MEKELLE UNIVERSITY

INSTITUTE OF WATER AND ENVIRONMENT

EVALUATING FIELD IRRIGATION PERFORMANCE AND WATER PRODUCTIVITY AT MAI GOBO SMALL SCALE IRRIGATION SCHEME IN EASTERN TIGRAY, ETHIOPIA

By

MEZGEBU TESFAYE G/MARIAM

M.Sc. THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER OF SCIENCE DEGREE

IN

IRRIGATION ENGINEERING AND MANAGEMANT

Advisors: Solomon Habtu (PHD)

Tesfa_alem G/her (Ass. Pro)

April 2025

Mekele, Tigray

DECLARATION

I, **Mezgebu Tesfaye G/mariam,** hereby present for consideration by Institute of Water and Environment at Mekelle University, my research thesis in partial fulfillment of the requirement for the degree of masters in **Irrigation Engineering and Management** entitled **Evaluating field application efficiency and water productivity at Mai Gobo small scale irrigation scheme in eastern Tigray, Ethiopia**. I sincerely declare that this thesis is the product of my own efforts. No other person has published a similar thesis and study which I might have copied, and at no stage will this be published without my consent and that of the **Institute of Water and Environment**.

Name of the student ______________________ Signature & date ____________________

Approval

	Name	Signature	Date
Main Advisor	________________________	______________	________________
Co-advisor	_________________________	______________	____________
PG coordinator	______________________	______________	____________
Director	______________________________	______________	____________

ABSTRACT

Water is a critical factor for crop production, yet poor irrigation management practices hinder efforts to enhance livelihoods and expose people and the environment to risks. This study aimed to evaluate field irrigation performance, water productivity, and the contribution of the SSI scheme to household income, while identifying key challenges and opportunities for its development. Data was collected from nine experimental farmers' fields, with measurements on water volumes, depths, and soil moisture contents. Additionally, 15 irrigation beneficiaries were interviewed. The CROPWAT 8.0 model calculated crop water requirements and irrigation scheduling, while SPSS was used for statistical analysis. The irrigation system showed high efficiency, with 100% conveyance efficiency, 72% water application efficiency, and 93.8% distribution efficiency, though gross water demand and supply varied significantly during the season. Water productivity indicators included crop water use efficiency of 11.2 kgm^{-3}, irrigation water use efficiency of 10.5 kgm^{-3}, and economic water productivity of 52.4 $ETBm^{-3}$. The average net income contribution of the SSI scheme was ET Birr 20,829.9 per year, representing a 159% increase in income compared to before the scheme's development. Major challenges included adverse weather conditions, pests, diseases, and lack of technical support, while opportunities included favorable agro-ecology, access to credit, and potential for high water and labor input in the area. The study shows that the Mai Gobo SSI scheme significantly improved irrigation system performance, crop water productivity, and household income.

Key words: Performance evaluation, Field irrigation efficiency, Household income, Net income generation, Water use efficiency, Crop water productivity, Irrigation scheduling.

TABLE OF CONTENTS

Contents Page

DEDICATION

I dedicate this thesis manuscript to my family and friends especially, to my mom Hareg and brother Gebremedhin for their affection, love, moral and financial support during my studies.

AKNOWLEDGMENTS

First and for most, I would like to express my sincere appreciation and heartfelt gratitude to my Major advisor Dr. Solomon Habtu and Co-advisor Mr. Tesfa-alem Gebregziabher for their positive and valuable, professional guidance, constructive comments, suggestions and encouragements.

This study would not have been possible without the infinite kindness, hospitality, generosity and patience of the farmers at Mai Gobo village, to whom I would like to thank them for their time, interest and sympathy. This research is dedicated to them too.

Equally, my heartfelt appreciation and thanks are extended to Mekelle University Institute of Water and Environment for offering me financial support to my thesis research study.

My thanks are also extended to Dr. Eyasu Yazew for his necessary support and unforgettable treatment to me during my learning and research work.

ACRONYMS AND ABREVIATIONS

ADLI	…	Agricultural Development Led Industrialization
ASALs	…	Arid and Semi-arid Lands
BoFED	…	Bureau of Finance and Economic Development
CRS	…	Catholic Relief Services
CSA	…	Central Statistics Agency
ICID	…	International Commission on Irrigation and Drainage
IEM	…	Irrigation Engineering and Management
ILRI	…	International Livestock Research Institute
IMF	…	International Monetary Fund
IPCC	…	Intergovernmental Panel on Climate Change
IWMI	…	International Water Management Institute
Mha	…	Million hectares
MoARD	…	Minister of Agriculture and Rural Development
MoFED	…	Minister of Finance and Economic Development
MoWR	…	Minister of water resources
PASDEP	…	Plan for Accelerated and Sustained Development to End Poverty
RWH	…	Rainwater Harvesting
SAERT	…	Sustainable Agricultural and Environmental Rehabilitation of Tigray
SGVP	…	Standard Gross Value of Production
SPSS	…	Statistical Package for Social Science
WAPCOS	…	Water and Power Consultancy Service
WOARD	…	Woreda Office of Agriculture and Rural Development
KOARD	…	Kebele Office of Agriculture and Rural Development

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Background of the study

According to Webb and Braun (1994), Ethiopia's history is accentuated by famine because of three closely related factors, namely: **Population pressure**, especially on the highlands with an altitude of higher than 1,500 MSL where about 80 % of the population is concentrated, **Natural resource base degradation** and **droughts**. Tigray, located in the northern part of the country is one of the most drought prone and food-insecure regions of Ethiopia. According to FAO (2009), farming, industrial and urban water demands in developing countries will increase by 40% by 2030. Climate change is likely to intensify the water scarcity and lead to greater competition for water between countries and across watersheds and basins. The poor and vulnerable populations of sub-Saharan Africa including Ethiopia will likely face the greatest risk due to the low adaptation capacity to climate shocks (IPCC, 2007).

According to Awulachew et al. (2007), Ethiopia comprises 112 million hectares (Mha) of land surface. Of this, cultivable land area estimates vary between 30 to 70 Mha. Currently, high estimates show that only 15.8 Mha of land is under cultivation. According to Awulachew (2010), Ethiopia has an estimated 5.3 million ha of potentially irrigable land of which 3.7 million ha is from surface water (small, medium and large scale) while the remaining 1.6 million ha is from rainwater harvesting technologies and groundwater. The current irrigated land is estimated at 1,304,493 ha (CSA, 2020).

SSI schemes are the responsibility of the MoARD and regions, while MSI and LSI are the responsibility of the MoWR. Note that, while it is relatively easy to identify and map MSI and LSI, the information related to SSI is not readily available and data about many RWHs are extremely difficult to capture due to poor information management and availability of data.

Ethiopia's water distribution supplies 93% to irrigated land, leaving 6 % to the domestic sector and 1% to the industry (Eyasu, 2005) but in terms of output, irrigated agriculture accounts for approximately 3 % of total food crop production (MoWR, 2002).

In Ethiopia, although irrigation has been long practiced at different farm levels, there is no efficient and well-managed irrigation water practice (Dessalegn, 1999). The reason could be because there have been little efforts made to investigate the irrigated land management and water use in the country. Even some research results have indicated that sometimes no difference is observed between rainfed and SSI user smallholders in their food security status (Peden et al., 2002). Gebremedhin and Pedon (2000) stated that in Ethiopia, most problems of small-scale irrigated agriculture that hinder its further development arise from the operational methods adopted rather than its construction and design. Moreover, irrigation development planning in Ethiopia gave emphasis to the agronomic, engineering and technical aspects of water projects with little consideration to issues of management, beneficiary participation, availability of institutional support services such as credit, extension and input supply and marketing.

To achieve sustainable production from irrigated agriculture, it is apparent that the management of important resources of water and land need to be improved. Crop responses to different inputs including fertilizer application depend on the level of water availability (Pala et al., 1996). According to Brown et al. (1987), the application of fertilizers does not only increase plant shoot and root growth but also increases evapotranspiration and hence metabolism through a large root system and greater extraction of stored water. Hence, irrigation and fertilizers are the most important inputs for high crop production and better water management. Generally, in the country and specific to the Rift Valley Lake Basin, several irrigation projects have failed or have had limited livelihood impacts and have been unsustainable because of different limitations such as less integration of the socio-economic, existing local community water management practices, institutional, technical and policy weaknesses (IFAD, 2005).

Past assessments of the efficiency of agricultural water use (e.g., Wallace, 2000) have shown that for rain-fed crops the fraction of rainfall used for crop transpiration is comparatively low, ranging from 15 to 30 % and sometimes as low as 5 % (Rockstrom and Falkenmark, 2000). Similarly, low values have been proposed by Wallace and Gregory (2002) for irrigated agriculture (13 – 18% of irrigation water delivered). The challenge to improve the low efficiency is daunting, given the wide diversity of causes underlying water loss throughout the systems of water use and management evolved by man. Numerous ways have been devised or advocated, and much attention has been paid recently to improving the efficiency of water use in agriculture (Howell, 2001).

Nonetheless, progress has been slow due to several problems: one is that water supply and use for agricultural production span a range of disciplines from hydrology, engineering and soil science to eco-physiology, plant sciences and animal sciences. Hence, with the tendency of each discipline to focus on its own specialty, the approach is often fragmented and lacking in comprehensiveness. Another problem is that lack of a definitive means to relate the efficiency of the various parts of the water productivity system to the overall efficiency of the whole, especially when going from scales of farm fields to watersheds and regions. Moreover, determining the different components of the water balance represents a challenge in any agricultural system but it is a prerequisite for performance assessment prior to proposing improvements.

Finally, and importantly, most of the time there is insufficient practical incentive for farmers to improve their water use efficiency that either the cost of the water is kept artificially low by governmental subsidies, or the farmers have little motivation to conserve water given the common perception that the water they save will go to other users without any benefit to them. Coupled with this is the problem of climate change that may increase the severity and variability of weather thus disrupting established systems of production and causing out migration into the fragile areas of the Arid and Semi-Arid Lands (ASALs). Such a change could require expensive investments in modifying existing systems of food production and establishing new ones (FAO, 1987).

Drawing lessons learnt from large scale irrigation systems, the Kenyan government is now shifting policy focus to commercial small-scale projects to exploit the country's irrigation potential (Kenya, 1994 in; Kenya, 2007) the same is true in Ethiopia (MoWR, 2007). There is a consensus that the small-scale irrigation systems have greater chances of success (Amon, 1992) because their inceptions are people driven, managed by farmers and thus enjoy greater communal participation due to their easy integration into the social systems. According to Orodho (1998), the SSISs are found throughout the country and can be described as age-old indigenous irrigation schemes. Moreover, in most of these schemes farmers still use traditional technologies of crop husbandry. Even though the contribution of farmer based small-scale irrigation for semi-cash cropping has not been studied though such schemes cover more than 40% of the irrigated land in the country (Dessalegn, 1999).

Water is the major limiting factor for crop diversification and production. More than 80 % of water resources have been exploited for agricultural irrigation (Silta, 2011). To cope with the water-shortage it is necessary to adopt water saving agriculture counter measures as efficient use of irrigation water is becoming increasingly important and the adoption of sustainable water management and irrigation development programs as well as strong linkages with private sectors and markets with institutional support are essential. In addition, these could provide plenty of opportunities in terms of a coping strategy for climatic change, poverty reduction, wealth creation, growth of economy and reducing the environmental impact of agricultural expansion to marginal land under rapid population growth (Awulachew et al., 2005).

Irrigation has the potential to stabilize agricultural production and mitigate the negative impacts of variable or insufficient rainfall in Ethiopia. In some areas of the country including the study area, delayed onset of rainy seasons, early withdrawal and mal distribution of rain were challenges, from which great lessons have been drawn to seriously investigate expansion of small, medium and large-scale irrigation in perspective. With all these facts on hand and even water resources development for agriculture as a policy priority, poorly planned and managed irrigation schemes undermine the efforts to improve livelihoods and expose the people at risk in Ethiopia.

Universally, irrigation farming as an alternative to rain-fed agriculture which is accepted to be a vital aspect of development in both economic and welfare terms but the questions “how irrigated agriculture is managed with limited water and land resources” have not been yet satisfactorily answered. Specifically in the study area, there is no compiled document or information available on the level of irrigation water management.

1.2 Statement of the problem

Rural livelihoods in many parts of Sub-Saharan Africa are under considerable stress (Denison and Manona, 2007). The economic and political environment are experiencing a period of significant transformation while poverty remains endemic. Agriculture remains at the core of rural livelihoods and has a major influence on livelihood outcomes (Sokoni and Shechambo, 2005).

In many developing countries, growing demand for irrigation, as well as increased population and limited management are placing increasing pressure on water resources. To maintain sustainable water, use in agriculture and ensure food security, a substantial improvement in agriculture water use efficiency is required (Fishman et al., 2015). Irrigation is a crucial input in the agricultural production process and movement towards market-oriented production that often requires greater application of irrigation techniques (World Bank, 2008).

Small scale irrigation is frequently cited as an innovation that can bolster rural livelihoods through climate adaptation, food security and poverty reduction (Bennin and Mugarura, 2006). Smallholder irrigation development has shown throughout the developing world that it can be used as a key drought mitigation measure and as a vehicle for the long-term agricultural and macro-economic development of a country (Sokoni and Shechambo, 2005). In Ethiopia, irrigation development is a priority for agricultural transformation, but poor practices of irrigation management discourage efforts to improve livelihoods and expose people and the environment to risks (Kidane et al., 2014).

Despite these increasing investments in small scale irrigation the current water management practices and institutional arrangements in the country seem to jeopardize the sustainability of the irrigation schemes (IFAD, 2005). As improved irrigation is relatively new to the country traditional water management and operation still dominate small-scale production in Ethiopia (Eyasu, 2005).

There is discrepancy between irrigation plans and delivery driven by three primary constraints: institutional capacity and capability, technical capacity and tools and inadequate policies and regulations. There are significant institutional challenges that prevent irrigation plans from being fully implemented, which include no standardized approach across agencies for mapping/monitoring existing projects, lack of project ownership, lack of institutional memory, and insufficient technical staff. Many government agencies and private sector/ NGO stakeholders lack the technical capacity and tools necessary for efficient irrigation planning and implementation. There is also no national database available on existing irrigation projects or irrigation needs which could make data accessible from the federal to the local level and no reliable baseline data at any level making it difficult to plan, coordinate, budget or manage irrigation schemes.

According to Theodore et al. (2007), in looking at the future, water scarcity is considered as the single biggest water problem worldwide. Global food production may soon be limited by water availability, as it already is now in many geographical areas, but it will be increasingly difficult to generate additional water supplies for agriculture without impacting on the environment and other users of water. It is obvious then that the solution to this conflict lies mostly in improving the efficiency of water use for food production. Similarly, FAO (2012) also forecasts that without changes in efficiency of water use, by 2050 the world will need as much as 60 % more water for the abstraction in 2005 for agriculture which remains a challenge to the sector.

Mai Gobo sand dam is one of the irrigation dams constructed so far in Tigray. Currently, the sand dam irrigates 50 % less than its design capacity, that is 13.9ha (Geoffrey, 2018). Moreover, the productivity of the irrigation scheme is not known so far.

Since there is no research conducted on any aspect of this irrigation scheme in general. Thus, this study aimed at evaluating field irrigation performance, irrigation water productivity at farm level, contribution of the irrigation scheme to HH net income generation and main challenges and opportunities of the irrigation scheme.

1.3 Objective

1.3.1 General objective

- To evaluate the irrigation efficiencies and water productivity and contribution to livelihood income in the Mai Gobo sand dam irrigation scheme as contribution to sustainability of irrigated agriculture.

1.3.2 Specific objectives

- To evaluate field irrigation performance,
- To evaluate water productivity at farm level,
- To evaluate the contribution of the irrigation scheme to household (HH) net income generation,
- To assess the main challenges and opportunities of the Mai Gobo sand dam SSI.

1.4 Research questions

- How efficient is the irrigation system in delivering water to crops at different stages of growth?
- What are the crop water use efficiency (CWE) and irrigation water productivity (IWP) in the Mai Gobo SSI?
- What is the average net income contribution of the Mai Gobo SSI scheme to beneficiary households?
- What are the main challenges & opportunities for irrigation development in the area?

1.5 Structure of the thesis

The MSc thesis is organized in six chapters. The first chapter contains background, the problem statement and objective of the study, research questions and the research design. The second chapter covers the conceptual and theoretical framework along with the literature reviews relevant to the study. It includes the concept of water and agriculture, irrigation development in

Ethiopia, current trends of irrigation development, theoretical description of the main variables and the need for performance evaluation.

The third chapter presents a detailed account of the methods and materials carried out to accomplish the research task, including the research techniques, the study area description and selection of respondents, sources of data and acquisition methods, method of data analysis and issues of reliability and validity of the research outcomes. Chapter four covers the results and discussions part in line with the four specific objectives while the fifth chapter presents the conclusion of the main results and recommendations for further improvement. Lastly, the sixth chapter presents the scope and limitations of the research in terms of access and financial resources.

2. LITERATURE REVIEW

2.1 Introduction

This chapter reviews relevant literature on small-scale irrigation farming, specifically, on field irrigation performance, irrigation water productivity and contribution of irrigation scheme to household's net income generation and the main challenges and opportunities of small-scale irrigation schemes. The reviews were done based on the thematic areas of the study such as socio-psychological, economic, technical and physical and environmental factors. The chapter finally provides the theoretical framework and conceptual understanding of the research on the small-scale irrigation scheme.

2.2 Theoretical review of small scale irrigation farming

Mutsvangwa and Doranalli (2006), defined irrigation as the ministering of land through the artificial application of water to ensure double cropping as well as steady supply of water in areas where rainfall is unreliable. According to Burrow (1987), small holder irrigated horticulture had proven to be a viable and attractive option for poor farmers in developing countries. He further asserted that returns from intensive irrigated horticulture even on tiny plots could greatly exceed returns from rain-fed cereal production. In addition, in many developing countries small scale irrigation schemes were counted on to increase production, reduce unpredictable rainfall and provide food security and employment to poor farmers.

According to Kaswamila (2004), the problems related to irrigation development and management can be categorized as follows: a) Environmental factors: water scarcity and poor water quality especially as related to sediment concentration, land degradation as a result of poor operation and management activities, which is partly related to inefficient water management resulting in water wastage and water logging as well as land-use regulation, b) Capacity of the farmers: lack of know-how in, and access to, the opportunities of irrigation technology, weak economic base of most farmers and the relatively high development costs involved in developing irrigation schemes, and c) Government policy: institutional and legal support: limited or no priority given to irrigation development during national and local planning and budgeting, poor management structures in place to support farmers and promote irrigation development.

Irrigation development is an expensive undertaking, and a few farmers are finding problems in securing adequate finance as initial capital to engage in irrigation farming. Credit institutions require collateral security before granting credits and most of the farmers will not have such. Moreover, the financial institutions are reluctant to provide credit to many other irrigation enterprises because they are seen as unable to service their loans. Hence, the availability of credit also affects the demand for agricultural land. As the money supply and the supply of bank loans increase many applicants can secure funds.

There seems to be a general view that market access is one of the critical factors that determine success of small-scale irrigation farming projects. This is an acceptable view even among professionals working in developing countries. For example, presenting results of an expert survey by Gebremedhin & Haggblade (2001) found that the main views on determinants of success in African agriculture include technology, collaboration, markets and a favorable policy environment and management. In this study, social scientists chose markets and favorable policy environment as the most prominent determinates of success.

To eradicate poverty, water management institutions play a significant role in the allocation and distribution of irrigational water. Cultural bonds may equally foster mutual ties out of which such an institution can be built, and such natural social cohesion forms a strong basis upon which to form an institution (SAWAF, 2002). The main function of irrigation water management organizations is normally to manage the annual flow of irrigation water from the main feeding canal, coordinate the sharing of irrigation water among the different farming units and presuppose responsibility for the maintenance and repair of the on-farm infrastructure. On economics, the price that farmers pay for water in many parts of the world is much less than that of that water while water pricing may be a useful instrument to promote new technologies that lead to more efficient water use, but it has many shortcomings if applied rigidly, especially in poor rural areas (Hussain et al., 2007).

Despite the huge amount of existing water in the country the demand for water (domestic, industrial and irrigation activities) still exceeds the supply from various resources such as surface waters and groundwater (MoWR, 2002; Awulachew et al., 2007). The increasing competition for water resources within different sectors like irrigation, industries and household use increases the value of catchment as the appropriate unit of analysis to address the challenges facing water resources management (Rosegrant et al., 2006).

The development of small-scale irrigation is one of the major intervention areas to boost agricultural production in the rural parts of the country. This helps poor farmers to overcome rainfall and water constraint by providing a sustainable supply of water for cultivation and livestock, strengthening the base for sustainable agriculture, providing increased food security to poor communities through irrigated agriculture and contribute to the improvement of human nutrition (FAO, 2003).

Tigray is one of the most land-degraded states of Ethiopia. The region is characterized by subsistence farming households raising cereal and vegetable crops for local consumption and sale. Crop production in the region has failed to keep pace with population growth due to recurrent droughts, environmental degradation and wars, including the most recent conflict with Eritrea (Ersado, 2005). In response to severe environmental degradation and population-resource imbalance the regional government of Tigray has initiated a major rural development program called (SAERT) through which several small-scale dams have been constructed (Ersado et al., 2004).

2.3 Small scale irrigation farming

Hillel (1997) stated that Africa has promoted small-scale irrigated agriculture as a means of ensuring food security as well as improving the standard of living of the rural people for many years. Various studies such as those conducted by You et al. (2010) show that small-scale irrigation improves food security and livelihoods of rural farmers in Africa. However, according to Birendra et al. (2011), the economic and social output from irrigation projects has been often lower than estimated at the planning stage. Specifically, in a recent report which evaluated more than 200 irrigation projects subsidized by the World Bank, for example, 23% were rated unsatisfactory. Arcus (2004) argued that many accounts of irrigation projects report failed to meet estimated agricultural production targets due to poor maintenance and disappointing economic returns on investments.

Moreover, according to Lyne et al. (2009), despite their important role in improving livelihoods of rural communities, small-scale irrigation schemes have had limited performances of operating irrigation systems. Generally, this has averaged less than 50% efficiency due to poor infrastructure, limited knowledge of crop production among smallholders, limited farmer participation in the management of water, ineffective extension and mechanization services and lack of reliable markets, effective credit services and predominance of subsistence-oriented farming.

According to Zeleke (2015), most operational irrigation schemes in the country are characterized by a poor level of technical, hydraulic, operational and service delivery performance, water logging and salinization, lack of adequate institutional setups for management, inadequate physical water control facilities, canal sedimentation and lack of adequate maintenance, lack of appropriate asset management etc. Some of these challenges are critical to small-scale community managed schemes, while others are fundamental to large-scale schemes. (Mihret and Ermias, 2014) study in the case of Ethiopian rift valley lake basin, the production gain from irrigated agriculture is below the expected value due to the inefficient scheme water management. Generally, it is observed that from 147 irrigators, water supply unreliability (68% of all scheme users' observation), unfair distribution of water (79.1% of all scheme users' opinion) and timeliness of water distribution (66 % of all scheme users' remark) are major problems in all investigated schemes.

According to Abraham et al. (2014), studies in the case of Ahferom Woreda, Tigray pointed out that loss of water, pests and diseases are the most common challenges in using small scale irrigation. On average non-farm income earning of the users and non-users was 3233.48 Birr and 5165.14 birr respectively, the non-users non-farm income was 1931.66 Birr more than the users earning. The average farm income of the user and non-users was 18602.16 Birr and 3975.459

Birr respectively. Higher farm income encourages farm households to participate and specialize in irrigation.

According to Hintsa et al. (2015), at the southern zone of Tigray, 57.4 % of the small-scale irrigation scheme beneficiaries are practicing both full and supplementary irrigation systems while the irrigation rounds per year were 24.6 %, 55.7 % and 19.7% for three, two and one times respectively. Moreover, the irrigation intervals for cabbage, onion and maize were 12, 15 and 24 days, respectively. According to Kinfe et al. (2012), at the central zone of Tigray, it is revealed that income, gender, access to market information and health condition of households are important determinants for participating in small scale irrigation schemes. This analysis further revealed that irrigation participation, family labor force, livestock ownership and access to market information and credit are positively and significantly associated with household income. In addition, it also revealed that the gender difference of household heads in irrigation participation indicated female-headed households face shortage of labor and market information, made them rent/share out their land. In addition, a study by Gebregziabher et al. (2009), using a survey of beneficiaries of selected small scale irrigation schemes in the Tigray region, revealed that household income of irrigation users was higher than that of non-irrigators by about 50 %.

According to Isaac (2012), the study held along Tana River in central division of Darissa district, Kenya, on the impact of small scale irrigation farming, even though, several organizations and government departments offer agricultural technical assistance and provision of farm inputs to the locals there was very little use of farm inputs like fertilizers, pesticides etc, very low membership to farmers’ organization and very little training/information on irrigation farming. Moreover, the main challenges facing farming in the study area include lack of capital to finance farming, lack of or inadequate technical skills for farming due to inadequate assistance from agricultural officers among others.

Reviewing more than 12 research related to this research topic the main findings they found were related to: 1. the challenges of SSI schemes 2. The income contribution rate of the SSI schemes 3. Productivity of the SSI schemes 4. Water use efficiency of the SSI schemes using manual calculation considering the water input and output. The unanswered question here was that irrigation water application efficiency should be considering the FAO recommended crop water requirement/demand, which is the ratio of the calculated crop water demand simulated by CROPWAT 8.0 model to the actual amount of water used by the crop per fixed plot size per crop per irrigation season.

2.3.1 Water and agriculture

According to IFAD (2014) and Hess (2010), only 20% of the world's total crop land is irrigated. However, these lands contribute to some 40% of the global agricultural harvest. The figure indicates that irrigated agriculture on average is roughly more than 2.5 times as productive as rainfed agriculture. Agriculture depending on rainfall has failed to produce enough food and with increasing rainfall variability productivity of rainfed agriculture is expected to diminish. As such, without significant investments in irrigation, agricultural production is unlikely to cope with ever increasing demand for food.

In Africa, agriculture forms the backbone of most of the continent's economies providing about 60 % of all employment (Birendra et al., 2011) and at present, the total cultivated area in Africa is estimated at 143.3 million ha with about 12.2 million ha benefiting from irrigation (FAO, 1995). During the last decade per capita agricultural production has not kept pace with population growth. Consequently, as per the (FAO's) assessments at the end of the 1990s 30 countries in Africa had over 20% of their population undernourished, rising to 35% in the 18 worse affected countries. Moreover, in terms of absolute numbers between 1997 –1999, 200 million people were malnourished with 194 million of these people living in Sub-Saharan Africa (SSA).

The food gap estimated at 17 million tons in 2000 was filled by imports (14.2 million tons) and food aid (2.8 million tons) at a cost of US$18.7 billion. In 2001 close to 30 million people required food emergencies due to droughts, floods and civil strife (You et al, 2010). Agricultural growth offers possibilities for reducing risks of food shortages at all levels, increasing overall supply of food, creating economic opportunities for vulnerable people and improving dietary diversity and the quality of food consumed by farm households (Lyne et al., 2009).

However, according to Ortman and King (2010), progress in the sector can only be achieved if the main constraints are successfully addressed such as: variability in climate, limited access to technology, low levels of rural infrastructure and poor institutional structures. In addition, other areas that need addressing are the poor political and economic governance, the need to introduce supportive policy and legislation, the need to develop rural entrepreneurship capacity, combat HIV/AIDS, mobilize savings for investment and improve the performance of cash crops.

Ethiopia is endowed with one of the most biodiversity ecosystems in the world. It has earned the name “the Water Tower of Eastern Africa” for having more than ten rivers each of which has irrigation potential and has the largest livestock population in Africa (est. 114 million), i.e. 2.5 per capita (MEDIC, 1999). According to FAO (2012), agriculture plays an important role in the development of the national economy contributing about 50% of the gross domestic product GDP and employs 85 % of the population.

While, currently, in Ethiopia about 15 million people are facing food insecurity either chronic or transitory in nature and about 5 to 6 million people are chronically foods insecure every year. These are people who do not have the capacity to produce or buy enough food to meet their annual food needs even under normal weather and market conditions while the remaining 10 million are vulnerable with a weak resilience to any shock. Under any emergency circumstances, the likelihood of these people falling back into food insecurity is high (FAO, 2012). To address food insecurity of the rapidly growing population in Ethiopia, the current agricultural area assumed to increase by 25% while average yields are assumed to increase by one-half by 2020 (Ehui et al., 2002).

Agriculture sector in Ethiopia is characterized by traditional method of farming with little surplus output and is heavily influenced by weather conditions. Only 20% farm production is supplied to the local market while more than 60% of production is used for own consumption which puts the vulnerable food insecure households in perspective (Dejene, 2006). Even in a year of good rain, the occurrence of floods affects the livelihoods of riparian residents with little capacity to neither protect them from the seasonal flood nor mitigate the impact. Excess water is also responsible for the erosion of soil in the highlands. Recent studies show that the sediment yields in different rivers range between 180 and 900 ton/year per km^2 (Rodeco, 2002).

It is estimated that the Trans boundary Rivers alone carry about 1.3 billion tons of sediment each year to neighboring countries (MoWR, 1993). Poor watershed management and farming practices have contributed to these rates. Moreover, since the 1970s, recurrent drought, unreliable and poor distribution characters of rainfall have resulted in crop and pasture failure. These have in turn brought about food shortage and famine, particularly in the northern part of the country including the study area Tigray. In addition, combinations of natural and manmade factors have resulted in serious and growing food insecurity problem in many parts of the country.

Irrigation development has been given priority in the Agricultural Development Led Industrialization (ADLI) strategy of Ethiopia. Under the program, irrigation is planned to be introduced and implemented in areas where agro-ecological conditions are in harmony with the interventions (GoE, 2001). On top of this, the Ethiopian government in collaboration with its development partners has developed a Food Security program (FSP) within the framework of the Plan for Accelerated and Sustained Development to Eradicate Poverty (PASDEP) which is a guiding strategic framework for the five-year period 2012 to 2017. In the PASDEP and the FSP, due emphasis has been given to developing and using the huge potential of the country for irrigated agriculture to produce food crops as well as raw materials needed for agro-industries (FAO, 2006).

With all these facts on hand and even water resources development for agriculture as a policy priority, poorly planned and managed irrigation schemes undermine the efforts to improve livelihoods and expose the people at risk in Ethiopia. The major lesson that emerges from country experiences is that for agricultural growth to occur, several factors need to be addressed in the rural sector such as infrastructure, social services, technology, marketing infrastructure and seasonal credit availability along with the building of an appropriate institutional environment (UNDP, 2007).

According to Sokoni and Shechambo (2005), to reduce risks associated with rainfall variability and increase yields of food crops, more public investments in yield enhancing technologies such as small-scale irrigation and irrigation management systems have been recommended as one important rural development and poverty reduction strategy. According to Lipton et al. (2004) cited by Haile (2008), there are four interrelated mechanisms by which irrigated agriculture can reduce poverty through: (i) increasing production and income and reduction of food prices that helps very poor households meet the basic needs and associated with improvements in household overall economic welfare, (ii) protecting against risks of crop loss due to erratic, unreliable or insufficient rainwater supplies, (iii) promoting greater use of yield enhancing farm inputs and (iv) creation of additional employment, which together enables people to move out of the poverty cycle. Therefore, irrigation can be an indispensable technological intervention to increase household income. Moreover, to increase water and land productivity, assessing the quantity and quality of available water and land resources and projecting them for the future is very essential.

2.3.2 Irrigation development in Ethiopia

Irrigation is a very old practice, dating back to the earliest civilizations of humankind. It served as one of the key drivers behind growth in agricultural productivity, increasing household income and alleviation of rural poverty, thereby highlighting the various ways that irrigation can impact poverty (Damanto et al., 2014). To meet food requirements by 2020, (FAO, 2000) estimated that food production from irrigated areas will need to increase from 35% in 1995 to 45% in 2020. This indicates that access to water for irrigation will become an issue of global concern and competition in the future, especially in the arid and semi-arid regions of the world.

For countries with arid and semi-arid climates, the lack of certainty about rainfall along with the raising population pressure would require irrigation development as a primary means for future food strategies while Ethiopia is one of the countries in this category (Elahi, 1992). With the steady increase of the global population, the contribution of irrigation towards boosting agricultural production is enormous, particularly in some emerging and least developed countries, irrigation development and use is a backbone to the extent that it is responsible for the nation's welfare and feeding most of their population. In these countries an increase in production of 100-

400% is being attained by irrigation which depicts the importance of irrigation to agricultural production (FAO, 2005).

In Ethiopia, traditional irrigation was practiced before centuries (Bekele et al., 2012). Moreover, in the highlands of Ethiopia, irrigation practices have long been in use since ancient times for producing subsistence food crops and continue to be an integral part of Ethiopian agriculture (Awulachew et al., 2007; MoA, 2011a). Though in Ethiopia, modern irrigation began in the 1950s through private and government owned schemes in the middle awash valley where big sugar, fruit and cotton state farms are found (Kidane, 2015). Moreover, the main purpose of irrigation development in the 1960s was to provide industrial crops to the growing agro-industries in the country while the agro-industries were established by foreign investors and had the objective of increasing export earnings. In addition, during the 1960s irrigation was seen as part of the modernization of the country's agricultural economy. It was considered an important investment for improving rural income through the increased agricultural production but in 1975 the rural land proclamation was introduced in the country. Following the rural land proclamation the irrigated private farms were nationalized and converted to state farms by the Derg regime.

The current government has undertaken various activities to expand irrigation in the country. The country’s Agricultural Development Led Industrialization (ADLI) strategy considers irrigation development as a key input for sustainable development. Thus, irrigation development, particularly small-scale irrigation is planned to be accelerated (MoFED, 2010). Most of the traditional irrigated lands in Ethiopia are dominantly supplied by surface water sources while ground water uses has just been started on a pilot basis in the East Amhara region (MoA, 2011a). According to MoA (2011a), pressurized sprinkler irrigation system was once practiced in fincha state farm, eastern Amhara, southern Tigray and on some private farms in the rift valley.

Irrigation in Ethiopia could represent a cornerstone of the agricultural development of the country, contributing up to 140 billion birrs to the economy and potentially moving up to 6 million households into food security (Bernard, 2012). Small-scale irrigation is a policy priority in Ethiopia for rural poverty alleviation and growth (CSA, 2007 and MoWR, 2007). Only less than 5% of total renewable water resources are withdrawn annually (Graciana, 2011). So, there is considerable scope for expansion. The challenge posed by recurrent drought, declining agricultural production at household level and ever-increasing population pressure necessitated close attention to water resource management and small-scale irrigation development (Hune, 2003).

SSI development is one of the components of water resource development. Ethiopia has large water potentials that could be used for a wide range of irrigation development programs. It has 12 major river basins with an annual water runoff volume of more than 122 billion cubic meters (Kidane, 2015). In addition, the groundwater potential is estimated to be more than 2.6 billion cubic meters (Awulachew et al., 2005). For Ethiopia, increasing agricultural productivity, enabling households to generate more income, increasing their resilience as well as transforming their livelihoods stands out as the most pressing agenda now and for the coming decades.

In Tigray, surface irrigation is the predominant form of irrigation; it includes spring development, river diversion, flood spreading, micro dams and pond systems while the canal systems are mainly unlined and the density of tertiary canals on farmers' fields is often not high enough to ensure efficient water management. In addition, there are also limited ground water systems (Zaman, 2006).

2.3.3 Current trends of irrigation development

Since freshwater resources are essentially finite on earth and the development of additional supplies for human use is increasingly limited by economic and ecological reasons, making more efficient use of the water must be a major focus in coping with the growing water scarcity (Gleick, 2003). This objective will be particularly relevant in food production systems for two reasons. One is that agricultural water use represents the lion's share of the water diverted by man for various uses worldwide (Seckler et al., 1998).

The relentless growth of human population coupled with the intensifying desire for higher living standards, including the continuous shifting to diets based more and more on meat and dairy products are straining water resources all over the world, especially in the more arid regions. Adding to the strain is the increased awareness of the need for water in the preservation of the environment and ecosystems (Falkenmark, 2000). The second is the intensifying competition for water with other sectors of our society and the general perception that agricultural water use is often wasteful and has less value than other uses and should be reduced even in the face of future increases in food demand (Postel, 2000).

Over the next five years, Ethiopia has already planned in the PASIDP to increase its total area of irrigated land from the current 640,000 hectares (~4 % of currently cultivated land) to about 1.8 Mha. SSI and RWH will account for about two-thirds of this expansion as they require lower capital and technical investments (EIAR, undated). However, beyond the next five years, Ethiopia will have to significantly expand its irrigation sector to reach the full irrigable potential of over 5 Mha. This 280 % increase from current irrigation levels will require tremendous resources including funding, human capacity, infrastructure and other human and capital investments. According to the Ethiopian Growth and Transformation Plan (GTP 2010/11-2014/15), the main objectives of the water sector development plan are to develop and utilize water for different social and economic priorities in a sustainable and equitable way to develop irrigation schemes to ensure food security, to supply raw materials for agro-industries and to increase foreign currency earnings. However, Ethiopia faces four key technical, socio-economic, institutional and environmental challenges that must be overcome to meet this ambitious target, behind-schedule delivery & Low-performance of schemes are among the challenges.

2.4 The need for performance evaluation

As far as irrigation management is concerned, the water needs to be gauged and properly utilized; both excessive and inadequate water applications have negative effects (Mihret, 2013). Inadequate irrigation application results in crop water stress and yield reduction while excess irrigation application can result in pollution of water sources due to the loss of plant nutrients through leaching, runoff and soil erosion. Likely, the desired frequency of irrigation depends on factors such as soil texture, rooting pattern, topography, evapotranspiration rate, rainfall, crop type and/or developmental stage (Hanson et al., 2003).

Irrigation scheduling can increase net farm income in crop production. The potential returns of irrigation scheduling are derived from three factors: increase irrigation efficiency, reduced cost of irrigation and opportunity cost of water (Fardad and Gorgar, 2002). Similarly, another report revealed that adequate irrigation design, good irrigation management and scheduling have been recognized as keys to increasing crop production on a sustainable basis. As a result, scheduling irrigation according to crop water needs minimizes the chances of under or over watering (Qassim and Ashcrft, 2012). Likewise, there is less crop failure and leaching of fertilizers beyond the root-zone and more profit for growers under well-established crop water requirement (Adeniran et al., 2010). Crop water requirement is inclusive of crop modeling strategies which are proactive to sustainable agriculture particularly in the view of climate change. Therefore, crop production should be supported by prediction data (Beshir, 2017).

2.5 Theoretical description of the main variables

Small scale farmers are the ones who depend on his efficiency in the utilization of basic production resources available to him or her. He/she makes a significant and important contribution to the national product (99 % of total crops output).

Efficiency is expressed in (%) or fraction and is defined as output of a specific operation in relation to the input.

2.5.1 Description of field irrigation performance variables

This extension circular describes various irrigation efficiency, irrigation distribution uniformity, and crop water use efficiency evaluation terms that are relevant to irrigation systems and management practices currently used in Nebraska, in other states and around the world. The definitions and equations described can be used by crop consultants, irrigation district personnel and university, state and federal agency personnel to evaluate how efficiently irrigation water is applied and/or used by the crop and can help to promote better or improved use of water resources in agriculture (Irmak et al., 2011).

As available water resources become scarcer, more emphasis is given to efficient use of irrigation water for maximum economic return and sustainability of water resources. This requires appropriate methods of measuring and evaluating how effectively water extracted from a water source is used to produce crop yield. Tendency to over irrigate exists. Efficient use of water is also influenced by cost of labor, ease of controlling water, crops being irrigated, type of irrigation system and soil characteristics. Various terms are used to describe how efficiently irrigation water is applied and/or used by the crop. Incorrect usage of these terms is common and can lead to a misrepresentation of how well an irrigation system is performing (Irmak et al., 2011).

Irrigation efficiency is generally defined from three points of view: (1) the irrigation system performance, (2) the uniformity of water application, and (3) irrigation water productivity. These irrigation efficiency measures are interrelated and vary on a spatial and temporal scale. The spatial scale may be defined for a single field or on a larger scale up to a whole irrigation district or watershed. The temporal scale can vary from a single irrigation event to a longer period such as part of the growing season or a period of years (Irmak et al., 2011).

(1) The field irrigation performance variables

Irrigation system performance describes the effectiveness of the physical system and operating decisions to deliver irrigation water from a water source to the crop. Several efficient terms are used to evaluate irrigation system performance. These include water conveyance efficiency, water application efficiency, soil water storage efficiency, irrigation efficiency, overall irrigation efficiency and effective irrigation efficiency (Irmak et al., 2011).

Efficient water use is defined as the ratio between the actual volume of water used for a specific purpose and the volume extracted or derived from a supply source for the same purpose. Functionally expressed as:

$$Ef = Vu/Ve \quad \text{(1)}$$

Where: E_f - Efficiency, dimensionless

V_u - Volume utilized, m3

V_e - Volume extracted from the supply source, m^3

Water conveyance efficiency (Ec): is defined as the efficiency of conveyance of water from the source to the point where it leaves the point of distribution. Starting with the first step of the chain of efficiencies, poor conveyance efficiency implies leaky conduits or substantial evaporation of the water in route. Evaporative loss is normally a minor portion even for open conveyance and storage unless there is a long-time lag before the water arrives at the farm. For example, a very long and slow conveyance in a shallow and broad stream will lead to high evaporative losses under warm weather. Evaporative loss can also be indirect through transpiration by riparian vegetation adjacent to unlined canal or stream. Improvements in Ec could be very costly (e.g., converting open channels to closed conduits) or at least more than nominal (e.g., repairing cracks and sprung joints widely spread along the conduit length). The state of many networks around the world is such that many programs of modernization in irrigation are focused on reducing losses at this step (Playan and Mateos, 2005).

Irrigation water is normally conveyed from a water source to the farm or field through natural drainage ways, constructed earthen or lined canals, or pipelines. Many conveyance systems have transmission losses, meaning that water delivered to the farm or field is usually less than the water diverted from the source. Water losses in the conveyance system include canal seepage, canal spills (operational or accidental), evaporation losses from canals and leaks in pipelines. The water conveyance efficiency is typically defined as the ratio between the irrigation water that reaches a farm or field to that diverted from the water source (Irmak et al., 2011).

Water conveyance efficiency also can be applied to evaluate individual segments of canals or pipelines. Typically, conveyance losses are much lower for pipelines due to reduced evaporation and seepage losses. In Nebraska, irrigation water is frequently pumped from wells located in the field and carried in pipelines. Water delivery through open canals is also common, especially in the central and western parts of the state. Since there is minimal water loss in closed/pressurized conveyance systems, the conveyance efficiency can be as high as 100 %.

Water application efficiency (Ea): is the efficiency with which the water leaving the distribution point of the irrigation system falls on to the soil surface. After the arrival of the water at the edge of the field the next efficiency step is application efficiency. (Ea) is closely linked to uniformity of water distribution by the chosen water application system. For surface irrigation, if the rate of application is not correctly matched to the infiltration rate of the soil and slope of the land water would be unevenly distributed from the head to the tail of the field and (Ea) would be low. An extreme poor situation may be represented by furrow irrigation on a coarse sand (extremely high infiltration rate) in a field of very little slope such as on some newly developed desert lands in North Africa. When surface irrigation is practiced well under the right conditions, however, (Ea) would fall in the good situation range and can be as high as 0.8 (Howell, 2003).

Water application efficiency (Ea) provides a general indication of how well an irrigation system performs its primary task of delivering water from the conveyance system to the crop. The objective is to apply the water and store it in the crop root zone to meet the crop water requirement. (Ea) is a measure of the fraction of the total volume of water delivered to the farm or field to that which is stored in the root zone to meet the crop evapotranspiration needs (Irmak et al., 2011). Moreover, water losses during surface (furrow) irrigation include runoff, evaporation from water in the furrow channels, evaporation from the soil surface and percolation below the root zone. Runoff loss can be significant if tail water is not controlled and reused. In cases where runoff water is recovered and reused, the volume of irrigation water delivered to the farm or field (Vf) should be adjusted to account for the net recovered tail water. In Nebraska, irrigators commonly block the lower end of furrows to prevent runoff. Blocking furrow ends, however, can result in non-uniform water distribution and excessive deep percolation at both the upstream and downstream ends of the field. The application efficiency of furrow irrigation is impacted by management practices, stream size, soil characteristics and field slope. The normal practice is to supply continuous flow for the entire irrigation set time. Some farmers use surge irrigation to reduce overall application depths and improve infiltration uniformity along the furrow. In surge irrigation, water is intermittently applied to the furrows, usually resulting in less runoff and more consistent opportunity time along the furrow (Irmak et al., 2011).

Poor water distribution causes water stress in areas receiving relatively low amounts of water and oxygen stress in areas that are waterlogged for several days. For (Ea) to have practical meaning, it needs to be sufficient and well distributed to avoid undesirable water stress and oxygen stress (in the root zone) in the farm or field. Thus, reporting of both application efficiency and water distribution uniformity would provide a better indication of overall irrigation system performance. Proper irrigation management can increase application efficiency and poor irrigation management can result in inefficient use of water and reduce application efficiency. Over irrigation may result in leaching chemicals below the crop root zone, a case for yield reduction and result in wasting water resources. Improper timing and inadequate irrigation applications that do not meet the crop water requirement may impose stress on the crop and reduce grain yield and yield quality (Irmak et al., 2011).

Soil water storage efficiency (Es): the main goal in most irrigation applications is to maximize water storage in the soil root zone to satisfy crops (ET) while minimizing deep percolation and surface runoff. The soil water storage efficiency indicates how well the system uses the available root zone storage capacity to store water to meet crop needs. Thus, in most cases maximizing water storage from irrigation is beneficial. Soil water storage efficiency (Es) is defined as the ratio of the volume of water stored in the root zone to the volume of water required to fill the root zone to near field capacity (Irmak et al., 2011).

The maximum amount of water that should be applied to achieve high (Es) for a given irrigation event is the difference between the field capacity and average water content in the soil root zone prior to the irrigation event. A high (Es) means that the irrigation brings the soil root zone to field capacity but does not lead to deep percolation. In most cases, it is suggested not to refill the soil profile to the field capacity but rather to leave some storage capacity for a potential rainfall event. Thus, refilling the soil profile to about 90 % of the field capacity can be a good strategy. Sprinkler and micro irrigation systems usually supply only sufficient water to satisfy crop (ET) needs without filling the soil root zone. In furrow irrigation, the usual practice is to irrigate every furrow to provide more storage space within the root zone for potential rainfall. In such cases, the use of (Es) may be meaningless because the goal with (Ea) is not to maximize root zone water storage.

Irrigation efficiency (Ei): is the ratio of the amount of water consumed by the crop to the amount of water supplied through irrigation (surface, sprinkler or drip irrigation). It is a special case of water use efficiency. It is the measure of efficiency for irrigation given specified boundaries. There are many ways of measuring efficiency, some of which are conventional and well-known, others which are new and attempt to capture efficiency for the whole system and the temporal elements of efficiency. Unlike productivity (which has units), however, efficiency is expressed as a %, being a measure of net to gross water use or net days of irrigation to gross days of irrigation.

Sometimes, irrigation water may be applied for uses other than simply satisfying water used by crops for ET. Other beneficial uses include water used for removal of salts (leaching requirement), microclimate control (evaporative cooling during extreme heat or frost protection), seedbed preparation, germination of seeds, softening of a soil crust for seedling emergence and ET from plants beneficial to the crop (windbreaks or cover crops for orchards). Some water also may be beneficially applied for chemigation. When more than ET water is considered, the term irrigation efficiency (Ei) is used to define the effectiveness of the irrigation system in delivering all the water beneficially used to produce the crop. Irrigation efficiency is defined as the ratio of the volume of water that is beneficially used to the volume of irrigation water applied (Irmak et al., 2011).

Water losses that occur because of excessive deep percolation, runoff, weed ET, wind drift, and spray droplet evaporation are normally not considered as beneficial uses and thus tend to decrease irrigation efficiency. A major problem with using irrigation efficiency as a performance parameter is the subjectivity involved in the definition of beneficial use. Some irrigation practitioners consider spray droplet evaporation losses beneficial since evaporation during sprinkling cools the crop canopy and is partially compensated for by transpiration reduction. Most irrigation systems in Nebraska operate primarily to supply water for crop ET, which allows water application efficiency (Ea) and irrigation efficiency (Ei) to be used interchangeably. Other factors that impact beneficial uses and thus irrigation efficiency are local water regulation agency allocation rules and farmer-practiced irrigation management strategies.

Overall irrigation efficiency (Eo): is the actual amount of water supplied to meet crop evapotranspiration and/or percolation/seepage observed under field conditions or is the efficiency with which water from the irrigation dam or draw-off point on the farm boundary is delivered through the irrigation system to the point where it falls onto the surface. The overall irrigation efficiency (Eo) represents the efficiency of the entire physical system and operating decisions in delivering irrigation water from a water supply source to the target crop (Irmak et al., 2011).

Irrigation water distribution uniformity: All irrigation systems apply water non-uniformly to a varying degree. The irrigation system performance efficiency terms described previously do not directly account for the uniformity or non-uniformity of irrigation application within a given field. Yet, the non-uniformity of the applied water can significantly affect irrigation performance. Non-uniform irrigation application results in areas that are underwatered or over-watered. Thus, both under and overwatered areas may experience yield reduction. With favorable climate conditions, optimum crop growth and yield are obtained with high uniformity of irrigation application in which each plant has an equal opportunity to access the applied water and nutrients (Irmak et al., 2011).

In addition, the uniformity of irrigation application depends on many factors that are related to the method of irrigation, topography, soil (infiltration) characteristics, and the irrigation system's pressure and flow rate. For surface irrigation, non-uniformity can be caused by: (i) differences in opportunity time for infiltration caused by advance and recession, (ii) spatial variability of soil-infiltration properties, and (iii) non-uniform grades. For micro-irrigation, non-uniformity can be due to: (i) variations in pressure caused by pipe friction and topography, (ii) variations in hydraulic properties of emitters or emission points (from clogging or other reasons), (iii) variations in soil wetting from emission points, and (IV) variations in application timing. For all irrigation methods, poor management also can cause non-uniformity.

Christiansen's uniformity coefficient for furrow systems: The uniformity of application is evaluated using Christensen's uniformity coefficient (Jurriens et al., 2001).

Low-quarter distribution uniformity for furrow systems: The distribution uniformity is more commonly used to characterize the irrigation water distribution over the field in surface irrigation systems, but it also can be applied to micro and sprinkler irrigation systems. The low-quarter distribution uniformity (DU) is defined as the average depth infiltrated in the lower one-quarter of the field divided by the average depth infiltrated over the entire field (Irmak et al., 2011).

Typically, DU is based on the post-irrigation measurement of water depth that infiltrates the soil because it can be more easily measured and better represents the water available to the crop. However, using post-irrigation measurements of infiltrated water to evaluate DU ignores any water intercepted by the crop and evaporated and any soil water evaporation that occurs before the measurement. Any water that percolates below the root zone or the sampling depth also will be ignored.

Water supply indicators: Molden et al. (1998) states that the water supply indicators (relative water supply, relative irrigation supply and water delivery capacity) are better suited to place the irrigation system in its physical and management context. Higher values of these indicators indicate a more generous supply of water. In this case, productivity to land may be more important. Where the water supply indicators show a lower value, it indicates a situation of a more constrained water supply and values of productivity per unit of water are more important.

According to Bos et al. (1994), these indicators deal 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.

Relative water supply (RWS) and relative irrigation supply (RIS): As Molden et al. (1998) cited, relative water supply as presented by Levine (1982) and relative irrigation supply as developed for this indicator set (Perry, 1996) are used as the basic water supply indicators. Both RWS and RIS relate supply to demand and give some indication as the condition of water abundance or scarcity and how tightly supply and demand are matched.

Water delivery capacity ratio: According to Molden et al. (1998), water delivery capacity ratio can be expressed as the ratio of the canal capacity to deliver water at system head to peak consumptive demand. The same authors mentioned that water delivery capacity is meant to give an indication of the degree to which irrigation infrastructure is constraining cropping intensities by comparing the canal conveyance capacity to peak consumptive demands. Again, a lower or higher value may not be better but needs to be interpreted in the context of the irrigation system and in conjunction with the other indicators.

(2) Crop water productivity variables

Irrigation system performance and irrigation uniformity parameters discussed previously to evaluate the engineering and operational aspects of the irrigation system. Different parameters are used to evaluate the crop water productivity. The three most used parameters for evaluating crop water productivity are crop water use efficiency, irrigation water use efficiency, and water use efficiency (Irmak et al., 2011). The description for the crop water productivity variables is presented as follows:

Crop water use efficiency (CWU_E): is mostly used to describe irrigation effectiveness in terms of crop yield (crop productivity). It is defined as the ratio of the mass of economic yield or biomass produced per unit of irrigation water used in ET (Irmak et al., 2011).

Irrigation water use efficiency (IWU_E): is used to characterize crop yield in relation to total depth of water applied for irrigation (Irmak et al., 2011). The CWU_E is a better indicator when quantifying the efficiency of a crop production system because it directly reflects the amount of grain yield produced per amount of water used rather than per depth of water applied which is the case with the IWUE. This is because not all irrigation water applied to the field is used for crop ET. Thus, IWUE does not account for the irrigation application losses and actual water used by the crop.

What is water use efficient? Water use efficiency (WUE): is a term commonly used to describe the relationship between water (input) and agriculture product (output). When used in this way the term is strictly speaking a water use index. Water use efficiency is also often used to express the effectiveness of irrigation water delivery and use.

Irrigation productivity: is a measure of the economic or biophysical gain from the use of a unit of irrigation water in crop production and is expressed in productive crop units of kg/ha, kg/m3 or $/m3. As the name portrays, this is the product that is obtained from the irrigated crop to which the diverted water was planned for. Here we just consider our product from the irrigation process but do so in ways that capture the whole system of water use and re-use. We include irrigation products from drain water use and rice ratoon products if any, because they originated from irrigation. Benchmark water use efficiency looks at the total amount of water used to produce the yield (Irmak et al., 2011).

Productivity of water (PW): is a measure of the economic, livelihood or biophysical outputs derived from the use of a unit of water. Such outputs could be brick making, crop production, fishing, livestock watering etc. Units are jobs per m3, $/m3, total biomass (kg/m3) and families per command area etc. The productivity of water in an irrigation system is more than what comes from the intended or unintended products within the total command area i.e. water diverted for irrigation system can be used for many other uses e.g. domestic purposes, fishing, brick making etc. Water productivity is therefore a wider consideration of the products that come from the diverted water for the irrigation system.

Summary

Irrigation efficiency is measured using various terms that assess how effectively water is applied to the field and utilized by crops. High irrigation efficiency leads to reduced operating costs, better production per unit of water, and enhanced environmental benefits and management. However, improper use of efficiency terms can result in a misleading understanding of how well an irrigation system is functioning. It is crucial for both producers and irrigation management professionals to choose the appropriate efficiency and uniformity parameters when evaluating irrigation systems. Several adjustments to the volume of water applied can enhance irrigation efficiency and uniformity. However, achieving 100% efficiency is not always practical or desirable. The efficiency and uniformity indices discussed in this publication offer valuable measures for improving irrigation management, conserving water, and protecting environmental quality in irrigated agriculture

2.5.2 Determination of crop water requirement

Crop water requirement is defined here as "the depth of water needed to meet the water loss through evapotranspiration (ETc) of a disease-free crop, growing in large fields under non restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment". To calculate (ETc) a three-stage procedure is recommended and the procedures are presented as follows:

(1) The effect of climate on crop water requirements is given by the reference crop evapotranspiration (ETo): which is defined as "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". The four methods presented by the Blaney-Criddle, Radiation, Penman-Montieth and Pan Evaporation methods are modified to calculate (ETo) using the mean daily climatic data for 30- or 10-day periods. (ETo) is expressed in mm per day and represents the mean value over that period.

Primarily the choice of method must be based on the type of climatic data available and on the accuracy required in determining water needs. Climatic data needed for the different methods are concerning accuracy; only approximate possible errors can be given since no base-line type of climate data exists. The modified Penman method would offer the best results with minimum possible error of plus or minus 10 % in summer and up to 20 % under low evaporative conditions. Therefore, the researcher chooses the modified penman method in the crop water requirement (CWR) determination using CROPWAT 8.0.

(2) The effect of the crop characteristics on crop water requirements is given by the crop coefficient (kc): which presents the relationship between reference (ETo) and crop evapotranspiration (ETc). Values of (kc) given in the FAO literature are shown to vary with the crop, its stage of growth, growing season and the prevailing weather conditions. (ETc) can be determined in mm per day as mean over the same 30- or 10-day periods.

(3) The effect of local conditions and agricultural practices on crop water requirements: includes the local effect of variations in climate over time, distance and altitude, size of fields, advection, soil water availability, salinity, method of irrigation and cultivation methods and practices for which local field data are required (soil type, TAW, infiltration rate, irrigation application efficiency, maximum rooting depth of the crop and initial soil moisture depletion fraction).

CROPWAT 8.0 model: is a computer program developed by FAO that can calculate crop and irrigation water requirements and irrigation scheduling from climate-soil-crop data (Swennenhuis et al., 2009). It is a DOS or Windows based decision support system designed as a tool to help agro-meteorologists, agronomists and irrigation engineers carry out standard calculations for evapotranspiration and crop water use studies particularly for the design and management of irrigation schemes.

The program allows the development of irrigation schedule for different management conditions and the calculation of water supply for different areas under different crops; specifically, it allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions and the assessment of production under rainfed conditions or deficit irrigation. Key outputs are reference evapotranspiration (ETo), crop water requirements, crop irrigation requirements and irrigation scheduling (Blum, 2005).
The features of the CROPWAT 8.0 model program include:

- Monthly, decade and daily input of climate data for calculation of (ETo).
- Monthly, decade and daily calculation of crop water requirements including crop coefficients and daily soil water balance.

Climate data:
Import data by using CLIMWAT2.0 FAO model, select near meteorology station or use from secondary data of the nearby meteorological station.
The meteorological data required for ETo (mm day^{-1}) computation are.

- Average minimum and maximum temperature monthly (Celsius degrees)
- Average Relative Humidity monthly (percentage)
- Average wind speed monthly (kilometer per day)

- Average sunshine (hours/day)
- Average solar radiation monthly, mega joule per square meter MJ/m2/day.
- Average ETO monthly, millimeters per day mm/day.

Rainfall Data:

Import rainfall and effective rainfall data by using CLIMWAT 2.0 FAO model or from the collected primary/secondary data.

Soil Data:

Import soil data using FAO's Harmonized world soil database viewer 1.2 (HWSD) model including Longitude and latitude data's or can use from the soil laboratory data's following the procedural soil analysis.

Then finally, the optimal required crop water/crop evapotranspiration demand was determined in the CROPWAT 8.0 model using equation (2) by Doorenbos and Pruitt (1977), presented as follows:

$$ETc = Kc \times ETo -------------------------------- \quad (2)$$

Where: Kc is the crop coefficient and ETo is the reference evapotranspiration computed using a previous day's daily weather variables as inputs using the Penman-Monteith model (Asare et al., 2012). The highest Kc values were found for mid-season, corresponding to the reproductive stage. As a result, the largest water consumption is expected to occur during this stage (Silta, 2011). The reference crop evapotranspiration (ETo) was determined in the CROPWAT 8.0 model using equation (3) by (FAO, 1998a), presented as follows:

$$ET\_o = (0.408\,\Delta\,(Rn - G) + \gamma\,(900/\,(T + 273))\,u2\,(e\_s - e\_a)\,)/(\,\Delta + \gamma\,(1 + 0.34\,u2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:

ET_o = Reference evapotranspiration (mm/day)

R_n = Net radiation at the crop surface (MJ/m2 per day)

G = Soil heat flux density (MJ/m2 per day)

T = Mean daily air temperature at 2 m height (°C)

u2 = Wind speed at 2 m height (m/sec)

e_s = Saturation vapor pressure (kPa)

e_a = Actual vapor pressure (kPa)

$e_s - e_a$ = Saturation vapor pressure deficit (kPa)

Δ = Slope of saturation vapor pressure curve at temperature T (kPa/°C)

γ = Psychrometric constant (kPa/°C)

The main shortcomings of irrigation models comprise a conceptual representation of the main irrigation system components including the groundwater and drainage systems and their interactions (Nicolas, 2002).

Description of reference crop evapotranspiration (ETo):

Based on comparative studies of reference evapotranspiration methods and recommendations from a panel of experts and researchers convened by FAO in 1990, the FAO Penman-Monteith equation has been widely adopted as the most accurate method for estimating evapotranspiration (Menzel et al., 2019). This method has been proven to reliably predict ETo across various locations and climates, and it is also applicable in data-scarce situations. Calculations can be performed using the CROPWAT model, as shown in equation (2). The required data includes monthly temperature (maximum and minimum), humidity, sunshine, and wind speed.

Description of crop evapotranspiration (ETc)

Estimating ET_c is crucial for determining the soil water balance and scheduling irrigation. ET_c is influenced by weather conditions and crop growth (Menzel et al., 2019). Specific irrigation events are considered in the estimation process. The procedures for estimating ET_c were first established by Doorenbos and Pruitt (1977) and further refined by Allen et al. (2020) through a series of recommended crop coefficient (Kc) values that allow the calculation of crop evapotranspiration from reference evapotranspiration (ET_o), as presented in equation (2). Crop evapotranspiration (ET_c) refers to the evapotranspiration of a disease-free crop, grown in large fields, well-supplied with water and nutrients. The updated crop coefficient values are provided by Allen et al. (2020).

2.5.3 Soil moisture content measurement

Soil serves as a reservoir of water for the use of plants. Soil moisture or soil water is expressed as % of water on oven dry basis either on weight basis or volume basis. The moisture % is generally expressed on weight basis. The moisture % on weight basis (Pw) can be converted into moisture % on volume basis (Pv) if bulk density (BD) of soil is known.

Materials required

Screw auger, aluminum moisture cans, plastic sheet, top pan balance and drying oven.

Total available water (TAW)

Soil water availability refers to the capacity of soil to retain water available to plants. After heavy rainfall or irrigation, the soil will drain until field capacity is reached. Field capacity (FC) is the amount of water that a well-drained soil should hold against gravitational forces or the amount of water remaining when downward drainage has markedly decreased. In the absence of water supply, the water content in the root zone decreases because of water uptake by the crop.

As water uptake progresses, the remaining water is held to the soil particles with greater force, lowering its potential energy and making it more difficult for the plant to extract it. Eventually, a point is reached where the crop can no longer extract the remaining water, and the water uptake becomes zero when a wilting point is reached. Wilting point is the water content at which plants will permanently wilt. As the water content above field capacity cannot be held against the forces of gravity and will drain and as the water content below wilting point cannot be extracted by plant roots, the total available water (TAW) in the root zone is the difference between the water content at field capacity and wilting point. Generally, TAW is the amount of water that a crop can extract from its root zone, and its magnitude depends on the type of soil and the rooting depth.

Readily available water (RAW)

Although water is theoretically available until the wilting point, crop water uptake is reduced well before wilting point is reached. Where the soil is sufficiently wet, the soil supplies water fast enough to meet the atmospheric demand of the crop and water uptake equals ETc. As the soil water content decreases, water becomes more strongly bound to the soil matrix and is more difficult to extract. When the soil water content drops below a threshold value, soil water can no longer be transported quickly enough towards the roots to respond to the transpiration demand and the crop begins to experience stress. The fraction of TAW that a crop can extract from the root zone without suffering water stress is the readily available soil water (RAW).

The fraction p is a function of the evaporation power of the atmosphere.

A numerical approximation for adjusting p for ETc rate is:

$$p = p\_Table + 0.04\,(5 - ETc) \qquad (4)$$

Where: the adjusted p is limited to $0.1 \leq p \leq 0.8$ and ETc is $mm\,day^{-1}$.

3. METHODS AND MATERIALS

3.1 Description of the study area

A) Location

Tigray is the northern most state of Ethiopia located between latitudes $12^0$15’N and $14^0$50’N and longitudes $36^0$27’E and $39^0$59’E. It is bounded in the north by Eritrea, to the west by Sudan and to east and south by Afar and Amhara regional states of Ethiopia respectively, (Fredu, 2008). According to the central statistical agency (CSA, 2007) of Ethiopia, Tigray has an estimated population of 4,565,000 of which 80.5 % are estimated to be rural inhabitants while 19.5 % are urban and according to (Tigray region BoFED, 2005) cited by (Misgina,2006), the region covers an area of 80,000 sq. km. The altitude of the region ranges from 500 to 3935 meters above sea level to result for 11.5% dega (highland), 40.5% woyna dega (temperate) and 48% Kola (lowland) agro ecologically and the average annual rainfall is between 650-980 mm.

Tigray is the northern most state of Ethiopia located between latitudes $12^0$15’N and $14^0$50’Nand longitudes $36^0$27’E and $39^0$59’E. It is bound in the north by Eritrea, to the west by Sudan and to east and south by Afar and Amhara regional states of Ethiopia, respectively (Fredu, 2008). The region has seven administrative zones: Western, Northwestern, Central; Eastern, southeastern, Southern zones and Mekelle zone with a total of 88 Woredas/ towns and 810 Kebelles/tabias where each tabia consists of small villages called Kushets (UN-OCHA, 2021).

The study area or Mai Gobo sand dam is found in the Mai Gobo kebele/tabia, Tewlehe kushet or specific watershed Endabagabat at a position of $55^0$19’20’’ latitude and $31^0$57’01’’ longitude and at an altitude of 1719 m above sea level, in the eastern zone of Tigray, Hawzen woreda. The study area is located around 20 km far from Hawzen town which is the capital town of the woreda and 112 km far from Mekelle.

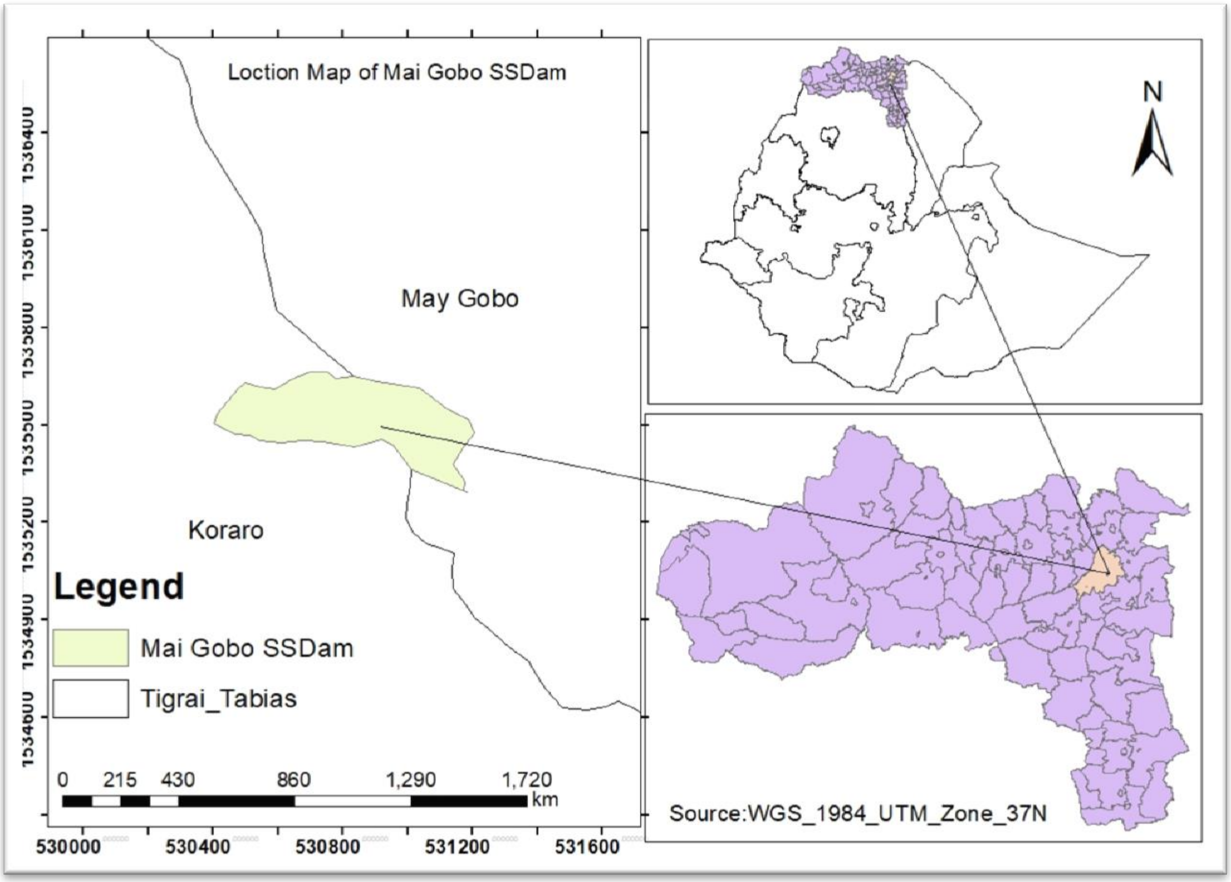

Figure 3.1: Location map of Mai Gobo sand dam SSI scheme

According to KOARD and WOARD secondary data's (2018), currently, the kebele has a total population of 2643 from this 1309 are male and 1334 female while the specific village/kushet/ tewlehe also has a total population of 656 of which 323 are male and 333 female and has total household heads of 135 out of these 94 male headed households and 41 female headed households. In addition, all the population in the kebele is rural inhabitants and the socio-economic condition of the community almost totally depends on both agriculture and livestock production activities.

B) The geographic and hydrologic condition of the study area

The irrigation scheme is in the Tekeze basin. The watershed drainages to the sand dam collect water from the sources of Gere'alta Mountains valley with little tree cover. The irrigation scheme is located along the right and left banks of the sand dam embankment, being exposed to an erosion problem severely. The size of the watershed is 437 ha. The weather condition of the kebele is kola and has an average annual rainfall of 450 mm (KOARD and WOARD, 2018). The sand dam was constructed in 2011 and currently has an irrigation potential of 15.5 ha with 31 beneficiary households out of those 30 are male and 1 is female headed households.

C) Climate

Concerning climate, the study area experiences nine months of dry season and three months of rainy season, most of its rain fall occurred from the middle of June to the middle of September. The average annual mean temperature of the study area is 20.15°C, with a minimum of 11.9°C and a maximum of 28.4°C (NMA/Mekelle branch, 2018).

D) Background of the beneficiary respondents

The background information of the beneficiary respondents and their irrigation experiences were analyzed using SPSS software. The findings from the respondents' background data are presented in Appendix I, Table 10, based on secondary data. The analysis of this data is detailed as follows:

Out of the total 15 respondents, 14 were male and 1 was female, making up 50% of the beneficiaries in the small-scale irrigation scheme. Regarding marital status, 13 respondents (86.7%) were married, 1 (6.7%) was divorced (female), and 1 (6.7%) was widowed. The average family size was 6, with a minimum of 2 and a maximum of 9 members. The average family dependency ratio was 2.5 (ranging from 0 to 5), and the average number of active labor force members per household was 3.42 (ranging from 2 to 6).

In terms of education, 60% of the household heads were able to read and write, 33.3% were illiterate, and 6.7% had completed high school or higher education. Regarding irrigation farming experience, 33.3% of respondents had less than 6 years of experience, 53.3% had 6-10 years, 6.7% had 11-20 years, and 6.7% had more than 20 years of experience. Finally, when asked about the number of irrigation seasons per year, 60% of respondents (9 in total) cultivated twice a year, while 40% (6 respondents) cultivated three times a year.

E) Land use and farming system

According to Hawzen woreda Finance and planning office (2018), the total coverage area 80,949ha from this cultivated land 16,272ha (20.1%), grazing land 61,479.25ha (75.94%), forest and bush land 3,197.75ha (3.95%) covers. Agriculture and livestock rearing are the main livelihoods of the woreda.

F) Rainfall

Rainfall is a major factor controlling the hydrology of the area. It is the main input of water to the earth's surface and for surface water potential analysis. The maximum and minimum monthly rainfall is obtained in August (181.4 mm) and December (1.2 mm) respectively (NMA/Mekelle branch, 2016-2017).

G) Temperature

The maximum air temperature occurs in June (30.5^{o}C), the minimum air temperature occurs in December (9^{o}C) and the mean annual temperature of the study area is 20.15^{o}C (NMA/Mekelle branch, 2016-2018)

3.2 Methods

3.2.1 Scheme characterization

Characterization of the irrigation scheme was conducted through field observations and pump discharge measurements. The primary irrigation method in the district is sand dams. The backwater effect of the sand dam extends approximately 1.5 kilometers upstream from the headwork. The sand dam has a width of about 75 meters at the tail and 25 meters at the head, with an average width of 50 meters. Following the construction of the sand dam in 2011, the groundwater table on both sides of the command areas rose up to 3 meters above ground level, providing a reliable source of irrigation. Since 2012, a total of 21 shallow wells (13 communal and 8 individual) have been constructed in the area, serving as irrigation sources.

All irrigators in the area utilize water pumps to draw water from shallow wells. The communal wells are situated at the center of the farm fields, while the individual wells are located at the borders and centers of the fields. Water is delivered directly to the farm inlet or edge through pump delivery hoses, which experience minimal leakage, making conveyance losses negligible.

Although a water user association exists in the area, with all users being members, the management of water from both communal and individual wells is handled by the users themselves. Water is delivered via pumps and hoses to the farm field inlets. The conveyance efficiency was calculated using equation (13) in section 3.2.4. Conveyance efficiency tests were conducted across 9 sample plots, and the overall conveyance efficiency (Ec) of the Mai-Gobo irrigation scheme was determined based on these measurements.

3.2.2 Experimentation and crop selection

Given the relatively small size of the irrigation area, which covers 15.5 hectares, the selection of experimental plots was based on crop type, irrigation season, and location. After conducting extensive field observations and discussions with farmers, leaders of the water user association, and Development Agents (DAs) in the kebele/tabia, more than 13 farmers who had prepared tomato seedlings for irrigation were initially identified. Following this, the farmers were informed about the research objectives and asked for their consent to participate. Once the farmers agreed, representatives with similar soil types, slopes, and crops were selected, with 9 plots chosen purposively 3 from the upper, 3 from the middle, and 3 from the lower end of the irrigation area. These plots were selected to evaluate irrigation system efficiency and water productivity at the field level, allowing comparisons based on water resource usage. Selection criteria included the location (head, middle, and tail), similarity in water management practices, crop type, soil type, slope, and the farmers' willingness to collaborate. As a result, a total of 9 tomato-growing farmers were chosen. The tomato variety Roma VF was chosen for the research area due to its high yield potential, promising average yield under local conditions, and relatively short growing season.

3.2.3 Data collection

The study was conducted on the dry season when crops were being cultivated under irrigation. The data collection work was conducted from early January to mid-June 2018. During the study period, regular visits and observations were made to assess the crop characteristics, management practices and method of water applications and practices related to water management at the experimental plots. Both primary and secondary data were collected.

A) Secondary data collection

Secondary data was collected from different sources, published and unpublished documents of respective offices and departments. Climatic data of the nearest station (Hawzen station) were collected from the national meteorological station Mekelle branch and other relevant data from Mai Gobo Kebele/babia Office of Agriculture and Rural Development and Hawzen woreda Office of Agriculture and Rural Development, Woreda Office of Water and Mine Energy and Finance and Economy Development. These secondary data were related to agricultural crops and livestock (type, productivity and market price), irrigation crops (potential, marketing, and productivity), water resource data, demography and different background data. These data were collected by the researcher on soft and hard copies during the study period.

B) Primary data collection

The primary data was obtained through field measurements and/or observations, laboratory analyses, individual interviews, focus group discussion and key informant interview which include field topography and configurations, soil data, irrigation delivery and structures, crop growth stages, data measuring and recording, irrigation phases and field irrigation method. To locate the boundary of the command area, the watershed and to show the experimental plots point data were taken through (GPS) at each experimental plots, watershed out let and at the boarder of the irrigation command areas and those point data were transferred to map source then be downloaded to global mapper and (GIS) software, and then digitized to locate the command area, experimental plots and the watershed within the boundary on Arc GIS. For the field measurements two technical assistants were employed by 1500 EBT for five months from January up to June. These assistants were selected considering educational level which were grade 10 and above, willingness and having relationship with the farmers and jobless collaborating with the researcher every field data was collected for the intended level and numbers.

1) Field survey

A topographic survey was conducted on each of the selected farmers' fields or experimental plots using the following procedures:

i) To determine the size of the experimental plots and the slope percentage, the plot size was calculated by multiplying the average length by the average width. The slope percentage was calculated using the formula: (vertical difference / horizontal difference) × 100. This was done by placing stakes at the four corners of the plots and measuring the elevation at each point using an engineer's line level.

ii) To assess the furrow slope percentage and uniformity in the direction of flow, additional stakes were placed 5 meters apart along the furrow, starting from the edge of the field or the inlet of the furrow. The same formula was used to calculate the slope percentage for each stake placement.

iii) To determine the productivity of the experimental plots growing Roma VF, an Open Pollinated Variety (OPV) of tomato, productivity measurements were taken after the crop had reached maturity and the tomatoes were harvested. The researcher used the zigzag method within a 1-meter square area, marking four points near the corners of the plot and one in the center with stakes. After collecting and weighing the tomatoes from each 1-meter square sample, the average weight of the five samples was calculated. This average weight represented the productivity in kg/m² for the experimental plot. To find the total productivity of the plot, the average weight was multiplied by the total farm size. This procedure was applied consistently across all experimental plots.

2) Soil characterization, sampling and analysis

Before going to the intended soil characterization the crop parameters were reviewed from the FAO literatures for the experimented plot crop type which was tomato (effective root zone, crop coefficient (Kc), crop yield response fraction (Ks) and growth stage lengths), but the main concern with the soil characterization was the effective root depth of tomato this was selected as according to Brouwer et al. (2001), which recommends as 50-100cm here for the overall experimental characterization the researcher used the maximum root depth of 100cm while the other crop parameters are explained under 3.2.5. This section focuses on the three soil characterization types, methods and procedures; **i**) for soil moisture holding capacity, **ii**) data for distribution uniformity and **iii**) actual soil moisture contents before and after irrigation in every event, the data collection procedure and analysis and the methodology used for each data collection and analysis are presented as follows.

I) Data for soil moisture holding capacity analysis

Composite disturbed and undisturbed soil samples were collected once from each test plot before the first irrigation was applied for land preparation. The composite disturbed soil samples were obtained using the zigzag method, collecting samples from near the four corners and the center of each plot at depths of 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, and 80-100 cm. Soil samples were taken using an auger at specified depths, and the soil was removed from the grooves of the auger and stored in plastic bags. An equal amount of soil from each pit and depth was mixed thoroughly, and about 100 grams of soil was selected for analysis of soil texture and pH.

Undisturbed soil samples were also collected from the center of each plot at the same root depths (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, and 80-100 cm) for analysis of bulk density, field capacity, permanent wilting point, and soil moisture content. To collect the undisturbed samples, a core sampler was used. After sampling, the core was immediately covered with a lid to prevent moisture loss. The wet soil sample was weighed on a digital pan balance directly on-site to minimize moisture evaporation, and the data was recorded. The samples were then transported to the soil laboratory at Mekelle University for further analysis.

II) Data for distribution uniformity

Undisturbed soil samples were collected through core samplers after 24 hours of each irrigation event at 10 sample pits/points along the furrow water flow directions in the furrows at the desired representative parts of the plots at (head, middle and tail end) from effective root zone of the crop in depth at four wetted soil layer (0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm). The same procedure was followed for each experimental field at each growth stage (three times at the initial, development, mid-stage and late season stages). The moisture contents of the soil layers were computed to determine the depth of water stored in the root zone. For calculating the distribution uniformity, the effective root depth of the crop was taken as the zone of distribution and the soil moisture depths at four wetted soil layers were summed and considered as one soil moisture depth in the effective root zone. At the initial stages, the samplings were taken from the bank sides of the furrow close to the plant.

III) Data for analysis of actual soil moisture contents before and after irrigation in every event

For this analysis, undisturbed soil samples were collected at an interval of 20 cm up to 100 cm depth using auger, both before and after each irrigation event across the 9 experimental fields. The same procedure used for undisturbed soil sample collection was consistently applied. The detailed procedures and methods used for soil moisture analysis are outlined below:

Gravimetric method

Soil serves as a reservoir of water for the use of plants. Soil moisture or soil water is expressed as % age on oven dry basis either on weight basis or volume basis.

The moisture %age is generally expressed on weight basis. The moisture percentage on weight basis (Pw) can be converted into moisture %age on volume basis (Pv) if bulk density (BD) of soil is known.

Materials

Screw auger, aluminum moisture cans, core sampler, cover lid, plastic sheet, top pan balance and drying oven.

Procedure

Soil samples (100gm) were collected from nine representative plots. The soil samples were placed in a container of known weight and then weighed. The samples were then placed in an oven for 24 hours at a temperature of 105^0C and the dry soil with the container were weighed again. Then, the soil water content was calculated using equations (3) (FAO,1989).

Take soil samples up to required depth at random in the plot. Avoid places of water logging like the corners of the plot. Draw the soil sample with an auger from the desired depth and remove it from the grooves of the auger on a plastic sheet. Select about 100 g of soil and transfer it to the moisture box quickly and cover it with its lid so that soil moisture is not lost through evaporation due to exposure for a long time but for this case the researcher used core sampler and weighed the samples automatically. Close the bore with soil and tap it with a metal rod. The hole after refilling must be at the same level as the rest of the soil surface.

While sampling in a crop, select the spot in a row between the two plants. During early seedling stage, take the sample as near the plant as possible (about 10 cm away from the plant). With the advanced age of crops the sample drawn at a point midway between the two rows.

Gravimetric method (in terms of weight)

Procedure

Soil samples weighing 100 grams were collected from nine representative plots. These samples were first placed in a container, weighed, and recorded. The samples were then placed in an open oven within the same container and reweighed after drying. The soil water content was determined using equation (3) (FAO, 1989).

Calculate the moisture percentage PW as:

$$PW = \left(\frac{W_{S1} - W_{S2}}{(W_{S2})}\right) \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (5)$$

Where:

PW = Moisture content by weight percentage (%)

W_{S1} = Weight of the wet soil sample (grams)

W_{S2} = Weight of the dry soil sample (grams)

Volumetric method (in terms of volume)

Materials - Sampling tube or a core sampler, moisture cans, lid, top pan balance and hot air oven.

Procedure

Take a sample of soil with a core sampler or a tube auger whose volume is known (VS_1). Weigh the sample in a moisture can (WS_1). Dry it in an oven to a constant weight at 105^0C (WS_2).

Calculate the moisture %age by the relationship as:

$$PV = ((W_{S1} - W_{S2}) / (DW \times V_{S1})) * 10 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where:

PV = Soil water content by volume (%)

W_{S1} = Weight of the wet soil sample (grams)

W_{S2} = Weight of the dry soil sample (grams)

DW = Density of water (g/cm^3)

V_{S1} = Volume of the core sampler (cm^3)

Texture

The textural analysis was done using hydrometric method. Then the soil textural classes were determined using USDA soil textural triangle (Bouyoucos, 1951 and Asadu, 1996).

pH measurement

The pH of the soil was measured potentiometrically in the supernatant suspension of a 1:1.5 soil-to-liquid mixture, following the method outlined by Staney and Bernard (1992).

Bulk density

The core soil samples were dried at 105 °C for 24 hours and the bulk density was calculated using the following equation.

$$BD = W_{S2}/V_{S1} \quad \text{..........} (7)$$

Where:

BD = Soil bulk density (g/cm3),

W_{S2} = Weight of dry soil (g), and

V_{S1} = Volume of core sampler (cm3)

Field capacity, permanent wilting point and Total available water determination

In the laboratory, soil samples were analyzed for field capacity (FC) and permanent wilting point (PWP) using pressure plate apparatus at 1/3 and 15 bar, respectively. The soil moisture content measurements before irrigation and one day after irrigation for this case (sandy soil) were made by gravimetric method which involves collecting soil samples with core sampler/auger, weighing the wet soil samples at site immediately and record, removing the water by drying in an oven dry at 105^0C and re-weighing the sample as dry weight to determine the amount of water removed. Soil samples were taken to the laboratory as the treatment numbers desire with their codes per each plot. For every nine plots, soil samples were taken before irrigation and after irrigation for every irrigation event from the desire root depth 0 - 20 cm, 20 – 40 cm, 40-60cm, and 60-80cm and 80-100cm soil layers per test pit. Different soil moisture content variables in each sample were determined on weight and volume basis as follows.

Field capacity (FC)

The field capacity is expressed as the ratio of the weight of water contained in the soil to the weight of the soil retaining that water.

$$FC = (weight\ of\ water\ retained\ in\ certain\ volume\ of\ soil)/(Weight\ of\ the\ same\ volume\ of\ soil) \ldots\ldots (8)$$

Moisture content at field capacity of the soil profile was determined using undisturbed soil samples taken through core sampler at depths of (0-20, 20-40, 40-60, 60 -80 and 80-100 cm). In determination of the moisture content at field capacity, first the soil sample was saturated for a day (24 hr) and a pressure plate was adjusted at the pressure of 1/3 bar. The pressure was exerted continually until no further release of soil moisture from the sample was observed. Then soil moisture content at field capacity was calculated as weight and volume basis as follows.

$$\Theta_{FC}\ (w/w) = ((W_{ws} - W_{ds})/(W_{ds})) \times 100 \ldots\ldots (9)$$

Where:

Θ_{FC} (w/w) = Soil moisture content on weight basis (%),

W_{ws} = Weight of the wet soil sample (g),

W_{ds} = Weight of the soil sample after oven drying (g) and then the moisture content of soil samples was converted to the volumetric water content (Θ_{FC}(v/v)) by multiplying with bulk density (BD) as:

$$\Theta_{FC}\ (v/v) = \Theta_{FC}\ (w/w) \times BD\ (g/cm3) \ldots\ldots (10)$$

Soil moisture content was also expressed in terms of equivalent ($_{mm/m}$) depth as:

$$Equivalent\ depth\ (mm/m) = 10 \times \Theta_{FC}\ (v/v)\ (\%) \ldots\ldots (11)$$

To change into equivalent depth available soil water in the root zone by (Allen et al., 1998),

$$FC\ (mm)\ =\ 1000\ \times\ \Theta\_FC\ \ (v/v)\ \times\ D \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

Where:

FC= Available water in the root zone (mm),

Θ_{FC} (v/v) =Moisture content at field capacity (m^3/m^3) in decimal, and

D= Root depth (m).

Moisture content in the effective root zone FC (mm) was determined as

$$FC\ (mm)\ =\ 1000 \sum_{i=0}^{n} (\Theta_{FC}\ \left(\frac{v}{v}\right)_i\ \ x\ D_i \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

Where:

FC = Total moisture content in the effective root zone (mm)

(ΘFC (v/v) i = Volumetric water content in the i^{th} soil layer (m3/m3)

Di = Depth of i^{th} soil layer (m)

n = number of soil layers in the root zone

Permanent wilting point (PWP)

The permanent wilting point is expressed as the ratio of the weight of water contained in the soil to the weight of the soil retaining that water.

$$PWP = \frac{Weight\ of\ water\ retained\ in\ certain\ volume\ of\ soil}{Weight\ of\ the\ same\ volume\ of\ soil} \ldots\ldots\ldots\ldots \quad (14)$$

Moisture content at permanent wilting point of the soil profile was determined using undisturbed soil samples taken through core sampler at depths of (0-20, 20-40, 40-60, 60-80 and 80-100 cms). In determination of the moisture content at permanent wilting point, first the soil sample was saturated for a day (24 hr.) and the pressure plate was adjusted at the pressure of 15 bars. The pressure was exerted continually until no further release of soil moisture from the sample was observed. Then soil moisture content at permanent wilting point was calculated as weight and volume basis as the same procedure as field capacity.

$$PWP\ (mm) = 1000 \sum_{i=0}^{n} (\Theta_{PWP} \left(\frac{v}{v}\right)_i x\, D_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (15)$$

Where:

PWP (mm) = the amount of water (in millimeters) at the permanent wilting point.

θ_{PWP} = the volumetric water content at the permanent wilting point (in volumetric ratio, v/v).

$(v/v)_i$ = the water content in the i th layer (in volumetric ratio).

D_i = the depth of the i^{th} soil layer.

Total available water (TAW)

The total available moisture (TAM) is the difference in moisture content of the soil between the Field Capacity (FC) and Permanent Wilting Point (PWP). Its amount is determined by the relationship between the Volumetric Soil Moisture Content (SMC), which represents the liquid phase in the soil volume, and the Soil Water Pressure (SWP) which is a measure of the metric forces by which the water is retained in the soil.

Total available water (TAW) was calculated using the following formula as:

$$TAW\ (mm\ /\ m) = 10(\Theta_{FC} - \Theta_{PWP}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Where:

θ_{FC} = Moisture content at Field Capacity (as a percentage by volume)

θ_{PWP} = Moisture content at Permanent Wilting Point (as a percentage by volume)

TAW = Total Available Water in the root zone (in mm/m)

Moisture content in the effective root zone TAW (mm) was determined using equation (6) by (Allen et al., 1998), presented as follows:

$$TAW\ (mm) = 1000 \times \sum_{i=0}^{n} (\Theta_{FC} - \Theta_{PWP})_i \times D_i \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(17)$$

Where:

TAW = Total moisture content in the effective root zone (in mm)

(θ_{FC}− θ_{PWP}) = Volumetric water content difference in the i^{th} soil layer (in m³/m³ or decimal)

Di = Depth of the i^{th} soil layer (in m)

n = Number of soil layers in the root zone

Readily available water (RAW)

The fraction of TAW that a crop can extract from the root zone without suffering water stress is the readily available soil water and can be expressed as:

$$RAW\ =\ p\,TAW\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ (18)$$

Where:

RAW = readily available soil water in the root zone (mm)

P = Average fraction of total available soil ater (TAW)

The factor p varies depending on the crop type. It typically ranges from 0.30 for shallow-rooted plants with high evapotranspiration rates (ETc > 8 mm/day) to 0.70 for deep-rooted plants with low evapotranspiration rates (ETc < 3 mm/day). A value of 0.50 for p is commonly used for many crops, but for tomatoes, the recommended value is 0.40 (Allen et al., 1998). According to Allen et al. (1998), the typical soil moisture characteristics for loamy sand soil include the following ranges for field capacity (FC), permanent wilting point (PWP), and total available water (TAW) in m³/m³: Θ_{FC} = 0.11–0.19, Θ_{PWP} = 0.03–0.10, and Θ_{TAW} = 0.06–0.12.

3) Actual stored moisture after irrigation (ASM)

The actual stored moisture after irrigation (ASM) in volume (m^3) or depth (mm) was the difference of the soil moisture content before irrigation and after irrigation in volume (m^3) or depth (mm). For this analysis, undisturbed soil samples were collected from the center of the experimental fields from the selected root depths of (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm) before and after 24 hours of every irrigation application event at all the 9 experimental plots following the same procedure explained for undisturbed soil sample collection procedure and analysis (2). The formula used to calculate the (ASM) was as follows:

$$\boldsymbol{ASM\ (mm) = 1000 \times \sum_{i=0}^{n} (\Theta_{AI} - \Theta_{BI})_i \times D_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{19})$$

Where:

ASM = the actual stored or retain water after irrigation (mm)

Θ_{AI} = the actual moisture after irrigation in volume (m3/m3)

Θ_{BI} = the actual moisture before irrigation in volume (m3/m3)

Di = depth of i^{th} soil layer (m)

The detailed procedures applied for the determination of soil moisture content before and after irrigation application were presented as follows:

Soil moisture content before irrigation (Db)

The moisture content before irrigation is expressed as the ratio of the weight of water contained in the soil to the weight of the soil retaining that water.

$$\boldsymbol{Db = \frac{weight\ of\ water\ retained\ in\ certain\ volume\ of\ soi}{Weight\ of\ the\ same\ volume\ of\ soil}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{20})$$

Moisture content before irrigation of the soil profile was determined using undisturbed soil samples taken through core sampler at the desired depths of (0-20, 20-40, 40-60, 60 -80 and 80-100cms). In determination of soil moisture content before irrigation, first weigh the wet soil sample (Wws) then removing the water by drying in an oven dry at 105^0C and re-weighing the sample (Wds) as dry weight to determine the amount of water removed. Then the calculation was as follows for weight and volume basis

$$\Theta_{BI} \ (w/w) = ((W_{ws} - W_{ds})/\ (W_{ds})) \times 100 \ldots\ldots (21)$$

Where:

Θ_{BI} (w/w) = Soil moisture content on weight basis (%)

W_{ws} = Weight of the wet soil sample (g)

W_{ds} = Weight of the soil sample after oven drying (g) and then the moisture content of soil samples was converted to the volumetric water content ϴBI (%) by multiplying with bulk density (BD) as:

$$\Theta_{BI} \ (v/v) = \Theta_{BI} \ (w/w)\ x\ BD \ldots\ldots (22)$$

To change into equivalent depth available soil water in the root zone (Allen et al., 1998)

$$Db\ (mm) = 1000 \times \Theta\_BI \ (v/v) \times D \ldots\ldots (23)$$

Where:

Db is available water before irrigation in the root zone (mm),

Θ_{BI} (v/v) is moisture content before irrigation (m3/m3) in decimal, and D is the root depth (m).

The soil moisture content in the effective root zone before irrigation (mm) was determined using equation (8) by (Allen et al., 1998), presented as follows:

$$Db(mm) = \sum_{i=0}^{n} (\theta_{BI} \ \left(\frac{v}{v}\right)_i \times D_i \ldots\ldots (24)$$

Where:

Db (mm) = Moisture content before irrigation in the effective root zone

(ϴBI (v/v) i = Volumetric water content before irrigation in the i^{th} soil layer ($m3m^{-3}$)

Di = Root depth of i^{th} soil layer (m)

n = Number of soil layers in the root zone

Soil moisture content after irrigation (Da)

The moisture content after irrigation is expressed as the ratio of the weight of water retained in the soil to the weight of the soil retaining that water.

$$\boldsymbol{Da} = \frac{\boldsymbol{weight\ of\ water\ retained\ in\ certain\ volume\ of\ soil}}{\textbf{Weight of the same volume of soil}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{25})$$

Moisture content after irrigation of the soil profile was determined using undisturbed soil samples taken through core sampler at the desire depths of (0-20, 20-40, 40-60, 60-80 and 80-100cms). In determination of the moisture content after irrigation, first weigh the wet soil sample (Wws) then removing the water by drying in an oven dry at 105^0C and re-weighing the sample (Wds) as dry weight to determine the amount of water removed. Then the calculation was as follows for weight and volume basis:

$$\Theta_{AI}\ (w/w) = ((W_{ws} - W_{ds})/(W_{ds})) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (26)$$

Where:

Θ_{AI} (w/w) = Moisture content on weight basis (%)

W_{ws} = Weight of the wet soil sample (g),

W_{ds} = Weight of the soil sample after oven drying (g), and then the moisture content of soil samples was converted to the volumetric water content ϴAI (m3/m3) by multiplying with bulk density (BD) as:

$$\Theta_{AI}\ (v/v) = \Theta_{AI}\ (w/w) \times BD \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (27)$$

Soil moisture content was also expressed in terms of equivalent (mm/m) depth as:

$$Equivalent\ depth\ (mm/m) = 10 \times \Theta_{AI}\ (\%) \ldots\ldots (28)$$

To change into equivalent depth available soil water in the root zone (Allen et al., 1998)

$$Da\ (mm) = 1000 \times \Theta_{AI}\ (v/v) \times D \ldots\ldots (29)$$

Where:

Da = Available water after irrigation in the root zone (mm),

Θ_{AI} (v/v) = Moisture content after irrigation (m3/m3) in decimal, and

D = Root depth (m).

The soil moisture content in the effective root zone after irrigation (mm) was determined using equations (9) by (Allen et al., 1998), presented as follows:

$$Da\ (mm) = 1000 \sum_{i=0}^{n} (\Theta_{AI} \left(\frac{v}{v}\right)_i \times D_i \ldots\ldots (30)$$

Where:

Da (mm) = Moisture content in depth after irrigation in the effective root zone

(Θ_{AI} (v/v) i = Volumetric water content after irrigation in the i^{th} soil layer (m3/m3)

D_i = Depth of i^{th} soil layer (m)

n =Number of soil layers in the root zone

Potential soil moisture storage /Actual soil moisture depletion/

The potential soil moisture storage depth which is equal to the actual allowable depletion depth in the selected fields just before the time of irrigation was computed (Walker and Skoerboe, 1987) as follows

$$SMD\ (mm/m) = 10 \times (\Theta_{FC} - \Theta_{BI}) \ \ldots\ldots (31)$$

Where:

SMD = Actual soil moisture depletion at the time of irrigation and it is the maximum amount of water which can be stored in the root zone now of irrigation without deep percolation loss,

ΘFC and ΘPWP = are soil moisture contents in % volume at FC, PWP and ΘBI = is soil moisture content in % volume before irrigation.

The potential soil moisture storage depth (mm) which is equal to the actual allowable depletion depth in the selected fields just before the time of irrigation was computed as follows:

$$SMD\ (mm) = 1000 \times (\Theta_{FC} - \Theta_{BI}) \times D \ \ldots\ldots (32)$$

The actual allowable depletion depth or potential soil moisture storage in the effective root zone before the time of irrigation was computed using equation (10) by (Walker and Skoerboe, 1987), presented as follows:

$$SMD\ (mm) = 1000 \times \sum_{i-0}^{n} (\theta_{Fc} - \theta_{BI})_i \times D_i \ \ldots\ldots (33)$$

Where:

Θ_{FC} = Soil moisture content of the ith soil layer in (m^3/m^3) in decimal at

FC, Θ_{BI} = Soil moisture content of the ith soil layer in (m3/m3) in decimal before irrigation

Di = Depth of ith soil layer.

The actual soil moisture depletion fraction (P) at the time of irrigation was computed using equation 11 as follows:

$$P = ((\Theta_{FC} - \Theta_{BI})) / ((\Theta_{FC} - \Theta_{PWP})) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (34)$$

Where:

Θ_{FC} and Θ_{PWP} = Soil moisture contents in % volume at FC, PWP and

Θ_{BI} = Soil moisture content in % volume before irrigation and compared with the literature value depletion fraction (p) for the crop growth stages which was computed by numerical approximation for adjusting Table value for (ETc ≠ 5 mm/day) using equation by (Allen et al., 1998), presented as follows:

$$P = P\,table + 0.04\,(5 - ETc) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (35)$$

Where:

P= table is the recommended P value equal to 0.40 for tomato (ET_c = 5mm/day) (Allen et al., 1998).

Determination of deep percolation ratio (DPR)

One of the frequent field observation activities was on the furrow characteristics as the observation the furrow were closed end, so the runoff ratio was neglected. The only loss on the irrigation system was through deep percolation. This can express as the ratio between the percolated water beyond the root zone to the volume of water applied to the field. Another possibility of loss was the evaporation from the soil, since the evaluation period was after 24 hours the loss was marginal and can be neglected. Therefore, deep percolation ratio was calculated for each test plot and average experimental locations as:

$$DPR = 100 - Ea \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. (36)$$

Where:

DPR = Deep percolation ratio in (%),

Ea = Application efficiency in (%)

4) Yield data collection

To assess the overall impact of irrigation water and crop water productivity performance parameters on yield, the yield of tomato was estimated using well known sampling procedure, which was zigzag method, the procedure was select five locations having size of one m^2 one at the center and four near to the four corners of the experimental fields.

The products on each m^2 were collected and weight, then summed and divided into the number of samples to know the average product per m^2 on the experimental field. Ones the average product per m^2 of the field was known to be multiplying by the field area gives the total product of the experimental field in Kg m^{-2} or Kg ha^{-1} then can conduct the water productivity analysis. The same procedures follow for each test plots. According to FAO (2012), a good commercial tomato fresh fruit yield ranges from 60 to 120 tone ha^{-1} for processing and up to more than 150 tone ha^{-1} for fresh market cultivars.

3.2.4 Field irrigation performance indicators

Irrigation performance evaluation analysis was conducted using irrigation efficiency indicators. The irrigation system evaluations were made for the following indicators; namely, conveyance efficiency, application efficiency, water storage efficiency, irrigation efficiency and overall irrigation efficiency. Additionally, the distribution uniformity and water supply efficiency were also evaluated.

A) Conveyance efficiency estimation

The conveyance efficiency estimation was investigated using equations (13) by (Irmak et al., 2011), presented as follows:

$$Ec = \left(\frac{Vf}{Vt}\right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (37)$$

Where:

Ec = Water conveyance efficiency (%)

Vf = Volume of irrigation water that reaches the farm or field (m3)

Vt = Volume of irrigation water diverted from the water source (m3)

Conveyance efficiencies were observed in every experiment plot and every irrigation event, though water deliveries were through hoses conveyance losses were negligible.

B) Estimation of water application efficiency

The applied irrigation water to the fields was calculated using equation (27) presented below.

The irrigation application efficiency of each field was calculated using equation (14) by (Irmak et al., 2011), presented as follows:

$$Ea = (Vs/Vf) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (38)$$

Where:

Ea = Water application efficiency (%)

Vs = Volume of irrigation water stored in the root zone (m3)

Vf = Volume of irrigation water delivered to the farm or field (m3)

The depth of water applied to the field was estimated by dividing the volume of water applied to the field by the area irrigated as equation (23) below. The depth of water retained in the effective root zone was calculated using equation (15) by (Allen et al., 1998), presented as follows:

$$Zr = 10\sum_{i=0}^{n}(\theta_{AI} - \theta_{BI})_i \times D_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (39)$$

Where:

Zr = Depth of water retained into effective root zone of the soil (mm),

θ_{BI} and θ_{AI} = Moisture content of the i^{th} soil layers before and after irrigation on oven dry volume basis (%) respectively,

Di = Depth of i^{th} soil layers of the root zone (m).

n = Number of soil layers in the root zone.

According to FAO (1989), Reported that the attainable application efficiency according to the US (soil conservation science) ranges from 55% - 70%, value below this limit would normally be considered unacceptable while in ICID/ILRI this value is about 57%. In general, according to

Michael (1997), water application efficiency decreases as the amount of water applied during each irrigation increases.

C) Estimation of water storage efficiency (Es)

The depth of water retained in the soil compartments of the effective root zone was computed using equation 15 above and the depth of water needed in the effective root zone prior to irrigation/actual soil moisture depletion/ in depth was estimated by equation (16) given by (Allen et al., 1998), presented as follow:

$$Wn = 10\sum_{i=0}^{n}(\theta_{FC} - \theta_{BI})_i \times D_i \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (40)$$

Where:

Wn = Depth of water needed in the effective root zone prior to irrigation (mm),

Θ_{FC} and Θ_{BI} = Soil moisture contents at field capacity and before irrigation of the i^{th} soil layers in volume (%) respectively, and

Di = Depth of soil profile in i^{th} root zone (m).

Then the soil water storage efficiency of the fields was calculated using equation (17) given by (Irmak et al., 2011), presented as follows:

$$Es = ((Vs \,/\, (Vfc - Vb)) * 100 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (41)$$

Where:

Es = Soil water storage efficiency (%)

Vs = Volume of water stored in the soil root zone from an irrigation event (m3)

Vfc = Volume at field capacity in the crop root zone (m3)

Vb = Volume of water in the soil root zone prior to an irrigation event (m3)

Which can also calculate as: (Zr/Wn) *100 or by converting the depth of water in to volume multiplying the depth by the sizes of fields. According to FAO (1989), it reported that the effectiveness of stored soil water might be between 40% - 90%.

D) Irrigation efficiency (Ei)

Irrigation efficiency is the ratio of the amount of water consumed by the crop to the amount of water supplied through irrigation (surface, sprinkler or drip irrigation). First the consumptive uses were simulated from the CROPWAT 8.0 model then irrigation efficiency was calculated using equation (18) given by (Irmak et al., 2011), presented as follows:

$$Ei = \left(\frac{ETb}{Vf}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (42)$$

Where:

Ei = Irrigation efficiency (%)

ET_b = Volume of water beneficially used (m3)

Vf = Volume of water delivered to the field (m3)

E) Overall irrigation efficiency (Eo)

The overall irrigation efficiency (Eo) represents the efficiency of the entire pHysical system and operating decisions in delivering irrigation water from a water supply source to the target crop (Irmak et al., 2011). It was calculated by multiplying the efficiencies of water conveyance and water application efficiency using equation (19) given by (Irmak et al., 2011), presented as follows:

$$Eo = (Ec \times Ea) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (43)$$

Where: Eo = Overall irrigation efficiency (%)

Ec = Water conveyance efficiency (decimal)

Ea = Water application efficiency (decimal)

According to Brouwer et al. (2001), reported that Eo 50 – 60 % is good, 40 % is reasonable while 20 – 30 % is poor for furrow irrigation system.

F) Distribution of uniformity efficiency

All irrigation systems apply waters uniformly to a varying degree. The irrigation system performance efficiency terms described previously do not directly account for the uniformity or non-uniformity of irrigation application within a given field. Yet, the non-uniformity of the applied water can significantly affect irrigation performance. The lower-quarter distribution uniformity was calculated using equation (20) given by (Irmak et al., 2011), presented as follows:

$$D\,U\; = \left(\frac{Dlq}{Dav}\right) x\; 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (44)$$

Where:

DU = distribution uniformity (%)

Dlq = average depth of water infiltrated in the low one quarter of the field (mm)

Dav = average depth of water infiltrated over the field (mm)

The Christiansen uniformity coefficient was also evaluated by calculating using equation (21) given by (Jurriens et al., 2001), presented as follows:

$$CU = 100\left(1 - \frac{\sum_{i-1}^{n}|d|}{nX}\right)\; d = X_i - \ddot{X} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (45)$$

Where:

Cu = Christensen's uniformity coefficient (%)

d = Deviation of observation from the mean (cm)

n = Number of observations

$\ddot{X}$ = Average depth infiltrated (cm)

Xi = Depth of infiltrated at observation point i (cm)

A low DU (<60%) indicates that the irrigation water is unevenly distributed, while a high DU (<80%) indicates that the application is relatively uniform over the entire field (Irmak et al., 2011).

G) Water supply analysis

The relative irrigation supply (RIS) estimation was investigated using equation (22) given by (Perry, 1996) presented as follows:

$$Relative\ irrigation\ supply = ((Total\ irrigation\ supply\ )/(\ Irrigation\ demand))/(\ Irrigation\ demand) \ldots\ldots (46)$$

Where:

Irrigation supply = only the surface diversions and net groundwater draft for irrigation

Irrigation demand = the crop ET less effective rainfall

Both RWS and RIS gave some indications about the water abundance or scarcity and the ratio of supply to demand (Molden et al., 1998), since there is no rain no need to talk about relative water supply.

The water delivery capacity (WDC) estimation was investigated using equation (23) given by (Molden et al., 1998), presented as follows:

$$WDC = (Canal\ capacity\ to\ deliver\ water\ at\ the\ system\ head)/(Peak\ consumptive\ demand) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (47)$$

Where:

Canal Capacity to deliver water at the system head = the present discharge capacity of the canal at the system head, and Peak consumptive demand = the peak crop irrigation requirement for a monthly period expressed as a flow rate at the head of the irrigation system.

According to Molden et al. (1998), Values much greater than 1 indicate that their capacity is not a constraint to meeting crop water demands. Values close to 1 indicate that there may be difficulties meeting short-term peak demands from the scheme.

3.2.5 Irrigation water demand and supply per growth stages analysis

Demand irrigation water requirement and actual water supplied according to the farmers thought were analyzed per experimental test plots growth stages, the tomato growth season was determined by field observation was used crop height, leaf color, leaf size, flowering and fruit stage. Then summarized to show the difference on each of the three strata's (head, middle and tail end) of the experimental scheme. Since there was no rain during the cropping season so water supply was only irrigation water. The technical procedures followed to make that analysis were presented as follows:

First determine the required input data to run CROPWAT 8.0 model as explained under the next section in determination of demand irrigation water requirement.

Second, from the CROPWAT 8.0 model, calculate the net and gross IWRs and other necessary data like: - (ETo) (mm/day), (ETc) (mm/day), (ETc) (mm/dec) and the irrigation schedule (flow l/s/ha, irrigation interval in days and number of application times) each growth stages.

Third, calculate the average discharge rate of the water supply sources based on pump delivery hoses capacity (lit/sec). Fourth calculate the actual delivered volume (m^3) of water at the water source and farm inlet/edge for every irrigation event of each experimental fields. The number of irrigation applications per each growth stage was identified and recorded. Fifth determine the actual stored soil moisture (ASM) in volume (m^3) and depth (mm) on every irrigation event of each field per each growth stages following the same procedure explained for actual stored soil moisture after irrigation application (3), and the calculation was made using equation (7). The detailed procedure followed was as follows:

1) Determination of demand irrigation water requirement (IWR)

Determination of crop/irrigation water requirements was needed to know how much of the applied irrigation water was consumed by the crop. The irrigation water requirement (IWR) of the experimental crop tomato was estimated using CROPWAT 8.0 windows computer program. The determination of (IWR) by the model depends on the determination of the reference evapotranspiration (ETo) value using the available climatic data, altitude, latitude and longitude. The twelve years mean monthly climate data was taken from the nearest meteorological station (Hawzen) as (Appendix I. table 1) and the altitude, latitude and longitude were taken by the researcher using toposheet for altitude and geographical positioning system (GPS) for latitude and longitude.

The other relevant data's for CROPWAT 8.0 model including growth stages and stage lengths (days) determination, total growth length (days) and planting date were determine by the researcher through field survey and observation, depletion level (P) in fraction, total available water (TAW) and soil texture were determine in the soil laboratory following the same procedure explained for soil characterization, sampling and analysis (2), and crop coefficients (Kc), effective root depth (Zr), yield response factors (Ky), irrigation application efficiency (Ea) in % and maximum rain infiltration rate in mm/day were obtained from FAO guidelines (Allen et al., 1998, FOA, 1989 and Brouwer et al., 2001), and feed to CROPWAT 8.0 model. The irrigation water requirement (IWR) was computed by the CROPWAT model using the water budget equation as follows:

$$IWR = ETc - Pef \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 48$$

Where:

ETc = Crop evapotranspiration (mm/season), and Peff was effective rainfall (mm/season) in this case Peff = 0, so IWR = ETc. For the demand and supply analysis the reference crop evapotranspiration of tomato in a daily basis (mm/day) were estimated, demand IWR/ETc (mm) for each growth stages were calculated using equation (24) for each experimental plot.

$$IWR/ETc = ETo \times Kc \times stage\ length\ days \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (49)$$

Where:

IWR = irrigation water requirement (mm/days)

ETo = reference crop evapotranspiration (mm/day)

Kc = crop coefficient unit less

The net irrigation requirement was determined using equation 25 for each experimental plot as:

$$IR_{net} = IR \times A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (50)$$

Where:

IR_{net} = net irrigation requirement (m^3), and the gross irrigation requirement was also determined using equation 26 for each experimental plot as:

$$IR_{gross} \;=\; (IR_{net})/Eo \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(51)$$

Where:

IRgross = Gross irrigation requirement (m^3) and

Eo = Over all irrigation efficiency.

The scheduling criteria would apply available soil moisture of TAM at the time of sowing and refilling the crop root zone to field capacity. Finally, the decadal gross irrigation water requirement (IRg) of the scheme would be determined by considering the area coverage, the irrigation efficiency and the daily operation hours of the irrigation scheme. After determining the net and gross water demand for each growth stage of each test plots, the next procedure was to determine the net and gross water supplied by the farmers of each test plots per growth stages. According to FAO (2012), processing tomato consumes 400 - 800 mm of water from emergence/transplanting to harvest, depending on climate, plant type, soil, irrigation and crop management and over the peak growing period, max water use averages 4-7 mm/day in a sub-humid climate, but can reach 8-9 mm/day in more arid areas. The life cycle varies from 95-115 days for processing tomatoes or up to more than 145 days for undetermined fresh market tomato.

The main irrigation application scheduling criteria used in the CROPWAT 8.0 software were as follows:

- **Irrigation application**: refill soil to field capacity
- **Irrigation timing**: irrigate at fixed interval per stage, the fixed interval was as follow: initial stage 3, development stage 5, mid-stage 5 and late stage 6.
- **Field efficiency**: used from the practical field application efficiency on the experimental scheme (72%)

Cropping season: of the three experimental locations was the same from 2, Feb - 27, May/2018.

2) Irrigation water supply determination

Flow measurement was made through intensive water application discharge rate sampling of the different pumps delivery hoses at different power accelerators (maximum, medium and low level) since the pumps had similar discharge capacity/ horsepower/ and the same delivery hose diameter the average values of the tested sample discharge rates were decided as average discharge rate of the pumps in (liter/second). This was done on the field before the test plots water application data collection began.

The same procedure was applied on each of the three power accelerators, the technical procedures were as follows: first prepared circular water tanker having capacity up to 70 liters then turn on the pump on the desire power accelerator after discharge began the water filled in to the water tanker. Immediately the time taken to fill the tanker was recorded using stopwatch. Then, the water in the tanker was converted into volume (m^3) and using conversion factor change the volume (m3) of water into liter. Finally, the discharge rate (lit/sec) was found by dividing the pumped water in liter by the time (sec) taken to fill the tank. Since the average discharge rate in (lit/sec) of the hoses were calculated then to know the supplied volume of water per each field, the farmers' water application time were recorded on every irrigation event using stopwatch on the time of cut-on and cut-off time. Irrigation application continued until the farmers felt that enough water was applied to their fields in every irrigation event. When the irrigator completes irrigating the test plot, the time difference between the cut-on and cut-off was recorded in every irrigation event and the same procedures were followed for every test plot. The applied discharge amount and the depth of water applied were computed as follows:

$$Q \ = (Q\_av \ \times \ T\_app)/1000 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (52)$$

Where:

Q = Discharge in m^3

Q_{av} = Average discharge rate in lit/sec

T_{app} = Application time in sec

The amount of inflow depth (D) applied over the entire area was computed as follows:

$$D \ = (Qav \ \times \ Tapp)/A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (53)$$

Where:

D = depth of water applied (mm)

A = entire area over which water is applied (m^2)

T_{app} = application time for the entire area (sec)

Q_{av} = discharge rate in (lit/sec)

The depth/volume of water applied at the water source and the actual stored soil moisture after irrigation in (%) or volume were determined from the water supply and considered as the gross and net water supply respectively, per each growth stages. Then finally, analyze the demand (IWR) and water supply difference per each growth stage. This was expressed as gross supplied water - demand gross (IWR) gives the difference, if positive shows over application, if negative the inverse. The final demand versus supply analysis was presented in percent (%) as the difference/demand (IWR) times 100 which indicate the ratio of over/under application to the demand (IWR) per each growth stages.

3.2.6 Irrigation water productivity at farm level

Irrigation system performance, irrigation distribution uniformity and water supply parameters were discussed previously to evaluate the engineering and operational aspects of the irrigation system. Internal and external performance indicator parameters were used to evaluate the irrigation water productivity. Results of all water productivity values would be expressed in physical (kg/m^3) and economic (ETB/m^3) terms. The procedures following to do this determination were as follows:

i. Calculate the applied total irrigation water in volume (m^3) of each experimental field per growth stages using equation 27,
ii. Calculate the harvested yield (Kg) following recommended sampling procedure and the same procedure explained for yield data collection (4).
iii. Determine the net and gross crop water demand (m^3/season) and the actual crop consumptive use (ETa in m^3/season) using CROPWAT 8.0 model per each growth stages as explained in determination of demand (IWR) (3.2.5).

iv. Finally, calculate the internal and external productivity indicators. The external productivity performance indicator types were output per cropped area (ETB/ha) and output per unit of water consumed (ETB/m^3). Other pertinent data like crop farm gate market price and crop local market price at the nearby towns of qoraro and Hawzen were collected from district and woreda offices of agriculture and rural developments. The internal irrigation water productivity performance indicators determinations were computed using equations as follows:

Crop water use efficiency (CWUE): **-** crop water use efficiency (kg/m^3) was calculated using equation (29) by (Irmak et al., 2011), presented as follows:

$$CWU\_E = Yi/(ETc) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (54)$$

Where: CWU_E = crop water uses efficiency (kg m^{-3})

Yi = yield of the irrigated crop (kg ha^{-1})

ETc = ET for irrigated crops (m3 ha^{-1})

Irrigation water use efficiency (IWUE): IWUE in Kg/m^3 was calculated using equation (30) by (Irmak et al., 2011), presented as follows:

$$IWUE = Yi/IRg \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (55)$$

Where:

IWU_E = Irrigation water uses efficiency (kg m^{-3})

Yi = Economic yield of the irrigation level crop (kg ha^{-1})

IRg = Depth of irrigation water applied for irrigation (m3 ha^{-1})

Water use efficiency: - under this title there are three pertinent performance issues such as the benchmark water use efficiency (WUE_b) in kg/m^3, irrigation water productivity (IWP) in kg/m3 or ETB/m^3 and economic water productivity (EWP) in ETB/m^3. Therefore, the calculations used to determine these performance indicators were computed using equations (31-33) by (Irmak et al., 2011), presented as follows:

$$WUEb = Yi/(IRg) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (56)$$

Where:

WUE_b = Benchmark water use efficiency (kg m^{-3})

Yi = Yield of irrigated crop (kg ha^{-1})

IRg = Total irrigation applied (m3 ha^{-1})

$$IWP = Yi/ETc \quad or \quad (Yi \times \alpha)/(ETc) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (57)$$

Where:

IWP = water irrigation productivity (kg m^{-3}or ETB m^{-3})

Yi = actual harvestable yield (Kg),

α = monetary value of harvestable yield (ETB kg^{-1}),

ETc = crop evapotranspiration in mm or m^3.

$$EWP = (SGVP)/(Volume\ of\ supplied\ irrigation\ water) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (58)$$

Where:

EWP = Economic Water Productivity (ETB/m3)

The external performance indicators determination was computed using equations as follows:

$$Output\ per\ cropped\ area\ (ETB/m2) = (SGVP)/(Irrigated\ crop\ land) \ldots\ldots\ldots\ldots. (59)$$

$$Output\ per\ unit\ of\ water\ consumed\ (ETB/m3) = SGVP/(Volume\ of\ water\ consumed\ by\ ET)..(60)$$

Where:

SGVP = Standard Gross Value of Production

The denominator of equation 31 was a surrogate estimate for the water used to produce yield. It neglects deep percolation losses, groundwater use, and surface runoff. Experienced irrigation practitioners use (WUE_b) for a specific region and to identify differences between irrigation methods, irrigation management, or both. According to Batticani (2006), cited in FAO (2012), tomato water productivity for biomass (Kg/ET) ranges from 1.3 to 3.5 Kg/m^3, with 3 Kg/m^3 being considered as common for favorable conditions & practices and the low end of the range is likely observed in climates of high evaporative demand, as well as where frequent wetting of exposed soil surface by rain or irrigation.

3.2.7 Evaluating the contribution of the SSI scheme to HH's net income generation

The irrigation scheme net income contributions to the irrigators were evaluated considering the yearly net income gained of the beneficiaries before and after irrigation following the development of the SS dam scheme. The method and procedures used to collect and analyze the data were as follows: Both primary and secondary data collection methods were used. The data were quantitative and qualitative types, the data collecting procedure and methodology were as follows: sampling methods were two types, first select the irrigation scheme purposively considering the research gap and the sponsorship opportunity and then the objectives of the project development plan in the area were discussed with the project organizer Mekelle university institute of water and Environment.

Second the beneficiary selection was made using stratified sampling. Then with DAs and water user association leaders identified the beneficiary population and determined representative sample sizes following well known procedure and representative sampling formulas as equation (36).

Third, prepared questionnaires (Appendix II)), (structured and semi –structured questionnaires) were used for key informant interview of WUA, DA and woreda experts) while structured questionnaires were used for the individual beneficiary's interview. Fourth conduct all the interviews and make consecutive observations using structured checklist to insight the delivered information and record. Fifth Collected pertinent secondary data from woreda and district offices of agriculture and rural developments mainly focusing on the crops, fruits, vegetables and livestock.

The collected information data types were of types, product and productivity and marketing of products before and after the irrigation scheme. Other data such as the irrigated area per crop type per season, irrigation intervals per crop, number of irrigation seasons, total yield expected per crop per hectare, farm gate prices of each crop, local price of each cultivated crop from offices and informal information from beneficiaries, consumers and traders which helps to calculate the net income were also collected. Sixth data arrangement, multiplying, adding, subtracting and dividing were made to gate the gross and net income of the beneficiaries per year before and after the development of the irrigation scheme. Finally, the data analysis was made using excel work sheet and a single factor analysis of variance (one way ANOVA).

The methodology used to collect and analyzed the data was, for the data collection process the researcher was conducted all the interviews briefing the objective of the study with a great respecting to the interviewees from February - mid June/2018 and the data analysis also made by the researcher after all pertinent data were collected using excel work sheet and SPSS software from June – July/2018.

Economic Analysis

For the three experimental locations (head, middle and tail end) of the small-scale irrigation scheme an efficiency analysis was made systematically to compare yield which would be produced with the total production cost. The basis for estimating the total income was the yield, which produced from volume of applied depth of water and the unit price that farmers were likely to obtain, considering the seasonal and the local market conditions. Multiplying the harvested yield with the estimated unit price gave the estimated gross income. The net contribution (net benefits) of a project to farmers was determined by subtracting total production costs from the gross benefits gained from the sale of tomato yield. The total production costs were prices of (inputs, labor, transport and fuels and lubricants). Economic efficiency was then found by dividing net benefits to the total production cost. Finally, the three experimental locations were compared to each other.

3.2.8 Assessing the main challenges and opportunities of the SSI scheme

Here the method and data type used were primary data and qualitative data types. The procedures used to collect and analyze the data were the same as the above procedures under 3.2.7. The only difference here was the primary data collection method and qualitative data type was used to assess the main challenges and opportunities of irrigation development, and the analysis was made using a single factor analysis of variance (one way ANOVA) only. The sampling method and beneficiary selection used to represent the scheme in both objectives data collection was as follows:

For both objectives of the study. The researcher used a stratified random sampling method to select the farmers for the survey. This sampling method was quite accurate and allowed the comparative analysis of farmers' perception according to different groups of interest, providing more information for this purpose than other sampling methods. The command area of the irrigation scheme of Mai Gobo was divided into three strata purposively, upstream (head-end farmers), middle (middle farmers) and downstream (tail-end farmers) users. According to the well-known random sampling formula farmers would be interviewed from each stratum and within it randomly selected.

Stratified Sampling was possible when it makes sense to partition the population into groups based on a factor that may influence the variable that was being measured. Stratified sampling works best when a heterogeneous population is split into homogeneous groups. Under these conditions, stratification generally produces more precise estimates of the population %s than estimates that would be found from a simple random sample. Therefore, to select the sample households, the equation 36 by Taro (1967), was applied.

$$n = \frac{N}{1+N\,(e)^{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(61)}$$

Where:

n = Number of required samples for each irrigation group (sample size),

N = Total population size (number of household owners) in each irrigation group.

e = Confidence level (0.50 (50%) level of precision); since the number of beneficiaries was small (31 farmers) the researcher uses confidence level of 50%. The number of sample respondents was 15.

3.2.9 Methods of data analysis

Both quantitative and descriptive analysis techniques were employed for data analysis. Data collected through household questionnaires were analyzed using Statistical Package for Social Science (SPSS) software. Descriptive statistical methods, including frequency, percentage, mean, and standard deviation, were used to analyze the questionnaire data. Crop water demand, supply, permanent wilting point, available soil moisture, total available soil moisture, bulk density, soil pH, electrical conductivity, and water pH were analyzed using the CROPWAT model, along with discharge measurements from the diesel pump, soil tests, and irrigation water tests.

For the analysis of text and narrative data, the collected information was categorized into study themes and analyzed qualitatively through descriptions or narratives. Content analysis was also used to compare the provisions outlined in the scheme's bylaws and assess the agreements concerning the transfer of ownership from the government to the users. The quantitative results from descriptive statistics and interviews were utilized to support the qualitative findings.

3.3 Materials/tools and equipment

- Geographical position system (GPS)
- Tape meter
- Soil sampling apparatus and lab
- Digital pan balance

4. RESULTS AND DISCUSSIONS

4.1 Soil characteristics in the study site

Soil physio-chemical properties of each test plot were investigated based on soil laboratory analysis. The soil properties of all the experimental test plots in the scheme locations (moisture content at field capacity (FC) and permanent welting point (PWP), soil pH, soil texture and bulk density) were investigated for the purpose of understanding the general feature and behavior of the soil type in the experimental locations. Different field measurements and observations were taken and analyzed using different field kits and soil laboratory apparatus.

4.1.1 Soil texture analysis

The results on soil texture are presented in Table 4.1 based on laboratory analysis. The average sand, silt & clay in % age of the soil in the experimental locations were found as: at upstream 78.2, 9.7 and 12.1 %, at midstream 79.3, 11.5 and 9.3 % and at downstream location 74.9, 9.2 and 15.9 % respectively. The textural class of each experimental plot was found loamy sand at all. The overall result shows almost similar soil texture along the entire irrigation scheme. The soil texture of the experimental location implied very suitable for crop and horticulture production (Allen et al. 1989). In the downstream location the sand size shows an increasing tendency in depth from surface to subsurface whereas a reverse trend is observed in the midstream location.

Table 4.1: Texture of the study site

Soil properties	Upper stream location (U/S)						Midstream location (M/S)						Downstream location (D/S)					
	Root depth in (cm)						Root depth in (cm)						Root depth in (cm)					
	0-20	20-40	40-60	60-80	80-100	Average	0-20	20-40	40-60	60-80	80-100	Average	0-20	20-40	40-60	60-80	80-100	Average
Sand %	78	77	77	81	79.0	78.2	83	83	80.3	75	75	79.3	74.3	74.7	76.3	75.7	73.7	74.9
Silt %	8	11	9	9	10.3	9.7	11	9.3	9.7	14	14	11.5	9.3	9.3	7.3	11	11	9.2
Clay %	14	12	14	10	10.7	12.1	6	7.7	10	11	11	9.3	9.3	10	13	15	15	15.9
texture class						loamy sand						loamy sand						Loamy sand

4.1.2. Soil pH, bulk density, field capacity, PWP and TAW

A) Soil pH

According to laboratory analysis, the soil pH values at the experimental locations were recorded as 8.7, 8.2, and 8.3 at upstream, midstream, and downstream locations, respectively. The average pH value across the entire scheme was 8.4. The pH values at these locations displayed a decreasing trend in depth, from surface to subsurface, within the effective root zone (1m). These results indicate that the overall pH of the soil is slightly suitable for tomatoes crop production (Allen et al., 1998).).

B) Bulk density (BD)

According to the soil laboratory analysis results on bulk density is presented in table 4.2. The bulk density values of the three experimental locations were found: 1.48, 1.47 and 1.47 (gcm^{-3}) for upstream, midstream and downstream locations respectively. The average bulk density value of the entire scheme was found: 1.47 (gcm^{-3}). The average bulk density value of the entire experimental scheme on the desired soil layers were found as: 1.47, 1.46, 1.48, 1.48, and 1.48 gcm^{-3} for (0-20), (20-40), (40-60), (60-80) and (80-100) cm of soil layers, respectively. The bulk density values of the irrigation scheme show almost similar values on all experimental locations and depths of soil layers except at the downstream observed an increasing tendency from surface to subsurface (1.46 – 1.49 gcm^{-3}). The obtained bulk density value of the experimental site indicated suitable for better crop production. Miller and Donahue (1995) recommended soil bulk density less than 1.6 gcm^{-3} for sands and 1.4 gcm^{-3} for clays for better plant growth.

C) Field capacity (FC)

The field capacity results, based on laboratory analysis of soil water holding capacity using the pressure plate apparatus, are presented in Table 4.2. The average soil moisture content at field capacity (FC) in terms of volume for the experimental locations within the effective root zone (1m) were 15.9%, 16.8%, and 16.6% for the upstream, midstream, and downstream locations, respectively. Generally, the soil moisture content at field capacity decreased with depth in the upstream location, while the midstream and downstream locations showed the opposite trend, with increasing moisture content from surface to subsurface. The weighted average soil moisture content at field capacity across the entire experimental scheme was 16.5%.

The average soil moisture content at field capacity for the entire scheme, at selected root depths, was as follows: 15.5% for the 0-20 cm and 20-40 cm layers, 16.8% for the 40-60 cm layer, 17% for the 60-80 cm layer, and 17.4% for the 80-100 cm layer. This pattern indicates an increase in soil moisture content with depth, likely due to the loamy sand's infiltration characteristics.

The soil moisture content at field capacity in the experimental test pits ranged from 14% to 19% by volume. The field capacity values for the entire experimental site were within the acceptable range for loamy sand texture. According to Allen et al. (1998), the acceptable available water content for loamy sand at field capacity is between 11% and 19% (m^3/m^3). Due to quick drainage, this type of soil may require frequent irrigation to maintain optimal moisture level for the production of tomato.

D) Permanent wilting point (PWP)

The results on permanent wilting point (PWP) are presented in table 4.2 based on laboratory analysis of soil water holding capacity using pressure plate apparatus. The average (SMC) at (PWP) values in volume % of the three experiment locations in the effective root zone of (1m) was found: 8.9, 9.5 and 9.5 % for upstream, midstream and downstream locations respectively. The (SMC) at (PWP) value results of the experimental scheme locations showed an increasing tendency in depth in the mid and downstream locations from surface to subsurface while the reverse trend is observed in the upstream location. The weighted average (SMC) at (PWP) value in volume % of the entire experimental scheme in the effective root zone (1m) was found as: 9.3

%. The average (SMC) at (PWP) values in volume % of the entire experimental scheme per the selected root depths of soil layers were found as: 8.4, 8.5, 9.8, 9.8 and 10 % for (0-20), (20-40), (40-60), (60-80) and (80-100) cm respectively. This shows an increasing tendency in depth from surface to subsurface. All the (SMC) at (PWP) value in volume % results at the entire experimental scheme test pits were found under acceptable soil moisture content at PWP value ranges of loamy sand texture class. According to Allen et al. (1998), the acceptable available water content of loamy sand texture at PWP is between 3 and 10 (m^3m^{-3}).

E) Total available water (TAW)

The results on the total available water (TAW) are presented in table 4.2 based on soil laboratory analysis. The average (TAW) values in volume % of the three experimental scheme locations were found as: 7, 7.4 and 7.1 % for upstream, midstream and downstream locations respectively. The weighted average TAW value in volume % of the entire scheme was found to be: 7.2%. The average TAW values in volume % on the desired soil layers of the entire experimental scheme were found as: 7, 7.1, 7.1, 7.2, and 7.4 % for (0-20), (20-40), (40-60), (60-80) and (80-100) cm respectively. This shows an increasing tendency from surface to subsurface. All the TAW value results along the entire experimental scheme test pits were found under acceptable TAW value ranges of loamy sand texture class. According to Allen et al. (1998), the acceptable available water content of loamy sand texture for TAW is between 6 and 10m^3m^{-3}.

Table 4.2. Soil pH, Bulk density, Field capacity, Permanent welting point and TAW results

	soil sampling location of the scheme														
	Upper stream location (U/S)					Midstream location (M/S)					Downstream location (D/S)				
	Root depth in (cm)					Root depth in (cm)					Root depth in (cm)				
soil parameters	0 - 20	20 - 40	40 - 60	60 - 80	80 - 100	0 -20	20 - 40	40 - 60	60 - 80	80 - 100	0 - 20	20 - 40	40 - 60	60 - 80	80 - 100
Soil pH	8.77	8.70	8.67	8.67	8.73	8.23	8.20	8.20	8.17	8.17	8.30	8.30	8.27	8.27	8.30
BD (gcm^{-3})	1.48	1.47	1.48	1.49	1.48	1.47	1.46	1.47	1.48	1.48	1.46	1.46	1.48	1.47	1.49
FC in vol (%)	16.9	16.6	16.6	14.5	15.2	15.5	15.4	17.5	17.9	18.0	14.0	14.7	16.4	18.6	19
PWP in vol (%)	9.8	9.0	9.4	8.0	8.4	7.9	8.2	10.3	10.7	10.3	7.6	8.2	9.7	10.7	11.3
TAW in vol (%)	7.1	7.6	7.3	6.5	6.8	7.6	7.2	7.2	7.2	7.7	6.4	6.5	6.8	7.9	7.8
TAW (mm)	14.2	15.2	14.5	13.0	13.5	15.2	14.3	14.3	14.5	15.4	12.9	12.9	13.5	15.8	15.6

4.2 Field irrigation performance

4.2.1 Soil storage efficiency (Es)

The results on (Es) are presented in table 4.7 below based on well-known procedure discussed in the methods. The soil storage efficiency (Es) value was calculated using equation (17) in section (3.2.4). The soil storage efficiency (Es) values of the three experimental locations per growth stages were found as: at upstream 60, 77, 77.6 and 56.8 %, at midstream 56.5, 68.4, 72.8 and 50 % and at downstream location 75.8, 72.6, 61 and 58.6 % for initial, development, mid and late season stages respectively and the soil storage efficiency (Es) values of the three experimental locations was found: 67.8, 62 and 67 % for upstream, midstream and downstream locations respectively. The average soil storage efficiency (Es) value of the entire experimental scheme per growth stages were found as: 64, 72.6, 70.5 and 55 % for initial, development, mid and late season stages respectively and the weighted average soil storage efficiency (Es) value of the entire experimental scheme was found 65.5 %.

From similar study by Worku (2013) in the case of west hararge Oromia, 94.3 % (Es) in clay soil texture which is very high. All the soil storage efficiency (Es) values of the whole duration on the experimental locations were found at acceptable (Es) value ranges. According to FAO (1989), the effectiveness of stored soil water might be between 40 - 90 %. The results of this analysis implied that the soil storage efficiency values of the experimental locations showed higher at the upstream followed by downstream and midstream locations.

The factors for the (Es) value variation on the growth stages is because of the variation in irrigation scheduling (frequency, timing, and duration), climatic condition variation and growth stages, ideally, the irrigation depth and/or intervals (frequency) vary with crop development. The factors for the (Es) value variation on the experimental locations were because of the variations in irrigation scheduling (frequency, timing, and duration), soil management and slightly climatic condition. Thus, the soil storage efficiency of the scheme indicated that the irrigation system was adequate in fulfilling the soil moisture required for better productivity of the crop (FAO, 1989).

a) Actual stored moisture after irrigation (ASM)

The results on actual stored moisture after irrigation (ASM) of the experimental locations per growth stages are presented in table 4.3 based on soil laboratory analysis. The actual stored soil moisture after irrigation (ASM) was calculated using equation (7) in section (3.2.3).

The average (ASM) of the whole duration values in volume percent of the experimental locations on the desired root depths of soil layers was found: at upstream 2.6, 2.6, 2.5, 2.5 and 2.5 %, at midstream 2.8, 2.3, 2.2, 2.2 and 2.2 % and at downstream location 2.7, 2.6, 2.4, 2.3 and 2.1 % in volume for (0-20), (20-40), (40-60), (60-80) and (80-100) cm respectively. The average (ASM) of the whole duration values in volume percent of the three experimental locations per growth stages on the effective root depth (1m) was found: at upstream 2.3, 2.9, 2.9 and 2.2 %, at midstream 2.2, 2.6, 2.7 and 1.9 % and at downstream location 2.7, 2.6, 2.2 and 2.2 % in volume for initial, development, mid and late season stages respectively and the average (ASM) of the whole duration values of the three experimental locations on the effective root depth (1m) was found as 2.5, 2.3 and 2.4 % in volume for upstream, midstream and downstream locations, respectively.

The weighted average (ASM) of the whole duration values in volume percent of the entire experimental scheme on the desired root depths of soil layers were found: 2.7, 2.5, 2.4, 2.3 and 2.3 % in volume for (0-20), (20-40), (40-60), (60-80) and (80-100) cm respectively. The weighted average (ASM) of the whole duration values of the entire experimental scheme per growth stages on the effective root depth (1m) was found as 2.4, 2.7, 2.6 and 2.1 % in volume for initial, development, mid and late season stages respectively and the overall weighted average (ASM) of the whole duration value of the entire experimental scheme on the effective root depth (1m) was found 2.4 % in volume.

The average actual stored soil moisture after irrigation (ASM) results of this analysis showed higher at the upstream followed by downstream and midstream locations. The justification for the higher actual stored moisture (ASM) value at the upstream location was that the irrigation application interval (frequency) days were short and higher application times. In addition, the moisture content before irrigation was lower at the upstream. The availability of ASM is inversely proportional to the availability of soil moisture content before irrigation values and directly proportional to the soil water storage efficiency (Es) as presented in section 4.2.1 table 4.3 and is found higher at the upstream (68 %) followed by downstream (67 %) and midstream (62 %) locations.

Table 4.3. Actual stored moisture (ASM) after irrigation application in volume (%) results

growth stage	Location	Moisture in volume (%)	Root depths in (cm) & (Θv) in volume (%)					
			0-20	20-40	40-60	60-80	80-100	Average
initial stage	Upstream	AI	14.14	14.31	14.44	14.56	14.70	14.43
		BI	11.85	12.01	12.17	12.30	12.49	12.16
		ASM	2.29	2.30	2.27	2.26	2.21	2.27
development stage	Upstream	AI	14.88	15.01	15.09	15.18	15.26	15.09
		BI	11.90	12.06	12.23	12.36	12.53	12.22
		ASM	2.98	2.95	2.86	2.82	2.73	2.87
middle stage	Upstream	AI	14.94	15.03	15.11	15.21	15.29	15.12
		BI	11.91	12.07	12.24	12.37	12.53	12.23
		ASM	3.03	2.96	2.87	2.84	2.76	2.89
late season	Upstream	AI	14.01	14.19	14.32	14.44	14.59	14.31
		BI	11.85	12.00	12.16	12.30	12.49	12.16
		ASM	2.16	2.19	2.16	2.14	2.10	2.15
Average		ASM	2.62	2.60	2.54	2.52	2.45	2.54
initial stage	Mid- stream	AI	15.20	14.84	15.06	15.23	15.58	15.18
		BI	12.68	12.75	12.98	13.16	13.56	13.02
		ASM	2.52	2.09	2.08	2.07	2.02	2.16
development stage	Mid- stream	AI	15.67	15.32	15.54	15.71	16.06	15.66
		BI	12.60	12.79	13.11	13.21	13.62	13.07
		ASM	3.07	2.53	2.43	2.50	2.44	2.59
middle stage	Mid- stream	AI	15.83	15.49	15.71	15.88	16.24	15.83
		BI	12.64	12.80	13.19	13.22	13.64	13.10
		ASM	3.19	2.69	2.52	2.66	2.60	2.73
late season	Mid- stream	AI	14.99	14.63	14.84	15.01	15.35	14.96
		BI	12.56	12.77	12.96	13.48	13.62	13.08
		ASM	2.43	1.86	1.88	1.53	1.73	1.88
Average		ASM	2.80	2.29	2.23	2.19	2.20	2.34
initial stage	down stream	AI	15.57	15.71	15.63	15.80	15.79	15.70
		BI	12.54	12.73	13.00	13.25	13.47	13.00
		ASM	3.03	2.98	2.63	2.55	2.32	2.70
development stage	down stream	AI	15.44	15.55	15.51	15.69	15.66	15.57
		BI	12.54	12.72	12.91	13.13	13.38	12.94
		ASM	2.90	2.83	2.60	2.56	2.28	2.63
middle stage	down stream	AI	15.00	15.09	15.10	15.21	15.29	15.14
		BI	12.51	12.70	12.92	13.09	13.33	12.91
		ASM	2.49	2.39	2.18	2.12	1.96	2.23
late season	down stream	AI	14.88	15.03	14.98	15.14	15.13	15.03
		BI	12.49	12.67	12.85	13.06	13.29	12.87
		ASM	2.39	2.36	2.13	2.08	1.84	2.16
Average		ASM	2.70	2.64	2.38	2.33	2.10	2.43
scheme average		ASM	2.71	2.51	2.38	2.34	2.25	2.44

b) Actual soil moisture content before irrigation (Θ_{BI})

The results on soil moisture content before irrigation (Θ_{BI}) in volume % values of the experimental locations per growth stages are presented in table 4.4 and the average (Θ_{BI}) of the 9 test plots in (Appendix I. table 7) based on soil laboratory analysis. The (Θ_{BI}) results were calculated using equation (8). The average soil moisture content before irrigation (Θ_{BI}) in volume % of the whole duration values of the three experimental locations on the desired root depths of soil layers was found as: at upstream 11.9, 12.0, 12.2, 12.3 and 12.5 %, at midstream 12.6, 12.8, 13.1, 13.3 and 13.6 % and at downstream location 12.5, 12.7, 12.9, 13.1 and 13.4 % in volume for (0-20), (20-40), (40-60), (60-80) and (80-100) cm respectively.

The average (Θ_{BI}) in volume % of the whole duration values of the three experimental locations per growth stages in the effective root depth (1m) were found as: upstream 12.2, 12.2, 12.2 and 12.2 %, at midstream 13.0, 13.1, 13.1 and 13.1 % and at downstream 13, 12.9, 12.9 and 12.9 % for initial, development, mid and late season stages respectively. The average (Θ_{BI}) in volume % of the whole duration values of the three experimental locations in the effective root depth (1m) was found as 12.2, 13.1 and 12.9 % for upstream, midstream and downstream locations respectively. The weighted average soil moisture content before irrigation (Θ_{BI}) of the whole duration value of the entire scheme in the effective root depth (1m) was found 12.7 % in volume.

The average soil moisture content before irrigation (Θ_{BI}) values of the three experimental locations showed an increasing tendency in depth from surface to subsurface and duration values of the experimental locations showed higher at midstream followed by downstream and upstream locations. The justification for the average soil moisture content before irrigation (Θ_{BI}) values increasing tendency in depth from surface to subsurface is because of the arid climatic condition characterized by high evapotranspiration rate at the surface than the subsurface and the loamy sand soil texture characterized by high infiltration rate at the surface than subsurface (Brouwer et al., 2001). The justification for the average soil moisture content before irrigation variations observed along the experimental locations is because of the variations in soil characteristics (infiltration), irrigation water management and field management practices (Brouwer et al., 2001). The soil moisture content before irrigation variations observed per growth stages is mainly because of the variations in irrigation water management (irrigation application interval days, irrigation application times and duration of application).

Table 4.4. Actual soil moisture content before irrigation (ӨBI) in volume % results

			Root depths in (cm) & (ӨBI) in volume (%)					
S/No	Locations	growth stages	0-20	20-40	40-60	60-80	80-100	Average
1	Upstream	Initial stage	11.9	12.0	12.2	12.3	12.5	12.2
2	Upstream	Development stage	11.9	12.1	12.2	12.4	12.5	12.2
3	Upstream	Middle stage	11.9	12.1	12.2	12.4	12.5	12.2
4	Upstream	late season	11.9	12.0	12.2	12.3	12.5	12.2
Average			11.9	12.0	12.2	12.3	12.5	12.2
1	Mid-stream	Initial stage	12.7	12.8	13.0	13.2	13.6	13.0
2	Mid-stream	Development stage	12.6	12.8	13.1	13.2	13.6	13.1
3	Mid-stream	Middle stage	12.6	12.8	13.2	13.2	13.6	13.1
4	Mid-stream	late season	12.6	12.8	13.0	13.5	13.6	13.1
Average			12.6	12.8	13.1	13.3	13.6	13.1
1	Downstream	Initial stage	12.5	12.7	13.0	13.3	13.5	13.0
2	Downstream	Development stage	12.5	12.7	12.9	13.1	13.4	12.9
3	Downstream	Middle stage	12.5	12.7	12.9	13.1	13.3	12.9
4	Downstream	late season	12.5	12.7	12.9	13.1	13.3	12.9
Average			12.5	12.7	12.9	13.1	13.4	12.9
Scheme average			12.3	12.5	12.7	12.9	13.2	12.7

C) Actual soil moisture content after irrigation (Θ_{AI})

The results on the average soil moisture content after irrigation (Θ_{AI}) in volume % values of the three experimental locations are presented in table 4.5 and the average (Θ_{AI}) in volume % values of the 9 test plots in (Appendix I. table 8) based on soil laboratory analysis. The soil moisture content after irrigation (Θ_{AI}) value was calculated using equation (9) in section (3.2.3). The average soil moisture content after irrigation (Θ_{AI}) in volume % of the whole duration values of the three experimental locations on the desired root depths of soil layers was found: at upstream 14.5, 14.6, 14.7, 14.9 and 15 %, at midstream 15.4, 15.1, 15.3, 15.5 and 15.8 % and at downstream 15.2, 15.3, 15.3, 15.45 and 15.5 % for (0-20), (20-40), (40-60), (60-80) and (80-100) cm respectively. The average soil moisture content after irrigation (Θ_{AI}) in volume % values of the three experimental locations per growth stages on the effective root depth (1m) was found: at upstream 14.4, 15.1, 15.1 and 14.3 %, at midstream 15.2, 15.7, 15.8 and 15 % and at downstream 15.7, 15.6, 15.1 and 15.0 % for initial, development, mid and late season stages respectively and the average soil moisture content after irrigation (Θ_{AI}) in volume % of the whole duration values of the three experimental locations on the effective root depth (1m) was found: 14.7, 15.4 and 15.3 % for upstream, midstream and downstream locations respectively.

The weighted average soil moisture content after irrigation (Θ_{AI}) in volume % of the whole season value of the entire scheme on the desired root depths of soil layers was found: 15.1, 15, 15.1, 15.3 and 15.4 % for (0-20), (20-40), (40-60), (60-80) and (80-100) cm respectively and the weighted average soil moisture content after irrigation (ΘAI) in volume % of the whole season value of the entire experimental scheme on the effective root depth (1m) was found: 15.2 %. The result of this analysis shows that the average soil moisture content after irrigation (Θ_{AI}) values of the experimental locations showed higher at midstream followed by downstream and upstream. The average soil moisture content after irrigation (Θ_{AI}) values of the three experimental locations showed an increasing tendency in depth from surface to subsurface.

The justification for the average soil moisture content after irrigation (Θ_{AI}) values increasing tendency in depth from surface to subsurface is because of the arid climatic condition characterized by high evapotranspiration rate at the surface than subsurface and the loamy sand soil texture characterized by high infiltration rate at the surface than subsurface (Brouwer et al., 2001). The justification for the average soil moisture content after irrigation variations observed along the experimental locations is because of the variations in soil characteristics (infiltration), irrigation water management and field management practices (Brouwer et al., 2001). The soil moisture content after irrigation variations observed per growth stages is mainly because of the variations in irrigation water management (irrigation application interval days, irrigation application times and duration of application).

Table 4.5. Average actual soil moisture content after irrigation (Θ_{AI}) in volume % results

S/No	Location	growth stages	Root depths in (cm) & (Θ_{AI}) in volume (%)					
			0-20	20-40	40-60	60-80	80-100	Average
1	Upstream	initial stage	14.1	14.3	14.4	14.6	14.7	14.4
	Upstream	development stage	14.9	15.0	15.1	15.2	15.3	15.1
	Upstream	mid-stage	14.9	15.0	15.1	15.2	15.3	15.1
	Upstream	late season	14.0	14.2	14.3	14.4	14.6	14.3
Average			14.5	14.6	14.7	14.9	15.0	14.7
2	middle stream	initial stage	15.2	14.8	15.1	15.2	15.6	15.2
	middle stream	development stage	15.7	15.3	15.5	15.7	16.1	15.7
	middle stream	mid-stage	15.8	15.5	15.7	15.9	16.2	15.8
	middle stream	late season	15.0	14.6	14.8	15.0	15.4	15.0
Average			15.4	15.1	15.3	15.5	15.8	15.4
3	Downstream	initial stage	15.6	15.7	15.6	15.8	15.8	15.7
	Downstream	development stage	15.4	15.5	15.5	15.7	15.7	15.6
	Downstream	mid-stage	15.0	15.1	15.1	15.2	15.3	15.1
	Downstream	late season	14.9	15.0	15.0	15.1	15.1	15.0
Average			15.2	15.3	15.3	15.5	15.5	15.4
scheme average			15.0	15.0	15.1	15.3	15.4	15.2
Min			14.0	14.2	14.3	14.4	14.6	14.3
Max			15.8	15.7	15.7	15.9	16.2	15.8

D) Actual soil moisture depletion (AMD) & (RAW) in volume (%)

The results on actual soil moisture depletion (AMD) and the actual readily available water (RAW) are presented in table 4.6 based on the soil laboratory analysis data. The actual soil moisture depletion (AMD) and the actual readily available water (RAW) in percent at the time of irrigation in the desired root depths of soil layers were calculated using equations (10 and 11) in section (3.2.3), respectively. The average actual soil moisture depletion (AMD) of the whole duration values in volume % of the three experimental locations on the desired root depths of soil layers was found: at upstream 5, 4.5, 4.4, 2.1 and 2.7 %, at midstream 2.9, 2.6, 4.4, 4.6 and 4.4 % and at downstream 1.5, 2, 3.5, 5.4 and 5.7 % for (0-20), (20-40), (40-60), (60-80) and (80-100) cm, respectively.

The average actual moisture depletion (AMD) of the whole duration values in volume percent of the three experimental locations on the effective root depth (1m) was found: 3.8, 3.8 and 3.6 % for upstream, midstream and downstream locations respectively. The average actual moisture depletion (AMD) of the whole duration values in volume percentage of the three experimental locations per growth stages on the effective root depth (1m) was found as: at upstream 3.8, 3.7, 3.7 and 3.8 %, at midstream 3.8, 3.8, 3.8 and 3.8 % and at downstream location 3.6, 3.6, 3.7 and 3.7 % for initial, development, mid and late season stages respectively. The average actual readily available water content before irrigation in percent of the whole duration values of the three experimental locations on the effective root depth (1m) was found: 53, 51 and 50 %, for upstream, midstream and downstream locations, respectively.

The weighted average actual moisture depletion (AMD) values of the entire experimental scheme on the desired root depths of soil layers was found: 3.1, 3.0, 4.1, 4.1 and 4.3 % in volume for (0-20), (20-40), (40-60), (60-80) and (80-100) cm respectively and the weighted average actual soil moisture depletion (AMD) value of the entire experimental site on the effective root depth (1m) was found: 3.7 % in volume, while the average actual readily available water content before irrigation in percent value of the entire scheme was found: 51%.

The results of the actual moisture depletion (AMD) before irrigation on the experimental locations showed a decreasing tendency in depth at the upstream location from surface to subsurface while an inverse trend is observed at the downstream location. This is because of the soil water holding nature of the soil texture in depth and the AMD values are directly proportional to the soil water holding capacity in depth values at (FC, PWP and TAW). The actual soil moisture depletion variation within the three experimental locations is because of the variations in the irrigation water application depth and/or timing, field management, soil water holding capacity and soil structure of the experimental locations. The results of the actual readily available water imply the irrigation application time was done before the critical depletion level reaches and the actual readily available water content before irrigation values of the three experimental locations are found under the acceptable range of depletion level (P) for all crop types and above the recommended P value for tomato crops. According to Allen et al. (1998), the acceptable depletion level P for all crops is from 50 – 60 % while for tomato crop, it is 40 %.

Generally, AMD values on the entire experimental scheme shows there was no critical depletion of water before irrigation but the amount of available water content before irrigation varied within the desired root depths. This is because of the variations in the soil structure and soil water holding nature within depth.

Table 4.6. Average actual moisture depletion (AMD) and (RAW) in volume (%) results

Growth stage	Upstream					Mid-stream					Downstream				
	Root depths in (cm) (ΘBI) in volume (%)					Root depths in (cm) (ΘBI) in volume (%)					Root depths in (cm) (ΘBI) in volume (%)				
	0-20	20-40	40-60	60-80	80-100	0-20	20-40	40-60	60-80	80-100	0-20	20-40	40-60	60-80	80-100
Initial stage	11.9	12.0	12.2	12.3	12.5	12.7	12.8	13.0	13.2	13.6	12.5	12.7	13.0	13.3	13.5
Dev. stage	11.9	12.1	12.2	12.4	12.5	12.6	12.8	13.1	13.2	13.6	12.5	12.7	12.9	13.1	13.4
Mid-stage	11.9	12.1	12.2	12.4	12.5	12.6	12.8	13.2	13.2	13.6	12.5	12.7	12.9	13.1	13.3
Late stage	11.8	12.0	12.2	12.3	12.5	12.6	12.8	13.0	13.5	13.6	12.5	12.7	12.9	13.1	13.3
Average	11.9	12.0	12.2	12.3	12.5	12.6	12.8	13.1	13.3	13.6	12.5	12.7	12.9	13.1	13.4
FC (%)	16.9	16.6	16.6	14.5	15.2	15.5	15.4	17.5	17.9	18.0	14.0	14.7	16.4	18.6	19.1
AMD (%)	5.0	4.5	4.4	2.1	2.7	2.9	2.6	4.4	4.6	4.4	1.5	2.0	3.5	5.4	5.7
TAW (%)	7.1	7.6	7.3	6.5	6.8	7.6	7.2	7.2	7.2	7.7	6.4	6.5	6.8	7.9	7.8
P %	70	60	61	33	39	38	36	61	64	57	23	31	52	69	73
Average p (%)		53				51					50				

4.2.2 Water application efficiency (Ea)

The results on water application efficiency are presented in table 4.7 based on a well-known procedure discussed in the methods. The application efficiency (Ea) value was calculated using equation (14) in section (3.2.4). The water application efficiency (Ea) values of the three experimental locations per growth stages were found as at upstream, 82.7, 75.6, 82.7 and 82 %, at midstream 82.4, 76.5, 78 and 84.8 % and at downstream 58.3, 58.1, 56, and 60.2 % for initial, development, mid-and-late-season stages respectively. The average application efficiency value of the experimental locations was found to be 80.3, 79.5 and 59 % for upstream, midstream and downstream locations respectively. The weighted average application efficiency value of the entire scheme was found to be 72 %. The weighted average application efficiency value is high when comparing with the previous study result which is reported as 51.5 % from the study in the west hararge by Worku (2013). The results of this analysis implied that the application efficiency values of the experimental locations showed higher at the upstream followed by midstream and downstream locations. The irrigation application efficiency (Ea) value results of the upstream and midstream locations are found higher than the FAO (1989) attainable value range. While the (Ea) result at the downstream location is found at the attainable value range.

According to FAO (1989), the attainable application efficiency according to the US (Soil conservation science) ranges from 55 % - 70 % values, below this limit would normally be considered unacceptable. A factor for the variations among the (Ea) value results of the three experimental locations was because of variations in the delivery frequency or timing, duration of the delivery or depth, soil structure and field management practices as Allen et al. (1998). In general, according to Micheal (1997), (Ea) decreases as the amount of water applied during each irrigation application increases. Based on field observation and field data, on the downstream location the irrigation delivery frequency and timing were lower while the duration of delivery was higher. The justification for the high-water application efficiency results on the upstream and midstream locations was because of the following factors, duration of application was short, and the irrigation application interval and timing were moderate. The (Ea) variations among growth stages were because of variations at irrigation application management and climatic condition.

4.2.3 Irrigation efficiency (Ei)

The results on (Ei) are presented in table 4.7 below based on well-known procedure discussed in the methods. The irrigation efficiency (Ei) was calculated using equation (18) in section (3.2.4). The average (Ei) values of the three experimental locations per growth stages were found as: at upstream 34.2, 55.6, 145.7 and 178.2 %, at midstream 38.6, 61.4, 156.4 and 209.8 % and at downstream location 29.3, 53.2, 161.3 and 130.3 % for initial, development, mid and late season stages respectively and the average (Ei) values of the three experimental locations were found as: 91.7, 101.8 and 85.1 % for upstream, midstream and downstream locations respectively. The average (Ei) value of the entire experimental scheme per growth stages were found as: 34, 57.2, 155.7 and 168.4 % for initial, development, mid and late season stages respectively and the weighted average (Ei) value of the entire experimental scheme was found: 93.4 %.

The irrigation efficiency value results of the experimental locations per growth stages showed similar tendency which is increasing from initial up to late season stage at the upstream midstream locations and the implication of the irrigation efficiency value results of the experimental locations showed higher at the midstream followed by upstream and downstream locations. The justification for the irrigation efficiency greater than 0%at the mid & late season stages was that the applied volume of water at this stage was below the demanded volume of water, while the crop gates the demand gap from the readily available water (RAW) before irrigation so since applied volume of water is less than the beneficiary used volume of water the efficiency would be greater than 100 %.

The results of this analysis also showed that the (Ei) values at the initial and development stages were very low whereas at the mid and late season stages very high in every location. This is because of poor irrigation scheduling practice of the farmers and the nature of the crop water use efficiency. From field observation almost all the farmers applied the same amount of water throughout the season.

4.2.4 Overall irrigation efficiency (Eo)

The results on (Eo) are presented in table 4.7 based on well-known procedure discussed in the methods. The overall irrigation efficiency (Eo) was calculated using equation (19) in section (3.2.4). Since the results on conveyance efficiency values of the experimental locations were found 0%in every test plot. The overall irrigation efficiency (Eo) values were found to be the same as the water application efficiency values.

The overall irrigation efficiency (Eo) values of the experimental locations per growth stages were found as: at upstream, 82.7, 75.6, 82.7 and 82.2 % at midstream 82.4, 76.5, 78.1 and 84.8 %, and at downstream 58.3, 58.1, 56 and 60.2 % for initial, development, mid and late season stages respectively and the average (Eo) values of the three experimental locations was found as: 80.3, 79.5 and 59 % for upstream, midstream and downstream locations respectively. The weighted average (Eo) value of the entire site was found 72 %. The results of this analysis implied that the overall irrigation efficiency values of the experimental locations showed higher at the upstream followed by midstream and downstream locations.

The (Eo) value results at upstream & downstream locations were found higher than the recommended (Eo) value range, while the (Eo) results at downstream were found at the recommended (Eo) value range. According to Brouwer et al. (2001), (Eo) 50 – 60 % is recommended, 40 % is reasonable while 20 – 30 % is poor for furrow irrigation system. The justification for high (Eo) results at upstream and midstream locations was because of the following factors, duration of application was short, and the irrigation application interval and timing were moderate. The (Ea) variations among growth stages were because of variations at irrigation application management and climatic condition.

Table 4.7. Irrigation system performance analysis results

S/No	Growth stages	Moisture content	Experimental locations			
			Upstream	Mid-stream	Down stream	Average
1	Initial stage	Volume diverted (Vt) in (mm)	156.6	138.9	182.8	157.6
		AMD in (mm)	215.6	202.5	140.4	182.6
		ASM in (mm)	129.5	114.5	106.5	116.8
		ET_b (beneficiary use in volume (mm))	53.6	53.6	53.6	53.6
		Water application efficiency (Ea) (%)	82.7	82.4	58.3	74.1
		Storage efficiency (Es) (%)	60.1	56.5	75.8	64.0
		Irrigation efficiency (Ei) (%)	34.2	38.6	29.3	34.0
2	Development stage	Volume diverted (Vt) in (mm)	199.8	181.0	208.8	194.4
		AMD in (mm)	196.2	202.3	167.2	188.7
		ASM in (mm)	151.1	138.4	121.4	137.0
		ET_b (beneficiary use in volume (mm))	111.1	111.1	111.1	111.1
		Water application efficiency (Ea) (%)	75.6	76.5	58.1	70.5
		Storage efficiency (Es) (%)	77.0	68.4	72.6	72.6
		Irrigation efficiency (Ei) (%)	55.6	61.4	53.2	57.2
3	Mid-stage	Volume diverted (Vt) in (mm)	174.7	162.8	157.8	163.5
		AMD in (mm)	186.2	174.6	145.0	170.2
		ASM in (mm)	144.5	127.1	88.6	120.0
		ET_b (beneficiary use in volume (mm))	254.5	254.5	254.5	254.5
		Water application efficiency (Ea) (%)	82.7	78.1	56.1	73.4
		Storage efficiency (Es) (%)	77.6	72.8	61.1	70.5
		Irrigation efficiency (Ei) (%)	145.7	156.4	161.3	155.7
4	Late season	Volume diverted (Vt) in (mm)	78.6	66.7	107.5	83.1
		AMD in (mm)	113.7	113.2	110.4	112.5
		ASM in (mm)	64.6	56.6	64.7	62.0
		ET_b (beneficiary use in volume (mm))	140.0	140.0	140.0	140.0
		Water application efficiency (Ea) (%)	82.2	84.8	60.2	74.6
		Storage efficiency (Es) (%)	56.8	50.0	58.6	55.1
		Irrigation efficiency (Ei) (%)	178.2	209.8	130.3	168.4
Total		Volume diverted (Vt) in (mm)	609.7	549.5	656.8	598.4
		AMD in (mm)	722.3	704.2	568.8	665.3
		ASM in (mm)	489.7	436.6	381.1	435.8
		ET_b (beneficiary use in volume (mm))	559.2	559.2	559.2	559.2
		Water application efficiency (Ea) (%)	80.3	79.5	59.0	72.8
		Storage efficiency (Es) (%)	67.8	62.0	67.0	65.5
		Irrigation efficiency (Ei) (%)	91.7	101.8	85.1	93.4

4.2.5 Irrigation distribution uniformity

The irrigation distribution uniformity was investigated using two parameters; these are Christensen's uniformity coefficient (CU) and low - quarter distribution uniformity (DU). The results on CU and DU are presented in tables (4.8 and 4.9) below. The Christiansen's uniformity coefficient (CU) was calculated using equation (21) in section (3.2.4). The average (CU) values of the experimental locations on the desired root depths of soil layers were found as: upstream 97.2, 96.8, 96.6 and 96.2 %, at midstream 96.9, 96.8, 96 and 95.7 % and at downstream 96.7, 96.2, 96.3 and 96.2 % for (0-25), (25-50), (50-75) and (75-100) cm respectively.

The average (CU) values of the three experimental locations per the growth stages was found: at upstream 98.3, 97.7, 97.1 and 93.7 %, at midstream 96.7, 96.4, 98.3 and 94.1 % and at downstream location 97.8, 97.4, 96.6 and 93.7 % for Initial, development, mid and late season stages respectively. The average (CU) values of the three experimental locations at the effective root depth (1m) were found to be: 96.7, 96.4 and 96.4 % for the upstream, midstream and downstream locations respectively. The average (CU) value of the entire experimental scheme on the desired root depths of soil layers were found: 97, 96.6, 96.3 and 96 % for (0-25), (25-50), (50-75) and (75-100) cm respectively. The average (CU) value of the entire experimental scheme per growth stages on the effective root depth (1m) was found as: 97.6, 97.1, 97.3 and 93.8 % for initial, development, mid and late season stages respectively. Finally, the weighted average (CU) value of the entire scheme on the effective root depth (1m) was found 96.5 %.

The Low - quarter distribution uniformity (DU) was calculated using equation (20) in section (3.2.4). The average (DU) values of the three experimental locations on the desired root depths of soil layers were found to be: at upstream 96.8, 96, 95.6 and 94.6 %, at midstream 95, 94.4, 92.9 and 92.4 % and at downstream location 92.9, 91.7, 92.2 and 91.4 % for (0-25), (25-50), (50-75) and (75-100) cm respectively. The average (DU) values of the three experimental locations per growth stages on the effective root depth (1m) were found as: at upstream 97.4, 96.7, 96.2 and 92.9 %, at midstream 95.7, 94.2, 93.7 and 91.2 % and at downstream location 96.5, 91, 90.6 and 90.1 % for initial, development mid and late season stages respectively. The average (DU) values of the experimental locations on the effective root depth (1m) were found: 95.8, 93.7 and 92 % for upstream, midstream and downstream locations, respectively.

The weighted average (DU) value of the entire experimental scheme on the effective root depth (1m) was found 93.8 %.All the average (CU) and/or (DU) values of the whole duration of the three experimental locations were found higher than the attainable (DU) and/or (CU) value range (60 – 80 %). According to Irmak et al. (2011), lower (DU) values (< 60 %) indicate that the irrigation water is unevenly distributed, while higher (DU) values (< 80 %) indicate that the application is uniform over the entire field. According to Worku (2013), in the case of west hararge Oromia, it reported that average (DU) and (CU) values of 92.4 and 94 % respectively, which is nearly like these results. The results of this analysis implied that the average (DU) &/or (CU) values of the experimental locations showed almost similar tendency and values but comparatively higher at the upstream followed by midstream and downstream locations.

The justification for the higher (DU) and (CU) value results on the experimental locations and/or fields is that the topography of the entire scheme is similarly flat, the size of the experimental farms was small and easy to manage, and the field management practice of the farmers was good. The justification for the similarity on the (DU) and (CU) values within the experimental locations and/or fields is that it is because of the similarity on the topography which is less than 2 % slope in the entire experimental fields, method of irrigation application, soil characteristics (infiltration), structure and grading, irrigation system pressure & flow rate (3.15 lit/sec) and climate.

Table 4.8. Christiansen's distribution uniformity (CU) results of the experimental locations

Experimental location	growth stages	Root depth in (cm) and CU in (%)				
		0-25	25-50	50-75	75-100	Average
Upstream	Initial stage	98.7	98.3	98.1	98.0	98.3
	Development stage	98.7	97.8	97.8	96.5	97.7
	mid-stage	98.6	97.6	96.4	95.9	97.1
	late season stage	93.0	93.5	94.0	94.3	93.7
	Average	97.2	96.8	96.6	96.2	96.7
Midstream	Initial stage	98.0	97.5	95.9	95.4	96.7
	Development stage	97.8	97.7	95.7	94.3	96.4
	mid-stage	98.4	98.1	98.1	98.5	98.3
	late season stage	93.5	94.0	94.2	94.5	94.1
	Average	96.9	96.8	96.0	95.7	96.4
Downstream	Initial stage	98.7	97.7	97.5	97.2	97.8
	Development stage	98.0	97.2	96.9	97.3	97.4
	mid-stage	97.1	96.4	96.7	96.4	96.6
	late season stage	93.2	93.6	94.0	94.0	93.7
	Average	96.7	96.2	96.3	96.2	96.4
Scheme average		97.0	96.6	96.3	96.0	96.5

Table 4. 9. Low-quarter distribution uniformity (DU) results of the experimental locations

Experimental location	growth stages	Root depth in (cm) and DU in (%)				
		0-25	25-50	50-75	75-100	Average
Upstream	Initial stage	98.5	97.7	96.8	96.6	97.4
	Development stage	98.3	96.5	97.0	94.8	96.7
	mid-stage	97.6	97.0	95.7	94.2	96.2
	late season stage	92.6	92.8	93.0	93.0	92.9
	Average	96.8	96.0	95.6	94.6	95.8
Midstream	Initial stage	97.3	96.5	94.4	94.3	95.7
	Development stage	96.8	96.2	93.0	90.7	94.2
	mid-stage	95.0	93.6	93.0	93.1	93.7
	late season stage	91.0	91.5	91.0	91.3	91.2
	Average	95.0	94.4	92.9	92.4	93.7
Downstream	Initial stage	98.0	96.9	95.9	95.4	96.5
	Development stage	91.6	88.7	92.4	91.5	91.0
	mid-stage	92.0	92.1	90.4	87.6	90.6
	late season stage	90.0	89.0	90.2	91.0	90.1
	Average	92.9	91.7	92.2	91.4	92.0
Scheme average		94.9	94.0	93.6	92.8	93.8

4.2.6 Field irrigation water demand and supply

1) Field irrigation water requirement

The result on (CWR) is presented in table 4.10 below based on CROPWAT 8.0 software analysis and determined using equation (25) in section (3.2.5). The daily average (ET_c) value of the experimental scheme was found: 4.5 mm/day and the (CWR)/(ET_c) values in depth (mm/stage) of the experimental scheme per growth stages were found to be: 53.6, 111.1, 254.5 and 142.4 mm for initial, development, mid and late season stages respectively. The total seasonal (CWR)/(ET_c) value of the experimental scheme was found: 561.8 mm/season.

The result of this analysis implied that the seasonal (ETc) value of the experimental scheme was found at the recommended (ETc) value ranges of tomato 400 - 800 mm of water from transplanting to harvest depending on climate, plant type, soil, irrigation and crop management (FAO, 2012).

Table 4.10. The daily & per growth stage (ETc/CWR) in (mm) of the experimental scheme

Month	Growth stage	ETc	ETc	Eff. Rain	Irr. Req.
		mm/day	mm/dec	mm/dec	mm/dec
Feb	Initial stage	2.77	24.9	0	24.9
Feb	Initial stage	2.87	28.7	0	28.7
Total		2.8	53.6	0	53.6
Feb	Development	3	24	0	24
Mar	Development	3.79	37.9	0	37.9
Mar	Development	4.92	49.2	0	49.2
Total		3.9	111.1	0	111.1
Mar	Mid-stage	5.97	65.6	0	65.6
Apr	Mid-stage	6.27	62.7	0	62.7
Apr	Mid-stage	6.32	63.2	0	63.2
Apr	Mid-stage	6.3	63	0	63
Total		6.2	254.5	0	254.5
May	Late stage	5.88	58.8	0	58.8
May	Late stage	5.15	51.5	0	51.5
May	Late stage	4.58	32.1	0	32.1
Total		5.2	142.4	0	142.4
Grand total		4.5	561.8	0	561.8

4.2 .7 Irrigation schedule recommendation for the experimental scheme

The results on irrigation schedule recommendation were presented in table 4.11 below based on CROPWAT 8.0 software.

The recommended number of irrigation times of the experimental scheme per growth stages was found as: 8, 6, 6 and 5 times for initial, development, mid and late season stages, respectively. The recommended total number of irrigation times of the scheme was found: 25 times. The recommended irrigation timing at fixed interval days per growth stages was found as: 3, 5, 5 and 6 days for initial, development, mid and late season stages, respectively.

The net irrigation recommendation values in depth of the experimental scheme per growth stages were found as: 68.6, 138, 187.6 and 162.7 mm for initial, development, mid and late season stages respectively. The gross irrigation recommendation values in depth of the experimental scheme per growth stages were found as: 95.3, 191.6, 260.6 and 226 mm for initial, development, mid and late season stages respectively. The total net and gross irrigation recommendation values in depth of the entire scheme were found: 557 and 773.5 mm, respectively.

The results of the net and gross irrigation analysis implied that the net and gross values of the experimental scheme showed higher at the midstream followed by downstream and upstream locations. The results of the net and gross irrigation recommendation implied that the seasonal value of the experimental scheme was found at the recommended ETc value ranges of tomato 400 - 800 mm of water from transplanting to harvest depending on climate, plant type, soil, irrigation and crop management (FAO, 2012).

Table 4.11. Irrigation schedule recommendation of the experimental scheme

Application date	day	Growth stage	Net Irr mm	Gr. Irr mm	Irrigation interval (days)	No of irrigation (times)
04-Feb	3	Initial stage	8.3	11.5	3	1
07-Feb	6	Initial stage	8.3	11.5	3	1
10-Feb	9	Initial stage	8.3	11.5	3	1
13-Feb	12	Initial stage	8.6	12	3	1
16-Feb	15	Initial stage	8.6	12	3	1
19-Feb	18	Initial stage	8.6	12	3	1
22-Feb	21	Initial stage	8.9	12.3	3	1
25-Feb	24	Initial stage	9	12.5	3	1
Sub-total			68.6	95.3	3	8
02-Mar	29	Dev. Stage	16.6	23	5	1
07-Mar	34	Dev. Stage	19	26.4	5	1
12-Mar	39	Dev. Stage	21.2	29.5	5	1
17-Mar	44	Dev. Stage	24.6	34.2	5	1
22-Mar	49	Dev. Stage	26.7	37.1	5	1
27-Mar	54	Dev. Stage	29.8	41.4	5	1
Sub-total			137.9	191.6	5	6
01-Apr	59	Mid-stage	30.1	41.9	5	1
06-Apr	64	Mid-stage	31.4	43.6	5	1
11-Apr	69	Mid-stage	31.4	43.6	5	1
16-Apr	74	Mid-stage	31.6	43.9	5	1
21-Apr	79	Mid-stage	31.6	43.9	5	1
26-Apr	84	Mid-stage	31.5	43.7	5	1
Sub-total			187.6	260.6	5	6
02-May	90	Late stage	36.7	51	6	1
08-May	96	Late stage	35.3	49	6	1
14-May	102	Late stage	32.4	45	6	1
20-May	108	Late stage	30.9	42.9	6	1
26-May	114	Late stage	27.4	38.1	6	1
27-May	End	End	0	0		0
Sub-total			162.7	226	6	5
Total			557	773.5	4.75	25

2) Field irrigation water supply

The results on irrigation water supply of the experimental locations per growth stages are presented in table 4.12 and the average water application of the 9 plots in (Appendix I. table 4) and the total irrigation application of the 9 plots per each irrigation event in (Appendix I. table 5-6) based on irrigation water application discharge measurement. The average size of the experimental field areas in m^2 of the experimental scheme locations/strata/ were 135.0, 298.6 and 226.6 m^2 for upstream, midstream and downstream locations respectively. The average water application for the whole duration in volume and depth on the experimental locations was found in volume 4.3, 8.6 and 9.4 m^3 and in depth 31.5, 29 and 41.5 mm for upstream, midstream and downstream locations respectively. The average irrigation application interval (days) and total number of irrigation application (times) for the whole duration on the experimental locations were found: 5.6, 5.6 and 7.1 days and 19, 18.3 and 15.7 times for upstream, midstream and downstream locations respectively. The irrigation application interval days increases from upstream to downstream locations and the number of irrigation application times decreases from upstream to downstream. These results showed that the irrigation application interval was short and frequent in the upstream followed by midstream and downstream locations. This is simply because of the difference in irrigation scheduling among the irrigators.

The total water application in volume and depth for the whole season on the experimental locations was found: 82.3, 164.1 and 148.8 m^3 and 609.7, 549.5 and 656.8 mm for upstream, midstream and downstream locations respectively. The total water application in volume and depth for the whole duration per growth stages of the experimental locations was found as: at initial stage 21.1, 41.5 and 41.4 m^3 and 156.6, 138.9 and 182.8 mm, at development stage 27, 54.1 and 47.3 m^3 and 199.8, 181 and 208.8 mm, at mid stage 23.6, 48.6 and 35.8 m^3 and 174.7, 162.8 and 157.8 mm and at late season stage 10.6, 19.9 and 24.3 m^3 and 78.6, 66.7 and 107.4 mm for upstream, midstream and downstream locations respectively.

The average farm size of the entire experimental fields was found 220.09 m^2. The average total water application in volume and depth for the whole season of the entire experimental scheme was found 131.7 m^3 and 598.4 mm respectively. The experimental farm size of the 9 test plots (Appendix I. table 3) varied from 64.2 - 565.6 m^2. The average depth of water application throughout the whole farmer's experimental fields has varied from 24.7 – 55.0 mm and the average irrigation application interval days of the whole farmers experimental fields has also varied from 5.1 – 8.6 days. The number of irrigation applications among the entire test plots varied from 12 – 19 times per season. The average irrigation application interval within the 9 test plots was found: minimum 5.1 days and maximum 8.6 days.

Considering these results, there is a big difference in irrigation water application (interval, time and duration) among the selected beneficiary households. This implies the technical support from experts was poor and farmers irrigate their farms on guess or on their own perceptions.

Table 4.12. Average application of water on the experimental locations per growth stage

S/no	Locations	Growth stages	Average application			Total application			Irrigation Interval	No of irrigation
			Time (sec)	Vol. (m3)	depth (mm)	Time (sec)	Vol. (m3)	depth (mm)	days	time
1	Upstream	I. stage	1239.3	3.9	28.9	6712.3	21.1	156.6	4.2	5.67
		Dev. Stage	1545.8	4.9	36.1	8566.3	27.0	199.8	5.5	5.33
		Mid-stage	1498.0	4.7	34.9	7490.0	23.6	174.7	6.3	5.00
		Late stage	1122.6	3.5	26.2	3367.7	10.6	78.6	6.2	3.00
	Upstream		1351.4	4.3	31.5	26136.3	82.3	609.7	5.6	19.00
2	Mid-stream	I. stage	2536.9	8.0	26.8	13172.0	41.5	138.9	4.1	5.33
		Dev. Stage	3089.2	9.7	32.6	17162.0	54.1	181.0	5.6	5.33
		Mid-stage	3226.7	10.2	34.0	15430.7	48.6	162.8	6.1	4.67
		Late stage	2108.8	6.6	22.2	6326.3	19.9	66.7	6.7	3.00
	Mid-stream		2740.4	8.6	28.9	52091.0	164.1	549.5	5.6	18.3
3	Downstream	I. stage	3288.7	10.4	45.7	13149.7	41.4	182.8	5.8	4.00
		Dev. Stage	3188.3	10.0	44.3	15018.0	47.3	208.8	6.8	4.67
		Mid-stage	2875.1	9.1	40.0	11350.7	35.8	157.8	8.1	4.00
		Late stage	2576.4	8.1	35.8	7729.3	24.3	107.4	7.6	3.00
	Downstream		2982.1	9.4	41.5	47247.7	148.8	656.8	7.1	15.7
Scheme level			2358	7.4	33.6	41825	131.7	598.4	6	18

3) Irrigation of water demand and supply

The results on gross irrigation water demand and supply analysis are presented in (table 4.13-16) below based on water supply and demand crop water requirement data.

The gross water irrigation demand and supply analysis of the 9 experimental plots is presented as follows:

At the upstream location: the irrigation application interval days and number of irrigation application times scheduling of the 3 experimental plots were found very poor. That shows longer application intervals and a smaller number of application times per growth stages and throughout the season. The result of this analysis implied that the irrigation management ability of the farmers was poor, especially at plot-1 and plot-2. The gross total irrigation water supply of the 3 plots were found less than the recommended gross total demand irrigation water requirement at plot-1 & plot-2, while greater than the recommended value was found at plot-3. The gross total irrigation water supply per growth stages of the 3 upstream plots shows surplus at initial and development stages and supply gaps at mid & late season stages.

At midstream location: The irrigation scheduling of the 3 farmers were the same as the farmers at upstream. The result of this analysis implied that the irrigation management ability of the farmers was poor especially, at plot-4 and plot-6. The gross total irrigation water supply of the 3 plots were found less than the recommended gross total demand irrigation water requirement and the gross total irrigation water supply per growth stages of the 3 midstream plots shows surplus at initial and supply gap at development, mid & late season stages except surplus at development stage was observed at plot-4.

At downstream location: The irrigation scheduling of the 3 farmers were the same as the farmers at upstream but worst here especially at plot-9 and plot-8. The result of this analysis implied that the irrigation management ability of the farmers was very poor especially, at plot-9 and plot-8. The gross total irrigation water supply of the 3 plots were found less than the recommended gross total demand irrigation water requirement and the gross total irrigation water supply per growth stages of the 3 downstream plots shows surplus at initial & development stages except gap at development stage was observed at plot-9.and supply gap at mid & late season stages.

To show the gross demand of water irrigation and supply analysis per growth stages of the three experimental locations. The difference between the gross irrigation water supply and gross CWR was expressed as (the gross supplied minus the gross CWR) then expressed in percent as the difference divided by the Gross (CWR) times 100 (difference / gross CWR * 100).

The difference in percentage indicates that the percentage of the gross irrigation supply is over or under application of water from the gross CWR. Negative (-) value implied that the gross irrigation water supply gap in the actual field whereas positive (+) value implied surplus/over.

Finally, the gross irrigation water supply and demand CWR differences in percentage values per growth stages of the experimental locations were used for demanding irrigation water and supply analysis.

The total gross demand irrigation water requirement and supply variation in percent values of the three experimental locations per growth stages were found as: at upstream 64.8, 4.1, -33 and -65 %, at midstream 46.3, -5.7, -37.6 and – 70.5 % and at downstream 92.4, 8.7, -39.5, and -52.5 % for initial, development, mid and late season stages respectively. The average total gross demand irrigation water and supply variation in percent values of the whole season of the three experimental locations were found: -21, -29 and -15.1 % for upstream, midstream and downstream locations respectively.

The average total gross demand irrigation water and supply variation results of the three experimental locations showed higher at the midstream followed by upstream and downstream locations while the gross demand irrigation water and supply variation results per growth stages of the experimental locations showed almost similar tendency which is surplus at the initial and development stages except gap at development stage was observed at midstream location and below required/gap at the mid and late season stages.

These results implied that the gross irrigation scheduling of the three experimental locations per growth stages was very poor which shows demand and supply variation in percent at the range of surplus up to 92.4 % at initial stage at downstream and gap up to -70.5 % at late season stage at upstream location.

Generally, the high gross demand irrigation water and supply variation in percent values implied the irrigation scheduling by the farmers were poor and can cause yield reduction, especially on the experimental locations having water supply gap on the mid-stage, which is the most water sensitive stage as Allen et al. (1989).

Table 4.13. Gross irrigation water demand and supply analysis of the exp. plots (upstream)

Demand		Plot-1			Differ	Plot-2			Differ	Plot-3			Differ
Date	Gr. Irr	Date	Gr. Irr	Irr. inter		Date	Gr. Irr	Irr. Inter		Date	Gr. Irr	Irr. inter	
	Mm		mm	days	Mm		Mm	Days	mm		Mm	days	mm
04-Feb	12	03-Feb	33	1	22	03-Feb	37	1	26	03-Feb	37	1	25
07-Feb	12	08-Feb	28	5	17	07-Feb	42	4	30	07-Feb	27	4	15
10-Feb	12	15-Feb	30	7	18	10-Feb	43	3	32	13-Feb	30	6	19
13-Feb	12	21-Feb	21	6	9	16-Feb	28	6	16	16-Feb	27	3	15
16-Feb	12	26-Feb	20	5	8	20-Feb	33	4	21	21-Feb	35	5	23
19-Feb	12				-12	24-Feb	23	4	11	26-Feb	33	5	21
22-Feb	12				-12				-12				-12
25-Feb	13				-13				-13				-13
Sub-tot	95		132	5	37		207	4	112		189	4	94
Initial stage													
02-Mar	23	03-Mar	37	7	14	02-Mar	35	6	12	03-Mar	42	7	19
07-Mar	26	09-Mar	34	6	7	07-Mar	39	7	12	08-Mar	41	5	14
12-Mar	30	13-Mar	29	4	0	12-Mar	45	5	15	15-Mar	47	7	18
17-Mar	34	16-Mar	25	3	-9	18-Mar	49	6	15	21-Mar	52	6	17
22-Mar	37	21-Mar	27	5	-10	24-Mar	54	6	16	25-Mar	56	4	19
27-Mar	41	25-Mar	32	4	-9				-41				-41
Sub-tot	192		184	5	-8		221	6	29		238	6	46
Development stage													
01-Apr	42	01-Apr	28	6	-14	02-Apr	49	8	7	30-Mar	52	5	10
06-Apr	44	09-Apr	30	8	-14	08-Apr	53	6	9	07-Apr	60	7	16
11-Apr	44	17-Apr	28	8	-16	15-Apr	40	7	-4	13-Apr	40	6	-4
16-Apr	44	23-Apr	26	6	-18	22-Apr	47	7	3	19-Apr	50	6	6
21-Apr	44	26-Apr	22	3	-22	26-Apr	51	4	7	26-Apr	55	7	12
26-Apr	44				-44				-44				-44
Sub-tot	261		133	6	-127		241	6	-20		257	6	-4
Mid-stage													
02-May	51	02-May	19	6	-32	02-May	22	6	-29	02-May	34	6	-17
08-May	49	09-May	27	7	-22	10-May	37	8	-12	08-May	39	6	-10
14-May	45	15-May	22	6	-23	15-May	31	5	-14	14-May	33	6	-12
20-May	43				-43				-43				-43
26-May	38				-38				-38				-38
Sub-tot	226		68	6	-158		90	6	-136		106	6	-120
Late stage													
Total	774		517		-256		759		-15		789		16

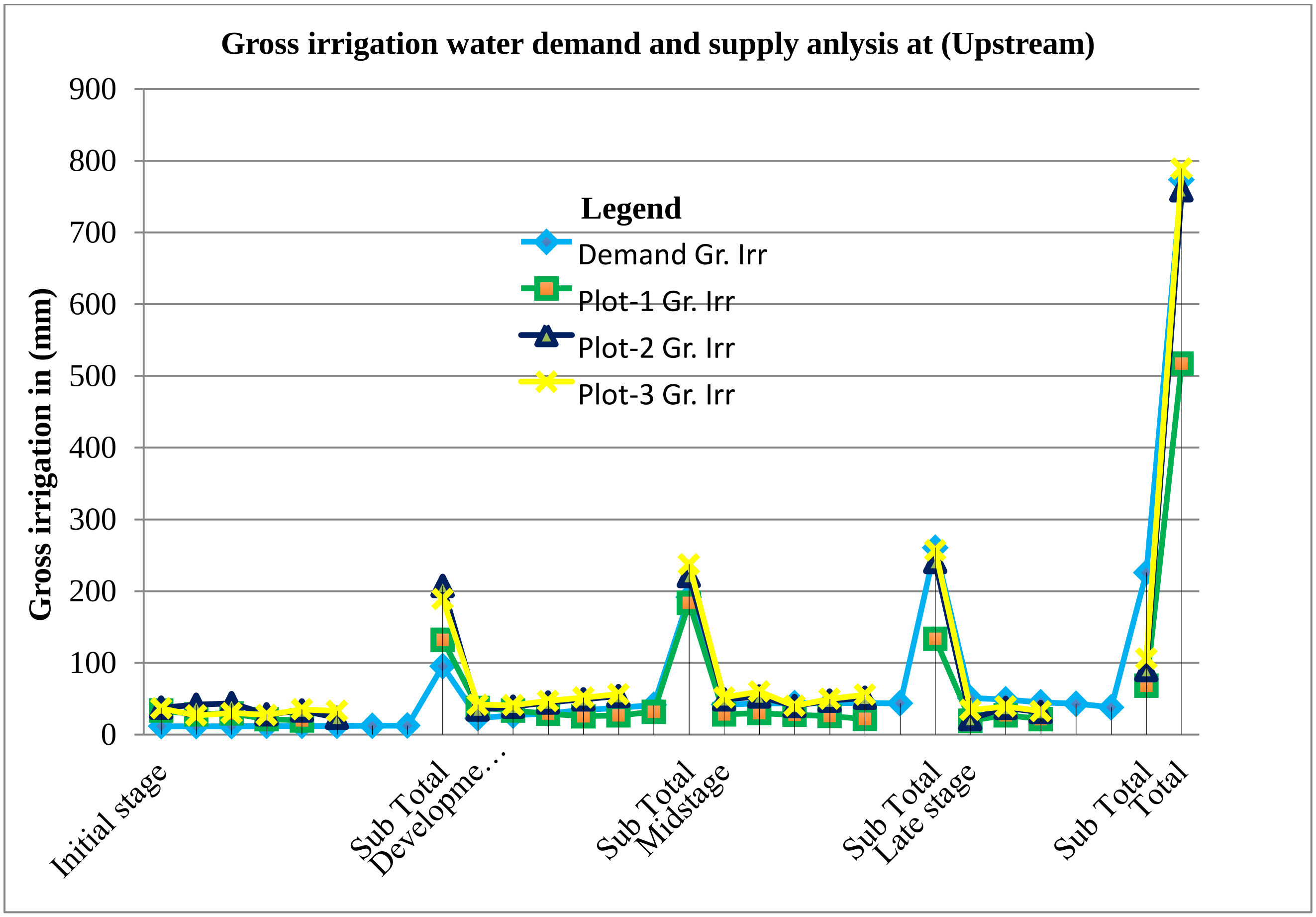

Figure 4.1. Gross irrigation water demand and supply analysis (upstream)

Source: Own data

Table 4.14. Gross water irrigation demand and supply analysis of the exp. plots (midstream)

Demand		Plot-4			Differ	Plot-5			Differ	Plot-6			Differ
Date	Gr. Irr	Date	Gr. Irr	Irr. inter		Date	Gr. Irr	Irr. inter		Date	Gr. Irr	Irr. inter	
	Mm		Mm	days	mm		mm	days	mm		Mm	Days	mm
04-Feb	12	02-Feb	29	0	17	03-Feb	21	1	9	03-Feb	22	1	10
07-Feb	12	06-Feb	31	4	19	05-Feb	20	2	9	06-Feb	21	3	9
10-Feb	12	11-Feb	29	5	17	07-Feb	30	2	18	11-Feb	24	5	13
13-Feb	12	06-Feb	42	5	30	12-Feb	31	5	19	16-Feb	28	5	16
16-Feb	12	23-Feb	47	7	35	16-Feb	36	4	24	22-Feb	24	6	12
19-Feb	12				-12	21-Feb	35	5	23				-12
22-Feb	12				-12				-12				-12
25-Feb	13				-13				-13				-13
Sub-tot	95		176	4	81		173	3	78		118	4	23
Initial stage													
02-Mar	23	28-Feb	40	5	17	27-Feb	37	6	14	27-Feb	28	5	5
07-Mar	26	04-Mar	38	6	12	03-Mar	28	6	2	02-Mar	26	5	0
12-Mar	30	10-Mar	45	6	16	06-Mar	38	3	8	06-Mar	24	4	-6
17-Mar	34	16-Mar	48	6	13	15-Mar	40	9	6	11-Mar	32	5	-2
22-Mar	37	22-Mar	47	6	10	21-Mar	30	6	-7	16-Mar	34	5	-3
27-Mar	41				-41				-41	22-Mar	28	6	-13
Sub-tot	192		219	6	27		173	6	-19		172	5	-20
Development stage													
01-Apr	42	27-Mar	39	5	-2	28-Mar	37	7	-5	28-Mar	31	6	-11
06-Apr	44	05-Apr	38	8	-6	04-Apr	46	6	2	04-Apr	37	6	-7
11-Apr	44	12-Apr	36	7	-7	10-Apr	49	6	6	10-Apr	25	6	-18
16-Apr	44	19-Apr	43	7	-1	14-Apr	49	4	5	15-Apr	31	5	-12
21-Apr	44				-44	20-Apr	40	6	-4	21-Apr	24	6	-20
26-Apr	44				-44				-44				-44
Sub-tot	261		156	7	-105		221	6	-40		148	6	-112
Mid-stage													
02-May	51	27-Apr	39	8	-12	27-Apr	27	7	-24	27-Apr	17	6	-34
08-May	49	05-May	36	8	-13	03-May	25	6	-24	02-May	17	5	-32
14-May	45	11-May	32	6	-13	11-May	28	8	-17	08-May	17	6	-28
20-May	43				-43				-43				-43
26-May	38				-38				-38				-38
Sub-tot	226		108	7	-118		79	7	-147		51	6	-175
Late stage													
Total	774		659		-115		646		-128		489		-284

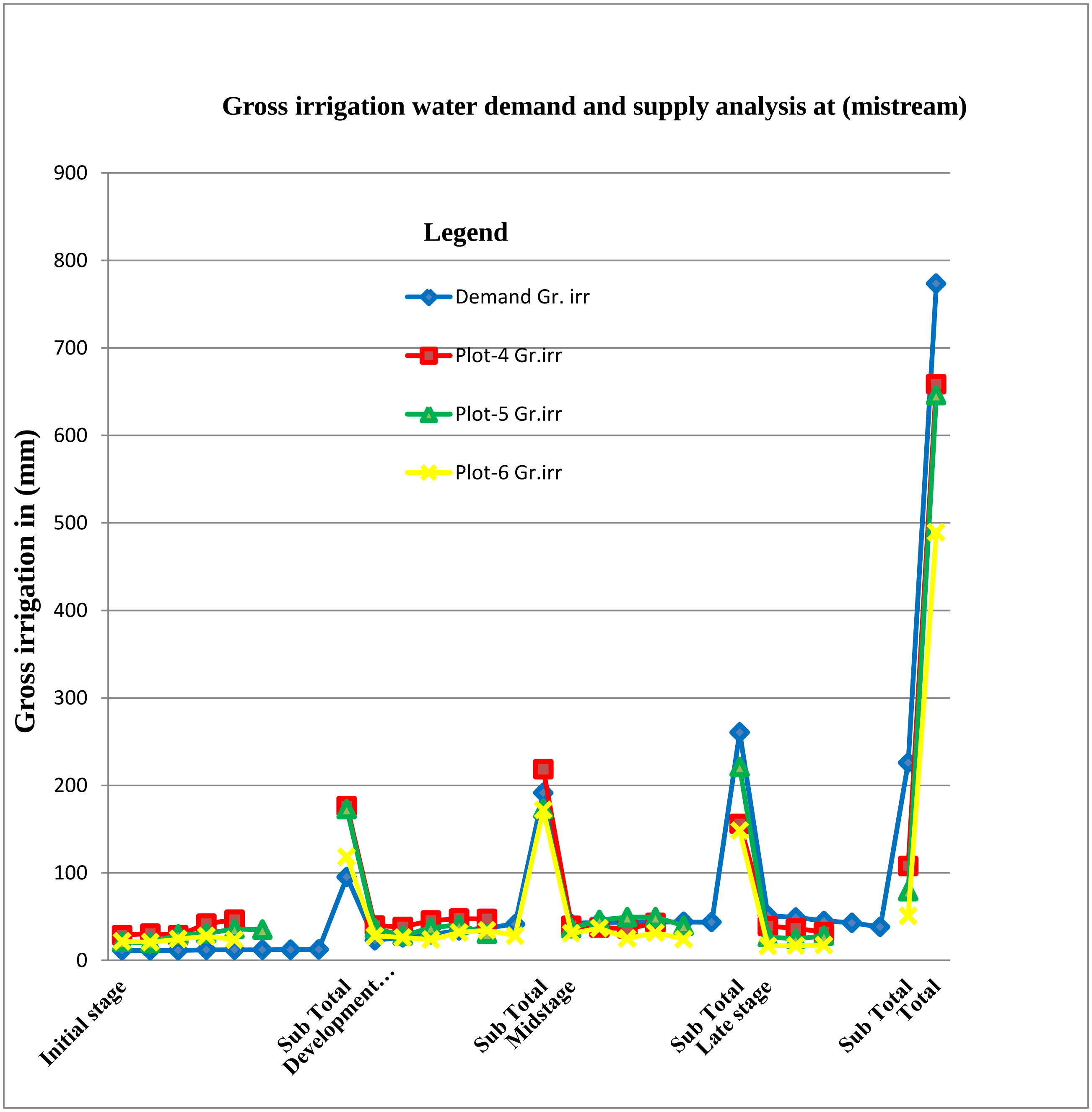

Figure 4.2. Gross water demand and supply analysis (midstream)

Source: Own data

Table 4.15. Gross water irrigation demand and supply analysis of the exp. plots (downstream)

Demand		Plot-7			Differ	Plot-8			Differ	Plot-9			Differ
Date	Gr. Irr	Date	Gr. Irr	Irr. inter		Date	Gr. Irr	Irr. Inter		Date	Gr. Irr	Irr. inter	
	Mm		Mm	days	Mm		mm	Days	mm		Mm	Days	mm
04-Feb	12	03-Feb	48	1	37	03-Feb	36	1	25	02-Feb	61	0	50
07-Feb	12	07-Feb	62	4	51	07-Feb	40	4	28	10-Feb	53	8	41
10-Feb	12	12-Feb	49	5	37	14-Feb	35	7	24	19-Feb	60	9	49
13-Feb	12	17-Feb	45	5	33	21-Feb	37	7	25				-12
16-Feb	12	23-Feb	32	6	20				-12				-12
19-Feb	12				-12				-12				-12
22-Feb	12				-12				-12				-12
25-Feb	13				-13				-13				-13
Sub-tot	95		236	4	141		149	5	53		175	6	79
Initial stage													
02-Mar	23	28-Feb	29	5	6	02-Mar	36	9	13	27-Feb	57	8	34
07-Mar	26	03-Mar	48	5	22	03-Mar	46	3	19	07-Mar	53	10	27
12-Mar	30	10-Mar	43	7	13	08-Mar	37	5	7	17-Mar	63	10	33
17-Mar	34	17-Mar	52	7	18	13-Mar	35	5	1				-34
22-Mar	37	23-Mar	32	6	-5	18-Mar	38	5	1				-37
27-Mar	41				-41	22-Mar	41	4	0				-41
Sub-tot	192		204	6	13		234	5	42		173	9	-19
Development stage													
01-Apr	42	29-Mar	38	6	-4	29-Mar	34	7	-8	27-Mar	84	10	42
06-Apr	44	05-Apr	49	6	5	06-Apr	41	7	-3	06-Apr	37	9	-6
11-Apr	44	11-Apr	30	6	-13	17-Apr	32	11	-12	17-Apr	35	11	-8
16-Apr	44	18-Apr	27	7	-17	24-Apr	36	7	-8				-44
21-Apr	44	24-Apr	36	6	-8				-44				-44
26-Apr	44				-44				-44				-44
Sub-tot	261		180	6	-81		142	8	-118		157	10	-104
Mid-stage													
02-May	51	30-Apr	34	6	-17	30-Apr	34	6	-17	27-Apr	47	10	-4
08-May	49	07-May	22	7	-27	08-May	33	8	-16	07-May	60	10	11
14-May	45	15-May	39	8	-6	13-May	20	5	-25	15-May	49	8	4
20-May	43				-43				-43				-43
26-May	38				-38				-38				-38
Sub-tot	226		95	7	-131		87	6	-139		157	9	-69
Late stage													
Total	774		715		-58		612		-162		661		-113

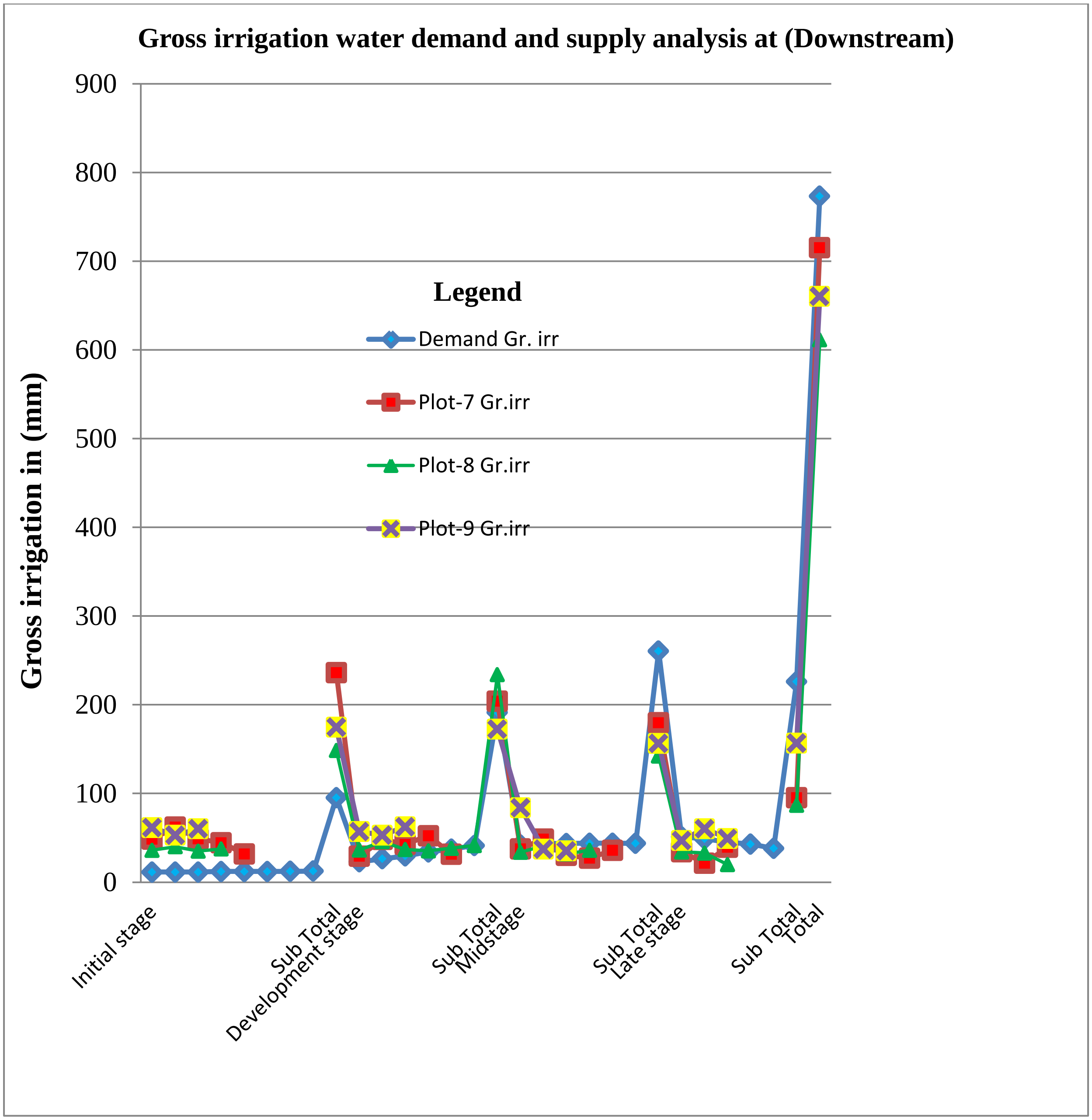

Figure 4.3. Gross water demand and supply analysis (downstream)

Source: Own data

Table 4.16. Gross water irrigation demand and supply analysis per growth stage

Stages	Demand	Upstream			Midstream			Downstream		
		Supply	Difference	%	Supply	Difference	%	Supply	Difference	%
Initial stage	95	156.6	61.6	64.8	138.9	43.9	46.3	182.8	87.8	92.4
Dev. Stage	192	199.8	7.8	4.1	181.0	-11.0	-5.7	208.8	16.8	8.7
Mid-stage	261	174.7	-86.3	-33	162.8	-98.2	-37.6	157.8	-103.2	-39.5
Late stage	226	78.6	-147.4	-65	66.7	-159.3	-70.5	107.4	-118.6	-52.5
Total	774	609.7	-164.3	-21	549.5	-224.5	-29.0	656.8	-117.2	-15.1

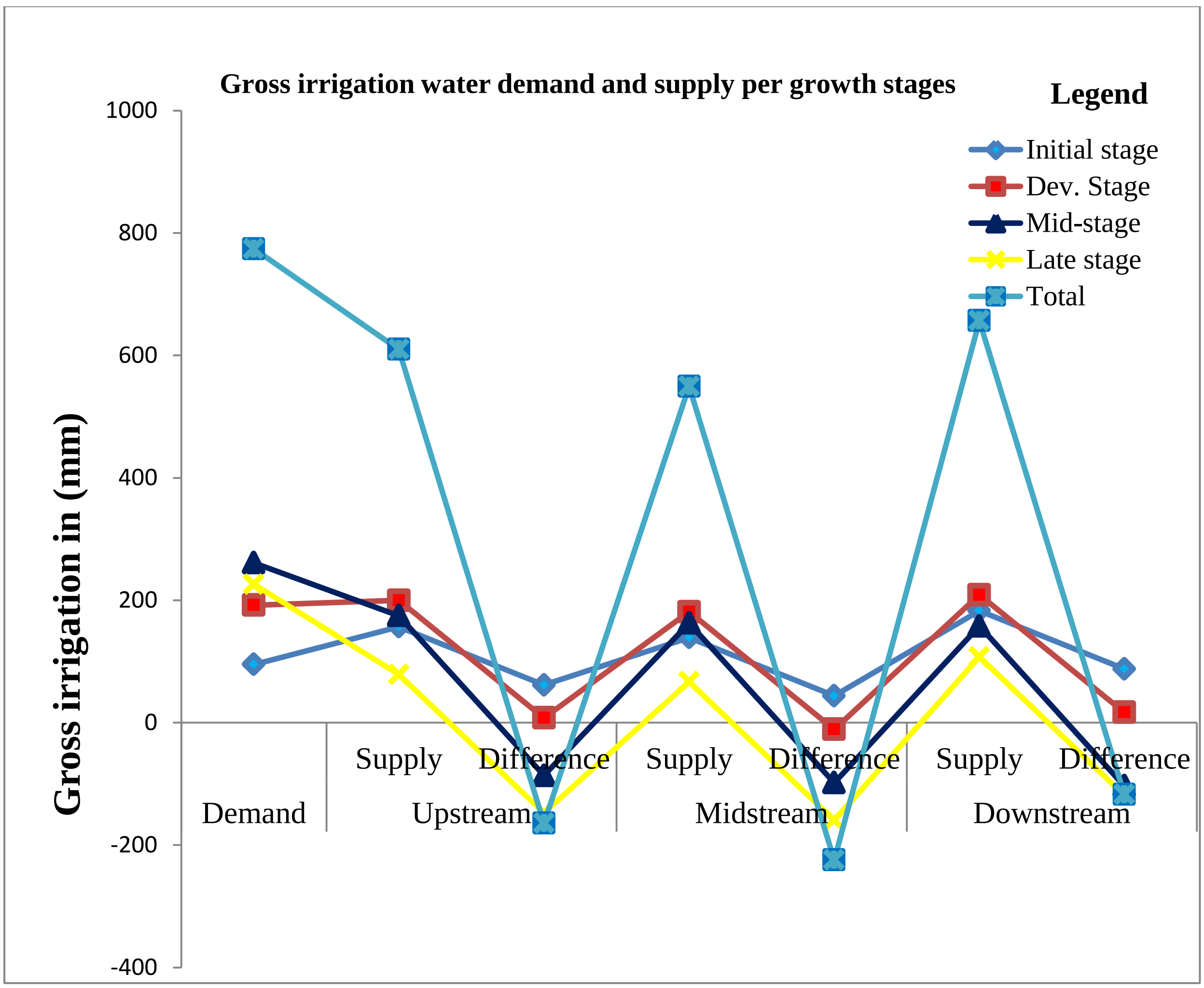

Figure 4.4. Gross water irrigation demand and supply per growth stages

Source: Own data

4.2.7 Water supply indicators analysis

The relative irrigation water supply (RIS) was calculated using equation (22) in section (3.2.4). Since there was no rainfall in the irrigation season, the relative water supply and relative irrigation supply was the same. The average relative irrigation water supply (RIS) values of the whole duration of the three experimental locations were found: 1.7, 1.4 and 1.8 for upstream, midstream and downstream locations respectively. The average relative irrigation water supply (RIS) value of the entire experimental scheme was found: 1.6. The results of this analysis implied that the average RIS values of the experimental locations showed almost similar tendency and value. This result indicates that the canal capacity or delivery hose capacity of the water supply systems had enough capacity to deliver the irrigation demand even on the peak period.

The water delivery capacity ratio was calculated using equation (23) in section (3.2.4). The average water delivery capacity ratio (WDC) values of the experimental locations were found as 2.7, 2.7 and 2.8 for upstream, midstream and downstream locations respectively and the average water delivery capacity ratio (WDC) value of the entire experimental scheme was found: 2.76. This result indicates the canal capacity/ delivery hose capacity of the experimental locations were more than double the peak consumptive demand of the experimental locations.

4.3 Irrigation water productivity

The results of the internal and external irrigation water productivity indicators are presented in Table 4.17, based on the actual water application, irrigation crop production, and crop water requirements calculated using the CROPWAT 8.0 model software. Additionally, the irrigation water productivity (IWP) of the 9 test plots is illustrated in Figure 4.5 and Appendix I, Table 9. The internal crop water productivity indicators were computed using the equations (29 - 33) from Section 3.2.6.

The crop water use efficiency (CWUE) values for the experimental locations were 3.9, 5.1, and 3.7 kg/m^3 for the upstream, midstream, and downstream locations, respectively. The irrigation water use efficiency (IWUE) values were 3.6, 5.2, and 3.1 kg/m^3 for the upstream, midstream, and downstream locations, respectively. Since there was only one source of water (irrigation), the

CWUE and IWP values were the same. The economic irrigation water productivity (EIWP) values for the experimental locations were 47, 60.7, and 43.9 ETB/m³ for upstream, midstream, and downstream locations, respectively. The average EIWP value across all experimental sites was 50.6 ETB/m³. Similarly, the economic water productivity (EWP) values for the locations were 43.3, 62, and 37.8 ETB/m³ for upstream, midstream, and downstream locations, respectively, with an overall average EWP value of 47.5 ETB/m³.

Furthermore, the external water productivity indicators were calculated using equations (34 and 35) from Section 3.2.6, considering output per cropped area and output per unit of water consumed. The output per cropped area values were 264,000, 340,800, and 248,000 ETB/ha for upstream, midstream, and downstream locations, respectively. The average output per cropped area for all experimental locations was 284,266.7 ETB/ha. The output per unit of water consumed was 47.4, 61.2, and 44.5 ETB/m³ for upstream, midstream, and downstream locations, respectively, with an overall average value of 51 ETB/m³.

These results are significantly higher than those from a previous study (Worku, 2013), which reported CWUE values of 1.72, 1.8, and 1.45 kg/m³ and IWUE values of 1.21, 1.81, and 2.1 kg/m³ for upstream, midstream, and downstream locations, respectively. The reported economic water productivity values were also much lower, at 8.9, 9, and 7.3 ETB/m³ for upstream, midstream, and downstream locations, respectively.

Economic feasibility results showed that the net benefit to variable cost ratio was 1.5 for upstream, 4.5 for midstream, and 2.5 for downstream, indicating that the midstream location was the most economically feasible, followed by upstream and downstream locations. These results demonstrate higher economic feasibility across all experimental locations.

In terms of water productivity for biomass (CWUE and IWUE), all the internal and external economic results indicate greater efficiency at the midstream location, followed by the upstream and downstream locations. The water productivity for biomass (kg/ET) of the entire experimental scheme was slightly higher than the FAO's attainable water productivity range (Batticani, 2006, cited in FAO, 2012), which is 1.3 to 3.5 kg/m³, with 3 kg/m³ considered typical under favorable conditions. This higher water productivity can be attributed to variations in temporal climatic conditions, irrigation methods, and field management practices. The differences across experimental locations and test plots were mainly due to variations in irrigation practices and field management.

Table 4.17. The irrigation water productivity results

S/No	Results	Units	Experimental locations			
			upstream	middle stream	down stream	Average
1	exp. Area	M2	135.0	298.6	226.6	220.1
2	Total product	Kg	297.1	848.1	468.3	521.4
3	Gross benefit	ETB	3564.9	10177.4	5619.7	6256.4
4	production cost	ETB	1415.0	1865.0	1620.0	1633.3
5	Net benefit	ETB	2149.9	8312.4	3999.7	4623.1
6	ETc	M3	75.9	167.8	127.9	123.6
7	Irrigation supplied to farm (Vf)	M3	82.33	164.1	148.8	131.7
8	Total water used (Vd)	M3	82.33	164.1	148.8	131.7
9	Actual water used by crops (ETa)	M3	75.2	166.3	126.2	122.6
	Results					
10	CWUE	Kg/m3	3.9	5.1	3.7	4.2
11	IWUE	Kg/m3	3.6	5.2	3.1	4.0
12	IWP	Kg/m3	3.9	5.1	3.7	4.2
13	Economic IWP	ETB/m3	47.0	60.7	43.9	50.6
14	Economic WP	ETB/m3	43.3	62.0	37.8	47.5
	External indicators					
15	Output per cropped area	ETB/ha	264000.0	340800.0	248000.0	284266.7
16	Output per unit of water consumed	ETB/m3	47.4	61.2	44.5	51.0
17	Economic analysis	unit less	1.5	4.5	2.5	2.8

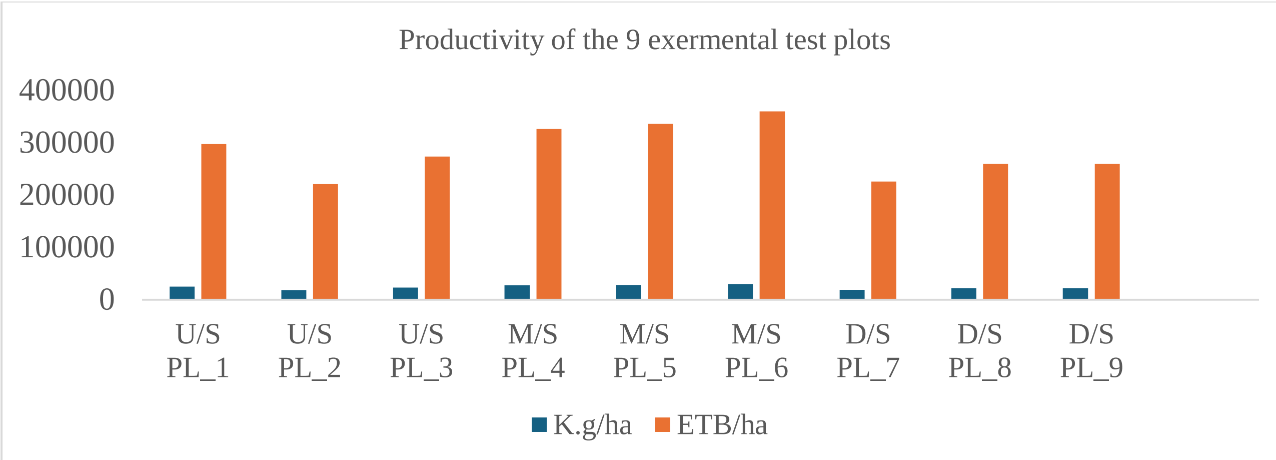

Figure 4.5. Crop water productivity of the 9 test plots.

- Vertical axis shows that Crop water productivity while Horizontal axis experimental plots.

4.4 Contribution of the SSI scheme to the HH's net income generation analysis

To assess the impact of small-scale irrigation (SSI) on household annual net income, all income sources agricultural (including cropping and livestock) and non-agricultural (off-farm), were considered, along with the costs associated with producing these agricultural products. An important aspect of this evaluation is the consideration of off-farm income, as the hypothesis suggests that non-irrigating households tend to rely more on off-farm income compared to irrigating households. Non-irrigating households may use off-farm activities to compensate for the income that could have been generated by irrigation activities.

To determine the net income contribution of the SSI scheme, the household net income before and after the implementation of the SSI scheme was compared. Secondary data were analyzed using Excel worksheets and a one-way analysis of variance, presenting the annual net income contribution of the experimental scheme to beneficiary households, both before and after the SSI scheme construction. The net income for the year 2012 cropping (before the SSI scheme) and the 2018 cropping year (after the SSI scheme) were used for this comparison.

The results regarding the contribution of the SSI scheme to household net income generation are shown in Table 4.18. While the gross income from rainfed crop production decreased from 6156.8 ETB to 4788 ETB per cropping year due to variations in weather conditions, pests, and diseases, other income sources—including irrigation, livestock production, and off-farm activities—showed a positive increase in net income. The variation in annual average income from on-farm and off-farm activities before and after the development of the SSI scheme is as follows: for rainfed production, 6156.8 ETB decreased to 4788 ETB; for irrigation production, 280.7 ETB increased to 27964.2 ETB; for livestock production, 3830 ETB increased to 16838 ETB; for livestock output, 1426.7 ETB increased to 6050.7 ETB; and for off-farm activities, 2480 ETB increased to 6098.7 ETB.The average agricultural production costs for beneficiaries also increased from before to after the SSI scheme development. For example, fertilizer costs rose from 1040.3 ETB to 3283.4 ETB, seed and chemical costs increased from 71.3 ETB to 470.7 ETB, and fuel and lubricant costs, which were previously zero, rose to 738 ETB.

The average annual gross income for beneficiaries was 14174.1 ETB before the SSI scheme and 39064.4 ETB after the scheme development. The average annual total production cost for beneficiaries increased from 1111.7 ETB to 5172.1 ETB. Consequently, the average annual net income for beneficiaries increased from 13,062.4 ETB before the SSI scheme to 33,892.3 ETB after the scheme development. This represents an increase of 20,829.9 ETB or 159% in annual net income over a 6-year period. This result is significantly higher than findings from a previous study in the region, which reported a 50% net income increase for irrigation users compared to non-users (Gebregziabher et al., 2009).

The minimum and maximum annual net income for beneficiaries before the SSI scheme development ranged from 6292.5 ETB to 20,510 ETB. After the SSI scheme was developed, the minimum and maximum annual net income values increased to 10,092.7 ETB and 58,457.4 ETB, respectively.

Table 4.18. The contribution of the SSI scheme to the household's net income generation

ID of respondent	Income before irrigation (2012) cropping year			Income after irrigation (2018) cropping year			Net income Difference (ETB)
	Gross income (ETB)	production costs (ETB)	Net income (ETB)	Gross income (ETB)	production costs (ETB)	Net income (ETB)	
1	14915	1440	13475.0	61574.1	7782.9	53791.2	40316.2
2	7137.5	845	6292.5	12403.65	2311	10092.7	3800.2
3	20832	845	19987.0	40142.2	5738	34404.2	14417.2
4	13915	845	13070.0	27862.1	4786.6	23075.5	10005.5
5	13105	1140	11965.0	19555.2	5057.3	14497.9	2532.9
6	15090	1140	13950.0	54231.1	6508	47723.1	33773.1
7	12312.5	550	11762.5	25138.26	3271.9	21866.4	10103.9
8	21650	1140	20510.0	58384.2	6269.3	52114.9	31604.9
9	7152.5	550	6602.5	60139.45	5783	54356.5	47754.0
10	21645	1460	20185.0	66240.3	6018	60222.3	40037.3
11	13940	1000	12940.0	43673.7	5657	38016.7	25076.7
12	13410	1140	12270.0	35052.85	5478	29574.9	17304.9
13	10724	1230	9494.0	29993.6	5680	24313.6	14819.6
14	12323	1500	10823.0	28063	4410	23653.0	12830.0
15	14460	1850	12610.0	23511.6	2830	20681.6	8071.6
Average	14174.1	1111.7	13062.4	39064.4	5172.1	33892.3	20829.9
Min	7137.5	550.0	6587.5	12403.7	2311.0	10092.7	3505.2
Max	21650.0	1850.0	19800.0	66240.3	7782.9	58457.4	38657.4

4.5 Main challenges and opportunities of the SSI scheme

Before the intended questioner preparation for identification of the main challenges and opportunities in the SSI scheme, 20 irrigation beneficiaries were requested to list out the main challenges and opportunities in the SSI scheme in their perception. Accordingly, the respondents listed twelve main challenges and 8 main opportunities through opinion poll method. Then, the respondents were requested to prioritize the main challenges and opportunities. The summary results on the main challenges and opportunities of the SSI scheme were presented in tables (4.19 and 4.20).

4.5.1 The main challenges of the SSI scheme development

The results on the main challenges of the SSI scheme development were presented in table 4.19 below. The results in table 4.19 indicated that the response of the 15 respondents on the 12 main challenges was indicated on average that the majority (74%) of the respondents were in agreement with the 12 main challenges that influence the performance of the SSI development at Mai Gobo irrigation scheme while the minority (26%) of the respondents have disagreed with the main challenges.

This summary implied that respondents were knowledgeable regarding those challenges or factors that influence the SSI development. Specifically, the indications and implications of the results in table 4.19 were discussed as follows, 60 % of the respondents reported the low yield of the irrigation farming due to poor irrigation and field management was one of the main challenges in the experimental area and 53.3 % of the respondents reported the unpromising price of products as among the main challenges due to poor marketing knowledge and poor marketing system, 53.3 % of the respondents also reported that lack of awareness is one of the challenges due to poor extension service system and poor technical support from the district and woreda experts. However, 53.3 % of the respondents reported poor input utilization as one of the challenges which led to poor land productivity and limited the sustainability and development of the beneficiaries as well as the irrigation system in the area.

Moreover, 0% of the respondents reported the weather (flood and wind) condition of the area is the first challenge due to prevailing climate change and 93.3 % of the respondents confirmed the presence of pests and diseases & considered as a challenge that affects sustainability of the irrigation development. And 73.3 % of the respondents reported that lack of extension service and technical support led to poor irrigation farming ability and limited participation in irrigation development.

Table 4.19. Main challenges of the SSI scheme development

Category	Variable	Count	Column N %
Low yield	Yes	9	60.0%
	No	6	40.0%
Un promising price of products	Yes	8	53.3%
	No	7	46.7%
Too small land holding	Yes	3	20.0%
	No	12	80.0%
Lack of awareness	Yes	8	53.3%
	No	7	46.7%
Pests and diseases	Yes	14	93.3%
	No	1	6.7%
Weather (flooding and wind)	Yes	15	100.0%
	No	0	0.0%
Lack of extension services and technical training	Yes	11	73.3%
	No	4	26.7%
Lack of startup capital or fear to loan from institutes	Yes	5	33.3%
	No	10	66.7%
Poor water and land management	Yes	7	46.7%
	No	8	53.3%
Poor input utilization	Yes	8	53.3%
	No	7	46.7%
Lack of mechanization technology and management	Yes	3	20.0%
	No	12	80.0%
Poor working habits	Yes	3	20.0%
	No	12	80.0%

4.5.2 The main opportunities on the SSI scheme development

The results on the main opportunities of the SSI scheme are presented in table 4.20 based on the respondent's perception. The results in table 4.20 indicated that the majority (69 %) of the respondents agreed with the main opportunities on the Mai Gobo SSI scheme development while the minorities (31 %) of the respondents disagreed.

Specifically, the results in table 4.20 indicated that, 66.7 % of the respondents reported that having enough working force on the beneficiary is one of the opportunities and 60 % of the respondents confirmed that high water potential is also another opportunity, 60 % of the respondents reported promising markets and market access in the nearby market and nearby town is also another opportunity and 60 % of the respondents reported having land for irrigation expansion in the command area is opportunity to the small scale irrigation development in the experimental site. However, 46.7 % of the respondents supported and 53.3 % of the respondents complained on the high commitment of the Ethiopian government as an opportunity to the small-scale irrigation development in the experimental site.

Moreover, 0%of the respondents reported that having suitable agro-ecology is the main opportunity in the experimental scheme, 86.7 % of the respondents supported having access to credit is opportunity for the small scale irrigation development and 73.3 % of the respondents also reported that availability of donors and NGOs to support irrigation management and development activities in the experimental scheme and woreda is an opportunity to the small scale irrigation development.

Table 4.20. Main opportunities on the SSI scheme development

Category	Variable	Count	Column N %
High water potential	Yes	9	60.0%
	No	6	40.0%
	Total	15	100.0%
High commitment of the Ethiopian government	Yes	7	46.7%
	No	8	53.3%
	Total	15	100.0%
Donors and NGOs to support irrigation management and development activities	Yes	11	73.3%
	No	4	26.7%
	Total	15	100.0%
Promising markets and market access	Yes	9	60.0%
	No	6	40.0%
	Total	15	100.0%
having access to credit	Yes	13	86.7%
	No	2	13.3%
	Total	15	100.0%
having enough working force	Yes	10	66.7%
	No	5	33.3%
	Total	15	100.0%
having land for irrigation expansion	Yes	9	60.0%
	No	6	40.0%
	Total	15	100.0%
having suitable agro-ecology	Yes	15	100.0%
	No	0	0.0%
	Total	15	100.0%

4.5.3 Farmers’ recommendations for improvement of irrigation system

The results on the farmers’ recommendations are presented in table 4.21 based on the respondent’s perception. The summary results indicated that on average, the majority (75 %) of the respondents agreed with the recommendations to improve the performance of the small-scale irrigation scheme while the minorities (25 %) of the respondents disagreed.

Specifically, the results in the recommendations according to the farmers perception indicates that 80 % of the respondents reported providing improved inputs on time and fairly is one of the solutions and 73.3 % of the respondents reported that strong institutional arrangement will improve the small-scale irrigation performance, 66.7 % of the respondents supported that improving market system is one of the recommended solutions to improve the scheme performance. However, 53.3 % of the respondents reported providing mechanization technologies will improve the overall performance of the scheme.

Moreover, 0% of the respondents reported as the main solution to the small-scale irrigation scheme constructing retaining wall on the sides of the banks and 0% of the respondents reported giving strong extension service will solve the awareness gaps and improve the scheme performance. Finally, 93.3 % of the respondents supported that giving training and technical support to farmers will improve the overall scheme performance.

Table 4.21. Farmers' recommendations for improvement of irrigation system

S/No	Category	Variable	Count	Column N %
1	Providing improved input on time and fairly	Yes	12	80.0%
		No	3	20.0%
		Total	15	100.0%
2	Strong institutional arrangement	Yes	11	73.3%
		No	4	26.7%
		Total	15	100.0%
3	Giving technical support to farmers	Yes	14	93.3%
		No	1	6.7%
		Total	15	100.0%
4	providing mechanization technologies	Yes	8	53.3%
		No	7	46.7%
		Total	15	100.0%
5	Giving strong extension services	Yes	15	100.0%
		No	0	0.0%
		Total	15	100.0%
6	Providing credit	Yes	4	26.7%
		No	11	73.3%
		Total	15	100.0%
7	Improving market system	Yes	10	66.7%
		No	5	33.3%
		Total	15	100.0%
8	Constructing retaining wall on the side banks of the SS dam	Yes	15	100.0%
		No	0	0.0%
		Total	15	100.0%

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The conclusions on the irrigation system performance indicators of the experimental scheme are drawn in line with the main results and discussions as presented as follows:

The conveyance efficiency results of the entire experimental scheme were almost perfect nearly 0 %. The average irrigation application efficiency (Ea) results of the experimental locations implied higher value at the upstream followed by midstream and downstream locations. The average irrigation water application value of the entire scheme was found to be 72%. The average (Ei) value results of the experimental locations implied higher value at midstream followed by upstream and downstream locations. The overall irrigation efficiency (Eo) results of the experimental locations were the same with the irrigation application efficiency (Ea) results.

All the average (DU) and (CU) values of the whole season of the experimental locations show increasing tendency in depth from surface to subsurface. The (DU) and (CU) value results of the whole duration of the experimental locations showed almost similar tendency and values. The justification for the more similarities on the (DU) and (CU) value result on the entire experimental fields were because of the similarities on the topography, methods of irrigation application, soil characteristics, soil structure and grading and climate on the entire experimental fields. These results of the analysis implied that the overall irrigation applications on the entire experimental fields were almost uniform over the entire fields.

The gross irrigation water scheduling performance per growth stages of the farmers on the experimental locations were poor that implied demand CWR and supply variation in percent from 92.8 % surplus water supply at initial stage up to 70.5 % water supply deficit at the late season stage. The tomato productivity value in the experimental scheme was found 22,000, 28,400 and 20,666.7 $kgha^{-1}$ for upstream, midstream, and downstream locations, respectively. All the internal and external irrigation water productivity indicator analysis results of the experimental locations showed higher efficiency values at the midstream followed by upstream and downstream locations. The water productivity for biomass ($kgET^{-1}$) in (kgm^{-3}) results of the entire experimental scheme were found in higher efficiency values in average 4.2 kgm^{-3} and this is slightly higher than the FAOs attainable water productivity. Except at the rainfed crop production, all the on-farm and off-farm activities income sources of the HH's implied increasing trend on the annual gross income from before to after the SSI scheme development. The annual net income generating contribution of the SSI scheme to the beneficiary HH's was found: ETB 20,829.9 or 159%.

The main challenges and opportunities of the SSI scheme: According to the beneficiaries, the main challenges of the SSI scheme development were:

- weather condition of the area (flooding, wind, and drought)
- pests and diseases
- lack of extension service and technical support
- low yield of crop production
- lack of awareness and poor input utilization and

The main opportunities of the SSI scheme in the study area were:

- having suitable agro ecology
- Having access to credit
- availability of donors and NGOs to support irrigation development and management
- having high water potential
- having enough working force
- promising market and market access
- having land for expansion

5.2 Recommendations

The findings of this study provide valuable guidelines for managing tomato irrigation in semi-arid regions like Tigray, northeastern Ethiopia, and other areas with similar climatic and management conditions. To optimize tomato irrigation requirements and improve water productivity, crop water needs should be adjusted based on local meteorological conditions. To address the existing constraints and harness the opportunities for small-scale irrigation (SSI), relevant stakeholders should focus on minimizing the factors limiting irrigation water productivity in the study area. The following specific recommendations are proposed:

1. Recommendations for Government Institutions:

a) Research should accompany the implementation process to accelerate upscaling and adaptation of recommendations, considering local conditions and ongoing developments in materials and knowledge. Capacity building and awareness promotion should be prioritized from the start.

b) Assess successful practices from other countries (in terms of policy, legal frameworks, strategies, and structures for small-scale irrigation) and adapt these to the socio-economic conditions of the region.

c) Identify capacity gaps and develop well-structured short- and long-term training programs for irrigation beneficiaries.

d) Strengthen technical support through timely supervision by extension services and offer solutions for challenges beyond farmers' technical and financial capacities.

e) Foster experiences sharing among small-scale irrigation farmers.

f) Facilitate access to long-term financial credit, particularly for introducing water harvesting technologies.

g) Improve marketing linkages and provide relevant market information to small-scale irrigation farmers.

h) Organize regular consultative meetings and forums among irrigation cooperatives or water user associations and all development partners.

i) Promote and expand irrigation cooperatives across the region.

2. Recommendations for Other Development Partners:

a) Provide financial and technical support for the expansion and development of small-scale irrigation.

b) Assist the government in sharing the best practices and successful experiences from other countries.

c) Actively engage in consultative meetings and forums to promote irrigation cooperatives and water user associations.

3. Recommendations for Water User Associations:

a) Irrigation cooperatives should ensure the effective distribution of inputs such as pesticides and motorized pumps to address members' needs.

b) Educate members and the broader community about the importance of cooperative principles, values, and the role of small-scale irrigation in improving livelihoods.

c) Establish strong and viable linkages with development/extension agents.

d) Build robust partnerships with other cooperatives and the private sector to address financial and marketing challenges.

e) Encourage full participation of members in planning, monitoring, and evaluating irrigation activities.

f) Get involved in the production and distribution of improved seeds.

g) Promote the efficient utilization of both water and land resources.

These recommendations aim to foster the growth and sustainability of small-scale irrigation systems, enhance productivity, and improve the livelihoods of farmers in the study area.

6. SCOPE AND LIMITATIONS

6.1 Scope of the research

This research has focused on evaluating the irrigation system performance indicators, the contribution of the irrigation scheme to household (HH) net income generation, and the identification of main challenges and opportunities of the Mai Gobo sand dam. This study was conducted between January and June 2018 by participating fifteen farmers practicing irrigation farming at the sand dam scheme in the Mai Gobo area.

6.2 Limitations of the research

The research was undertaken in a village far from the town with limited transport access, therefore making appointments to access some of the farmers through the scheme had posed a challenge. However, efforts have been made to schedule interviews with farmers at convenient locations when and as need arise.

Some respondents were not forthright in their responses, especially regarding income and property and considered the research team as government agents and expected some monetary gain from the research team. Efforts were made to explain the purpose of the research as purely academic and that all the information could be held in confidence. Finally, most of the small-scale farmers do not keep records. As such, even though they were willing to deliver the information asked for, recalling exact figures and dates was cumbersome.
This limitation was overcome by use of case studies and focused group discussions.

REFERENCES

Abraham Gebrehiwot Y., Addis Adera G., Mesfin Tilahun G (2015). The impact of small-scale irrigation on income of rural farm households: Evidence from Ahferom Woreda in Tigray, Ethiopia. International Journal of Business and Economics Research. Vol. 4, No. 4, 2015.

Adeniran, K.A., Amodu, M.F., Amodu, M.O. and Adeniji, F.A. (2010). Water Requirements of Some Selected Crops in Kampe Dam Irrigation Project. AJAE, 1, 119-125. Agriculture: - The Kenyan experience in Ruigu, G. M. and Rukuni, M. (eds.) Irrigation Policy in Kenya and Zimbabwe. Nairobi. PP. 65-84.

Alila, P.0. (1987). Grassroots participation in small-scale and large-scale irrigation.

Allen, R.G., L.S. Pereira, D. Raes and M. Smith, (1998). Crop Evapotranspiration: Guidelines for Computing Crop water Requirements. FAO Irrigation and Drainage paper No. 56, Rome, Italy.

Amon, I. (1992). Agriculture in the Drylands Principles and practice. London: Elsevier.

Arcus G (2004). Principle, approaches, and guidelines for participatory revitalization of smallholder irrigation schemes. Year 1 Progress Report, WRC Project No. K5//1463/4. Arcus Gibb, East London.

Asare, D.K., Tawiah, I.L., Frimpong, J.O., Yaro, M., Banson, K., Ayeh, E.O. and Heng, L.K. (2012) Yield, Water and Nitrogen Use by Drip-Irrigated Cabbage Grown Under Different Levels of Applied Water. IAEA-CN-191-14.

Awulachew SB, Yilma A, Loulseged D, Loiskandl W, Ayana M, Alamirew T, (2007). Water Resources and Irrigation Development in Ethiopia. Colombo, Sri Lanka: International Water Management Institute. pp. 78.

Awulachew, S. B. (2010). Irrigation potential in Ethiopia: Constraints and opportunities for enhancing the system. Addis Ababa, Ethiopia: International Water Management Institute.

Awulachew, S. B., and Merrey, D. J. (nd). Assessment of Small-Scale Irrigation and Water Harvesting in Ethiopian Agricultural Development.

Awulachew, S.B; Merrey, D.J; Kamara, A.B.; van Koppen, B.; de Vries, F.P; Boelee, E; Makombe, G. Experiences and Opportunities for Promoting Small-Scale/Micro Irrigation and Rainwater Harvesting for Food Security in Ethiopia; International Water Management Institute: Addis Ababa, Ethiopia, 2005.

Bandara, K. M. P. S. (2006). Assessing irrigation performance by using remote sensing. Wageningen University.

Bekele Y, Nata T, Bheemalingswara K (2012). Preliminary Study on the Impact of Water Quality and Irrigation Practices on Soil Salinity and Crop Production, Gergera Watershed, Atsbi-Wonberta, Tigray, Northern Ethiopia, MEJS. 4(1): 29-46.

Bekele, A. E. (2014). Five Key Constraints to Small Scale Irrigation Development in Ethiopia: Socio-Economic View.

Belay S.; Beyene, F. Small-scale irrigation and household income linkage: Evidence from Deder district, Ethiopia. Afr. J. Agric. Res. 2013, 8, 4441–4451.

Bernard Chazovachii. (2012). The impact of small-scale irrigation schemes on rural livelihoods: the case of panganai irrigation scheme bikita district Zimbabwe. Journal of sustainable development in Africa (volume 14, no.4, 2012) clarion university of Pennsylvania.

Beshir, S. (2017) Review on Estimation of Crop Water Requirement, Irrigation Frequency and Water Use Efficiency of Cabbage Production. Journal of Geoscience and Environment Protection, 5, 59-69

Birendra K, C, Schultz, B and Prasad, K (2011) Water Management to meet present and future food demand. Irrigation Drainage. Vol 60, p 348-359

Blum, A. (2005) Drought Resistance, Water-Use Efficiency, and Yield Potential— Are They Compatible, Dissonant, or Mutually Exclusive? Australian Journal of Agricultural Research, 56, 1159-1169. https://doi.org/10.1071/AR05069

Brown S.C., Keatinge J.D.H., Gregory P.J., Cooper P.J.M. (1987): Effects of Fertilizer, Variety and Location on Barley Production under Rainfed Conditions in Northern Syria: I. Root and Shoot Growth. Field Crops Res.; 16:5366. http://dx.doi.org/10.1016/0378-4290(87)90053-0

Brown E.P., & Nooter, R., (1995). Successful Small-Scale Irrigation in the Sahel. World Bank Technical Paper No. 171, Washington D.C

Burrow C. (1987) Water Resources and Agricultural Development in The Topics: New York, John Wiley and Sons.

CSA (2020). Farm management practices: Report on Private Peasant Holdings (Meher Season), III

Chafutsa W., Fandika, I.R., Kadympakeni, D.M., Chiipanthenga, H.M. and Mafunga, G. (2007) Comparative Study of Cabbage to Tea Ferilizer, Compost Manure and Inorganic Fertilizer under Furrow irrigation. Irrigation Drainage Team, Kasinthula Agricultural Experiment Station, Chikwawa.

CNEDD (2009) Niger Second National Communication on Climate Change. Conseil National de l'Environnement pour le Développement Durable, Niamey.

CSA, 2007 Summery and statistical report of 2007 population and housing census of Ethiopia, Ethiopia.

Dananto M.U.; Alemu, E. Irrigation water management in small scale irrigation schemes: The case of the Ethiopian rift valley lake basin. Environ. Res. Eng. Manag. 2014, 1, 5–15.

Dejene A. (2006). Trade Liberalization, Poverty, and Inequality in Ethiopia.

Denison J and Manona S (2007) Principles, Approaches and Guidelines for the Participatory Revitalisation of Small holder Irrigation Schemes.vil 1. A rough guide for irrigation development practitioners. WRC Report 308/07. Water Research Commission. Pretoria

Dessalegn R (1999). Water Resource Development in Ethiopia: Issues of sustainability and participation, Forum for Social Studies, Addis Ababa, Ethiopia

Dessalegn Rahmato (1999): Water Resource Development in Ethiopia. Forum for Social Studies, Addis Ababa, Ethiopia.

Ehui S, Benin S, Williams T, Meijer S (2002). Food security in sub-Saharan Africa to 2020. Socio-economic and Policy Research Working paper 49. ILRI (International Livestock Research Center), Nairobi, Kenya. 2-3

Ersado Lire, (2005). Small Scale Irrigation Dams, Agriculture Production, and Health: Theory and Evidence from Ethiopia. World Bank Policy Research Working Paper 3494. The World Bank: Washington DC.

Ersado Lire, G. S. Amacher and J. Alwang, (2004). Productivity and land enhancing technologies in northern Ethiopia: Health, public investments, and sequential adoption. American Journal of Agricultural Economics, 86(2): 321-331.

Eyasu Y.H. (2005). Development and Management of Irrigated Lands in Tigray, Ethiopia.

Falkenmark M (2000) Competing freshwater and ecological services in the river basin perspective: an expanded conceptual framework. Water Int 25:172–177

FAO (2012), Crop yield response to water (FAO 66). Land and Water Division, Rome, Italy, P 192-199

FAO, 1989 Irrigation Manual: Planning, Development, Monitoring and Evaluation of Irrigated Agriculture with Farmers Participation.)

FAO, 1995, Irrigation in Africa in figures, FAO Water Report 7, Rome: FAO

FAO, 2003. Irrigation in Africa South of the Sahara. FAO Investment Center Technical Paper 5. FAO: Rome.

FAO, (1987). the struggle for food Security. Rome: FAO

Fardad, H. and Golgar, H. (2002) An Economic Evaluation of Deficit Irrigation on Wheat Yield in Karaj. Iranian Journal of Agricultural Sciences, 33, 305-312

Fishman R.; Devineni, N.; Raman, S. Can improved agricultural water use efficiency save India's groundwater? Environ. Res. Lett. 2015, 10.

Food and Agricultural Organization (FAO) (2006). Special report on crop and food supply assessment mission to Ethiopia, FAO. Rome Italy.

Food and Agriculture Organization (FAO) (2000). Socio-Economic Impact of Smallholder Irrigation Development in Zimbabwe: Case Studies of Ten Irrigation Scheme. FAO: Harare, Zimbabwe, 2000.

Fredu Nega. (2008). Poverty, asset accumulation, household livelihood, and interaction with local institutions in Northern Ethiopia.

Gabremedhin E.Z., & Haggblade, S. (September 2001). Successes in African Agriculture:

Gebregziabher G.; Namara,E.R.; Holden,S.,(2009). Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia. Agricultural Water development. http://dx.doi.org/10.1016/j.agwat.2009.08.004

Gebregziabher G.; Namara,E.R.; Holden,S.,(2009). Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia. Agricultural Water development. http://dx.doi.org/10.1016/j.agwat.2009.08.004

Gebremedhin B. and D. Pedon (2000). Policies and institutions to enhance the impact of irrigation development in mixed crop–livestock systems in: Policies for sustainable land management in the highlands of Ethiopia: Summary of papers and proceeding of a seminar held at ILRI, Addis Ababa, Ethiopia, and 22–23 May 2000 Socioeconomics and Policy Research Working Paper 30. ILRI (International Livestock Research Institute), Nairobi, Kenya. 68 pp.

Gleick P (2003) Soft path's solution to 21st-century water needs. Science 320:1524–1528

Government of Ethiopia (2001). Rural Development Policies and Strategies of Ethiopia, Addis Ababa, Ethiopia

Graciana Peter (2011) the impact of small-scale irrigation schemes on household food security in Swaziland, Journal of Sustainable Development in Africa (Volume 13, No.6,).

Haile T. 2008. Impact of irrigation development on poverty reduction in Northern Ethiopia. (Dissertation), National University of Ireland, Cork.

Hanson B.R., May D.M. and Schwankl L.J. (2003). Effect of Irrigation Frequency on Subsurface Drip Irrigated Vegetables. Department of Land, Air and Water Resources, University of California, Davis, CA.

Hassanli A.M., Ahmadirad S. and Beecham S (2010). Evaluation of the Influence of Irrigation Methods and Water Quality on Sugar Beet Yield and Water Use Efficiency. Agricultural Water Management, 97, 357-362.

Hillel D (1997). Small-Scale Irrigation for Arid Zones. Principles and Options. FAO Development Series 2. Food and Agriculture Organization of the United Nations (FAO), Rome.

Howell TA (2001). Enhancing water use efficiency in irrigated agriculture. Agron J 93:281–289

Howell TA (2003) Irrigation efficiency. In: Stewart BA, Howell TA (eds) Encyclopedia of water science. Marcel Dekker, New York, pp 467–472

Hune N (2003). Rainwater harvesting technology and their contribution to household food security in dry land areas of Ethiopia. Proceedings of Food Security Conference, Addis Ababa, 13-15 August 2003. UNCC

Hussain I, Turral H, Molden DJ, Mobin-ud-Din A (2006). Impact of Small-Scale Irrigation Schemes on Poverty Alleviationin Marginal Areas of Punjab, Pakistan. International Research Journal of Finance and Economics.

Hussain I, Turral H, Molden DJ, Mobin-ud-Din A (2007) Measuring and enhancing the value of agricultural water in irrigated river basin (this issue)

IFAD (2014). Water facts and figures, http://www.ifad.org/english/water/key.htm. Rome, Italy: International Fund for Agricultural Development.

IFAD (International Fund for Agricultural Development) (2005). Special country program pHase II. Interim evaluation report number 1643-ET, Ethiopia IFAD (International Fund for Agricultural Development).

Irmak, Suat; Odhiambo, Lameck O.; Kranz, William L.; and Eisenhauer, Dean E., "Irrigation Efficiency and Uniformity, and Crop Water Use Efficiency" (2011). Biological Systems Engineering: Papers and Publications. 451.

Isaac Kipkogci (2012) FACTORS THAT INFLUENCE SMALL -SCALE IRRIGATION FARMING ALONG TANA RIVER IN CENTRAL DIVISION OF GARISSA DISTRICT, KENYA

Kaswamila, M (2004). The Role of Traditional Irrigation Systems in Poverty Alleviation in Semi-Arid Areas: The Case of Chamazi in Lushoto District, Tanzania. Mkuki na Nyota Publishers

Kidane D.; Mekonnen A.; Teketay D (2014). Contributions of Tendaho Irrigation Project to the improvement of livelihood of Agro pastoralists in the Lower Awash Basin, Northeastern Ethiopia. Ethiop. J. Res. Innov. Foresight 2014, 6, 1–19.

Kidane D.A (2015). Critical review of integrated river basin management in the upper Blue Nile River basin: The case of Ethiopia. Int. J. River Basin Manag. 2015. [CrossRef]

Kinfe Aseyehegn, Chilot Yirga and Sundar Rajan, (2012). EFFECT OF SMALL-SCALE IRRIGATION ON THE INCOME OF RURAL FARM HOUSEHOLDS: THE CASE OF LAELAY MAICHEW DISTRICT, CENTRAL TIGRAY, ETHIOPIA

Lesley (2002). Application Efficiency Determination.)

Lipton, M. (1996). Rural Reforms and Rural Livelihoods: The Contexts of International Experience. (M. Lipton, M. de Klerk & M. Lipton (Eds.) Land, Labor, and Livelihoods in Rural South Africa. Volume One: Durban: Indicator Press, University of Natal

Lyne MC, Hendricks SL, Chitja JM (2009). Agricultural growth and food security. In: S L Hendricks and M C Lyne (ed), Does food security improve when smallholders access a niche market? Lessons from the Embo Community in South Africa. The African Centre for Food Security, University of KwaZuluNatal, South Africa.

Management: Small-scale Irrigation in Kenya. Nairobi: World Resource Institute (WRI) and Acts.

Martin Plaut (2024). New study of Tigray Violence and casualties

MEDIC (1999): Survey of the Ethiopian Economy: Review of Post Reform Developments 1992/3-1997/8. Ministry of Economic Development and Cooperation, Addis Ababa.

Michael, A.M. (1997) Irrigation Theory and Practice Mihret Dananto Ulsido and Ermias Alemu (2014), Irrigation Water Management in Small Scale Irrigation Schemes: The Case of the Ethiopian Rift Valley Lake Basin)

Mihret Dananto Ulsido and Ermias Alemu, (2014). Irrigation Water Management in Small Scale Irrigation Schemes: The Case of the Ethiopian Rift Valley Lake Basin.

Mihret Dananto Ulsido, (2013). Irrigation System Analysis Techniques with Practical Illustrations. LAP Lambert Academic Publishing AG & Co. KG Lap Lambert. Saarbrücken, Germany.

Ministry of Water Resources. Climate Change National Adaptation Programme of Action (NAPA) of Ethiopia; Ministry of Water Resources and National Meteorological Agency: Addis Ababa, Ethiopia, 2007.

Misgina Gebrehiwot, (2006). An Assessment of Challenges of Sustainable Rural Water Supply: The Case of Ofla Woreda in Tigray Region.

MoA (2011a). Natural Resources Management Directorates. Small-Scale Irrigation Situation Analysis and Capacity Needs Assessment, Addis Ababa, Ethiopia.

MOFED, 2010. The Federal Democratic Republic of Ethiopia, Growth and Transformation Plan (GTP) 2010/11-2014/15, Draft. 2010 September, Addis Ababa.

MoWE, (Ministry of Water and Energy), 2011. Water and Development quarterly bulletin 5. MWR: Addis Ababa.

MoWR (2002). Water Sector Development Programme 2002–2016. Irrigation Development Program, Main report. MoWR, Addis Ababa, Ethiopia. p.p. 142

MoWR (Ministry of Water Resources). 1993. Improvement of the resource–population sustainability balance. Water Resources Development, MoWR, Addis Ababa, Ethiopia.

Muhammad S., Tegegne F., & Ekanem E. (2004). Factors Contributing to Success of Small Farm Operation in Tennessee. Journal of Extension. 42 (4).

Mutsvangwa T and Doranalli K (2006). Agriculture and Sustainable Development, Netherlands; The Hague University Press.

Nicolas, R. (2002) Improving Irrigation Water Use Efficiency, Productivity and Equity. Simulation Experiments in the Downstream Yellow River Basin. International Water Management Institute (IWMI), Colombo.

Orodho J.A., (1998). Population Growth. Gender and Food Production in Kenya: The case of Small-scale Farmers in Vihiga District. Nairobi: Union for African population studies.

Ortman GF, King RP (2010). Research on Agri-food supply chains in Southern Africa involving small scale farmers: Current status and future possibilities. Agrekon, 49: 397-417.

Pala M., Matar A. & Mazid A. (1996): Assessment of the Effects of Environment Factors on the Response of Wheat to Fertilizer in On-Farm Trials in Mediterranean Type Environments. Experimental Agriculture, 32(2): 339 - 349. http://dx.doi.org/10.1017/S0014479700026272

Peden D.; Dubale P.; Tsegaye E.; Behailu M.; Tadesse G.; Gebremedhin G., (2002). Community-based irrigation management in Ethiopia: Strategies to enhance human health, livestock and crop production, and natural resource management. International Water Institute \management Institute (IWMI), Addis Ababa, Ethiopia.

Playa ´n E, Mateos L (2005). Modernization and optimization of irrigation systems to increase water productivity. Agric Water Manag 80:100–116

Postel S (2000). Entering an era of water scarcity: the challenges ahead. Ecol Appl 10:941–948

Qassim A. and Ashcroft B. (2012) Estimating Vegetable Crop Water Use. Agriculture Information, DEPI, Victoria.

REST (2003): “Tigray Regional Development Profile”, REST Report for 2003.Tigray Regional development. PDF

Rodeco. 2002. Assessment and monitoring of erosion and sedimentation problems in Ethiopia-Final Report. Rodeco Consulting GmbH, Hydrology Studies Department, Ministry of Water Resources, Addis Ababa, Ethiopia.

Seckler D, Amarasinghe U, Molden D, de Silva R, Barker R (1998) World water demandand supply, 1990 to 2025: scenarios and issues. Research report 19, international water management institute, Colombo, Sri Lanka

Sitta, A. (2011) Optimizing Irrigated Horticulture and Prediction of Climate Change Impacts by Crop Modeling for Niger. MSc. Thesis, Faculty of the Graduate College of the Oklahoma State University, Niger.

Sokoni C and Shechambo T (2005). Changes in the Upland Irrigation System and Implications for Rural Poverty Alleviation. A case of the Ndiwa Irrigation System, West Usambara Mountain; Tanzania

Teshome Atnafie, (2006). Irrigation Policies, Strategies and Institutional Support Conditions in Ethiopia. Proceedings of Symposium on Best Practices and Technologies for Agricultural Water Management in Ethiopia, March 7-9, 2006, Addis Ababa Ethiopia

Theodore C. Hsiao. Pasquale Steduto. Elias Fereres, (2007). A systematic and quantitative approach to improve water use efficiency in agriculture. Irrig Sci (2007) 25:209–231

UNDP. (2007). Globalization, Agriculture and the Least Developed Countries [Internet]. Issues Paper, Istanbul. 9-11 July 2007. Available from: http://www.unohrlls.org.

WAE (Water Aid Ethiopia). 2008. Water aid; Think local, act local II. Impediments to effective financing of sanitation services in Ethiopia. The case of three local governments; WASH report [Internet]. Available from: http://www.wateraid.org.

Wallace JS (2000). Increasing agricultural water use efficiency to meet future food production. Agric Ecosyst Environ 82:105– 119

Wallace JS, Gregory P (2002). Water resources and their use in food production systems. Aquatic Sci 64:1–13

Worku nugussie, (2013). Technical performance evaluation of midhegdu SSI scheme in west hararge zone Oromia, Ethiopia.

World Bank (2008) Agriculture for Development. World Bank Report, World Bank Washington DC.

World Bank (1990). Gezira Irrigation Scheme in Sudan: Objectives, Design and Performance. Plusquellec, H, World Bank Technical Paper 20 Washington D.C.

You L, Ringler C, Nelson G, Wood-Sichra U, Robertson R, Wood S, Guo Z, Zhu T, Sun Y (2010). What Is the Irrigation Potential for Africa? A Combined Biophysical and Socioeconomic Approach. IFPRI Discussion Paper 00993. International Food Policy Research Institute, Washington, D.C.

Zaccaria D. S. (2011). A Methodology to Conduct Diagnostic Performance Assessment and Simulation of Deliveries in Large-Scale Pressurized Irrigation Systems.

Zaman H. (2006). Assessing the poverty and vulnerability impact of micro credit access in Bangladesh, a Case Study of BRAC, Office of the Chief Economist and Senior Vice President, the World Bank.

Zeleke Agide (2015). Hydraulic and Operational Performance of Irrigation Schemes in View of Water Saving and Sustainability.

APPENDICES

Appendix I. Tables

Appendix I. table 1. Twelve years means monthly climate data of Hawzem metrological station

Station	***Hawzen***				***Element: - Average Max.Temp.^{o}C***							
Year	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
2006	27.5	29.1	28.8	28.3	30.5	31.0	26.7	25.1	26.4	28.6	26.7	26.9
2007	27.1	29.6	31.5	30.8	31.4	29.4	25.1	24.5	25.1	28.3	26.6	26.2
2008	27.7	28.0	30.2	29.6	30.5	30.1	27.2	26.7	28.5	27.8	26.9	26.7
2009	27.4	27.6	29.8	27.8	30.5	32.4	26.5	27.2	28.6	27.8	27.7	28.2
2010	27.9	28.9	28.4	29.1	30.4	30.4	25.2	24.1	24.4	25.3	27.5	26.7
2011	27.6	28.0	27.9	28.8	28.3	37.9	36.4	24.6	25.7	26.8	27.1	25.5
2012	26.4	27.7	29.0	28.9	29.0	28.4	25.3	25.2	26.9	27.2	27.0	26.2
2013	27.0	28.7	29.4	29.6	29.4	29.5	25.5	24.6	26.0	26.0	25.8	25.3
2014	27.4	26.1	28.1	29.5	29.0	29.3	26.9	25.6	26.0	xx	26.1	26.0
2015	25.7	28.2	28.7	29.6	28.7	28.9	27.9	26.1	27.0	26.5	26.9	25.6
2016	25.8	26.5	28.3	Xx	28.3	29.3	25.8	25.2	26.0	26.3	25.7	25.6
2017	25.0	26.4	28.0	28.7	28.6	29.2	25.9	25.5	25.5	24.9	25.3	23.7
Average	**26.9**	**27.9**	**29.0**	**29.2**	**29.5**	**30.5**	**27.0**	**25.4**	**26.3**	**26.9**	**26.6**	**26.0**
Station	***Hawzen***				***Element: - Average Min.Temp.^{o}C***							
Year	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
2006	7.0	9.8	12.4	13.1	14.5	13.2	14.4	14.0	13.3	13.9	8.8	9.0
2007	9.3	10.5	10.1	13.4	14.7	13.2	13.4	13.6	12.3	10.3	8.0	4.6
2008	8.0	6.9	7.9	11.8	13.1	13.2	14.3	14.1	12.5	10.4	6.9	6.0
2009	6.8	8.9	10.7	9.8	12.8	14.4	13.6	13.6	13.9	10.6	7.4	8.8
2010	7.2	10.9	12.1	13.7	14.5	14.8	14.8	13.2	13.6	10.3	10.0	4.1
2011	6.6	7.8	8.2	10.1	13.2	29.5	22.8	13.7	10.3	6.9	7.7	7.1
2012	7.4	7.0	10.0	13.7	13.9	14.6	14.6	14.3	11.4	9.7	9.1	7.1
2013	7.7	8.8	10.8	13.6	14.6	14.4	14.4	14.1	11.7	11.7	9.7	5.9
2014	8.5	7.4	10.9	13.0	13.4	13.5	13.9	14.2	12.1	xx	9.3	7.1
2015	6.7	7.1	10.3	12.7	14.3	14.4	13.8	14.4	13.5	12.4	10.4	10.8
2016	10.1	9.3	14.5	Xx	14.5	14.2	14.5	14.0	13.3	11.7	7.5	6.3
2017	5.7	11.6	11.9	13.4	14.9	14.0	Xx	xx	14.2	12.5	10.8	8.2
Average	**7.6**	**8.8**	**10.8**	**12.6**	**14.0**	**15.3**	**15.0**	**13.9**	**12.7**	**10.9**	**8.8**	**7.1**

Appendix I. table 2. Particle size distribution of each test plots per location

plot numbers	soil properties	Upstream location					Midstream location					Downstream location				
		Root depth in (cm)					Root depth in (cm)					Root depth in (cm)				
		0-20	20-40	40-60	60-80	80-100	0-20	20-40	40-60	60-80	80-100	0-20	20-40	40-60	60-80	80-100
plot 1	% of sand	77	79	79	80	75	87	86	86	70	70	68	67	71	70	70
plot 2	% of sand	76	79	79	74	73	73	75	73	73	73	73	74	90	89	84
plot 3	% of sand	79	73	72	89	89	89	88	82	82	82	82	83	68	68	67
Average		77.3	77.0	76.7	81.0	79.0	83.0	83.0	80.3	75.0	75.0	74.3	74.7	76.3	75.7	73.7
plot 1	% of silt	7	5	3	7	12	7	8	12	24	22	15	15	7	7	6
plot 2	% of silt	8	12	9	14	16	19	15	14	14	16	12	13	5	5	12
plot 3	% of silt	10	17	16	6	3	6	5	3	3	4	11	9	8	7	6
Average		8.3	11.3	9.3	9.0	10.3	10.7	9.3	9.7	13.7	14.0	12.7	12.3	6.7	6.3	8.0
plot 1	% of clay	16	16	18	13	13	6	6	2	6	8	17	18	22	23	24
plot 2	% of clay	16	9	12	12	11	8	10	13	13	11	15	13	5	6	4
plot 3	% of clay	11	10	12	5	8	5	7	15	15	14	7	8	24	25	27
Average		14.3	11.7	14	10	10.7	6.3	7.7	10	11.3	11	13	13	17	18	18.3

Appendix I. table 3. Experimental field area sizes of the 9 test plots in (m^2) and (ha)

experimental locations	experimental field code	W1(m)	W2(m)	Average	L1(m)	L2(m)	Average	Area(m2)	Area(ha)
Upstream	plot 1	13.30	18.50	15.90	15.00	17.50	16.25	258.38	0.0258
Upstream	plot 2	15.00	15.00	15.00	5.50	5.50	5.50	82.50	0.0083
Upstream	plot 3	10.70	10.70	10.70	6.00	6.00	6.00	64.20	0.0064
Average								135.03	0.0135
Midstream	plot 4	13.20	13.20	13.20	12.90	12.90	12.90	170.28	0.0170
Midstream	plot 5	8.00	8.00	8.00	20.00	20.00	20.00	160.00	0.0160
Midstream	plot 6	14.00	14.00	14.00	40.40	40.40	40.40	565.60	0.0566
Average								298.63	0.0299
Downstream	plot 7	9.00	9.00	9.00	23.80	23.80	23.80	214.20	0.0214
Downstream	plot 8	19.40	19.40	19.40	15.00	15.00	15.00	291.00	0.0291
Downstream	plot 9	9.00	9.00	9.00	19.40	19.40	19.40	174.60	0.0175
Average				0.00			0.00	226.60	0.0227
scheme average								220.08	

Appendix I. table 4. Average water application of the 9 test plots

S/No	Location	Plot Name	Applied Time (sec)	Qav (l/s)	Volume (m3)	plot Area (m2)	Applied Depth (mm)	irrigation interval	No of irrigation
1	Upstream	Plot_1	2182.9	3.15	6.9	258.4	26.6	5.3	19.0
2	Upstream	Plot_2	1027.1	3.15	3.2	82.5	39.2	5.4	19.0
3	Upstream	Plot_3	844.2	3.15	2.7	64.2	41.4	5.4	19.0
Average			1351.4	3.15	4.3	135.0	31.5	5.4	19.0
4	Middle stream	Plot_4	2079.6	3.15	6.6	170.3	38.5	5.8	17.0
5	Middle stream	Plot_5	1701.1	3.15	5.4	160.0	33.5	5.2	19.0
6	Middle stream	Plot_6	4440.5	3.15	14.0	565.6	24.7	5.1	19.0
Average			2740.4	3.15	8.6	298.6	28.9	5.4	18.3
7	Downstream	Plot_7	2647.7	3.15	8.3	214.2	38.9	5.7	18.0
8	Downstream	Plot_8	3248.3	3.15	10.2	291.0	35.2	5.9	19.0
9	Downstream	Plot_9	3050.5	3.15	9.6	174.6	55.0	8.6	12.0
Average			2982.1	3.15	9.4	226.6	41.5	6.7	16.3
Scheme average			2358.0	3.15	7.4	220.1	34.0	5.8	17.9
Min			844.2	3.15	2.7	64.2	24.7	5.1	12.0
Max			4440.5	3.15	14.0	565.6	55.0	8.6	19.0

Appendix I. table 5. Amount of irrigation applications of the 9 plots per irrigation events

Location – upstream

Plot - 1 area = 258.38 m2

Growth stages	Number of irrigations (Average discharge = 3.15 l/sec)													
	Irr-1		Irr-2		Irr-3		Irr-4		Irr-5		Irr-6		Total	
	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)
Init. Stage	2735	8.6	2318	7.3	2426	7.6	1749	5.5	1628	5.1	0	0.0	10856	34.2
Dev.stage	3041	9.6	2750	8.7	2379	7.5	2091	6.6	2192	6.9	2618	8.2	15071	47.5
Mid-stage	2313	7.3	2444	7.7	2268	7.1	2119	6.7	1789	5.6	0	0.0	10933	34.4
Late stage	1595	5.0	2216	7.0	1775	5.6	0	0.0	0	0.0	0	0.0	5586	17.6
Total	9684	30.5	9728	30.6	8848	27.9	5959	18.8	5609	17.7	2618	8.2	42446	133.7
Plot - 2 area = 82.50 m2														
Init. Stage	978	3.1	1087	3.4	1139	3.6	739	2.3	875	2.8	615	1.9	5433	17.1
Dev.stage	911	2.9	1018	3.2	1171	3.7	1285	4.0	1403	4.4	0	0.0	5788	18.2
Mid-stage	1288	4.1	1388	4.4	1045	3.3	1240	3.9	1339	4.2	0	0.0	6300	19.8
Late stage	568	1.8	975	3.1	813	2.6	0	0.0	0	0.0	0	0.0	2356	7.4
Total	3745	11.8	4468	14.1	4168	13.1	3264	10.3	3617	11.4	615	1.9	19877	62.6
Plot - 3 area = 64.20 m2														
Init. Stage	745	2.3	545	1.7	614	1.9	556	1.8	716	2.3	672	2.1	3848	12.1
Dev.stage	849	2.7	833	2.6	958	3.0	1052	3.3	1148	3.6	0	0.0	4840	15.2
Mid-stage	1054	3.3	1222	3.8	815	2.6	1015	3.2	1131	3.6	0	0.0	5237	16.5
Late stage	698	2.2	798	2.5	665	2.1	0	0.0	0	0.0	0	0.0	2161	6.8
Total	3346	10.5	3398	10.7	3052	9.6	2623	8.3	2995	9.4	672	2.1	16086	50.7
Plot - 4 area = 170.28 m2														
Init. Stage	1557	4.9	1656	5.2	1545	4.9	2257	7.1	2516	7.9	0	0	9531	30.0
Dev.stage	2144	6.8	2073	6.5	2456	7.7	2578	8.1	2560	8.1	0	0	11811	37.2
Mid-stage	2131	6.7	2030	6.4	1960	6.2	2311	7.3	0	0.0	0	0	8432	26.6
Late stage	2120	6.7	1970	6.2	1736	5.5	0	0.0	0	0.0	0	0	5826	18.4
Total	7952	25.0	7729	24.3	7697	24.2	7146	22.5	5076	16.0	0	0	35600	112.1
Plot - 5 area = 160 m2														
Init. Stage	1065	3.4	1035	3.3	1500	4.7	1560	4.9	1830	5.8	1785	5.6	8775	27.6
Dev.stage	1860	5.9	1440	4.5	1905	6.0	2055	6.5	1530	4.8	0	0.0	8790	27.7
Mid-stage	1860	5.9	2340	7.4	2505	7.9	2505	7.9	2010	6.3	0	0.0	11220	35.3
Late stage	1350	4.3	1250	3.9	1420	4.5	0	0.0	0	0.0	0	0.0	4020	12.7
Total	6135	19.3	6065	19.1	7330	23.1	6120	19.3	5370	16.9	1785	5.6	32805	103.3
Plot - 6 area = 565.60 m2														
Init. Stage	3915	12.3	3705	11.7	4380	13.8	4980	15.7	4230	13.3	0	0	21210	66.8
Dev.stage	4995	15.7	4680	14.7	4260	13.4	5715	18.0	6165	19.4	5070	16	30885	97.3
Mid-stage	5520	17.4	6600	20.8	4515	14.2	5655	17.8	4350	13.7	0	0	26640	83.9
Late stage	2970	9.4	3025	9.5	3138	9.9	0	0.0	0	0.0	0	0	9133	28.8
Total	17400	54.8	18010	56.7	16293	51.3	16350	51.5	14745	46.4	5070	16	87868	276.8

Appendix I. table 6. Amount of irrigation applications of the 9 plots per irrigation events

Location – upstream

Plot - 7 area = 214.20 m2

Growth stages	Number of irrigations (Average discharge = 3.15 l/sec)													
	Irr-1		Irr-2		Irr-3		Irr-4		Irr-5		Irr-6		Total	
	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)	time in (sec)	vol in (m3)
Init. Stage	3296	10.4	4230	13.3	3320	10.5	3035	9.6	2172	6.8	0	0	16053	50.6
Dev.stage	1991	6.3	3280	10.3	2898	9.1	3564	11.2	2152	6.8	0	0	13885	43.7
Mid-stage	2555	8.0	3312	10.4	2056	6.5	1855	5.8	2442	7.7	0	0	12220	38.5
Late stage	2335	7.4	1466	4.6	2676	8.4	0	0.0	0	0.0	0	0	6477	20.4
Total	10177	32.1	12288	38.7	10950	34.5	8454	26.6	6766	21.3	0	0	48635	153.2
Plot - 8 area = 291 m2														
Init. Stage	3332	10.5	3695	11.6	3236	10.2	3455	10.9	0	0	0	0	13718	43.2
Dev.stage	3356	10.6	4225	13.3	3395	10.7	3278	10.3	3526	11	3830	12	21610	68.1
Mid-stage	3130	9.9	3767	11.9	2934	9.2	3323	10.5	0	0	0	0	13154	41.4
Late stage	3150	9.9	3045	9.6	1825	5.7	0	0.0	0	0	0	0	8020	25.3
Total	12968	40.8	14732	46.4	11390	35.9	10056	31.7	3526	11	3830	12	56502	178.0
Plot - 9 area = 174.6 m2														
Init. Stage	3405	10.7	2937	9.3	3336	10.5	0	0	0	0	0	0	9678	30.5
Dev.stage	3156	9.9	2938	9.3	3465	10.9	0	0	0	0	0	0	9559	30.1
Mid-stage	4658	14.7	2061	6.5	1959	6.2	0	0	0	0	0	0	8678	27.3
Late stage	2610	8.2	3345	10.5	2736	8.6	0	0	0	0	0	0	8691	27.4
Total	13829	43.6	11281	35.5	11496	36.2	0	0	0	0	0	0	36606	115.3

Appendix I. table 7. Average soil moisture before irrigation (ӨBI) of the 9 test plots

S/No	Location	Plot Name	Root depths in (cm) and (ӨBI) in (%)					
			0-20	20-40	40-60	60-80	80-100	Average
1	Upstream	Plot_1	13.84	13.98	14.14	14.27	14.56	14.16
2	Upstream	Plot_2	11.46	11.63	11.80	11.94	12.03	11.77
3	Upstream	Plot_3	10.35	10.50	10.65	10.81	10.95	10.65
Average			11.88	12.04	12.20	12.34	12.51	12.19
Minimum			10.35	10.50	10.65	10.81	10.95	10.65
Maximum			13.84	13.98	14.14	14.27	14.56	14.16
4	Mid-Stream	Plot_4	11.99	12.19	12.39	12.59	12.79	12.39
5	Mid-Stream	Plot_5	9.83	9.99	10.16	10.32	10.51	10.16
6	Mid-Stream	Plot_6	16.05	16.15	16.67	16.81	17.52	16.64
Average			12.62	12.78	13.07	13.24	13.61	13.06
Minimum			9.83	9.99	10.16	10.32	10.51	10.16
Maximum			16.05	16.15	16.67	16.81	17.52	16.64
7	Downstream	Plot_7	11.28	11.43	11.68	11.77	12.04	11.64
8	Downstream	Plot_8	17.82	18.03	18.24	18.53	18.72	18.27
9	Downstream	Plot_9	8.48	8.67	8.87	9.12	9.37	8.90
Average			12.52	12.71	12.93	13.14	13.38	12.94
Minimum			8.48	8.67	8.87	9.12	9.37	8.90
Maximum			17.82	18.03	18.24	18.53	18.72	18.27
Grand average			12.34	12.51	12.73	12.91	13.17	12.73
Grand Minimum			8.48	8.67	8.87	9.12	9.37	8.90
Grand Maximum			17.82	18.03	18.24	18.53	18.72	18.27

Appendix I. table 8. Average after irrigation soil moisture contents (ϴAI) of the 9 test plots

S/No	Location	Plot Name	Root depths in (cm) and (ϴAI) in (%)					
			0-20	20-40	40-60	60-80	80-100	average
1	Upstream	Plot_1	15.93	16.07	16.20	16.35	16.58	16.23
2	Upstream	Plot_2	14.50	14.63	14.75	14.81	14.85	14.71
3	Upstream	Plot_3	13.17	13.32	13.37	13.49	13.54	13.38
Average			14.53	14.67	14.77	14.88	14.99	14.77
Minimum			13.17	13.32	13.37	13.49	13.54	13.38
Maximum			15.93	16.07	16.20	16.35	16.58	16.23
4	Mid-Stream	Plot_4	14.90	15.06	15.22	15.38	15.46	15.20
5	Mid-Stream	Plot_5	12.21	12.37	12.53	12.70	12.86	12.53
6	Mid-Stream	Plot_6	19.3	17.9	18.3	18.5	19.3	18.65
Average			15.47	15.12	15.34	15.51	15.86	15.46
Minimum			12.21	12.37	12.53	12.70	12.86	12.53
Maximum			19.31	17.93	18.27	18.45	19.26	18.65
7	Downstream	Plot_7	13.77	13.80	13.76	13.91	13.93	13.84
8	Downstream	Plot_8	20.34	20.55	20.75	21.00	21.24	20.78
9	Downstream	Plot_9	11.67	11.79	11.51	11.58	11.34	11.58
Average			15.26	15.38	15.34	15.50	15.50	15.40
Minimum			11.67	11.79	11.51	11.58	11.34	11.58
Maximum			20.34	20.55	20.75	21.00	21.24	20.78
Grand average			15.09	15.06	15.15	15.30	15.45	15.21
Grand Minimum			11.67	11.79	11.51	11.58	11.34	11.58
Grand Maximum			20.34	20.55	20.75	21.00	21.24	20.78

Appendix I. Table 9. The productivity of the 9 test plots

S/no	Location & plot no	Area (m2)	Average (Kg/m2)	Total (kg)	Unit price (ETB)	Total (ETB)	Kg/ha	Qt/ha	ETB/ha
1	U/S PL_1	258.4	2.5	640.8	12.0	7,690.0	24,800.0	248.0	297,600.0
2	U/S PL_2	82.5	1.8	151.8	12.0	1,821.6	18,400.0	184.0	220,800.0
3	U/S PL_3	64.2	2.3	146.4	12.0	1,756.5	22,800.0	228.0	273,600.0
Average		**135.0**	**2.2**	**297.1**	**12.0**	**3,564.9**	**22,000.0**	**220.0**	**264,000.0**
min		64.2	1.8	118.1	12.0	1,417.5	18,400.0	184.0	220,800.0
Max		258.4	2.5	640.8	12.0	7,690.0	24,800.0	248.0	297,600.0
4	M/S PL_1	170.3	2.7	463.2	12.0	5,558.6	27,200.0	272.0	326,400.0
5	M/S PL_2	160.0	2.8	448.0	12.0	5,376.0	28,000.0	280.0	336,000.0
6	M/S PL_3	565.6	3.0	1,696.8	12.0	20,361.6	30,000.0	300.0	360,000.0
Average		**298.6**	**2.8**	**848.1**	**12.0**	**10,177.4**	**28,400.0**	**284.0**	**340,800.0**
min		160.0	2.7	435.2	12.0	5,222.4	27,200.0	272.0	326,400.0
Max		565.6	3.0	1,696.8	12.0	20,361.6	30,000.0	300.0	360,000.0
7	D/S PL_1	214.2	1.9	402.7	12.0	4,832.4	18,800.0	188.0	225,600.0
8	D/S PL_2	291.0	2.2	628.6	12.0	7,542.7	21,600.0	216.0	259,200.0
9	D/S PL_3	174.6	2.2	377.1	12.0	4,525.6	21,600.0	216.0	259,200.0
Average		**226.6**	**2.1**	**468.3**	12.0	**5,619.7**	**20,666.7**	**206.7**	**248,000.0**
Min		174.6	1.9	328.2	12.0	3,939.0	18,800.0	188.0	225,600.0
Max		291.0	2.2	628.6	12.0	7,542.7	21,600.0	216.0	259,200.0
Scheme average		**220.1**	**2.4**	**521.4**	12.0	**6,256.4**	**23,688.9**	**236.9**	**284,266.7**

Appendix I. table 10. Background data of the respondents

S/No	Categories	Variables	Count	Column N %
1	Sex of H/hold head	Male	14	93.3%
		Female	1	6.7%
		Total	15	100.0%
2	Age of HH's	Age <30	1	6.7%
		Age 30-45	4	26.7%
		Age 46-65	6	40.0%
		Age >65	4	26.7%
		Total	15	100.0%
3	Marital status	Married	13	86.7%
		Divorced	1	6.7%
		Widowed	1	6.7%
		Total	15	100.0%
4	Total family members	No <5	3	20.0%
		No 5-6	5	33.3%
		No 7-8	5	33.3%
		No >8	2	13.3%
		Total	15	100.0%
5	Educational status	Illiterate	5	33.3%
		read and write	9	60.0%
		high school and above	1	6.7%
		Total	15	100.0%

Appendix II. Questionnaires

Part I. Background of respondents

1. Sex of the household head 1, male 2, female
2. Age of the household head 1 = < 30, 2 = 30 - 45, 3 = 46 - 65, 4 = > 65
3. Occupation: 1. Farmer 2. Student 3. Trader 4. civil servant
   Other_______________
4. Marital status: 1. Married 2. Unmarried 3. Divorced 4. Widowed
5. Total family numbers of the household__________,
   Age below 15______ male____, female________, age 15-64 ________, male ______ female________, age above 64 _______, male ______ female ______
6. How many of the total family members are active labor force? ________ total,
   Male ______ female ___________
7. Educational status of the household head: 1. Illiterate 2. Read and write 3. High school and above

Part II. Households' Experience

1. Do you have any land with holding rights? 1= Yes 2= No
2. If yes, how many timad / (0.25 hectare) of total land do you have? Cultivable __________, non-cultivable _________________, total _______________
3. How many timad of Land did you cultivate (own and rent) in 2009/10? ____________total
   Rainfed ____________, irrigation _______________, perennial/fruits/ ______________, woodlot ____________
4. How many timad irrigable land do you have (own and rent)? _____________ total, specific in Mai Gobo SS dam site_________________
5. How long have you been in irrigation farming? _________ Year/s.
6. How much is the average plot distance from water source? ______?
7. How many times have you produced from your irrigation farmland at present? A. once a year B. twice a year C. three times a year
8. Have you cultivated the total of your irrigable land during the last dry season? 0 = No 1 = Yes
9. If no, what are the reasons for underuse the irrigable land? (Circle the answers)
   1 = Shortage of family labor
   2 = lack of appropriate seeds and inputs
   3 = Lack of oxen
   4 = water scarcity
   5 = Lack of credit or capital
   6 = pests and diseases
   7= others
10. Do you believe there is a water management problem? 0 = No 1 = Yes,

11. If yes, what will be the reason? 1. Weather 2. lack of knowledge 3. Lake of skills 4. Soil texture 5. others

12. Do you have problems related to water pumps? 0 = No 1 = Yes,

13. If yes, what are the problems? 1. Maintenance 2. Access to fuels 3. Expensive price 4. Access to spare parts 5. others

14. Participation of family members on different irrigation activities? Put a tick mark as appropriate.

Table 1: family participation in different irrigation activities

No	Types of activity	Husband	Wife	Children	Relatives	Labor
1	Land preparation					
2	Sowing					
3	Weeding					
4	Watering					
5	Harvesting					
6	Threshing					
7	Crop residue piling					
8	Livestock management					
9	Others					

15. What are the impacts of irrigation projects on your household food security? 1. more food secured 2. moderate food secured 3. less food secured 4. no changes
16. Do you get enough water for your irrigational and livelihood activities from this irrigation project? 0 = No 1 = Yes,
17. If you had a shortage of irrigation water, what do you do?
    1. Cultivate partially 2. Plant crops that require less irrigation water
    3. Share from others 4. Others

20. How do you evaluate this irrigation season's performance? 1. High 2. Medium 3. Low 4. Very low

Part III. Management aspect of the scheme

1. Are you dissatisfied with the current irrigation water supply system? 0 = No 1 = Yes,
2. . If Yes for Q #1, what kind of challenges and problems have you faced/observed in the existing irrigation schemes? Specify all below
    1. ______________________________ 2. ___________________________________
    3. ______________________________ 3. ___________________________________

3. Are there water user associations? 0 = No 1 = Yes,
4. If yes, are you a member of the association? 0 = No 1 = Yes,
5. Do you know the leaders of the association? 0 = No 1 = Yes,
6. If yes, how do you evaluate the performance of the leaders? 1. Low 2. Medium 3. High 4. Very high

Part IV. Access related question:

1. Do you have Access to extension services? 0 = No 1 = Yes,
2. If yes, how do you evaluate? 1. High 2. Very high 3. Medium 4 Poor.
3. Do you have access to technical support from districts or Woreda experts? 0 = No 1 = Yes,
4. If yes, how often?
   From district DAs 1. Once a week 2. Once per two weeks 3. Once a month
   4. Once per two months 5. Once a quarter
   From Woreda experts 1. Once per two weeks, 2. Once a month 3. Once per two months
   4. Once a quarter 5. More than a quarter
5. If yes for Q#3, how do you evaluate? 1. Poor 2. Medium 3. High 4. Very high
6. Do you get market information about prices and demand conditions of agricultural inputs and outputs? 0 = No 1 = Yes,
7. If yes, how do you evaluate? 1. High 2. Very high 3. Medium 4. Poor
8. Do/did you need credit to produce your agricultural products? 0 = No 1 = Yes,
9. Do you have Credit access? 0 = No 1 = Yes,
10. If yes, from where 1. RUSACCO 2. Dedebit micro finance 3. From banks 4. others
11. Have you ever taken training and/or technical support related to irrigation? 0 = No 1 = Yes,
12. How do you see the knowledge and skill on crop farming after and before irrigation? Put a tick mark as appropriate. 1. Excellent 2. Very good 3. Good 4. poor

Part V. Household income and cost related questions

1. Do you participate in Livestock farming? 0 = No 1 = Yes,
2. Does the SSI scheme have value on livestock farming? 0 = No 1 = Yes,
3. If the answer is yes, in which one and compare the income before and after the SSI scheme in the next tables.

Table 2: Compare the Livestock Production income before and after irrigation (taking 2009/10 season)

No	Type of animal	No of anima	Before irrigation				After irrigation (2009/10 season)				Difference in (ETB)
			Total owned	Consumed	If there is any sold animal		Total owned	consumed	If there is any sold animal		
					Sold in No	Income gained (ETB)			Sold in No	Income gained (ETB)	
1	Cow										
2	Bull										
3	Heifer										
4	Calf										
5	Ox										
6	Mules										
7	Horse										
8	Donkey										
9	Goat										
10	Sheep										
11	Poultry										
12	Bee colony										
13	Others										

No	Commodity type	Before irrigation				After irrigation (2009/10 season)				Difference in (ETB)
		Amount produced (liter, Kg, no)	Consumed (liter, Kg, no)	sold (liter, Kg, no)	Income gained (ETB)	Amount produced (liter, Kg, no)	Consumed (liter, Kg, no)	sold (liter, Kg, no)	Income gained (ETB)	
1	Dairy output									
	1.1 fluid milk									
	1.2 Butter									
	1.3 Yoghurt									
	1.4 Cheese									
2	Poultry									
	2.1 Egg									

	2.2 Chicken									
3	Honeybee									
	3.1 Honey									
	3.2 Bees wax									
	3.3 Bee colony									
4	Animal by-products									
	Hide and skin									
	Manure/Dung									

Table 3: Compare the Livestock output income before and after irrigation (taking 2009/10 season)

4. Have any members of your family been involved last year on off- farm activities? 0 = No 1 = Yes,
5. If yes, who? 1. Husband 2. Wife 3. Children 4. relatives
6. If the answer is yes, in which one from the next Table and compare the income before and after the SSI scheme.

Table 4: Compare the off-farm income before and after the irrigation scheme (take 2009/10 season)

No	Off-Farm activities	Before irrigation				After irrigation (2009/10 season)				Difference in (ETB)
		Working weeks/month	Working hours /week	wage/ income per day (ETB)	Income per month (ETB)	Working months	Working hours /week	wage/ income per day (ETB)	Income per month (ETB)	
1	Working on another farm (manual work)									
2	Daily laborer on construction or other non- farm activities									
3	Self- employment in manufacturing e.g. Artisan (blacksmith, weaving,									

	pottery, Tannery)									
4	Sales of fuel wood or Charcoal									
5	Teaching									
6	Driver									
7	Carpenter									
8	Tailor									
9	Remittance									
10	Trade									
11	Aid									
12	Others									

7. Do you believe there is land productivity change before and after the construction of the scheme? 0 = No 1 = Yes,

Table 5: land productivity before and after the existing scheme

No	Type of crops	Land size in timad	Before irrigation				After irrigation (2009/10 season)				Difference in (ETB)
			Productivity (Ql/td)	Total product (Ql)	Unit price in (ETB)	Total price in (ETB)	Productivity (Ql/td)	Total product (Ql)	Unit price in (ETB)	Total price in (ETB)	
1	Rainfed										
	Teff										
	Maize										
	Wheat										
	Barely										
	Sorghum										
	Dagusa										
	Other										
2	Irrigable										
2.1	Cereals										
	Teff										
	Maize										
	Wheat										
	Barely										
	Sorghum										
	Dagusa										
	Other										

2.2	Vegetable										
	Tomato										
	Potato										
	Pepper										
	Onion										
	Cabbage										
	Other										
2.3	Fruits										
	Avocado										
	Papaya										
	Mango										
	Lemon										
	Other										
3	Woodlot										
	Eucalyptus										
	Other										

8. Do you use fertilizers in your farmland? 0 = No 1 = Yes,
9. If yes, compare utilization before and after the existing scheme in the next table.

Table 6: Fertilizer utilization before and after the existing SSI scheme

No	Type of cultivation	Land size in timad	Fertilizer utilization (Ql/timad)										
			Before irrigation					After irrigation (2009/10 season)					Difference in (ETB)
			Dap		Urea			Dap		urea			
			Amount in (Ql)	Price in (ETB)	Amount in (Ql)	Price in (ETB)	Total (ETB)	Amount in (Ql)	Price in (ETB)	Amount in (Ql)	Price in (ETB)	Total birr	
1	Rainfed												
2	Irrigated												
	Total												

10. Do you have additional labor demand for your farm activities? 0 = No 1 = Yes,
11. Do you use fuel & lubricants for your irrigation system last year (2009/10 season)? 0 = No 1 = Yes,

12. If yes, how much did you use in the irrigation season last year?
Fuel: ----- liter, --------- birr and oil: ------ liter, -------------- birr, total---------------------------birr.
13. Do you use improved seeds & chemicals in your farmlands? 0 = No 1 = Yes,
14. If yes, compare the utilization before and after the SSI scheme?

Table 7: Improved seeds and chemicals utilization before and after the SSI scheme

No	Type of activity	Land size (timad)	Utilization										Difference In (birr)
			Before irrigation					After irrigation (2009/10 season)					
			Improved seeds		Chemicals		Total in (ETB)	Improved seeds		Chemicals		Total in (ETB)	
			Kg	ETB	liter	ETB		Kg	ETB	Liter	ETB		
1	Rainfed												
1.1													
1.2													
1.3													
Total													
2	Irrigation												
2.1													
2.2													
2.3													
Total													

15. Do you think that you are most profitable from your product? 0 = No 1 = Yes,
16. If yes, what crops do you think are most profitable?
    1. _________________ 2. _______________3. ______________
17. If not, who benefits from your product most? 1. Brokers 2. Whole sellers 3. Traders 4. Consumers
18. Where do you sell your produce? 1. Farm gate 2. Nearby market 3. Nearby town 4. To a city/Mekelle
19. To whom do you sell your produce? 1. Brokers 2. Whole sellers 3. Traders 4. Consumers
20. Have you faced transportation problems while selling your product? 0 = No 1 = Yes,
21. If yes, how? 1. High transportation costs 2. Lack of transportation 3. Lake of road access
22. What solutions do you take if you face market or transportation problems? 1. Sold in chief 2. Damp 3. Consume 4. Feed to animals

Part VI. Main challenges, opportunities and recommended solutions related Questions.

Main challenges

From your experience what are the main challenges/problems you faced in the SSI scheme?

1. Low yields
2. Un promising price of products
3. Too small landholdings
4. Lack of awareness
5. Pests and diseases
6. Weather (flooding and wind)
7. lack of extension services and technical training
8. Institutional arrangements and instability
9. Lack of start-up capital or fear of loans from institutes
10. Poor water & land management
11. Poor input utilization
12. Lack of mechanization technology and management
13. Poor working habits
14. others

Opportunities

1. High water potential
2. High commitment of the Ethiopia government
3. Donors and NGOs to support irrigation management and development activity
4. Promising markets and market access
5. Having access to credits
6. Having enough working force
7. Having land for irrigation expansion
8. Suitable agro ecology for crop and fruit production
9. others

Recommended solutions

1. Providing improved input on time and fairly
2. Strong institutional arrangement
3. Giving training to farmers and technical support
4. Providing mechanization technologies
5. Giving strong extension service
6. Providing credit
7. Improving market system
8. Constructing retaining wall on the side banks of the SS dam

Part VII. Interview guide for Woreda and zonal agriculture office

Date ______________________

This interview guide is prepared to get elicit information from Zonal and Woreda agricultural and water resource bureaus,

1. Personal data: Sex ______, age ___________ Education level ___________________ Year of service _______________
2. What is your profession? 1. Livestock 2. Crop science 3. Crop protection 4. Irrigation 5. Engineer
3. Are the farmers aware of the irrigation project in their area? 0 = No 1 = Yes,
4. What are the main strategic objectives of this irrigation project? 1._________________ 2. ______________ 3. ______________________ 4. _________________________
5. Do you think that the project is in the right direction to meet its objective? 0 = No 1 = Yes,
6. If yes, what are your indicators? 1.__________________________ 2. _____________________ 3. _________________________ 4. _______________________ 5. _______________________
7. If not, why? Because 1. ____ ____
8. Do you recommend a crop plan to the irrigators as the feasibility study report of the project? 0 = No 1 = Yes,
9. If yes, how do you evaluate the acceptance of the plan by the farmers? 1. Low 2. Medium 3. High 4. Very high
10. . Do you quantify the productivity of the irrigation scheme? 0 = No 1 = Yes,
11. . If yes, can you give me some crop productivity (QL/Ha) information for the main irrigated crops?

Table 8: Main irrigated crops productivity.

S/No	Crop types	Productivity			Remarks
		Minimum	Maximum	Average	
1					
2					
3					
4					

5					
6					
7					

12. Have you noticed any employment opportunities because of the irrigation scheme? 0 = No 1 = Yes,
13. If yes, can you give me some information on the employment pattern?

Table 9: Employment opportunities of the irrigation scheme

S/ No	Season	Employment									remark
		Minimum			Maximum			Average			
		Male	Female	total	Male	female	Total	male	Female	total	
1	Before irrigation scheme										
2	During construction of the irrigation scheme										
3	After Irrigation scheme construction										

14. Do you think, apart from employment, do the non-user groups benefited from the irrigation Project? 0 = No 1 = Yes,
15. If yes, please explain. 1. ____
    2. ____
    3. ____
    4. ____
16. How could you rate the economic wellbeing of the farmers after implementation of the irrigation project? 1. Low 2. Medium 3. High 4. Very high

Part VIII. Interview checklist for DAs of the District

Date______________________

1. How do you help the irrigation users?

____

2. Have there been any conflict pertaining to irrigation in the schemes? 0 = No 1 = Yes,

3. Do you make decisions pertaining to irrigation on your discretion or must you wait for Guideline to come down from Woreda office?

____

4. What is the relation between the Woreda agriculture office and the irrigation schemes?

____

5. What have people gained because of irrigation introduction?

____

6. How do water allocation and distribution to users?

____

7. How is land distributed to irrigation users?

____

8. How is the availability of water and utilization in the scheme?

____

9. How do you see the irrigation season performance specially tomato?

____