soil
Y	Depth of Water Infiltrated at a given Point
\bar{y}	Average Absolute Deviation of Infiltrated Water from the Mean
Z_r	Average Depth of Water Applied to the Root as Storage

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ABSTRACT

Water is scarce and expensive resource which needs to be utilized in a highly productive manner for agriculture. The main objective of this study was to evaluate the performance of the small scale irrigation scheme at Addis-Alem, Seharti Samre Woreda, Tigray Regional State. The importance of performance evaluation of small scale irrigation scheme mainly for advising irrigators on how to improve their system and management practice, intervention across different system levels, and to compute irrigation seasons and technologies. The scheme has command area of 60 ha during the current study time and serving about 240 beneficiaries. To achieve the aim primary and secondary data were gathered. The internal and external performances using minimum sets of performance which includes agriculture water use economical, and physical performances. In order to compute the irrigation water use efficiency of farmers at field level, nine farmer fields were identified from the irrigation scheme in the relation to their location (head, middle and tail end water users). The internal process which include conveyance, application, storage, runoff, deep percolation ratio, distribution efficiencies, and overall irrigation efficiency were used to check the performance of the irrigation scheme. The results of the analyses indicate that the conveyance and application efficiencies were found to be 51.297 and 68.07% respectively. The runoff ratio of the scheme was nil as the furrows are block end type. Deep percolation ratio in the same order of the scheme was found to 31.93%. Storage efficiency was also estimated 47.69%. Further, irrigation uniformity of 98.91% was attended. From the analysis of external indicators, the output per cropped area and output per command area were found as 4545.455 and 1363.636 US\$ha⁻¹ respectively. The output per irrigation supply of the scheme was 0.663 US\$ m⁻³. Output per water consumed in the scheme was 0.974 US\$ m⁻³. The water use performance of the scheme was computed, water supply and relative irrigation supply were found as 7.362. The irrigation ratio of the scheme was found to be 0.30 which means about 70% of the command area is not under irrigation during the study period. In general,, the performance of Addis-Alem irrigation scheme is low . But there is still a room for improving the performance of the scheme by resizing the main canal as well as the secondary and tertiary canals which were not adequately carrying the required irrigation water.

Key words, irrigation efficiency, irrigation supply, performance indicators, Addis-Alem small scale irrigation, Ethiopia

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Ethiopia has an estimated irrigation potential of 3.7 million hectares (ha) of land (Awulachew et al, 2007). During 2006, the total estimated area of irrigated agriculture in the country was 625,819 ha, which, in total, constitutes about 17% of the potential (MoWR, 2006). Despite its enormous potential to boost the country's economy irrigated agriculture is facing a number of problems. A relatively safe estimate is that 40 percent or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface runoff (FAO, 1989). In the country water development for agriculture is a priority, but poorly designed and planned irrigation undermines efforts to improve livelihoods and exposes people and environment to risks. Recent estimates indicate that the total irrigable area in Ethiopia is 197,225 ha around 3% of the irrigation potential (MoWR). Moreover, much of the increase in irrigable had come because of expansion of small scale irrigation. Yet, the existing irrigation development in Ethiopia, as compared to the resource, is negligible.

Irrigation is an agricultural operation that supplies the soil moisture deficit with water. To the agriculturalist, it is a component of successful crop husbandry particularly in a dry climate. A reliable and suitable irrigation water supply can give in improvement in agricultural production and assure the economic vitality. Many civilizations have risen on irrigated agriculture. Those provide basis for their society and enhance food security of their people. Some have estimated that as little as 15-20% of the world wide total cultivated area is irrigated Comparing irrigated and non-irrigated yields in some areas, this relatively small fraction of agriculture contributes as much as 30-40% of gross agricultural output (FAO, 1989). The agricultural sector is the leading sector in the country's economy contributing 47.7% of the total gross domestic products as compared to 13.3% from industry and 39% from services and provides livelihood to 85% of the population (World Bank, 2005). Both industry and services depend strongly on the performance of agriculture which provides raw materials, generates foreign currency for import of essential inputs and food for the fast growing population. Despite its importance for the national

economy, agriculture is largely based on subsistence farming. The productivity of the agricultural sector is very low and lags behind the population growth rate resulting in food insecurity. To address this problem, the Ethiopian Government designed an Agricultural Development Led Industrialization (ADLI) strategy which aims at using agriculture as the base for the country's overall development (MoWR, 2001). This strategy aims at enhancing the productivity of small scale farmers and improving food security both in the rural and urban areas. One of the policies within this strategy is stimulating and/or supporting the development of small scale irrigation. However, development of the chances of implementing such new irrigation projects needs huge Country's budget since such project requires high investment costs and funding organizations are not also comfortable to financially support the third world countries for developing new irrigation projects unless it is well justified. Accordingly, the new situations of the world economy necessitate irrigated agriculture to be more productive and cost effective. To achieve sustainable production from irrigated agriculture it is obvious that the utilization of the important resources in irrigated agriculture; water and land must be improved. Thus on-farm irrigation systems and operations need to be evaluated against the potential efficiency of the systems. Performance assessment has been an integral part of irrigation since man first started harnessing water to improve crop production. Evaluation involves measuring conditions at one or more points in a field selected to be typical or representative for the irrigation projects (Pereira and Trout, 1999).

The International Water Management Institute (IWMI) has prepared different “comparative” indicators that are helpful for comparing irrigated agriculture between countries and regions, between different infrastructures and management types, and between different environments and for assessment over time of the trend in performance of specific project. The set of indicators are small, yet reveal sufficient information about the output of the system. Therefore, performance of irrigation operation has to be evaluated periodically, both at system and at farm levels.

1.2 Problem statement

In Ethiopia, irrigation scheme performance is estimated to be low (on average 36% below design capacity), implying a loss of about 230,000 ha of irrigated land, leading to only 410,000 ha performing to the expectations, from the total irrigation schemes covering about

640,000 ha across the country (Awulachew, 2010). Due to the inefficient irrigation water management, both at system and farm level has led to a range of problems and further aggravated water availability and has reduced the benefits of irrigation investments (FAO, 1996). Despite the poor performance of the irrigations in the country, evaluation of small-scale irrigation systems is not common. This is particularly true in using the internal and external performance indicators. These indicators provide the information required for design, model validation, and mainly for advising irrigators on how to improve their systems and management practices, interventions across different systems and system levels, as well as to compute various irrigation seasons and technologies. Further, these indicators are small, not data-intensive and are cost-effective (Kloezen and Garces-Restrepo, 1998). In the study area there are lot of problems which are reduces the performance of the small scale irrigation system. Such as the size of the canal is not enough to pass the diverted water from the source and the scheme has so many inefficiencies in its different system. The main, secondary, and field canals are covered with sediment loads and vegetation as it was observed in the field. The flow of water at the different segment of the main canal is stagnant due to siltation. Hence, this study was undertaken with the general objective of assessing and evaluating the performance of Addis-Alem small scale irrigation scheme at Seharti Samre Woreda, Tigray, Ethiopia. The specific objectives of the study were;-

- To assess the performance of the irrigation scheme using internal and external performances.
- To assess whether or not the conveyance system is sized with in the design norms that were based on affair balance between capital and operating costs.
- To propose appropriate remedial measures for the unsuitable of surface irrigation system.

1.3 Scope of the study

The scope of this study in Seharti Samre woreda Addis-Alem irrigation scheme is to compute the performance of the scheme using the internal and external performances. Internal performance included conveyance efficiency, application efficiency, storage efficiency, runoff ratio, deep percolation ratio, irrigation uniformity, and overall irrigation efficiency. External performance also included agricultural, water uses, physical, and financial self sufficiency.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Surface irrigation systems

Surface irrigation is accomplished by impounding water on the land surface, or causing the water to flow over the surface. Surface irrigation events can be grouped into four distinct hydraulic phases: advance phase, ponding phase, depletion phase, and recession (Jureims, et al, 2001). The advance phase lasts from the beginning of the inflow up to the time that the advancing water front reaches the downstream end of the field (known as the advance time). The ponding phase or storage phase ended from the advance time until the time the inflow is stopped. The depletion phase is the time from cutoff time to the time the upstream end of the field or furrow falls dry following the discontinuation of inflow. The recession phase is the last phase when the receding water front reaches the end of the furrow or field. In surface irrigation, gravity is the major driving force to spread water over the area to be irrigated. Within the field, other forces redistribute water into the soil. The basic flow characteristics are much the same for all surface irrigation methods, the expectation being the difference in channel geometry and boundary conditions.

In the process of surface irrigation performance evaluation, the factors that affect the flow conditions need to be identified and analyzed (Jensen, 1983). Further, it is the least efficient user, as it is generally based on less advanced techniques. Even in countries like Egypt where irrigation has been practiced for centuries and is the dominant type of agriculture, 90% of the irrigated lands is under surface irrigation. The types used currently vary from traditional spate irrigation to sophisticated and automated systems aimed at better control of the technique (Hlavec, 1995). Emphasis should be given for evaluation of surface irrigation, as it will continue to be the major type of irrigation in the future. This practice is true, in particular in the developing world, where high technology is not easy to adopt, and where low value crops are grown (Strekoff, 1999).

The most common type of irrigation method is furrow irrigation, which is carried out using small channels or furrows that run along or across the contour depending on the principal slope of the land. There are various types of furrows, those that run along the contour, those

that are aligned with grades, and those that are aligned with no grades. From the mode of water control, furrows can also be categorized as open end and close ended. The water that is conveyed by the furrows infiltrates into the soil both laterally and vertically, the process that makes the method unique from the other methods. The most complex aspect of the hydraulics of the method is the infiltration process.

Furrows are suitable for irrigation of row crops James, (1988) and they are the most widely used irrigation methods in the world as they provide better on farm water management and flexibility under many surface conditions (Walker and Skegerboe, 1987).

Surface irrigation accounts for the major use of water resources. In California irrigation accounts for 80% of all water diverted for human consumption (Pitts, et al., 1996).

In spite of the advances achieved in improvement of irrigation technology, still significant gap remains between the efficiency theoretically achievable and that practiced in the field.

2.2 Irrigation Water Control and Management

According to Salman et al. (1999) "Water management" is described as the planned development, distribution, and use of irrigation water in accordance with predetermined objectives and with respect to both quantity and quality of the water resources. It is the specific control of all human intervention on surface and subterranean water. Every planning activity that has something to do with water can be looked upon as water management in the broadest sense of the term. According to U.S Bureau of Reclamation (2005) "Irrigation Water Management" means management of irrigation water on the farm.

There is no way that the cultivated area without a water management system can contribute significantly to the required increase in food production (Schultz and DeWrachien, 2002). The on-farm irrigation water need to be measured to determine the potential efficiency of the systems as designed and the actual efficiency that is obtained with present management (Merriam et al., 1983).

2.2.1 Regulation of flow discharge and water levels

Irrigation scheme flows are managed with the help of hydraulic structures and water reaches the fields at the give time and in the quantities needed. To transport water from the source (often at some distance from the cultivated fields) to the fields, an infrastructure consisting of canals and regulation structures is necessary. An organizational structure is needed to execute

the necessary tasks to manage and control the infrastructures (Ertsen, 2005). According to Kraatz and Mahajan, (1975) the water level and velocity control structures comprise a group of engineering works installed in open canal irrigation networks designed to regulate the water level in a canal, to control the quantity of water passing through it, to dissipate energy and enable water to be delivered accurately and safely to the fields without causing erosion. Such structures include checks or cross-regulators, drops (or falls) and chutes.

Water control refers to the ability of the system to distribute, apply or remove water at the right time, in the right quantity and at the right place. The main objectives of water control in an irrigation project are to deliver reliability (temporal), adequacy (volume balance, including seepage, operational and application losses) and equitable water to irrigation fields (spatial parameters) (Lowdermilk, 1981). In view of its aim, an irrigation system has to be planned, constructed, operated and managed in such a way that all of the farm fields in the command area will receive and discharge water in an appropriate, conveniently arranged and adjustable manner (Depeweg, 1999).

The measurement of irrigation water is an essential element for its fair distribution and economical use. Measurement serves to ensure the maintenance of proper delivery schedules, to determine the amounts of water delivered and to single out anomalies in distribution. According to Ertsen (2005) by means of weirs, dams, canals and other constructions, the spatial and temporal distribution of water is regulated. An important aspect of water control relates to the temporal and spatial distribution of water or in other words the modification of an (agriculturally) unfavorable timing of watering in the annual cultivation cycle. Unfavorable timing includes both the transfer of water to overcome shortages (irrigation) and to remove excess water (drainage). The collection, control, allocation and distribution of water to groups of fields and producers are the core processes of an irrigation system. Irrigation systems collect; transport and distribute water for agricultural production with the goal to supply the root zones of the cultivated crops with the necessary amount of water.

2.2.2 Irrigation water management

According to Wil and Vander (1994) managing the operation of an irrigation system is considered a major bottleneck in the improvement of its performance. Managing an irrigation system is not a simple task. Many different parties are involved; each with their own interests,

however information on irrigation water management in a detailed scale like at country level is not common due to the lack of data, reliability and accessibility of the data (Merdun and DeIrmenci, 2004).

The management of irrigation systems aims to achieve optimal crop production and efficient water use or in other term a reliable, predictable and equitable irrigation water supply to farmers. Inequity of water distribution occurs very often. Farmers are not sure when and how much water they can expect, which leads to very little cooperation and involvement in irrigation management and limited contribution to operation and maintenance costs (Wil and Vander, 1994).

Playan and Mateos (2004) defined that the function of the conveyance and distribution systems and services should provide sufficient water in a timely manner so that it can be used efficiently for crop production. Reliability and efficiency are then keywords for a modernization plan. The reliability of an irrigation service is the degree to which the irrigation system and its water deliveries conform to the expectations of the users. A reliable service allows efficient irrigation management within the constraints of the system.

The ever-increasing water demand compared with the depleting water resources warrants refined water use practices in irrigated agriculture to attain improved socio-economic benefits. In the past years the improvement in the irrigation system concentrated in the hardware component namely the physical aspects like structures but limited on the software part namely water usage for agricultural purpose. A good management, proper and timely application of water may result in better yield and reduction in drainage problems (Vidhya *et al.*, 2002). Irrigation water management has become a central issue in many countries, in particular after recent studies, which revealed the disappointing performance of many irrigation schemes.

Inefficient water use and inadequate water management, both at farm and scheme level mean much less area can be irrigated than planned and agricultural production falls well below target (Mehta, 1994). The responsibility for the management of the on-farm water distribution and the water application belongs to an individual farmer. The management is responsible for the operation and maintenance of the irrigation and drainage system (Depeweg, 1999).

2.3 Overview of Irrigation Development in Africa

FAO (1995) reported that the total water resources potential of Africa is 20,211 Bm³/year, out of which it uses 3,991 Bm³/year (19.75%). Agriculture accounts for 85 percent of the water used. The total irrigated land of the continent is estimated to be about 124 million ha. This figure includes all land where water is supplied for the purpose of crop production. It represents an average of 7.5 percent of the arable land. One reason why Africa has not achieved a Green Revolution similar to Asia is that the research system in Africa is not strong the challenges are great. Control of water and soil moisture in the field is a precondition for successful application of many of the results of agronomic research (FAO, 1995).

Irrigation technology focuses on irrigation techniques and efficiency has been improving since the beginning of the last century. But Jensen (1983) proposed that innovative new concepts would be needed to modernize the older irrigation systems such that the delivery systems and other factors do not limit the irrigation efficiencies. Economical irrigation systems that apply water to the fields with nearly perfect efficiency have not been developed yet.

One critical precondition required to close the gap between the African food production and consumption is to focus on irrigation development considering water as one of the basic resources (FAO, 1995). This resource has now become a critical constraint as its utilization by the various economic sectors is increasing. The strategy will lead to recognizing water as a scarce and valuable resource. For too long, it used to be considered cheap and plentiful. This is no longer true. The water resources, therefore, will have to be managed efficiently (FAO, 1995).

2.4. Irrigation Water Control and Management in Ethiopia

Almost all the irrigation schemes in Ethiopia initiated in the past have been functioning under anticipated targets (Habtamu, 1990). In spite of the considerable investment in irrigation development of both government and NGOs constructed community managed irrigation schemes, the overall performance has remained far under expectations (Sharma, 1998). Hundreds of reservoirs have been constructed but are not yet effectively used for irrigation (FAO, 1995).

Co-SAERAR (1999) stated that irrigation development in the country perform poorly because of shortage of technology or technical deficiencies, but rather because of faulty assumptions

and practices related to the operation and maintenance and overall management of the system. Given the complex set of constraints facing smallholder producers, providing access to irrigation water by itself is not sufficient; smallholders also need a broad range of support services (access to inputs, credit, output markets), knowledge of farming and secure land tenure (Kamara and McCornick, 2002). According to Tafa (2002) analysis of existing situation indicates that if irrigation is to play a crucial role as engine for further expansion of agricultural production, the management and organization of irrigation systems, including their institutional implications, must be substantially improved.

2.5. Performance Evaluation of Irrigation Practices

2.5.1 Importance of performance evaluation

Evaluation of farm irrigation systems specially plays a fundamental role in improving surface irrigation, a system which is usually considered inefficient in terms of water use. Evaluation of the system provide information used to advise irrigators on how to improve their system design and/or operation, as well as information on improving design, and developing real time irrigation management decisions.

According to Kloezen and Graces (1998) that effective irrigation management needs reliable performance assessment. Good farm irrigation management assures correct frequency of irrigations, correct application depth, uniform irrigation, minimum runoff, and minimum deep percolation except for that required for salt management, minimum erosion, and optimal return on irrigation investment.

Computing of performance is basically, ensure all activities proceed smoothly as planned threats to crop and production system performances and react in time to avoid or overcome the situation when it occurs. Specially, some of the major roles of performance assessment and evaluation are to ensure that the cropping intensity targets met, for accurate supply demand matching, water savings and to alert potential crisis event.

According to FAO (1989) the principal objective of evaluating surface irrigation systems is to identify management practices and system configurations that can be feasibly and effectively implemented to improve the irrigation efficiency. An evaluation may show that higher efficiencies are possible by reducing the duration of the inflow to an interval required to apply

the depth that would refill the root zone soil moisture deficit. The evaluation may also show opportunities for improving performance through changes in the field size and topography. Evaluations are useful in a number of analyses and operations, particularly those that are essential to improve management and control. Evaluation data can be collected periodically from the system to refine management practices and identify the changes in the field that occur over the irrigation season or from year to year. The surface irrigation system is a complex and dynamic hydrologic system and, thus, the evaluation processes are important to optimize the use of water resources in this system (Walker, 1989).

2.5.2 Irrigation performance

Irrigation performance measure the value of a particular item such as yield or canal discharge and have to include a measure of quality as well as of quantity, and be accompanied by appropriate standards or permissible tolerances (Rust and Snellen, 1993). In connection with main system performance, the authors concluded that the services provided by the system and the appropriate performance standards are greatly influenced by the design of that system. The improvement of irrigation practice requires knowledge of crop water requirement and yield responses to water, the constraints that are specific to each irrigation method and irrigation equipment, the limitation to water supply system, and the financial and economic implication of irrigation practice.

Improvement of irrigation method needs the considerations of the factors affecting the hydraulic process, the water infiltration and uniformity of water application to the entire field (Hlavec, 1992). The consideration of the different factors renders irrigation management a complex decision-making and field practice process (Periera and Luis, 1999).

Performance evaluation practices are meaningful if related with certain management objectives that are described for certain given situation. Some key indices or terms are developed that are used to describe the achievement of these objectives, followed by the identification of variables that are controllable and measurable and can be regulated to achieve the established indicators.

The indices are used to evaluate the farm irrigation system that could be categorized into delivery subsystem (the system extending from head-works to field canals), and water use subsystem (part of the system extending from field canals to water application system). The

indices should be subjected to management control so that they can be manipulated to improve system performance (Walker and Skogerobe, 1987).

Efforts have been made over the years to develop appropriate evaluation models that could use the irrigation parameters and variables to evaluate irrigation performance. Among these, the volume balance model is the basis for most design and field evaluation procedures. This has been proven with field and laboratory data. It allows quick and reliable definition of infiltration rates over the length of the field and it is easily extended to indications of uniformity and efficiency parameters (Walker and Skogerobe, 1987).

In response to the insufficient performance of existing irrigation system, focus was made on the performance evaluation of the schemes. This led to the establishment of performance criteria such as productivity, adequacy, equity, etc. However, in conducting performance of irrigation, more than one viewpoint exists. In addition, few of these criteria reflect the view of the farmers (Gowing et al., 1996). It is therefore essential that evaluation of the performance of surface irrigation systems be continued with a view to improve the performance of the systems and also to incorporate the view of the stake holders, i.e., the farmers in particular.

Different indices have been developed that are used for evaluating the performances of individual irrigation systems and for comparing the performances of different irrigation systems as well as farms. The type and number of indices (indicators) used for a particular situation depend on the level of details required for quantification, and on the number of disciplines selected for assessment. These may include, Agricultural, water use, economics, environment, management, physical etc. which are regarded as external indicators (Bos, 1997).

The common efficiency terms used for on-farm irrigation system evaluation (internal process indicators) include application efficiency, uniformity, storage efficiency and adequacy, and recently complementary terms such as runoff ratio, deep percolation ratio, are being applied (Jureims et al., 2001). The principal terms and their uses are identified below.

2.5.2.1 Internal performance

These indicators examine the technical or field performance of a project by measuring how close an irrigation event is to an ideal one. An ideal or reference irrigation is one that can apply the right amount of water over the entire region of interest (i.e. depth of root zone)

uniformly and without losses. Analysis of the field data allows quantitative definition of the irrigation system performance. The performance of irrigation practice is determined by the efficiency with which the water is conveyed through the canal, how irrigation is applied to the field, how adequate the amount is and how the application is uniformly applied to the field (Feyen and Dawit, 1999).

A. Conveyance efficiency

Significant volume of water is lost by the networks of the conveyance canals due to seepage and evaporation depending on the nature of the soil and agro-climatic zone in which the canals are located. Conveyance efficiency is defined as the ratio of the amount of water that reaches the field to the total amount of water diverted into the irrigation system.

The concept can also be viewed as the evaluation of the water balance of the main, lateral and sub-lateral canals and related structures of the irrigation system (Rust and Snellen, 1993). It is one of the several closely related and commonly used output measures of performance that focus on the physical efficiency of water conveyance by the irrigation system (Bos, 1997). Losses of irrigation water in the conveyance system can be a major component of the overall water losses particularly for farms located at significant distances from water sources where the main canals are long and unlined. The amount lost depends on quality of operation, and maintenance, and the nature of the soil that affects the seepage rate.

In Tanzania, a survey of the efficiency of improved and unimproved small scale irrigation schemes indicated that the conveyance efficiency for the main canals and the field canals (unlined) were 84 and 65% during the dry season and 85 and 74% during the wet season respectively. However, typical conveyance efficiency values generally reported are 70 and 50% for unlined poorly managed main and field canals respectively, while for the well managed canals the figures were 85 and 80% respectively (MoAFS, 2002).

B. Application efficiency

Depending on the type of the source, water is diverted to a canal for conveyance to the farm for distribution and finally for application to the crops in the field. When water is diverted into any water application system such as furrows, part of the water infiltrates into the soil for consumptive use by the crop, while the rest is lost as deep percolation and as runoff. The efficiency terms determine these components and compare them with the volume of water

actually applied to the field is regarded as application efficiency. The term is an indication of the effectiveness of the system in reducing losses during an irrigation event (Walter, and Berisavijevic, 1991)

The Application Efficiency is a term initially formulated by Israelson (1950) and measures the ratio between the volume or depth of water stored in the root zone for use by the plant to the volume or depth of water applied to the field. As reported by Walter and Berisavijevic (1991) the term has been expressed in different ways over the years to include different parameters by different authorities. Field irrigation efficiencies are influenced by factors such as soil type, field application methods, depth of application and climate. Very high values are achieved in arid climates and where water shortages prevail. However in the area where the water applied exceeds water required, indicating an over irrigation, emphases should be given to reduce the amount of irrigation water (Walters and Berisavijevic, 1991).

The level of irrigation efficiencies under which irrigation projects operate vary according to the efficiency of design of the system and its quality of operation. The availability of water for irrigation also influences the level of efficiency; as under water shortage conditions farmers attempt to reduce water losses. Modern farms under good management can achieve better management as evidenced from 70 and 93% application and distribution efficiencies respectively obtained for the modern Amibara Project, recorded for 250 m furrows using stream flows varying from 2.13 to 3.5 l s⁻¹ on Vertisols and alluvial soils (Kandiah, 1981).

The irrigation efficiencies vary in accordance with the type of surface irrigation. Walters and Berisavijevic (1991) found that sprinkler irrigation had the highest E_a (70%) while basin irrigation of rice had the lowest (30%). Wild flooding was also low (45%). For non rice crops, such as dry food crops, the authors reported that the figures were not significantly different from each other (basins 54, furrows 55, and borders 58%).

C. Deep percolation ratio

A component of the irrigation applied to a field percolates into the soil below the root zone. Part of the water is intentionally added to the irrigation water to maintain the salt balance of the soil through leaching additional salt brought by the irrigation water itself or through capillary process from saline groundwater (Smedema and Rycroft, 1983). Higher DPR values are indications of over irrigation. The volume of percolated water in excess of the leaching requirement is considered as lost water and is used to define the efficiency of irrigation. DPR

expresses the ratio between the percolated water beyond the root zone to the volume of water applied to the field (Feyen and Dawit, 1999).

D. Storage efficiency

Storage efficiency is an index used to measure irrigation adequacy. It is the ratio of the quantity of water stored in the root zone during irrigation event to that intended to be stored in the root zone. The value of E_r is important either when the irrigation tend to leave major portions of the field under-irrigated or where under-irrigation is purposely practiced to use precipitation as it occurs. This parameter is most directly related to the crop yield since it will reflect the degree of soil moisture stress. Usually, under-irrigation in high probability rainfall areas is a good practice to conserve water but the degree of under-irrigation is a difficult question to answer at the farm level (Walker, 1989). Adequacy has significant impact on the crop yields and thus on the economic return on water use. In an experiment, Raghuwanshi and Wallender (1998) found that the maximum return to water was achieved with irrigation adequacies of 63, 59, 54, 49 and 50%, for irrigation intervals of 10, 12, 14, 18, and 21 days, respectively.

An irrigation interval of 10 days with 63% adequacy gave the global maximum return to water. However, the Natural Resource Conservation Service of UK recommends irrigation adequacy for homogeneous soil condition to be 87.5% (Raghuwanshi and Walender, 1998).

E. Distribution uniformity

To fully identify the efficiency of an irrigation system, the uniformity of the water applied need to be evaluated. Irrigation water needs to be applied uniformly in a field in order to achieve uniform crop growth. In practice, however, perfect uniformity of application is not possible. The common measure of uniformity of irrigation is coefficient of uniformity which is expressed as the deviation of infiltrated depth of water from mean depth of infiltrated water in the field.

Distribution uniformity is closely related with the advance ratio (AR), the ratio between the advance time and the time of irrigation. Large advance ratio and low distribution uniformity indicate too long a furrow or too small initial stream. It also indicates too small management allowed deficit (MAD), or too large furrow spacing (Jensen, 1983). Infiltration, which is the movement of water into the soil, is an important factor affecting surface irrigation in that it determines the time the soil should be in contact with water (the intake opportunity time or the

contact time). It also determines the rate at which water has to be applied to the fields, thereby controlling the advance rate of the overland flow and avoiding excessive deep percolation or excessive runoff. The infiltration or intake rate is defined as the rate at which water enters into the soil, usually expressed in mm hr^{-1} (Savva and Frenken, 2002).

F. Overall scheme efficiency

Irrigation efficiencies are evaluated at scheme or farm level for the purpose of identifying the losses that occur in the irrigation system starting at the water abstraction point, through the conveyance system down to water application in the field, to determine the overall irrigation efficiency. As reported by the MoAFS (2002) for small irrigation schemes in Tanzania typical values measured were 28 and 34% for poorly operated, and for well operated canals, respectively. In addition to design and other technical factors, the farm efficiency is much regulated by the operation of the main supply system to meet the actual field supply requirements and the skill of the system operators (FAO, 1977).

2.5.2.2 External performance

External performance indicators evaluate irrigation systems based on relative comparison of absolute values, rather than being referenced to standards or targets. Many indicators used for external performance evaluation can be calculated from secondary data rather than primary data. These set of indicators are designed to show gross relationship and trends and are useful in indicating where more detailed study should take place, where a project has done extremely well, or where dramatic changes take place. According to Bos *et al.* (1994) external performance indicators are grouped as follow:

A. Irrigated agriculture performance

They are used for the evaluation of the project performance in terms of the production it results in. It expresses output of irrigated area in terms of gross or net value of production measured at local prices. This addresses the direct impact of operational inputs in terms of such aspects as area actually irrigated and crop production, over which an irrigation manager may have some but not full responsibility. According to Zeleke et al (2012), the result of the agricultural annual outputs per cropped area were 2666.667 US\$ ha^{-1} for Golgota, 2522.099 and 2750 US\$ ha^{-1} for Wedecha (subsystems Godino and Gohaworki) respectively.

B. Water use performance

This deals with the primary task of irrigation managers in the capture, allocation and conveyance of water from source to field by management of irrigation facilities. Indicators address several aspects of this task: efficiency of conveying water from one location to another, the extent to which agencies maintain irrigation infrastructure to keep the system running efficiently, and the service aspects of water delivery which include such concepts as predictability and equity.

C. Physical performance

Physical indicators are related with the changing or losing irrigated land in the command area by different reasons. Among those reason water scarcity and input availability are the main reason why lands in command area are not fully under irrigation in a particular season. From physical performance irrigation ratio and water delivery ratio are the two main indicators.

D. Economic performance

This indicator considers the production and the total cost of infrastructure for the scheme. It deals with the total revenues from the scheme, total cost spent for running the project and initial investment costs. Economic indicators deal with how much investment cost is spent on the project in comparison with total production and how much fee collected from water users for yearly maintenance and operation expenditure and whether the system is self-sufficient or not (Vermillion, 2000).

2.6. Interpretation of Irrigation Performance Assessment Results

The interpretation and application of the performance evaluation results require judicious consideration of all indices in view of their overall implications. Attempt to improve one index has to be considered in view of the impact on the other. They need to be viewed in light of profit maximization. The highest values are not always desirable as they may not always maximize net profits as they may incur additional costs. Improvement of uniformity can improve application efficiency, when irrigation water fills the soil moisture to field capacity. On the other hand, improving distribution uniformity does not necessarily improve application efficiency when the maximum amount of infiltration is less than the depth required to fill it to field capacity (James, 1988).

It is, therefore, important to establish the relationships between the performance indices to know how the other performance indices change, increase or decrease, when one index varies. Feyen and Dawit (1999) established that for furrow and border irrigation, as flow rates increase, DU, U_{cc}, and RR increase. These indices showed decreasing function when the length of furrows were increased. On the other hand, DPR increased as the furrow lengths increased, but decreased as flow rates increased which is in agreement with the hydraulics of channel flow. These results indicate that when all of the main performance parameters need to be established for a farm to form the basis for making decisions on farm operation improvement.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of study area

3.1.1. Location of the study area

The study is conducted in Maila-Haiba catchment area, which is found in Amdiwoyane, and Addis-Alem, Hintalo Wajirat and Seharti districts of south eastern zone of Tigray Regional state. It is situated at the distance of 35 km from Mekelle, the regional capital. Geographically, the catchment is located between 527045 to 541285 E UTM and 146665 to 1473416 N UTM. And its elevation varies from 2220 m to 2850 m. It covers a total area of about 60 km² and it is accessible by gravel road running from Mekelle to Samre and the different parts of the catchment are accessible through foot paths (Figure 1).

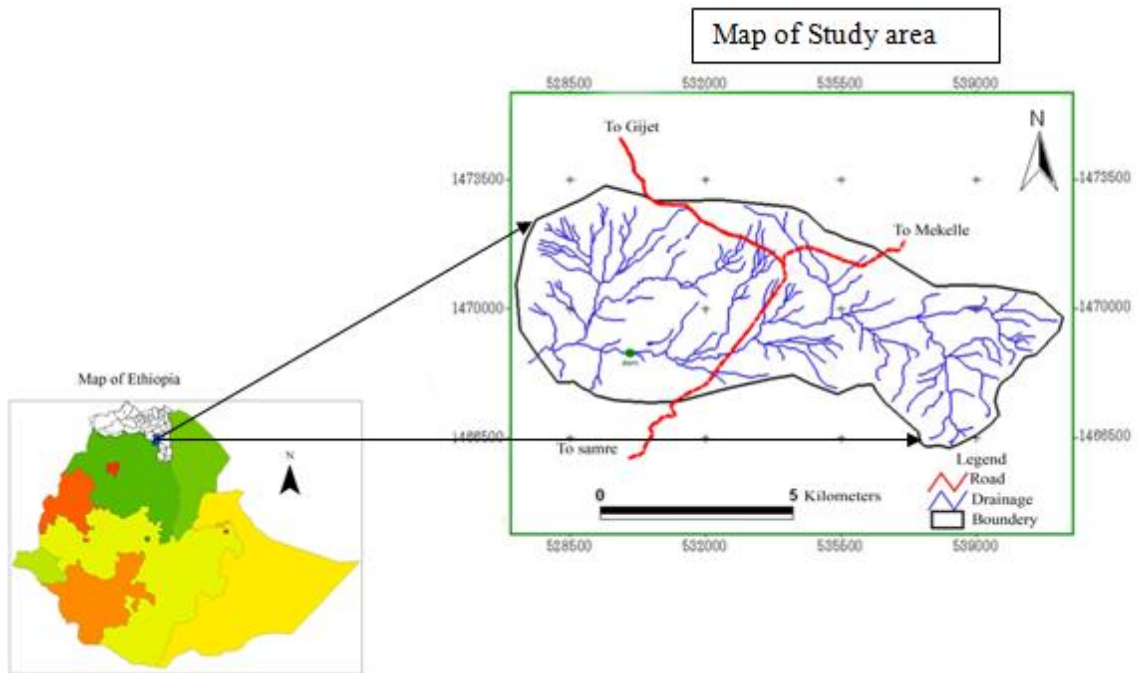


Figure 1: Location map of the study area

3.1.2 Climate

Data on climate of the study was collected from the Tigray meteorological Agency, the nearest meteorological station. The average rainfall in the study area is 685.4 mm/year mainly. The minimum and maximum temperatures in the study area are in the order of 9.2 and 29.2°C, over

the period of 2001-2016 respectively. The details of meteorological data of the study area were presented in appendix Table 2 and the reference evapotranspiration, mean monthly rainfall and temperature of the Meila- Haiba catchment were presented in figure 2 and the annual long period mean and total rainfall of the catchment presented in Figure 3.

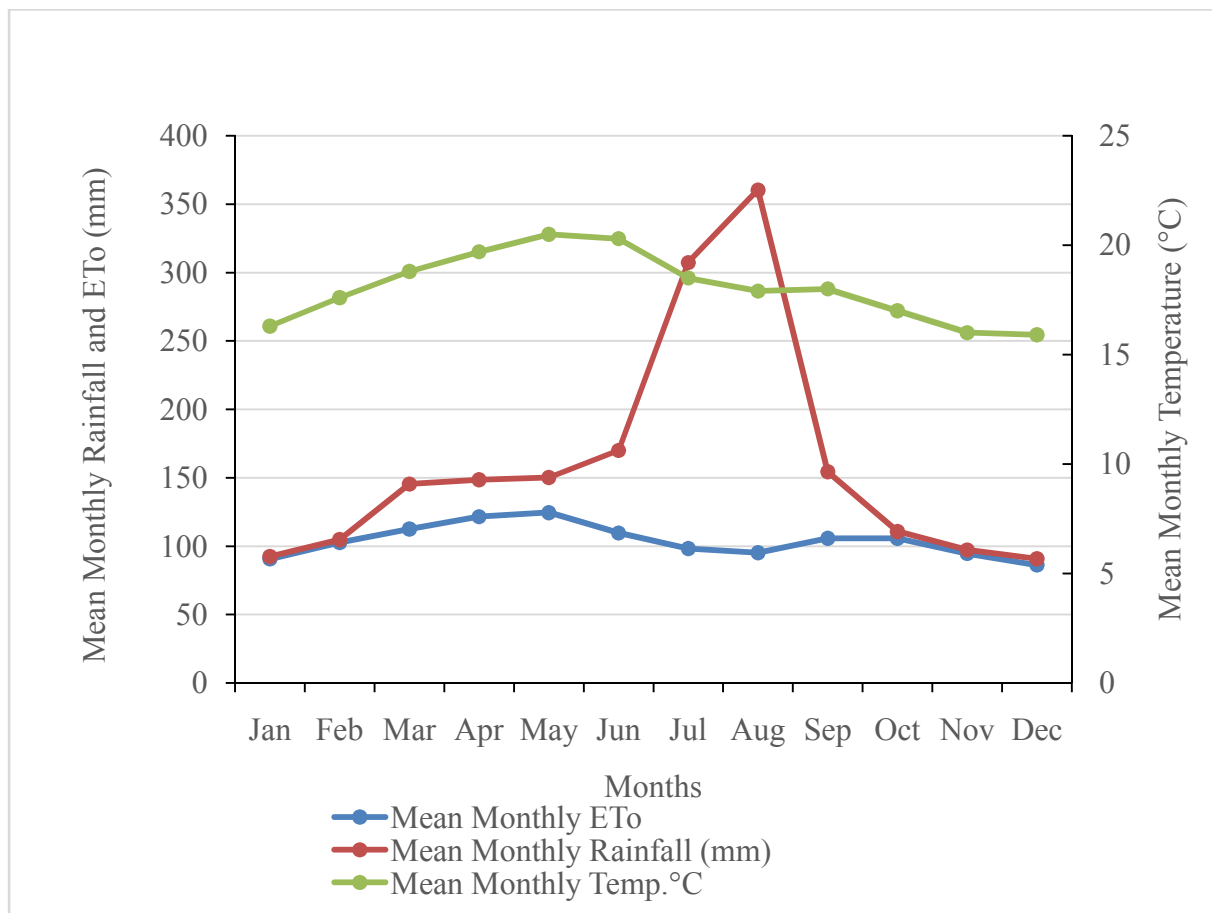


Figure 2: Graphical representations of the reference evapotranspiration (Eto), mean monthly rainfall, and temperature of the catchment.

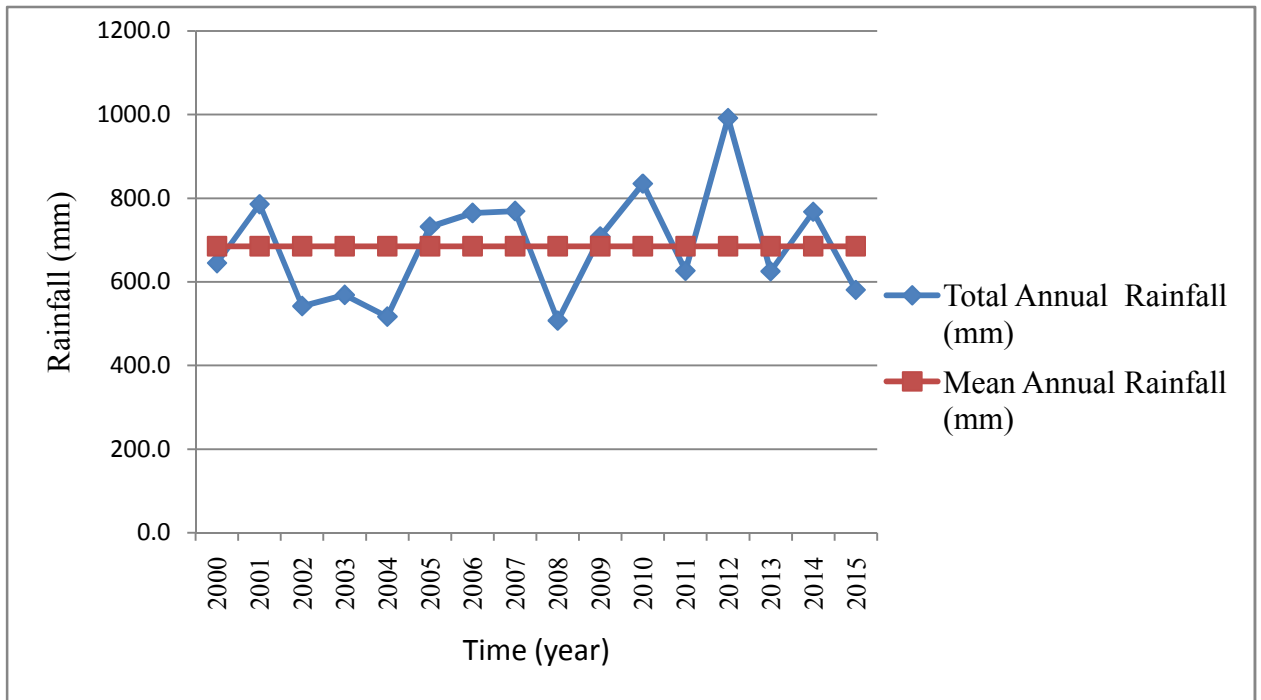
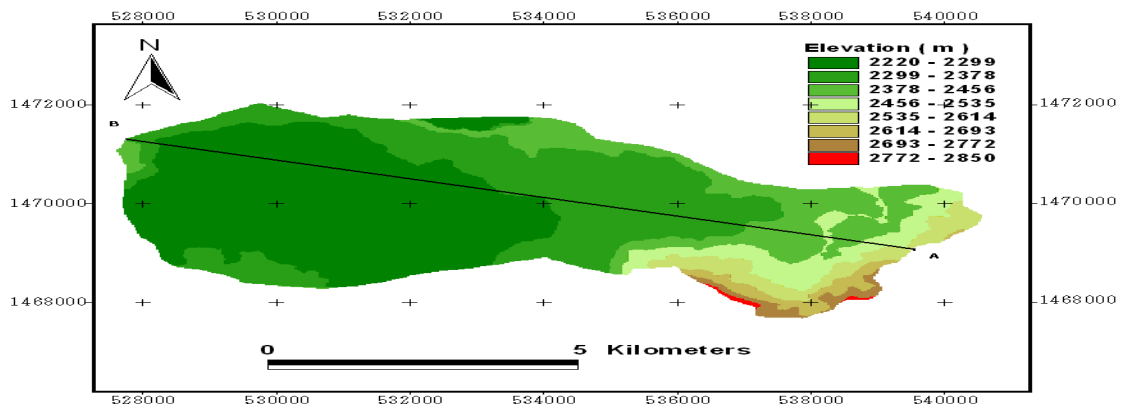


Figure 3: Graphical representations of the annual long period mean and total rainfall of the catchment.

3.1.3 Topography

The watershed delineation in this study has been done by using the Digital Elevation Model (DEM) of the North and North West part of Ethiopia, which is obtained from the Shuttle Radar Topography Mission (SRTM). The map of topography shown in Figure 4.



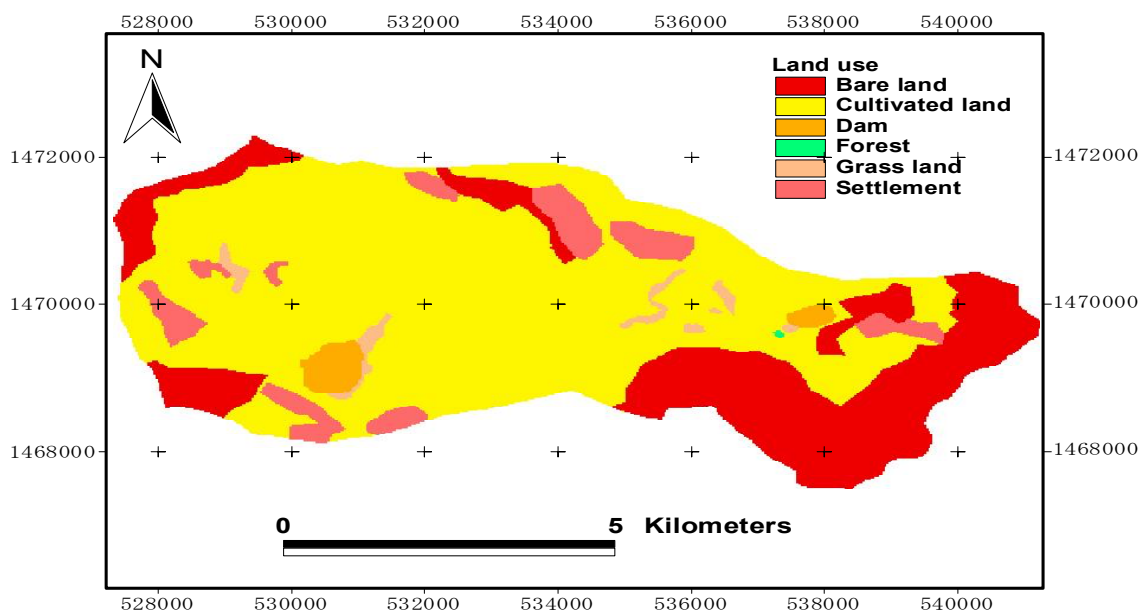
(Source, Redae Mehari, 2012)

Figure 4: Digital Elevation Model map of the catchment.

The study area is characterized by undulating surface having flat lands on the central catchment and continuous mountains on the west, south west, eastern and northern part. Most of the flat lands are alluvial deposited that are used for agricultural activities. The elevation ranging of the study area is 2220 to 2850 m. The peak elevation found in the eastern part of the study area. The topographical feature of most of the catchment area is uniform with flat topography of 0-5%.

3.1.4 Land use

In the study area there are six type of land use. These are forest land (0.37%), grazing land (2.03%), residential land (7%), cultivated land (63.7%), bare lands (25.1%) and water body (dam) (1.08%). The cultivated land is the largest portion of the total area and it is mainly agricultural crop production (teff, sorgum onion, maize and wheat etc). The scheme has a total design irrigable command area of 200 ha and it varies from year to year based on the water collected during the rainy season (COSAERT, 1998). The land use distribution of the study area is showing in figure 5.

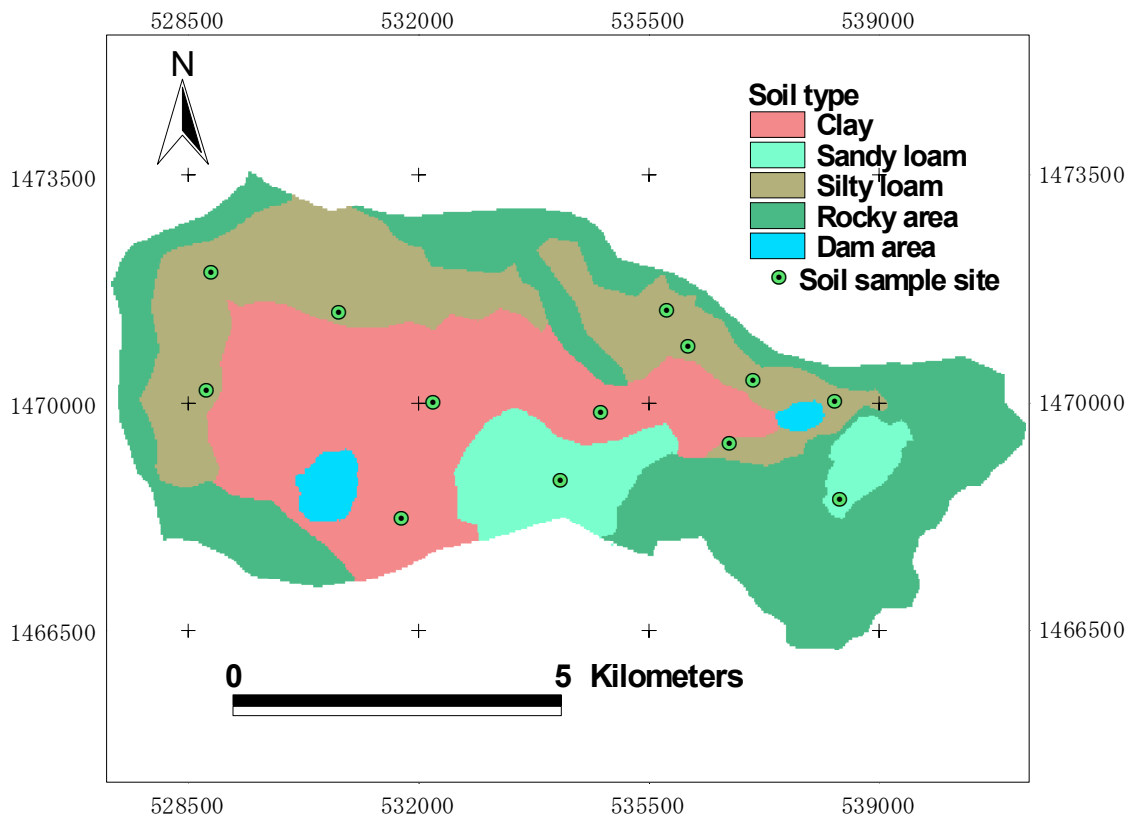


(Source, Redae Mehari, 2012)

Figure 5: Land use map of the study area

3.1.5 Soil

The map of major soil types in the study area was prepared from soil sample analysis in Tigray Agricultural Research center, Mekelle agricultural research center soil laboratory. Based on the soil sample analysis and taking into account the geological formations in the area, soils in catchment are grouped in to three types as clay, sandy loam, and silty loam. During the classification the United State Department of Agriculture (USDA) texture classification method applied.



(Source, Redae Mehari, 2012)

Figure 6: Soil map of the catchment.

3.1.6. Cropping pattern

The cropping pattern of the scheme was analyzed from household survey. Moreover, some discussions were also made with woreda experts and local development agents to cross check the data obtained. Description of crop characteristics; i.e., planting date and length of growing

period (LGP) were also collected from household survey results. The crop types that grown in the study area before years shown below in Table 1. During the study time only onion and maize were cropped with 20 and 40 ha of cropping area respectively.

Table 1: Cropping pattern of the scheme

S.no	Crop type	Area in (ha)	S.no	Crop type	Area in (ha)
1	Maize(AS11)	22	10	Chickpea	3.5
2	Maize (local)	51.3	11	Wheat	1.8
3	Onion(exotic)	30.9	12	Garlic	6.1
4	Onion(local)	14.5	13	Lettuce	0.1
5	Tomato	4.9	14	Spices(black)	0.01
6	Potato	0.8	15	“Dimbilal”	0.01
7	Cabbage	0.4	16	Lentil	2.9
8	Abish	1.6	17	“Gaya”	1.68
9	Spices(white)	0.2	-	-	-
Total					142.69

(Source, Mintesinot Behailu, et al, 2005)

3.2. Methods

The performance of the scheme was computed by using internal and external indicators. The internal performance indicators were conveyance efficiency, application efficiency, storage efficiency, deep percolation ratio, runoff ratio, distribution uniformity and overall scheme efficiency.

For computation of absolute performance efficiency, irrigation field with onion crop were selected. For this purpose, a total of nine farmers fields were selected from the irrigation scheme, i.e. three from the head (H₁, H₂ and H₃); three from the middle (M₁, M₂ and M₃) and three from the tail (T₁, T₂ and T₃) end water users of the irrigation scheme. The external indicators included in this study were agriculture, water use, physical and economic performance. The soil samples taken in the scheme was shown in Figure 7.

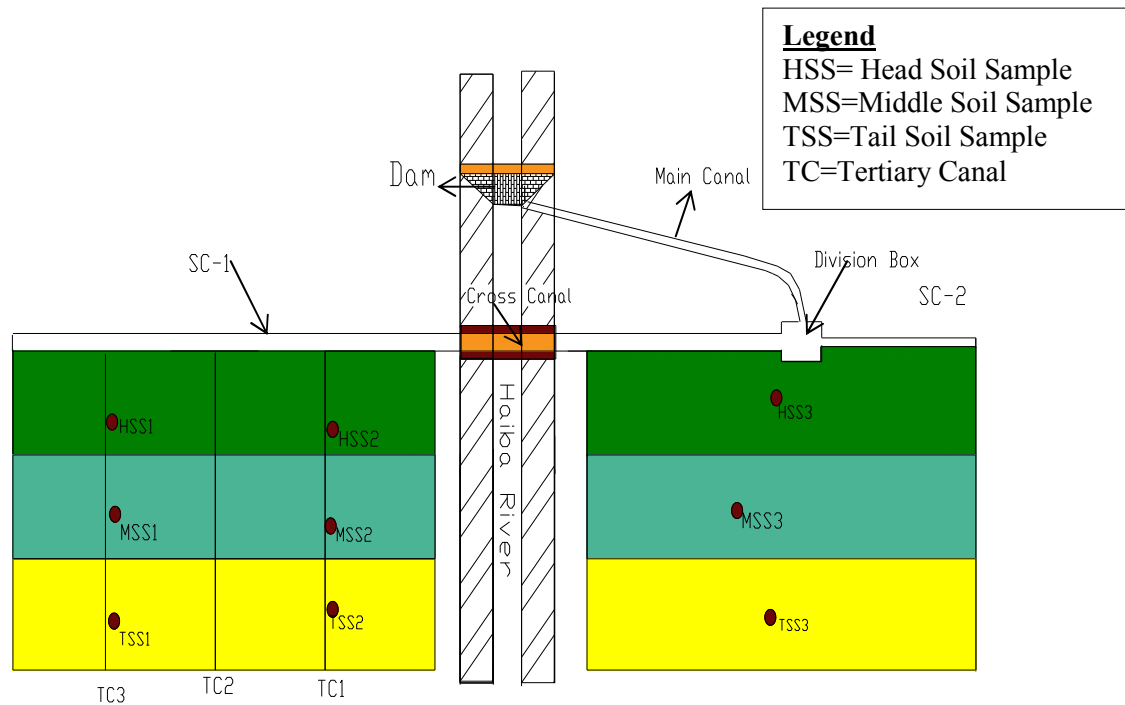


Figure 7: Layout of the irrigation scheme with their main, secondary, and tertiary canal

3.2.1. Data collection

All available data collection has been carried out in collaboration with the Bureau of water resource and Woreda Office of Agriculture. Data collected included primary and secondary data.

3.2.1.1. Primary data

Frequent field observations were made to observe and investigate the method of water applications, and practices related to water management techniques made by the farmers. Measurements of water discharge at diversion point of the irrigation scheme were taken and also at the secondary, tertiary and field canals. To compute soil texture of each farmer's field, nine soil samples from three locations from the scheme at three different depths were collected. Undisturbed soil samples were collected using core sampler from different depths and the bulk densities at different depths were determined.

Soil samples were also gathered to find the soil moisture content before and a day after irrigation by collecting 54 soil samples from the scheme with an interval of 20 cm to a depth

of 60 cm. It is presumed that the effective root zone of the irrigated vegetable crop is not more than this depth. The maximum effective root zone of onion is 60 cm (Allen *et al.*, 1998).

The moisture content of the collected soil samples was determined using gravimetric method.

The gravimetric moisture content on volume base was calculated using the equation (1) (FAO, 1989) as:

$$W\theta = \frac{W_w - W_d}{W_d} * 100 * Bd \dots\dots\dots (1)$$

where $W\theta$ is gravimetric soil moisture content (% volume bases), W_w is wet weight of the soil (g) W_d is dry weight of the soil (g) and Bd bulk density of soil ($g\ cm^{-3}$).

To find the amount of water applied by the farmers to their fields, the average head of water passed through the field canal and width of field canal were recorded. The floating method was used to determine the velocity of water in field canal. Total amount of water applied to the field is equal to:

$$Wf = h * w * v * t \dots\dots\dots (2)$$

Where Wf is total amount of water applied to field (m^3), h is height (head) of water in canal (m), w is width of canal (m), v is velocity of water ($m\ minute^{-1}$) and t is duration of time (minute) farmers irrigate a particular field.

3.2.1.2. Secondary data

For the selected irrigation scheme, secondary data were collected from the woreda Seharti Samre Agricultural and Rural Development Office and Water Resource Offices and irrigation offices at regional levels. The secondary data included total yields, farm gate prices of irrigated crops, area irrigated per crop per season, production cost per season, income generated by the irrigation associations and cropping pattern. Climatic data of the irrigation scheme was collected from the nearby metrological station.

Mekelle meteorological agency was the source of the climatic data for the irrigation scheme.

3.2.2. Laboratory Analysis

Soil analysis:

Soil samples were collected for analysis of selected soil physical properties. The properties analyzed were particle size distribution, bulk density and soil moisture contents at field

capacity and permanent wilting point. Particle size distribution was analyzed using the Bouyoucos hydrometer method. Bulk density was determined using the core method and water contents at field capacity and permanent wilting point were determined using the pressure plate apparatus method.

The soil sample were taken before and a day after irrigation. Samples for soil moisture determination were taken by the tube auger driven to depth of 60 cm, at 20 cm intervals. Samples taken were analyzed in the laboratory using gravimetric method to determine soil moisture content for water stored in the soil during each irrigation event. The soil sample placed in container to know weights and weighed to find total weights. The sample was then placed in an oven that was heated to 105 °C for 24 hrs. The sample and the container heating then weighted. The difference between before heating and after heating gave the moisture content of the soil sample.

3.2.3. Crop water requirement and irrigation scheduling

To estimate the crop water requirements (CWR), irrigation scheduling and irrigation water requirement (IWR) of the irrigated crops at field levels, and the irrigation scheme as a whole, the CROPWAT8 was used (FAO,1992). The effective rainfall is also calculated using this model.

3.2.4. Internal process

The internal performances for the scheme were computed based on field measured data. Accordingly, the conveyance efficiency of the scheme was computed by taking discharge measurement at different points. The measurements were taken at a point of diverting and at the secondary, tertiary and field canals. It was computed as the follows (Ramulu, 1998).

$$Ec = \frac{Wf}{Ws} * 100 \dots\dots\dots (3a)$$

The conveyance efficiency of the scheme was computed as:

$$Ec = Em * Es * Et * Ef \dots\dots\dots (3b)$$

Where Ec is conveyance efficiency (%), Em is conveyance efficiency of main canal (%), Es is conveyance efficiency of secondary canal (%), Et is conveyance efficiency of tertiary canal (%), Ef is conveyance efficiency of field canal (%), Ws is depth of water diverted from the source (m³) and Wf is depth of water applied to the field (m³).

The application efficiency was computed as the ratio of moisture added to the soil profile due to irrigation to the total water supplied to the farm or the ratio of moisture retained due to irrigation with total water added to the field. In this particular research soil samples were collected from different fields at different depths (0-20, 20-40 and 40-60 cm) and the amount of water stored in the root zone was determined by gravimetric method. Application efficiency was computed as follows (Ramulu, 1998):

$$Ea = \frac{Z_r}{D} * 100 \dots\dots\dots (4)$$

Where Ea is application efficiency (%), Z_r is average depth of water applied to the root zone as storage (mm), and D is average depth of water applied to the field (mm)

The runoff ratio is normally considered for this particular study as zero as the farmers are using furrows whose tail ends are closed. However, the deep percolation ratio was computed as the ratio of the percolated water beyond the root zone to the volume of water applied to the field. It was computed using the following formula (Feyen and Dawit, 1999):

$$DPR = 100 - Ea - RR \dots\dots\dots (5)$$

Where DPR is deep percolation ratio (%), Ea is application efficiency and RR is runoff ratio. The storage efficiency is an index used to measure irrigation adequacy. It is the ratio of the quantity of water stored in the root zone during irrigation event to that intended to be stored in the root zone. Based on the moisture content at field capacity, permanent wilting point and bulk density of the soils of the selected irrigation fields and the root depth of the crop irrigated, the depth of irrigation water required by the onion crop was calculated at the 25% moisture depletion level i.e. MAD of 0.25 (Allen *et al.*, 1998). After determining the storage and the required depths, the storage efficiency was calculated using the following formula (Ramulu, 1998):

$$Er = \frac{D_{sr}}{W_n} * 100 \dots\dots\dots (6)$$

Where E_r is storage efficiency (%), D_{sr} is water stored in the root zone (mm), and W_n is water desired to be stored in the root zone (mm). Distribution uniformity was determined by recording advance time and recession time at three equal points of the selected furrows. The

depth of water infiltrated during the opportunity time was derived from measurement of the infiltration rate of the soil, which was determined using float method. The irrigation distribution uniformity was computed following suggestion made by Ramulu, (1998):

$$Ed = \left(1 - \frac{\bar{y}}{d} * 100\right) \dots \dots \dots (7)$$

$$\bar{y} = \sum_{i=1}^n \frac{(y-d)}{n} \dots \dots \dots (8)$$

Where Ed is distribution uniformity (%), d is average depth of water infiltrated (mm) \bar{Y} is average absolute deviation depth of infiltrated water from the mean d (mm) and y is depth of water infiltrated at a given point (mm). Finally the overall scheme efficiency was calculated as the product of conveyance and application efficiency. It was computed using following formula (Ramulu, 1998):

$$Ep = Ec * Ea \dots \dots \dots (9)$$

Where Ep is overall scheme efficiency (%), Ec is conveyance efficiency (%) and Ea application efficiency (%).

3.2.5. External performance

The external performance of the scheme was evaluated using some selected indicators, which are normally classified into four groups, namely agricultural, water use, physical and economical performance as local price. To compute the total production of the scheme in all the crop types grown in the respective site, average yield per ha as well as an average price for each crop per kg was collected for the scheme.

The design feasibility study documents of the irrigation projects were collected from the Tigray regional state Bureau of water resource and agricultural and rural development for Addis-Alem irrigation project and were used as a source of information on the investment costs of the irrigation project. The results obtained on all the indicators were then used to compute the scheme. They were used for the evaluation of the project performance in terms of the production founded in the scheme. The selected indicators used to evaluate irrigated agriculture performance were:

Output per cropped area (US\$ ha⁻¹) which was calculated as the ratio of production in US\$ per irrigated cropped area (ha), Output per command area (US\$ h⁻¹) as the ratio of production in US\$ per Command area (ha), Output per irrigation supply (US\$ m⁻³) as the ratio of production in US\$ per diverted irrigation supply (m³) and Output per water consumed (US\$ m⁻³) as the ratio of production in US\$ per volume of water consumed (m³).

$$Total\ product\ value = Total\ product * Local\ price \dots\dots\dots (10)$$

Volume of water consumed by E_t is the actual evapotranspiration of crops, E_t which is calculated by:

$$E_{t_c} = K_c * E_{T_o} \dots\dots\dots (11)$$

Where E_{T_o} reference evapotranspiration (mm) K_c the crop coefficient (dimensionless) (Molden *et al.* 1998).

Similarly two types of indicators namely relative water supply and relative irrigation supply were used for evaluation of water use performance. Both relative water supply and relative irrigation supply were calculated by using approach suggested by (Perry, 1996):

$$RWS = \frac{TWS}{Crop\ water\ supply} * 100 \dots\dots\dots (12)$$

$$RIS = \frac{Irrigation\ supply}{Irrigation\ demand} * 100 \dots\dots\dots (13)$$

Where RWS (%) is relative water supply, TWS (m³) is total water supply or diverted water for irrigation plus rainfall, Crop water demand (m³) is the potential crop evapotranspiration (E_{T_p}), or the real evapotranspiration (E_{t_c}) when full crop water requirement is satisfied, RIS (%) is relative irrigation supply, irrigation supply (m³) is surface diversions and net groundwater drafts for irrigation, and irrigation demand (m³) is the crop ET minus effective rainfall. Physical indicators are related with the changing or losing of irrigated land in the command area by different reasons. The selected indicator used for evaluation of physical performance was irrigation ratio which can be expressed as the follows (Molden *et al.*, 1998).

$$Irrigation\ ratio = \frac{Irrigated\ crop\ area}{Command\ area} \dots\dots\dots (14)$$

Where Irrigated crop area (ha) is the portion of the actually irrigated land (ha) in any given irrigation `season, Command area (ha) is the potential scheme command area. Finally the economic indicators deal with how much investment cost is spent on the project in comparison with total production and yearly maintenance and operation expenditure and whether system is self-sufficient or not. The economic performance indicators used in the evaluation for this particular study were gross returns on investment and financial self sufficiency. The gross return on investment was calculated as the ratio of production to the cost of infrastructure at the irrigation scheme and the financial self sufficiency was calculated as the ratio of revenue from irrigation to the total operational and maintenance expenditure (Vermillion, 2000).

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Soil Analysis

The results of the soil analysis indicate that the soil of project area dominantly clay. The analysis of the soil result is presented in Table 2. The water holding capacities of the field soil are between 100.3-203.1 mm m⁻¹. The bulk density values ranged 1.179 to 1.775 gm cm⁻³ in the irrigation scheme. The bulk density values of the soils at the irrigation scheme were high indicating that there was compaction that could limit infiltration of water into and through the soil and root penetration. The moisture content of the soils was presented in Appendix table 7. Volumetric moisture content retained at field capacity varied from 30.56-41.08% at the irrigation scheme, while the volumetric moisture content at permanent wilting point varied from 10.25-30.05 % soil of the scheme. Consequently the total available water holding capacity of soils selected fields from the scheme ranged from 100.3-203.1 mm m⁻¹. In general soil of the scheme is high available water holding capacity.

The basic infiltration rate of soil at the irrigation scheme was found to be 17.60 mm hr⁻¹. The details of selected soil physical properties of the irrigation scheme is shown in Table 2, infiltration rate is presented in Appendix Table 2.

Table 2: Selected soil physical characteristics of Addis-Alem irrigation scheme

Field code	Soil depth (cm)	Particle size distribution (%)			Textural class	FC (%)	PWP (%)	TAW (mm m ⁻¹)
		Sand	silt	clay				
H	0-20	34	17	49	clay	30.56	10.25	203.1
	20-40	27	19	54	clay	31.05	10.95	201
	40-60	26	24	52	clay	31	10.85	201.5
M	0-20	25	21	54	clay	40.25	30.05	102
	20-40	25	23	52	clay	40	29.97	100.3
	40-60	35	15	50	clay	41.08	29.05	120.5
T	0-20	29	25	46	clay	40.10	28.65	114.5
	20-40	33	19	48	clay	41.05	29	120.5
	40-60	31	17	52	clay	40.95	29.05	119

H is field selected from head water users, M is field selected from middle water users and, T is field selected from tail water users, FC is moisture content of soil at field capacity, PWP is moisture content of soil at permanent wilting point, and TAW is total available water.

4.2. Irrigation Water Requirements of Major Crops in the Study Area

During the study time the major crops grown in the study area are onion and maize. Their seasonal and irrigation water requirements were indicated in Appendix Table 3, and 4. The results indicated that for each of the two crops, the seasonal crop and irrigation water requirements were equal since there was no rainfall during the study period. Accordingly, the seasonal crop and irrigation water requirement of onion, which was planted at the beginning of February and harvested during the first decade of May, was estimated as 283.2 mm (Appendix Table 3). The seasonal crop and irrigation water requirement of maize, which was planted at the beginning of January and harvested during the second decade of May was estimated to be 398.2 mm (Appendix Table 4). The estimated crop and irrigation water requirements indicated that maize crop, which has not equal length of cropping period with onion.

Furthermore, the two crops had the highest crop and irrigation water requirement during their mid-season stage, followed by the developmental stage. This being so, the water requirement of onion during the initial, developmental, mid-season and late-season stages accounted for 10.7, 36.2, 28.2, and 24.9% , respectively, of the seasonal water requirement of the crop. For maize, the initial, development, mid-season and late-season stages' water requirements accounted for 3.3, 21.2, 43.2, and 32.2% of the seasonal water requirement of the crop. These figures indicate that crops harvested for their fresh products require high amount of water even during their mid-season stage. The crop water requirement of onion and maize were presented in Figure 8.

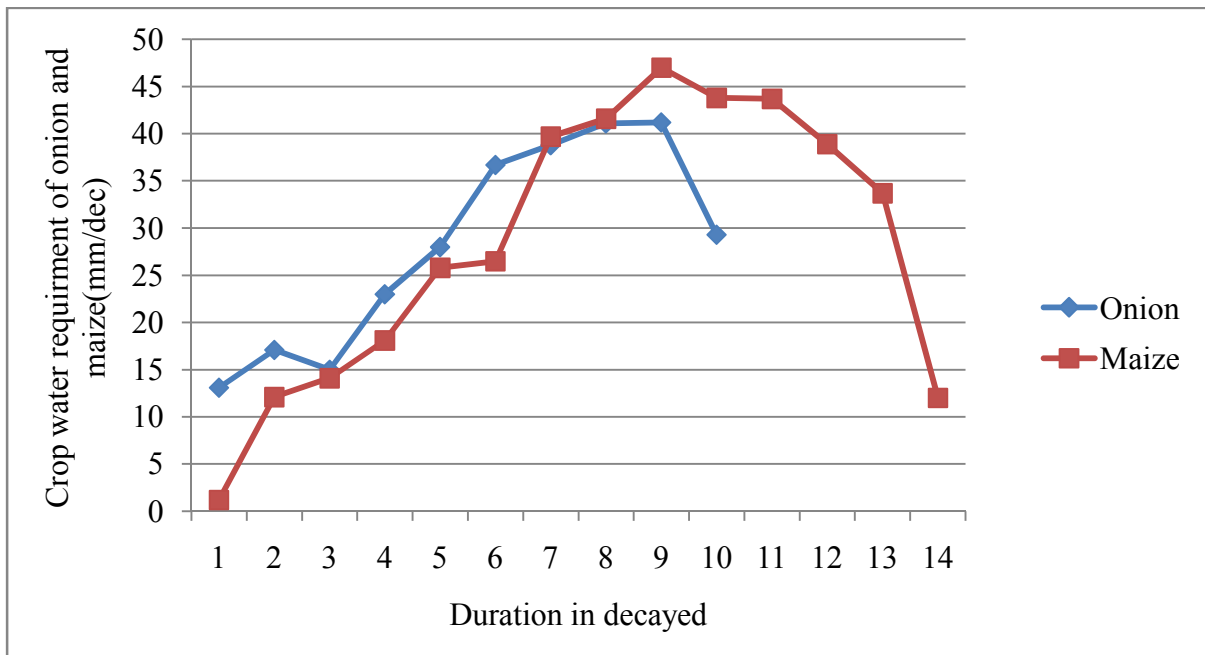


Figure 8: Crop water requirement of onion and maize

4.3. Internal Process Indicators

4.3.1. Conveyance efficiency

The efficiency of the scheme was determined by conducting field measurements. To measure the conveyance efficiency of the scheme the discharge is measured at different points. The average conveyance efficiency values which indicate the amount of water lost during transportation of water from the source to the field canal of the irrigation scheme. The detail of conveyance efficiencies for selected field in the irrigation scheme is shown in Appendix Table 6 and the average conveyance efficiencies in the scheme estimated 51.297 %.

In this irrigation scheme only about 250 m length of the main canal is lined, the remaining canal length is unlined. The division boxes not works properly and the main canal size is not enough to convey the water and over topping of water on main canal was common. However, the value of conveyance efficiency for the scheme is below the recommended value i.e.70% unlined poorly managed main canals (MoAFS, 2002). This efficiency happened due to improper construction of the channel and the farmers not aware on water uses interventions in different system levels. The conveyance efficiency of the scheme was presented in Figure 9.

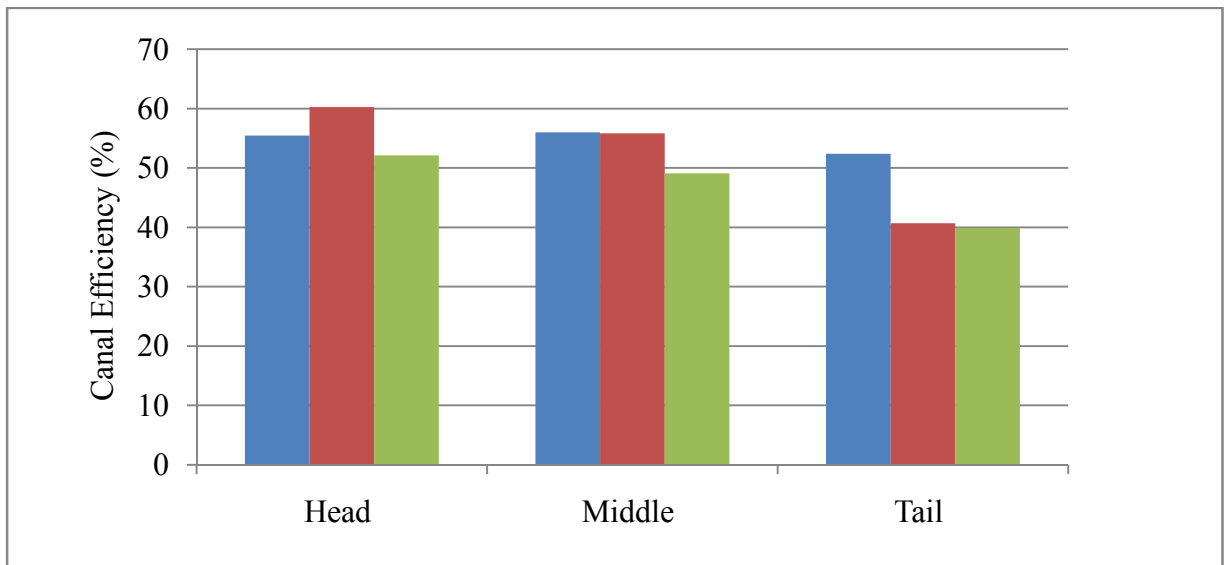


Figure 9: Conveyance Efficiency at the Head, Middle, and Tail of the canal

4.3.2. Application efficiency

The application efficiency of selected fields at the scheme was found to vary from 47.88 to 91.84% with an average of 68.07%. The detail of application efficiencies for the selected field in the scheme was shown in Appendix Tables 5.

Totally the application efficiency of the scheme was typical results for furrow irrigation (Savva and Frenken, 2002), which is recommended as 50-70% for properly designed furrow irrigation. Kandiah (1981) also reported an application efficiency of 70% for furrow irrigation. The application efficiency of the scheme was presented in Figure 10.

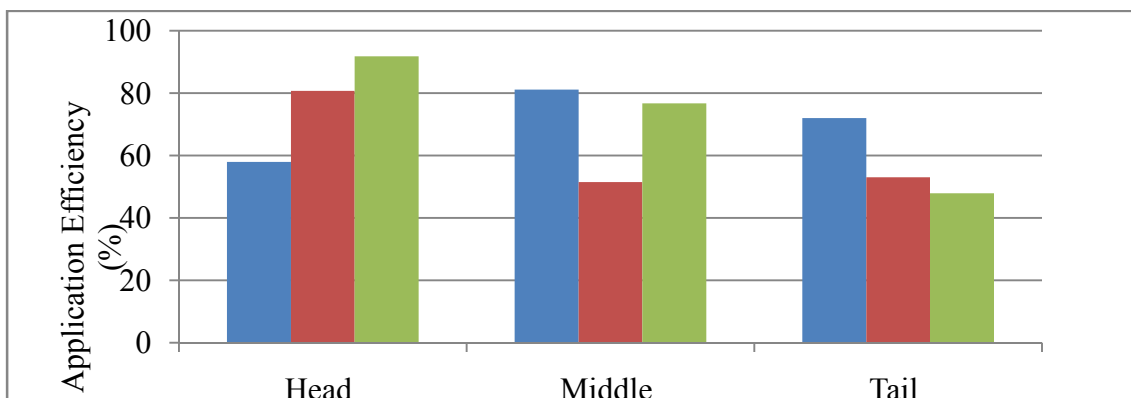


Figure 10: Application Efficiency of Head, Middle, and tail water users at nine selected farm's field

4.3.3. Deep percolation ratio

Deep percolation ratio shows the irrigation applied to a field percolates into the soil below the root zone. Higher deep percolation ratio values are indications of over irrigation. The average deep percolation ratio in the scheme was found to be 31.93%. In the scheme, there is high deep percolation ratio which indicates over irrigation.

4.3.4. Storage efficiency

The value of storage efficiency of selected fields from scheme was found to vary from 18.9 to 83.38% with an average storage efficiency of 47.69%. The details of storage efficiency for selected fields and the average storage efficiency in the scheme is shown in Appendix Tables 5 and the details of all samples collected from each farm at different depth was presented in Appendix Tables 7. In general the storage efficiency of the scheme was very poor as compared to 63% storage efficiency usually found in typical furrow irrigation systems (Raghuwanshi and Walender, 1998). This normally shows over irrigation of the field and this might be associated with the intention of the farmers on high return from high irrigation depth. The graph of the storage efficiency was shown in Figure 11.

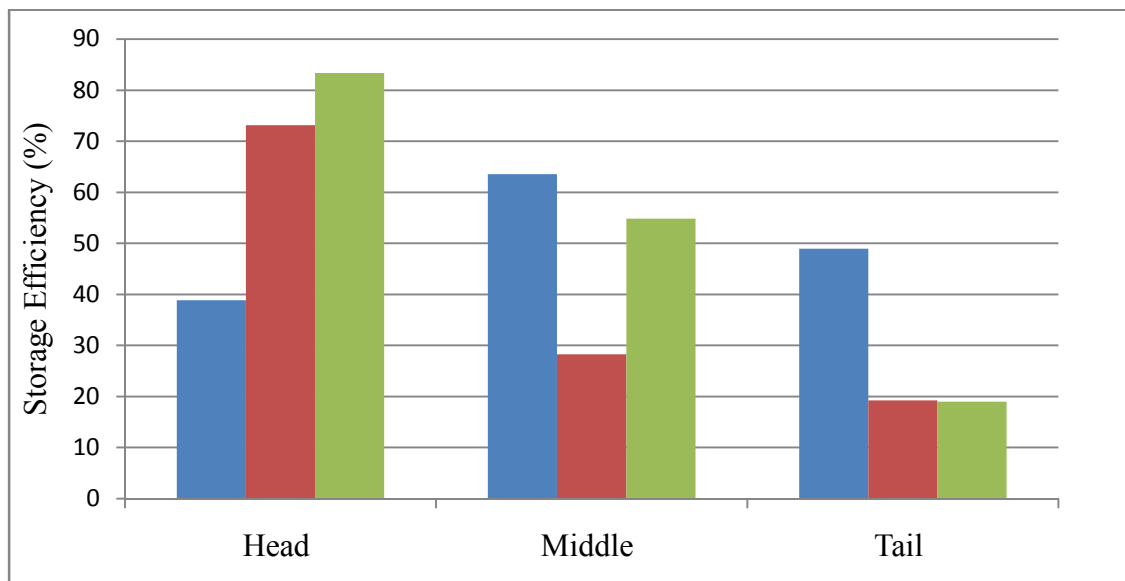


Figure 11: Storage Efficiency of Head, Middle, and Tail water users in the scheme at nine farm's fields

4.3.5. Irrigation uniformity

When irrigation water is applied uniformly in a field it helps to get uniform crop stand and uniform crop growth in the field. In this particular study the irrigation uniformity varies from

98.82 to 99.03% with an average value of 98.91%. The details of irrigation uniformity are presented in Appendix Tables 8.

The irrigation uniformity of the scheme was very good, which may be due to the short furrow length commonly 20 meter, closed furrow ends and large stream flow used. The irrigation uniformity figures observed in the scheme of present study is much higher than the advanced furrow irrigation systems, which is 70% as reported by Raghuwanshi and Walender (1998) and the modern Amibara Project irrigation as reported by Kandiah (1981) whose irrigation uniformity is found to be 93%.

4.3.6. Overall Scheme Efficiency

The overall efficiency of the scheme is the ratio of water made available to the crop to the amount released at the headwork. In other words, it is the product of conveyance efficiency and application efficiency. In the present study the overall efficiencies of the irrigation schemes at Addis-Alem was found to be 34.92%. The details of overall scheme efficiency of the scheme were derived from the data shown in Appendix Tables 5 and 6.

The overall efficiency of the scheme was very poor. Its value is below the range of values (40-50%) commonly observed in other similar African irrigation schemes (Savva and Frenken, 2002). The average irrigation efficiency of the scheme was presented below in Figure 12.

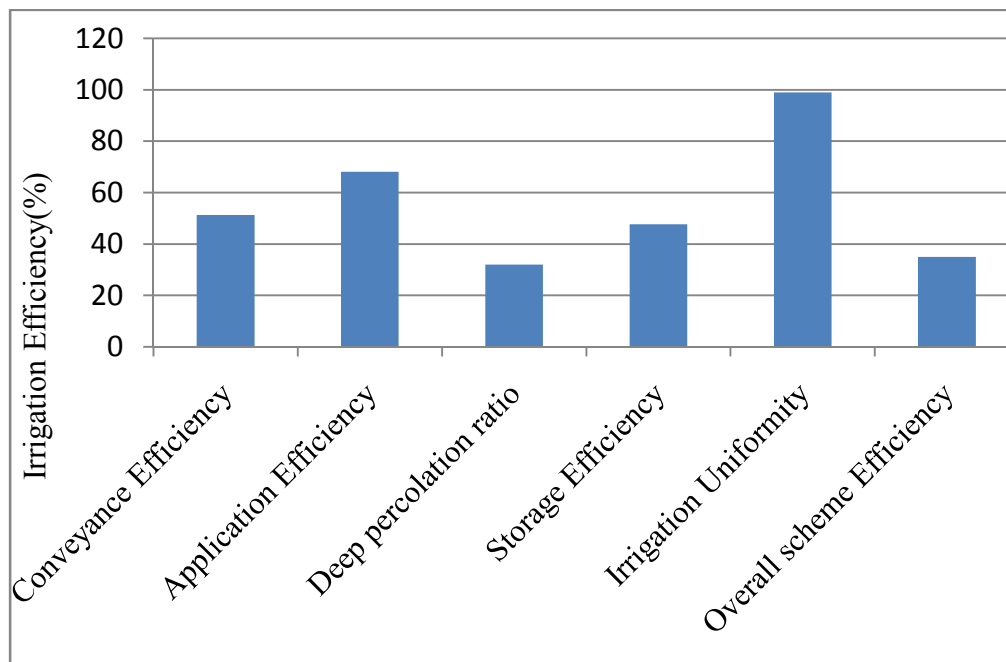


Figure 12: The overall average irrigation efficiencies

4.4. External Performances

4.4.1 Irrigated agriculture performance

This includes performance indicators, which are associated with the production. The major of such performance indicators included are output per unit cropped area, output per unit of command area, output per unit irrigation supply and output per unit water consumed.

Output per unit cropped area

The output per unit cropped area shows the response of the cropped area on generating gross return. This parameter gives a clue about the management practice in every scheme. According to the data collected from the irrigation scheme the output per unit cropped area was 4545.455US\$ ha⁻¹. This value is good as compared with the result of Zeleke et al (2012) in Golgota and Wedecha (subsystems Godino and Gohaworki) irrigation schemes. The detail of the output per unit cropped area is shown in Appendix Table 9.

Output per unit of command area

This indicator expresses the average return per design command area. It is an indication of whether all the command area is generating returns or not. The outputs per unit command area of the scheme was 1,363.636 US\$ ha⁻¹. The details of output per unit command area in the irrigation scheme is shown in Appendix Table 9 and the average output per unit command area was presented in Table 4.

The irrigated area of Addis-Alem was 60 ha. When this area is compared to the designed command area, in Addis-Alem irrigation scheme, 30% of the command area is under irrigation.

Output per unit irrigation supply

The outputs per unit irrigation supply show the revenue from agricultural output for each meter cube of irrigation water supplied. The total amount of water diverted to the project during the crop growth period was estimated based on the output per second of the diverted, the number of diverted and used, duration of operating hours each day, and total days taken by crops to mature. Addis-Alem irrigation project has a capacity of 0.1504 m³ per second was discharged and is operated for 8 hours each day. Therefore, it diverted 411,494.4 m³ during 95

and 140 days growth period of onion and maize respectively. Thus, the output per m^3 of water supply was found to be $0.663 \text{ US\$ m}^{-3}$.

Output per unit water consumed

The output per unit water consumed is used to describe the return on water actually consumed by the crop. This indicator gives due attention to the water consumed by the scheme and tells us how water is efficiently utilized by the scheme from economic point of view. The outputs per water consumed in Addis-Alem irrigation scheme was $0.974 \text{ US\$ m}^{-3}$ (Table 3). The irrigated agricultural performances shown in Figure 13.

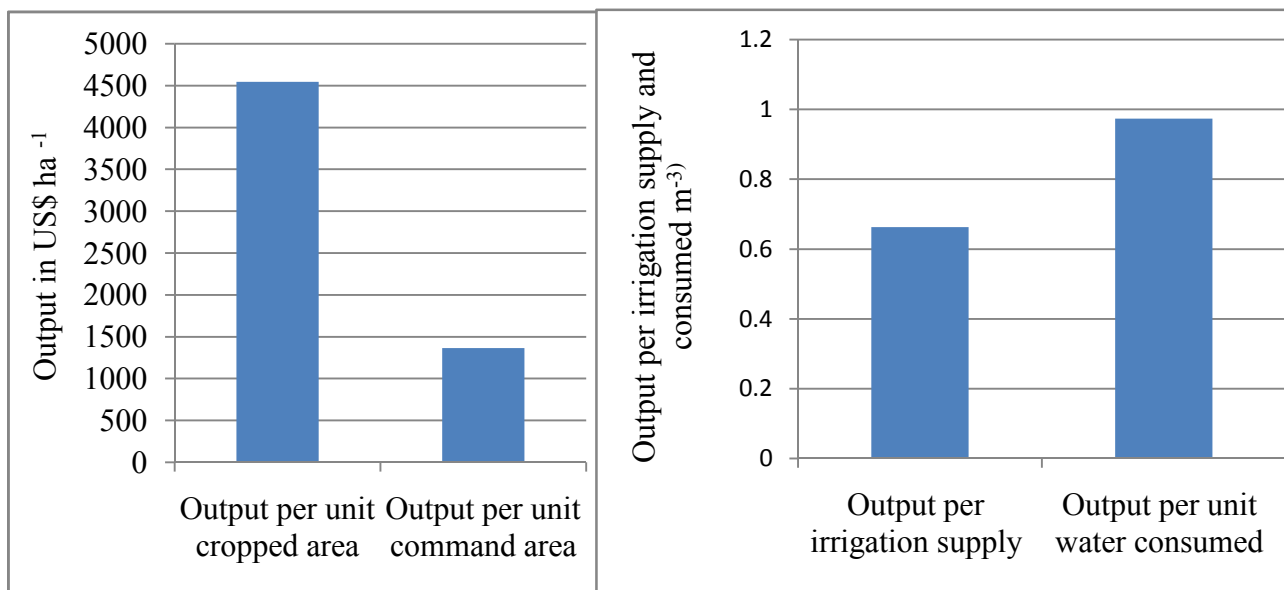


Figure 13: Irrigated agriculture performances

4.4.2. Water use performances

Relative water supply

The relative water supply depicts whether there is enough irrigation water supplied or not. Both the relative water supply and relative irrigation supply relate supply to demand, and give some indication as the condition of water abundance or scarcity, and how tightly supply and demand is matched. The relative water supply value below one normally indicates that the water applied is less than the crop demands and values above one indicate extra water is added

to the root zone beyond plant demands. The relative water supply of Addis-Alem irrigation scheme was found to be 7.362.

Relative irrigation supply

The relative irrigation supply shows whether the irrigation demand is satisfied or not. Since there was no rainfall in the area during study period the value of relative irrigation supply in Addis-Alem irrigation scheme is 7.362 (Table 3).

4.3.3. Physical performances

Physical performances are related with the changing or losing irrigated land in the command area by different reasons. The total design irrigable area of the scheme was 200 ha. During the study time only 60 ha irrigated. The irrigation ratio of the scheme was 0.30 which means about 70% of command area of the scheme was not under irrigation during the study period. The main reasons for this were farmers' capacity to afford inputs and weak institutional set up of water use association at the scheme. The detail of cropped land area during the study period of the scheme is shown in Appendix Table 9 and the irrigation ratio of the scheme is presented in Table 3.

4.3.4. Economic performances

Gross return on investment

This indicator considers the production and the total cost of infrastructure for the scheme. Table 3 shows that the gross return on investment of the irrigation scheme is 2.7014. The detail of the gross return on investment for the scheme is shown in Appendix Tables 10.

Financial self-sufficiency

Financial self-sufficiency indicates the ratio of revenue from the irrigation to the expenditure for operation and maintenance. It shows the compensation ratio of management and maintenance costs for irrigation system based on the income obtained from the irrigation. This in other words implies the sustainability of the scheme, and perception of the farmers towards the irrigation scheme. The financial self sufficiency of this particular research indicates 6.426 for Addis-Alem scheme. The detail of the financial self sufficiency data for the scheme is shown in Appendix Table 10.

Table 3: Different values for selected external performances at Addis-Alem irrigation Scheme
(Local prices is applied)

External indicators		Addis-Alem irrigation scheme
Agricultural performance	Output per unit cropped area (US\$ ha-1)	4545.455
	Output per unit command area(US\$ ha-1)	1363.636
	Output per irrigation supply (US\$ m-3)	0.663
	Output per unit water consumed (US\$ m-3)	0.974
Water use performance	Relative water supply (ratio)	7.362
	Relative irrigation supply (ratio)	7.362
Physical performance	Irrigation ratio (%)	0.30
Economic performance	Gross return on investment (US\$)	2.7014
	Financial self sufficiency (ratio)	6.426

CHAPTER FIVE

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY AND CONCLUSION

The main objective of this study was to evaluate the performance of the small scale irrigation scheme at Addis- Alem, Seharti Samre Woreda, Tigray Regional State, using internal and external performance indicators. This irrigation scheme has command area of 60 ha during the current study and serving about 240 beneficiaries..

To achieve the objective primary and secondary data were collected. Primary data collection includes discharge at diversion point, canal discharge, soil moisture and soil characteristics were determined. The soil type, bulk density, infiltration rate, gravimetric moisture contents at field capacity and permanent wilting point of the irrigation scheme were determined using different mechanisms or methods. The secondary data includes crop types, total yields, farm gate prices of irrigated crops, area irrigated per crop per season, incomes generated by the irrigation associations, investment costs and cost of production.

Both the internal and external performance indicators were evaluated using minimum sets of performance indicators which include agricultural, water use, physical and economic performance indicators. In order to evaluate the irrigation water use efficiency of farmers at field level, nine farmer fields were selected from the irrigation scheme in relation to their location (head, middle and tail end water users).

The internal process indicators used were include conveyance, application, storage and distribution efficiencies, runoff ratio, deep percolation ratio and overall irrigation efficiency were used to check the performance of the irrigation scheme.

The results of the analyses indicate that, the conveyance efficiency was found to be 51.297% and application efficiency was found to be 68.07%. The runoff ratio of the scheme was nil as the furrows are block end type. Deep percolation ratio of the scheme was found to be 31.93%. Storage efficiency was also estimated as 47.69%. Further, Irrigation uniformity of 98.91% was attended. From the analysis of external indicators, the outputs per cropped area was found to be 4545.455 US\$ ha⁻¹, but the value of the output per command area of scheme 1363.636 US\$ ha⁻¹. The output per unit irrigation supply of scheme is 0.663 US\$ m⁻³. Output per water

consumed was in the scheme is 0.974 US\$ m⁻³. The water use performance of the scheme was computed, water supply and relative irrigation supply were found as 7.362. The irrigation ratio of the scheme was found to be 0.30 which means about 70% of command area is not under irrigation during study period. In this scheme the conveyance, application, and storage efficiency were low. But the irrigation uniformity was very high and also there is over irrigation in the scheme.

5.2 RECOMMENDATION

In general, based on current assessment the performance of Addis-Alem irrigation scheme is low performance. But there is still a room for improving the performance of the scheme by:

- Resizing the main canal as well as the secondary and tertiary canals which were not carrying the required irrigation water.
- The hydraulic flow metering should be signed at the gate of the outlet of the dam to use the farmers simply how much water is diverted in to their farms.
- The conveyance loss is high in the irrigation scheme. Therefore it is highly recommended to be lined the whole canal.
- The users should be introduced rule and regulation about the irrigation scheme on how they operate and maintain.
- Aware the farmers' on how managed the irrigation water during transportation of water from the source to the farm field during irrigation time.

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APPENDIX I.TABLES

Appendix Table 1: Soil infiltration rate at Addis-Alem irrigation scheme using Double ring infiltrometer

Start time (minute)	End time (minute)	Start level (cm)	End level (cm)	Intake Difference (cm)	Cum. Intake (cm)
0	0	25	0	0	0
15	15	25	24.5	0.5	0.5
15	30	25	23.75	1.25	1.75
15	45	25	24.25	0.75	2.50
20	65	25	24	1.00	3.50
20	85	25	23.5	1.5	5.00
20	105	25	22.75	2.25	7.25
20	125	25	24.25	0.75	8.00
40	165	25	24.75	0.25	8.25
40	205	25	24	1.00	9.25
40	245	25	24.25	0.75	10.00
40	285	25	24.75	0.25	10.25
45	330	25	24.5	0.50	10.75
45	375	25	24.75	0.25	11

Appendix Table 2:-Average 15 years (2000-2015) climatic data at Addis-Alem and ETo CROPWAT8 output

Month	Min Tem.	Max Tem.	Humidity	Wind	Sunshine	Rad	ETo	Rainfall
	°C	°C	%	$\frac{Km}{day}$	hours	MJ/m ² /day	mm/day	mm
Jan	7.6	25.0	50	3.57	9.9	20.9	3.02	1.7
Feb	9.0	25.7	44	4.20	10.1	22.9	3.42	2.1
Mar	10.7	27.6	43	4.21	9.1	22.9	3.75	32.9
Apr	12.3	26.9	44	3.92	9.4	24.0	4.05	27.0
May	12.4	28.7	40	2.82	9.9	24.5	4.15	25.7
Jun	12.5	29.2	42	2.01	7.2	20.2	3.65	60.4
July	10.4	25.5	70	1.97	5.3	17.4	3.27	209.2
Aug	12.7	24.1	76	1.57	4.9	16.9	3.17	265.2
Sep	10.5	25.5	55	1.60	7.4	20.4	3.52	48.8
Oct	9.6	25.0	47	2.82	9.6	22.5	3.52	5.1
Nov	9.4	24.0	50	3.46	9.9	21.2	3.15	2.7
Dec	7.8	23.4	50	3.64	10.0	20.5	2.87	4.6
Average	10.4	25.9	51	3	8.6	21.2	3.46	685.4

ETo is reference evapotranspiration

Appendix Table 3: CROPWAT 8 output for onion water requirement

Month	Decade	Stage	Kc coeff	Etc mm/day	Etc mm/dec	Eff rain mm/dec	IR mm/dec
Feb	1	Initial	0.50	1.64	13.1	0.1	13.0
Feb	2	Initial	0.50	1.71	17.1	0.0	17.1
Feb	3	Deve.	0.53	1.87	15.0	2.1	12.9
Mar	1	Deve	0.63	2.30	23.0	8.2	14.8
Mar	2	Deve	0.75	2.80	28.0	12.0	16.0
Mar	3	Deve	0.87	3.33	36.7	10.9	25.8
Apr	1	Mid	0.98	3.88	38.8	9.1	29.7
Apr	2	Mid	1.02	4.11	41.1	8.5	32.6
Apr	3	Late	1.01	4.12	41.2	8.4	32.8
May	1	Late	0.89	3.66	29.3	5.9	21.9
Total					283.2	65.1	216.6

Kc is crop coefficient, Etc is crop evapotranspiration and IR is irrigation requirement

Appendix Table 4: CROPWAT 8 output for Maize water requirement

Month	Decade	Stage	Kc coeff	Etc mm/day	Etc mm/dec	Eff rain mm/dec	IR mm/dec
Jan	1	Initial	0.40	1.19	1.2	0.1	1.2
Jan	2	Initial	0.40	1.21	12.1	0.5	11.6
Jan	3	Deve.	0.41	1.28	14.1	0.5	13.5
Feb	1	Deve	0.55	1.81	18.1	0.1	18.0
Feb	2	Deve	0.75	2.58	25.8	0.0	25.8
Feb	3	Deve	0.94	3.31	26.5	2.1	24.4
Mar	1	Mid	1.09	3.97	39.7	8.2	31.4
Mar	2	Mid	1.11	4.16	41.6	12.0	29.6
Mar	3	Mid	1.11	4.27	47.0	10.9	36.1
Apr	1	Mid	1.11	4.38	43.8	9.1	34.7
Apr	2	Late	1.08	4.37	43.7	8.5	35.3
Apr	3	Late	0.95	3.89	38.9	8.4	30.5
May	1	Late	0.82	3.37	33.7	7.4	26.3
May	2	Late	0.72	3.00	12.0	2.7	8.6
Total					398.2	70.4	327.2

Kc is crop coefficient, ETC is crop evapotranspiration and IR is irrigation requirement

Appendix Table 5: Measured water depths applied to field, field application efficiency and storage efficiency of Addis-Alem irrigation scheme

Field code	Water depth (cm)	Canal width (cm)	Velocity (m/s)	Q (m ³ /s)	Elapsed time (min)	Area (m ²)	Total volume (m ³)	Depth applied (mm)	Water stored at Zr (mm)	Wn (mm)	Ea (%)	Er (%)
H1	15	20	0.5	0.015	220	3000	162	54	31.27	80.5	57.91	38.84
H2	13	20	0.85	0.0221	235	3000	218.79	72.93	58.87	80.5	80.72	73.13
H3	12	20	1.05	0.0252	225	3000	219.24	73.08	67.12	80.5	91.84	83.38
M1	10	20	0.6	0.012	130	1500	82.8	55.2	44.8	70.5	81.16	63.56
M2	11	20	0.4	0.0088	125	1500	58.08	38.72	19.95	70.5	51.52	28.29
M3	10	20	0.6	0.012	130	1500	75.6	50.4	38.67	70.5	76.73	54.85
T1	10	20	0.8	0.016	180	2500	129.6	51.84	37.34	76.3	72.03	48.95
T2	8	20	0.6	0.0096	188	2500	69.12	27.65	14.65	76.3	52.98	19.22
T3	9	20	0.5	0.009	110	2500	75.6	30.24	14.48	76.3	47.88	18.98
Mean											68.07	47.69

Appendix Table 6: Canal discharges at different point and conveyance efficiency of Addis-Alem irrigation scheme

Field code	Q(m ³ /s) main canal		Q(m ³ /s) 2 ^o canal		Q(m ³ /s) 3 ^o canal		Q(m ³ /s) field canal	Ec (%)
	Initial	Final	Initial	Final	Initial	Final		
H1	0.1504	0.1472	0.0556	0.0420	0.024	0.0180	0.015	55.449
H2	0.1504	0.1472	0.08	0.0650	0.033	0.0250	0.0221	60.243
H3	0.1504	0.1472	0.064	0.0450	0.035	0.0265	0.0252	52.104
M1	0.1504	0.133	0.033	0.0285	0.015	0.0110	0.012	56.006
M2	0.1504	0.133	0.038	0.0320	0.028	0.0210	0.0088	55.851
M3	0.1504	0.133	0.046	0.0325	0.021	0.0165	0.012	49.090
T1	0.1504	0.127	0.016	0.0125	0.017	0.0135	0.016	52.388
T2	0.1504	0.127	0.016	0.0125	0.030	0.0185	0.0096	40.681
T3	0.1504	0.127	0.016	0.0125	0.024	0.0145	0.009	39.857
Mean								51.297

Appendix Table 7: Soil moisture contents one day before and after irrigation of Addis-Alem irrigation scheme

Field code	Soil depth (cm)	Bd (g cm ⁻³)	Moisture before irrigation (%)	Moisture after irrigation (%)	Moisture stored (%)	Moisture stored (mm)
H1	0-20	1.573	10.95	36.32	25.37	50.74
	20-40	1.615	16.80	21.50	4.7	9.4
	40-60	1.488	21.59	25.62	4.03	8.06
H2	0-20	1.775	12.66	22.83	10.17	20.36
	20-40	1.434	16.32	25.85	9.53	19.06
	40-60	1.371	17.19	18.57	1.38	2.76
H3	0-20	1.532	26.28	32.11	5.83	11.66
	20-40	1.530	19.25	29.75	10.5	2.10
	40-60	1.243	26.37	28.43	2.06	4.12
M1	0-20	1.473	19.67	23.00	3.33	6.66
	20-40	1.443	19.56	24.31	4.75	9.5
	40-60	1.565	16.80	24.31	7.51	15.02
M2	0-20	1.499	20.19	29.39	9.2	18.4
	20-40	1.638	20.24	29.37	9.13	18.26
	40-60	1.648	20.11	28.94	8.83	19.66
M3	0-20	1.466	22.30	30.08	7.78	15.56
	20-40	1.461	23.30	28.95	5.65	11.30
	40-60	1.470	22.81	26.98	4.17	8.34
T1	0-20	1.586	10.21	23.23	13.02	26.04
	20-40	1.179	20.19	25.78	5.59	11.18
	40-60	1.590	16.74	19.87	3.13	6.26
T2	0-20	1.586	14.35	21.31	6.96	13.92
	20-40	1.353	23.83	27.67	3.84	7.68
	40-60	1.339	15.17	23.84	8.67	17.34
T3	0-20	1.508	8.42	21.94	13.52	27.04
	20-40	1.654	11.90	19.73	7.83	15.66
	40-60	1.508	17.31	19.60	2.29	4.58

H1, H2 and H3 are code of fields selected from head water users, M1, M2 and M3 are code of fields selected from middle water users, and T1, T2 and T3 are code of fields selected from tail end water users and Bd is bulk density.

Appendix Table 8: Advance time, recession time and irrigation uniformity of Addis-Alem irrigation scheme

Field code	Time taken for Advance(minute)			Time taken for Recession(minute)			Opportunity time (minute)			Depth infiltrated (mm)			Average depth infiltrate (mm)	Uniformity (%)
	10m	15m	20m	10 m	15m	20 m	10 m	15 m	20 m	10 m	15 m	20 m		
H1	0.34	0.75	1.05	30	31	31	30.15	31.15	30.12	40.05	41	40.75	40.6	98.99
H2	0.36	0.72	1.10	32	31	31	29.25	31.25	30.15	39.15	40.60	38.15	39.3	98.96
H3	0.31	0.71	1.05	33	32	32	32.6	33.3	32.35	42.05	42.75	42.33	42.38	99.03
M1	0.35	0.85	1.30	28	26	26	27.5	27.15	27.75	35.60	35.95	36.35	35.97	98.86
M2	0.37	0.87	1.24	30	29	30	28.15	29.25	28.72	38.12	38.74	38.95	38.60	98.94
M3	0.36	0.79	1.20	28	28	28	27.35	29.32	28.36	35.65	36.99	36.66	36.43	98.88
T1	0.38	0.84	1.15	27	26	27	25.55	25.75	26.15	34.15	35.15	35.02	34.77	98.82
T2	0.37	0.83	1.26	27	27	28	26.62	26.15	27.75	36.45	36.05	35.25	35.92	98.86
T3	0.39	0.81	1.25	26	27	28	27.62	28.05	28.75	35.55	35.75	34.95	35.42	98.44
Mean														98.91

Appendix Table 9: Crop production, productivity, production costs and prices of crop at Addis-Alem irrigation scheme (2017 production season, Local price)

Crop type	Total area (ha)	Productivity (Quintals ha ⁻¹)	Total products (Quintals)	Gross product value (US\$)	Production costs (US\$)	Revenue (US\$)	Price kg (US\$)
Onion	20	100	2000	109090.9091	30545.45455	78545.45455	0.5454
Maize	40	45	1800	50727.727	17298.9091	33428.36364	0.28182
Total	60	145	3800	159818.182	47844.3636	111973.8182	-

Appendix Table 10: Investment, operation and maintenance costs of Addis-alem irrigation project

Type of costs	Amount of money (US\$)
Initial investment cost	100959
Operation & maintenance cost in 2016/17	28181.82
Total	129140.8

APPENDIX II FIGURES



Appendix Figure 1: Haiba Dam



Appendix Figure 2: Measuring of discharge at the main canal using a float method.



Appendix Figure 3: Division box of the secondary canals.



Appendix Figure 4: Unlined secondary canal



Appendix Figure 5: Materials used for determination of field capacity and permanent wilting point



Appendix Figure 6: Measuring of Infiltration Rate using Double Ring Infiltrometer



Appendix Figure 7: Oven dry laboratory



Appendix Figure 8: Textural classification of soil in the laboratory