



**PERFORMANCE EVALUATION OF TSILWE SMALL SCALE  
IRRIGATION SCHEME IN GABA CATCHMENT ENDERTA DISTRICT,  
TIGRAY REGION**

**MSc THESIS**

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WATER RESOURCE ENGINEERING**

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HAWSSA, ETHIOPIA

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**A THESIS SUBMITTED TO THE INSTITUTE OF TECHNOLOGY SCHOOL OF WATER  
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**HAWASSA, ETHIOPIA**

**IN PARTIAL FULFILLEMENT OF THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF SCIENCE IN IRRIGATION AND DRAINAGE ENGINEERING**

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# Approval Sheet

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## **Declarations**

First, I declare that this thesis work is my bona fide work and that all sources of materials used for this thesis have been dully acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. This my original work has never been submitted to any university or institution for award of honors or any other purpose. I therefore do submit it for evaluation and consequent award of Master of Science degree in Irrigation and Drainage Engineering.

### **List of abbreviations and Acronyms**

CWR	Crop water Requirement
DA	Development Agent
ET <sub>c</sub>	Crop Evapotranspiration
ET <sub>o</sub>	Reference evapotranspiration
FAO	Food and Agriculture Organization
FC	Field capacity
GDP	Gross Domestic Product
GIS	Geographical Information System
GPS	Geographical Positioning System
GTP	Growth Transformation Plan
ha	hectare
hr	hour
IIMI	International Irrigation Management Institute
IR	Irrigation Requirement
IWMI	International Water Management Institute
K <sub>c</sub>	Crop Coefficient
K <sub>y</sub>	Crop yield response factor
m.a.s.l	Meter above sea level
MoWR	Ministry of Water Resource
NRCS	Natural Resource Conservation Service
PWP	Permanent Wilting Point
REST	Relief Society of Tigray
RIS	Relative Irrigation Supply
RWS	Relative Water Supply
TAW	Total Available Water
SSIS	Small Scale Irrigation Scheme
USDA	United States Department of Agriculture
WDC	Water Delivery Capacity
Z <sub>r</sub>	Root depth

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## **Abstract**

*This research (study) was conducted to evaluate the performance of Tsilwe SSIS in Enderta district, Tigray Regional State, Ethiopia. The performance of Tsilwe SSIS was not appraised since its operation. Therefore, this study was carried out to evaluate the performance of Tsilwe SSIS using Internal and external performance indicators. This study used primary and secondary data for assessing the irrigation performance. The primary data collected includes field observation, soil samples to characterize the soil in terms of physical characteristics and discharge measurement at main and field canals. Secondary data collected were total yield, area irrigated, crop type, and climate data. CROPWAT 8.0 model was used to calculate ETo and the crop water requirement. The analysis of internal performance indicators showed that the conveyance, application, storage, overall irrigation efficiencies and distribution uniformity were calculated and the results were 93.5%, 71.1 %, 60.2 %, 66.6 % and 87.2 % respectively. The analysis of water related indicators such as RWS and RIS were found to be 0.88 and 0.85 respectively. Since value of RWS and RIS is less than one this indicated that the total water supply is not enough to meet the crop demand and the WDC for Tsilwe irrigation system was calculated as 0.7, since this is less than unit that indicates the canal capacity is insufficient to get the peak consumptive requirement. Agricultural related indicators such as output per unit irrigated area is 153958.6 birr/ha and the output per unit command area is 95860.99 birr/ha. Water productivity indicators such as, Output per unit water consumed and Output per unit irrigation water supplied are 42.2 birr/m<sup>3</sup> and 1.83 birr/m<sup>3</sup> in TSSI scheme respectively. Based on the results obtained can be concluded that the water related indicators results were below the standard while the agriculture production indicators are found to be reasonable.*

**Keywords:** *Tsilwe small scale irrigation, Performance evaluation, Internal and external performance indicators*

# **1. Introduction**

## **1.1. Background**

In the absence of large population, Industries and recreation there was not much competition for water (Burt et al., 1997). Thus day by day in contrary to the limited availability of fresh water and land resources the world's population is increasing at alarming rate and its need for food and fiber production (Ingle et al. 2015). By the year 2025, 83% of the expected global population of 8.5 billion is expected to live in developing countries (Sener et al., 2007). Yet the capacity of available resources and technologies to satisfy the demands of this growing population for food and other agricultural commodities remains uncertain (Ingle et al. 2015). To meet future food demands and growing competitions for water, a more efficient use of water in irrigated agriculture will be essential (Mehadia, 2003).

In many part of the world including Ethiopia, the amount, frequency and distribution of rainfall, which is the principal source of water for crop production, is becoming more unpredictable and insufficient. Irrigation supports successful crop growing and stabilizes crop yields. In other expression, irrigation is required in most of the places having insufficient and uneven distribution of rainfall. This means in drought- prone areas of the world successful crop production is possible with the support of irrigation. Scaling up the use of these small-scaler irrigation systems should rise to the top of African development priorities (Abraham et al., 2015).

Ethiopia covers a land area of 1.13 million km<sup>2</sup> of which 99.3% is a land area and the remaining 0.7% is covered with water bodies of lakes (MoWR 2002). It has an estimated 55 million ha arable land area which is half of the total land mass. However, only about 20% of the total arable land is currently being utilized for crop production (Gabriel, 2014).

Ethiopia's economy is highly dependent on the agricultural sector, which contributes more than 45% of the GDP, provides livelihood for 85% of the population and supporting 60% of the foreign exchange earnings and accounts for 96% of the food produced in the country (Kelemework, 2008).

The agriculture is mainly dependent on rain fed and very traditional farming practices and make very limited use of improved farming technologies makes the country to stay under developed and puts the nation's food security in danger. In addition, drought is becoming frequent and many people have been repeatedly exposed to hunger and famine. At times when the country is hit by

drought it has a devastating consequence resulting in famine and the loss of life of thousands of its rural citizens. To alleviate the deep rooted poverty at household level, the Ethiopian government is practicing different drought proofing strategies (Beyera, 2004).

Though Ethiopia has abundant rainfall, surface and ground water resources, its agricultural system does not yet fully benefit from the technologies of water management and irrigation. The majority of rural dwellers in Ethiopia are among the poorest in the country, with limited access to agricultural technology, limited possibilities to diversify agricultural production given underdeveloped rural infrastructure, and little to no access to agricultural markets and to technological innovations. These issues, combined with increasing degradation of the natural resource base, especially in the highlands, aggravate the incidence of poverty and food insecurity in rural areas. Improved water management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity (Awulachew et al., 2010).

According to Awulachew et al., (2010) Ethiopia endows ample water resources which have 12 river basins with an estimated of 122 Billion  $m^3$  of surface water and ground water potential with an estimated of 2.6 to 13.5 billion  $m^3$  per year. This amounts to 1445  $m^3$  of water per person per year: a relatively large volume. But much of this water potential couldn't be used for irrigation or other purposes because of the limited water infrastructure to this surface and ground water resource and due to lack of water storage capacity and large spatial and temporal variations in rainfall, there is not enough water for most farmers to produce more than one crop per year with frequent crop failures due to dry spells and droughts.

However since last one decade the Ethiopian government has been involved in the construction of different water infrastructure structures in order to improve availability of the scarce water for both rain-fed and irrigated agriculture in Dryland area to exploit the water potentials, such as the Grand dam, Gibe I, II, and III, Tekeze, Tana Beles and different large irrigation schemes for sugar cane projects.

The estimations of the irrigation potential of Ethiopia vary from one source to the other, due to lack of standard or agreed criteria for estimating irrigation potential in the country. The earlier reports for example according to World Bank (1973) as cited in Rahmato (1999) show the irrigation potential at the lowest 1.0 and 1.5 million hectares, and the highest according to Tilahun

& Paulos (2004), estimated to 4.3 million hectares, according to Seleshi et al., (2007) estimated the irrigation potential of 3.5 million hectares, and Taye et al., (2011) estimated that the total potential irrigable land in Ethiopia is estimated around 3.7 million ha. Thus, the above variation in estimates indicates that for inaccurate review of the irrigation potential of the country. At the present only about 18% out of the 3.5 million ha of total irrigable potential is under irrigated (Seleshi et al., 2007). This indicated that yet, the existing irrigation development in Ethiopia, as compared to the resource the country has, is negligible.

To achieve sustainable production from irrigated agriculture it is obvious that the utilization of the important resources in irrigated agriculture; water and land must be improved. Thus on-farm irrigation systems and operations need to be evaluated against the potential efficiency of the systems. Performance evaluation has been an integral part of irrigation since man first started harnessing water to improve crop production. Evaluation involves measuring conditions at one or more points in a field selected to be typical or representative for the irrigation projects (Pereira and Trout, 1999). The principal objective of evaluating the performance of irrigation systems is to identify management practices and systems that should be effectively implemented to improve the irrigation efficiency. Moreover, performance is assessed for a variety of reasons: to improve system operations; to assess progress against strategic goals; as an integral part of performance-oriented management, to assess the general health of a system; to assess impacts of interventions; to diagnose constraints; to better understand determinants of performance; to compare the performance of a system with others or with the same system overtime (Molden et al., 1998).

As FAO (1989) described that for the long term irrigated agriculture faces a number of difficulty problems. One of the major concerns is generally poor efficiency with which water resource have been used for irrigation. A large part of the low performance may be due to inadequate water management at irrigation system and field levels. About 40% or more than of the diverted water for the irrigation system is wasted at farm-level through either deep percolation or surface runoff.

The attention given by the Government, NGOs and the beneficiaries to the water project: implementation, operation and management is very poor and slow (Mulubrhan and Gebretsadikan 2016). The improper on farm irrigation management practices in the region may lead to poor water distribution, non-uniform crop growth, water logging and salinity all of which decreases the yield per unit of land area and per unit of water applied (Eyasu, 2005).

## **1.2. Statement of the Problems**

The following were the problem statements that initiated the researcher to conduct a research on the title of performance evaluation of Tsilwe SSIS in Tigray, Ethiopia.

Irrigation system with poor management have the potential to degraded and waste the valuable land and water resources. Tsilwe SSIS is now irrigated about 33 ha whereas its proposed design was to irrigate about 53 ha thus the irrigation scheme is irrigated below its potential. There are a number of shortcomings to become the irrigation scheme below its potential such as poor operational and maintenance of the irrigation system and improper irrigation practices leads to poor water management which reduce the potential of the irrigation scheme and decrease the yield per unit of land and per unit of water applied. And also Tsilwe SSIS was not evaluated since its operation.

Evaluation of irrigation schemes performance has now an important to point out where the problem lies and also helps to identify alternatives that may be both effective and efficient in improving system performance. Hence, this study attempts to introduce the concept of performance indicators as a tool to evaluate the performance of small-scale irrigation endeavors at the Tsilwe small scale irrigation scheme

## **1.3. Objectives of the Study**

The general objective of this research was to study the performance of Tsilwe small scale irrigation scheme in Enderta Woreda, south Eastern Tigray Regional state.

### **The specific objectives of this study were**

- ❖ To evaluate the performance of Tsilwe SSIS with irrigation efficiency (conveyance, application, storage, distribution and overall irrigation efficiencies).
- ❖ To evaluate the performance of the Tsilwe small-scale irrigated schemes using external performance indicators (agricultural productivity, related indicators and physical indicators).

## **1.4. Research Questions**

The study was centered on the following questions.

- 1) Does the water availability at the irrigation scheme is enough?

- 2) Is the minimum set of indicators as identified by IIMI are suitable tools to describe and analyze temporal variation in performance in Tsilwe small scale irrigation scheme?

### **1.5. Significance of the Study**

This study is significant to identify the problems encountered on the performance of Tsilwe SSIS, so that possible measures will be taken when these shortcomings are identified to improve the production and productivity of Tsilwe SSIS generally other irrigation schemes of the Region's. Besides, being an empirical study it will help to add to the empirical literature that uses the combination of both Internal and external performance indicator approach in assessing other performance of SSI. Finally, understanding the evaluation of the small scale irrigation on performance and the determinant factors of internal and external indicators is a vital issue for designing appropriate irrigation systems, as well as technology interventions. Therefore, the outcome of this study may provide as a source of additional information which may be of significant use to policy makers and planners during the designing and implementation of small scale irrigation systems. And also this study supports as a bench mark and entry point for development works and future studies.

### **1.6. Scope of the Study**

This study is to evaluate the performance Tsilwe SSIS on internal and external performance indicators aspects. Those internal indicators were considered on the irrigation efficiencies and the external indicators were considered related to agricultural outputs, related to water indicators and financial indicators. Such studies reflect the condition of the small scale irrigation production process pre-unit irrigated area, command area and per unit water consumed intervention, and would have been helpful to compare more comprehensively and evaluate the relative effect of the technology intervention on small scale irrigation performance.

## **2. Literature Review**

### **2.1. Concept of Irrigation**

Irrigation is broadly defined as the culture of applying water to the soil to supplement the nature rainfall and provides moisture for plant growth (Uphoff, 1986). According to Wichelns, (2000). Irrigation is defined as the farmer's perspective to deliver the amount and quality of water required by plants throughout a growth period of the plant to optimize plant growth and crop production. And also irrigation is defined as human intervention to modify the spatial or temporal distribution of water to manipulate all or part of this water for the production of agricultural crop (Wichelns, 2000).

According to Garg (1989) irrigation is described as the degree to which water volume and quality, and the time of irrigation events match the requirements of plant throughout the season. Perfect success occurs when the volume, quality and timing of water deliveries would generate maximum crop yield given that non irrigation inputs are not limiting, irrigation may therefore, be defined as the science of artificial application of water to the soil, in accordance with the crop requirement throughout the crop period for full-fledged nourishment of the crops.

### **2.2. Historical Development of Irrigation Globally**

In the world, irrigation may be considered to date back to the prehistoric times in Mesopotamia and Egypt where they were used to water crops. Irrigation is an ancient agricultural practices which was vastly used by a number of countries of those early civilized such as Egypt, china, India and Iraq (Grove, 1989). Over 5000 years ago, runoff irrigation was practiced in Yava, Palestine. At the same time, so-called hydraulic societies developed in large river valleys, such as the Yangtse in China, Indus in India, Euphrates in Iraq and Nile in Egypt. Laws and by-laws regulated the distribution of irrigation water, which dominated the life cycle of farmers and citizens alike. Some 1500 years ago, the Marib dam in Yemen raised the water level of a non-perennial river to divert floods for irrigation purposes (FOA, 1999).

From the above, one can understand irrigation is an age-old art, perhaps as old as civilization. Nevertheless, the increasing need for crop production due to growing population in the world is necessitating a rapid expansion of irrigated agriculture throughout the world especially small-scale irrigation. Since then there have been numerous innovations that have helped improve the ease and efficiency of water application to crops.

## **2.3. Historical Development of Irrigation in Ethiopia**

According to Awulachew et al., (2010) there is no documented history of water management for agriculture. In Ethiopia irrigation can be dated back to the millennium old water storage structures for non-agricultural was used around Axum in Tigray shows the oldest usage of water in a controlled manner. However, there is no well documented resource material on water use for irrigation in Ethiopia.

Modern irrigation development in Ethiopia is not having centuries age. Modern irrigation was started at the beginning of the 1960's by private investors and was concentrated in the middle of awash valley (Zerihun and Ketema, 2006). In Ethiopia, irrigation has long been in use; however, irrigated agriculture is far from satisfactory despite substantial investment, public interest, and strategic support through government policy. Irrigated agriculture comprises only 3% of the total national food production (Tilahun & Paulos 2004).

### **2.3.1. Irrigation Typology in Ethiopia**

Irrigation systems can be classified according to size, source of water, management style, degree of water control, source of innovation and type of technology. In terms of management there are: governmental managed, farmer managed and jointly managed irrigation scheme in Ethiopia (Yusuf and Tena, 2007). Similarly Angelle, (2007) puts as traditional irrigation schemes, modern small-scale irrigation scheme, modern private irrigation and public irrigation depending on the size and type of technology, type of management, degree of water control and size of the land.

According to Desalegn (1999) in Ethiopia, irrigation development has been described in 3 main types: small, medium and large

**Small scale irrigation schemes:** - it includes traditional small scale schemes up to 100 hectare and modern communal schemes up to 200 hectare. The construction of small scale schemes is initiated by farmers with limited assistance from the government. The farmers manage it through their own water users association or committees. The farm size varies from 0.25 ha to 0.5 ha.

**Medium scale irrigation (MSI):-** schemes are those that can supply adequate amount of water to irrigate a command area of 200 to 3000 ha land.

**Large scale irrigation (LSI):-** schemes are those can supply irrigation water to a command area more than 3000 ha.

### **2.3.2. Current Status of Small-Scale Irrigation Schemes in Ethiopia**

**Small Scale:** this involves irrigation activities on small plots, comprising a small number of farmers, using relatively small reservoirs- rivers, dams or a cluster of wells controlled by the farmers using technology they can operate and maintain. In highland areas like Ethiopia, where water is delivered through gravity, small-scale irrigation schemes concern the upgrading of irrigation works, where the simple diversion structures, micro dams constructed by traditional communities with local means such as stone and brushwood (Gebremeskel, 2013).

Small-scale systems may have advantages over large-scale systems. These advantages include that small-scale technology can be based on farmers existing knowledge; local technical, managerial and entrepreneurial skills can be used; migration or resettlement of labor is not usually required; planning can be more flexible; social infrastructure requirements are reduced; and external input requirements are lower (Underhill 1990).

According to Awulachew et al. (2010) the current estimates of irrigation schemes of the country cover about 640,000 ha. However, there is some uncertainty about the exact number and location of some schemes, particularly small-scale irrigation and rainwater harvesting (RWH).

### **2.4. Irrigation Status in Tigray**

Tigray regional is found in the northern semi-arid parts of Ethiopia. About 85% of it's the population is dependent on agriculture. This sector is mainly dependent on rain, but the rain in the Region is erratic and unreliable (REST, 2003). Even though it has abundant water resources cultivating one crop per year and the crop that harvests are insufficient due to insufficient rainfall and improper use of water and land resources. To mitigate this problem the Regional government has been constructed different micro dams and river diversion. These micro dams and river diversion have directly and indirectly benefited the farmers and the community in environmental rehabilitation, improved agricultural production, and income diversification, stability of the market and self-reliance of the people of the Region (REST 2003).

According to REST (2003) the potential cultivable land in Tigray regional state is 1.5 million ha of which 1 million ha is under cultivated and 325,000 ha of land is suitable for irrigation. From this suitable irrigable land and abundant water resource only small amount of it is utilized because of lack of capital and inadequate skilled manpower.

As GTP (2011) reported that irrigable land of the region was planned to increase from 125,000 ha to more than 350,000 ha at the end of 2015. The ultimate goal of the region is to irrigate 50% of the total cultivated land at the final of second GTP (Gebreslasie, 2014).

## **2.5. Concept of Irrigation Performance and Evaluation**

According to Ros (2013) the performance of irrigation system can be defined as its efficiency, understood as the relation between actual results versus the intended outcomes of the system (inputs and outputs). Studies in performance indicators indicates that whether, the expected outcome of the system would be the improvement of food security and of life conditions of farmers through irrigated agriculture. The purpose of performance evaluation is to achieve an effective and efficient use of resources. Performance evaluation is regarded as the most important element for improving irrigation management.

The concept of evaluating irrigation systems has undergone major development during the last three decades; Irrigation performance indicators range from water distribution to agricultural, economic, social, and environmental aspects (Bos et al, 1994).

Nevertheless, the concept of ‘Irrigation system performance’ is in continuous evolution. There is a need for a generic assessment framework in this sense. This requires methodological improvements of evaluation and new performance indicators (Chaponnière et al, 2012).

## **2.6. The Necessity of Performance Evaluation of Irrigation Schemes**

The preeminent objective of evaluating the performance of irrigation systems is to identify the management practices and systems that should be effectively implemented to improve the irrigation efficiency (Molden et al., 1998). Performance is evaluated for a variety of reasons i.e. to improve system operations, to appraise progress against strategic goals, as an integral part of performance-oriented management, to evaluate the general health of a system, to evaluate impacts of interventions, to diagnose constraints, to better understand determinants of performance, and to compare the performance of a system with others projects or with the same system over time projects (Umm-e et al, 2012).

IWMI’s minimum sets of performance indicators were used by many researchers to compare different irrigation schemes. Comparison helps to identify ‘who is doing what right’ and what lesson can be learnt or who can be a benchmark for a particular activity (Molden et al., 1998).

## **2.7. Past Works in Performance Evaluation of Irrigation**

### **2.7.1. Past Works in Performance Evaluation of Irrigation Globally**

The IWMI, Sri Lanka, and the Agricultural Engineering Research Center (AERC), Taiwan, both perceives the increasing importance of developing a reliable methodology to assess the performance of irrigation and water resource systems (Sakthivadivel et al., 2001). Many irrigation systems were evaluated with external performance indicators have been developed by IWMI. As molde et al. (1998) affirmed that 18 irrigation schemes in 11 countries have been evaluated as presented in appendix Table1. Many researchers have been studied irrigation performance in different irrigation systems for instance assessment of performance irrigation at Taoyuan and Kaohsiung irrigation systems in Taiwan (Sakthivadivel et al., 2001); performance evaluation of irrigation Techniques through the implementation of fuzzy logic system at La Union farm san Jose, Northern Huila state, Colombia (Jonathan et al., 2014); performance evaluation of minor irrigations schemes at Kalwande minor irrigation schemes in Maharashtra district, India (Ingle et al., 2015); Evaluation of irrigation efficiency in Swaziland (Magwenzi, 2000); Irrigation performance assessment in Thrace district, Turkey (Sener and Selcuk, 2011); Comparative performance assessment of major irrigation systems in upper Deduru Oya Basin, Sri Lanka (Lakmali et al., 2015) . IIMI has indicated the minimum set of indicators covering agricultural, financial and water related issues are being applied in several countries like Mexico, Colombia, Egypt, Morocco, Sri Lanka and India (De Fraiture and Garces-Restrepo, 1997).

### **2.7.2. Past Works in Performance Evaluation of Irrigation in Ethiopia**

Irrigated Agriculture will be thought to be one of the solutions to enhance food security in Ethiopia (Awulachew et al., 2010). In recognition of both the benefit and hazards assessment and evaluation of irrigation schemes performance has now become a paramount importance not only to point out where the problem lies but also helps to identify alternatives that may be both effective and efficient in improving system performance (Mintesinot et al.,2005). In Ethiopia different performance evaluation of irrigation researches have been studied from the many studies some of them are: performance evaluation of small scale irrigation in Tekeze basin Tigray region (Mintesinot et al. 2005). This study was conducted on the evaluation of the performance of May Nigus micro dam irrigation scheme used only the comparative (external) indicators basis on different cropping period for 1997/98 to 2001/02 and this study obtained varied values on different

cropping periods the summarized results are shown in appendix table 2; performance evaluation at bedene Alemtena small scale irrigation scheme in Hallaba Special woreda, southern Ethiopia (Dessalew, 2016). This study was conducted on overall performance evaluation indicators. on farm performance evaluation at Adawa small scale irrigation scheme in Dire Dawa, Eastern Ethiopia (Zerihun and Ketema, 2006); Performance assessment at Shina-Hamusit and Selamko irrigation schemes in south Gonder Zone Amhara Region, Ethiopia (Abebe, 2015). For this study was conducted with some selected performance evaluation indicators and the obtained values is presented in appendix table 2. Technical performance evaluation at Midhegdu small scale irrigation scheme in western Hararge Zone, Oromia Region, Ethiopia (Worku, 2013) for Msc thesis and Assessment of small scale irrigation using comparative performance indicators in upper Awash River valley Oromia region, Ethiopia ( Yusuf, 2004).

## **2.9. Indicators of Irrigation Performances**

The irrigation performance is appraised either by internal or external indicators or a combination of both. Farmers and system managers can measure performance by comparing actual results to planned targets in order to improve irrigation service to water users, making use of internal indicators (Murray et al., 1993). The evaluation of surface irrigation at field level is an important aspect of both management and design of the system.

### **2.9.1. Internal Indicators of Irrigation Performance**

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

Irrigation efficiency is defined as the ratio of the amount of water that needed for proposed purpose divided by the total amount of water diverted to necessary place (Mati, 2011). Irrigation efficiency is a critical method to evaluate the performance of irrigation water use (Howell, 2003). Irrigation efficiency is the ratio between the volume used by plants through evapotranspiration process and the volume that reaches the irrigation plots and indicates how efficiently the available water supply is being used, based on different methods of evaluation. The design of the irrigation scheme, the degree of land preparation, and the skill and care of the irrigators are the principal factors

influencing irrigation efficiency. Efficiency in the use of water for irrigation consists of various components and takes into account losses during storage, conveyance and application to irrigation plots. Identifying the various components and knowing what improvements can be made is essential to making the most effective use of this scarce resource (Michael, 1997). The most common way to express the efficiency of irrigation systems is to subdivide it into conveyance and application, storage, distribution and overall irrigation efficiencies (Michael, 1997).

#### **2.9.1.1. Conveyance Efficiency ( $E_c$ )**

The ratio, in percent, of the amount of water delivered by a canal or pipeline to the amount of water delivered to the conveyance system. Water conveyance efficiency is used to measure the efficiency of water conveyance system associated with the canal network, watercourses and field channels; it is also applicable where the water is conveyed in channels from the well to the individual fields. It is one of the several closely related and commonly used output measures of performance that focus on the physical efficiency of the water conveyance by the irrigation system (Bos, 1997). According to Ramulu, (1998) conveyance efficiency ( $E_c$ ) mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals. Some indicative values of the conveyance efficiency ( $E_c$ ), considering the length of the canals and the construction materials in which the canals are constructed have different values. For instance for lined canals for all lengths of canals the recommended  $E_c$  is 95% (Mati, 2011 and FAO, 2002).

#### **2.9.1.2. Application Efficiency ( $E_a$ )**

Application efficiency sometimes called field application efficiency or on-farm application efficiency is referred as the ratio of the amount of water applied as net increase in soil moisture in the crop root zone to the total amount of water applied at the field level (Mati, 2011). It also can be defined as the ratio of the volumes (depth) of water stored in the root zone for use by the plant to the volume (depth) of water applied to the field to the amount of water needed for crop production compared with the amount applied to the field and depends on system uniformity and management. The major losses which affect the irrigation efficiency are drainage below the root zone and surface runoff. (Walters and Berisavijevic, 1991). Values of application efficiency are different basis of the irrigation systems. The indicative recommended values for furrow irrigation is range 50-90% (Rogers et al., 1997) and ranged as 55-70% (FAO, 2002).

### **2.9.1.3. Storage Efficiency**

For irrigation the soil water storage capacity is defined as the total amount of water that is stored in the soil within the plant's root zone. The soil texture and the crop rooting depth determine this; a deeper rooting depth means there is a larger volume of water stored in the soil and therefore a larger reservoir of water for the crop to draw upon between irrigations (Allen et al., 1998).

Walker (1989) described that Knowing the soil water storage capacity allows the irrigator to determine how much water to apply at one time and how long to wait between each irrigation. For example, the amount of water applied at one time on a sandy soil, which has a low soil water storage capacity, would be less than for a loam soil, which has a higher soil water storage capacity. This is assuming the crop's rooting depth is the same for both soils. Applying more water to the soil than can be stored results in a loss of water to deep percolation and leaching of nutrients beyond the root zone.

Only a portion of the total soil water is readily available for plant use; Plants can only extract a portion of the stored water without being stressed. An availability coefficient is used to calculate the percentage of water that is readily available to the plant. The maximum soil water deficit (MSWD) (also referred to as the management allowable deficit) is the amount of water stored in the soil that is readily available to the plant. The crop should be irrigated once this amount of moisture has been removed from the soil. Once depleted this is the amount that must be replenished by irrigation. It is also the maximum amount that can be applied at one time, before the risk of deep percolation occurs. However, in some cases leaching of salts is desirable and extra irrigation would be desired. Soil holds different amounts of water depending on their texture and structure (Werner, 2002).

Storage efficiency is an index used to measure irrigation adequacy. It is the ratio of the quantity of water stored in the root zone during irrigation event to that intended to be stored in the root zone (Allen et al., 1998). The requirement efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone.

### **2.9.1.4. Distribution Uniformity ( $D_u$ )**

Distribution uniformity ( $D_u$ ) is a measure of how evenly water is applied during an irrigation event. This uniformity of application can have a considerable effect on crop yield and optimum

water application. There are several interpretations in the literature, but a common measure for surface irrigation systems is to divide the average depth infiltrated calculated from the quarter of the field with the lowest infiltrated depths, by the average infiltrated depths. This is called the 'low quarter' (Jensen, 1983).

#### **2.9.1.5. Overall irrigation system efficiency ( $E_o$ )**

The overall irrigation efficiency is the total process of irrigation from the source of the water to the point where the water becomes available in the root zone of the plant. Irrigation efficiencies are evaluated at scheme or farm level for the purpose of identifying the losses that occur in the irrigation system starting at the water abstraction point, through the conveyance system down to water application in the field (Jensen, 1983).. As describe by the MoAFS (2002) for small irrigation schemes in Tanzania typical values conducted were 28 and 34% for poorly operated, and for well operated canals, respectively.

#### **2.9.2. External indicators of Irrigation Performance**

External indicators focus on outputs from a system derived from the main inputs of the system like land and water in to the system. The relative performance standards can be developed per type of irrigation scheme to facilitate evaluation of individual systems. The indicators might also prove useful to reveal about the relative health of the irrigation system (De Fraiture and Garces-Restrepo 1997).

According to IIMI (1994) the irrigation performance indicators are grouped in to three groups these are the irrigated agriculture performance indicator, the water related performance indicator and the financial performance indicator. In fact the IWMI proposed a set of nine indicators to compare the agricultural irrigation from these the four are categorized as basic external indicators (output per unit cropped area, output per unit command area, output per unit irrigation supply and output per unit water consumed) are related to output to unit land and water. These external indicators provides the basis for comparison of irrigated agriculture performance (Molden et al., 1998). The other five external indicators are identified as minimum comparative purpose. These are characterized to the individual system with respect to water supply and finance. The related water supply indicators are RWS, RIS and WDC and the financial related indicators are Gross return on investment and financial self-sufficiency (Molden et al., 1998).

### **2.9.2.1. Irrigated Agriculture Performance Indicators**

The irrigated agriculture performance indicators are used to evaluate the irrigation project performance in terms of the crop production. It shows that the output of the irrigated area in terms of gross or net value of production measured at local or world price (Abernethy 1991).

According to Bos et al (1997) the agriculture performance indicators have categorized in to two groups, as production per unit area indicators and production per unit water indicators.

### **2.9.2.2. Water Related Indicators**

Water related indicators describes the water supply indicators (relative water supply, relative irrigation supply and delivery capacity) are more suitable performance indicators related to water supply (Molden et al., 1998).

#### **Relative Water Supply (RWS)**

The relative water supply was originally developed by Livene, (1982). RWS is the measurement of total volume of water availability. The total volume is the applied water in form of the irrigation water plus the rainfall (De Fraiture and Garces-Restrepo 1997). RWS is useful to evaluate the degree of irrigation water stress or abundance in relation to irrigation demand. It is the inverse of irrigation efficiency presented by (Bos, 1997). Value for RWS greater than 1 indicates water supply is excess water supply of the demand; if it is less than 1, indicates that the water supply is a deficit of the demand. While if it is approach to 1, the supplied amount of water is optimum to the irrigation demand (Ingle et al., 2015). According Molden et al., (1998) investigation varied values for RWS were found to be between 0.8 and 4.1, from 18 different irrigation schemes in 11 countries of the world.

#### **Relative Irrigation Supply (RIS)**

The relative irrigation supply (RIS) is an indicators of how well crop water requirement is met or is satisfied in a scheme. Also stated that RIS is an inverse of the irrigation efficiency proposed (Molden et al. 1998). If the water requirement is met enough, the value of RIS is unity. While a value greater than one would indicate more water is supplied than required, and the value less than one would indicates that the crops are not getting enough water (Ingle et al., 2015). But according to Molden et al., (1998) reported that large variation of RIS values indicated between 0.4 and 4.8, among the studies of 18 different irrigation schemes in 11 countries of the world.

## **Water Delivery Capacity Ratio**

The water delivery capacity is meant to give an indication of the degree to which irrigation infrastructure is sufficient to convey the peak consumptive demands of the irrigation system; Values much greater than 1 indicates that their capacity is not a constraint to meeting crop water demands. Values less than to 1 indicate that there may be difficulties meeting short-term peak demands (Molden et al. 1998).

### **2.9.2.3. Physical performance indicators**

It is a useful indicator for assessing the sustainability of irrigated agriculture. Ascertaining the likely sustainability of a system over time requires determining a variation with respect to time (season, year, etc) of key indicators, tracing the secular trends and understanding the processes causing these trends (Rao, 1993). Assessment of time dependent variation of adverse effects like water logging, salinity, flooding etc are important for monitoring a system's physical sustainability. Sustainability has many dimensions and they will probably be more country specific and project specific. For this study irrigation ratio and sustainability of irrigated area indicators were selected.

#### **a) Irrigation Ratio**

Sener *et al.* (2007) developed a relation between currently irrigated areas to the command (nominal) area to be irrigated; to quantify the level of utilization of the potential irrigable area for irrigated agriculture for a particular production time period. Lower utilization of the given irrigable area would be existed due to different constraints; i.e. lack of irrigation infrastructure, shortage of irrigation water, lack of interest on irrigation due to less return and market problems, and reduced productivity due to (soil nutrient depletion, lack of improved technologies, lack of inputs and water logging) etc. Furthermore cropping intensity is an illustrative for land utilization capacities. The cropping intensities from 100 to 200% are considered good, while lower ratio indicates poor intensities (Burton *et al.*, 2000).

#### **b) Sustainability of irrigated area**

According to Bos (1997) sustainability of irrigated area is the ratio of currently irrigable area to initially irrigated area. This important indicator mainly used to observe the status of the irrigation systems either contracted or expanded. If the computed value is small or less than 1 it shows the

irrigable area is contracted and if it is large i.e. greater than one, it shows the irrigable area is expanded from the designed irrigable area, through including nearby farm areas. The contraction of irrigable land may be appeared due to different reasons, i.e. water shortage, water logging, flooding problems etc. On the other hand expansion might be occurred due to interests coming from neighboring farmers to irrigate extra land addition to designed one. This expansion of irrigable area indicates there is more sustainable of irrigation.

## **2.10. Soil Plant Water Relationship**

Plant growth depends on the use of two important resources, soil and water. Soil provides the mechanical and nutrient support necessary for plant growth. Water is essential for plant life processes. Effective management of resources for crop production requires the producer to understand relationship between soil, water and plants, knowledge about available soil water and soil texture will make deciding what crops to plant and when to irrigate, easier.

### **2.10.1. Physical Characteristics of Soil**

There are many variable in the physical characteristics of soil. These includes soil texture, soil structure, and bulk density.

**Soil texture:** according to Janine (2002) affirms that soil texture is determined by the size of the particles that make up the soil. The traditional method of determining soil particle size is done by separating the particles in to three convenient size ranges. These soil fractions or separates are sand, silt and clay. The soil texture is determined by the mass ratios or the percent by weight, of the three soil fractions.

**Soil Bulk Density:** soil dry bulk density is expresses as the ratio of the weight of a soil to its total volume. The soil bulk density is important because it is a measure of the porosity of the soil. The porosity of a soil is defined as the volume of pores in a soil (USDA NRCS 2014).

### **2.10.2. Soil and Water Interaction**

Soil and water interaction is important to understand the interactions between the soil and water, which include soil water content, how the soil holds water and soil water tension. Understanding these interactions can be very helpful when making planting and irrigation decision (USDA NRCS 2014).

**Soil water content:** The capacity of a soil to retain moisture that is readily available for plant growth is an important factor in irrigation and land use planning. This applies not only where there is adequate rainfall, but also in irrigation projects, where irrigation water has to be applied at the right time and at the right quantity. The amount of water available for plant uptake has been related to a soil's water budget (Allen et al, 1998).

The three terms associated with the water budget are field capacity (FC), wilting point (WP), and available water (AW). The WP, also called the permanent wilting point, may be defined as the amount of water per unit weight or per unit bulk volume in the soil, expressed in percentage that is held so tightly by the soil matrix that roots cannot absorb this water and a plant will wilt (Diallo and Mariko 2013). The field capacity (FC) and the permanent wilting point (PWP) are two levels of moisture that are used to calculate available water for plant and water depth to be applied by irrigation. Generally, field capacity is defined as the amount of water after excess water has drained away and the rate of downward movement has materially decreased. The permanent wilting point is defined as the value of soil wetness when plants wilt. Plant TAW may be defined as the difference between FC and WP. 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 (Diallo and Mariko 2013).

## **2.11. Crop-water Requirements, Irrigation Schedules and Depths**

Despite the fact that the physical determination of crop-water requirements (CWR), irrigation schedules and depths, is complicated and time-consuming, they remain vital to irrigation water management and planning (Abdelhadi et al., 1999). The introduction of CropWAT computer models has made it easier and possible to schedule irrigation and supply the exact amounts of water required by crops at every physiological stage in their growth cycle (Clarke et al., 1998).

### **2.11.1. CROPWAT Model**

According to Thorsten; (2006) CropWAT model is described as decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. CropWAT is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements using the inputs of climatic crop and soil data.

**Estimation of crop water and irrigation water requirements:** The CROPWAT model requires ETo, effective rainfall and crop data for estimating CWR and IR.

Reference evapotranspiration (ETo): the FAO Penman-Monteith equation has been adopted as the globally best performing method of estimating ETo based on the inputs geographical coordinates (latitude, longitude and elevation) of the nearby metrological station, monthly climatic data (minimum and maximum temperature, relative humidity, sunshine duration and wind speed). ETo for each month was calculated for a 'decade' (every ten days) (Supe et al., 2015).

**Effective Rainfall:** there are about four available options for calculating effective rainfall. These are: Fixed percentage, dependable rainfall (FAO/AGLW formula), empirical formula and USDA soil conservation service methods. Effective rainfall is calculated based rainfall inputs data collected from the nearby station gage (Supe et al., 2015).

**Crop data:** A Crop data consisting of the planting date, growth stage in day's crop coefficient (Kc) values, root depth, depletion fraction and the cropped area in percent (%) of the total area. The crop coefficient integrates the effects characteristics that distinguish a typical field crop from the grass reference, which has a constant appearance and complete ground cover. Consequently, different crops will have different crop coefficients. Growth stage as the crop develops, the ground cover, crop height and the leaf area change. Due to difference in in evapotranspiration during the various growth stages, the Kc for a given crop will vary over the growing period. (Allen et al., 1998).

**Irrigation scheduling:** the CROPWAT model estimates the irrigation scheduling with the soil data inputs. The soil data are includes TAM, maximum rooting depth and initial soil moisture depletion. The irrigation scheduling shows that the status of the soil moisture every time when new water enters in to the soil, either from rainfall or irrigation water (Supe et al., 2015).

### 3. Materials and Methods

#### 3.1. Descriptions of the Study Area

##### 3.1.1. Enderta Woreda

The study was carried out in Enderta district, which is one of the four districts in the southeastern administrative zone of Tigray National Regional State. It is found about 778 kilometers north of Addis Ababa capital city of Ethiopia, and geographically laid on 13° 15' 00" to 13° 38' 30" North Latitude and 39° 17' 30" to 39° 48' 30" Eastern Longitude, With an altitude ranging from 1500 to 2678 m.a.s.l., it shares borders with Kiltē`awlaelo district in the north, Hintalo Wajirat in the south, Afar regional state in the east and the district of Degu`a Tembien in the west. The Wereda covers a total area of 129865 ha of which 22215 ha is cultivable land (EBoARD, 2012).

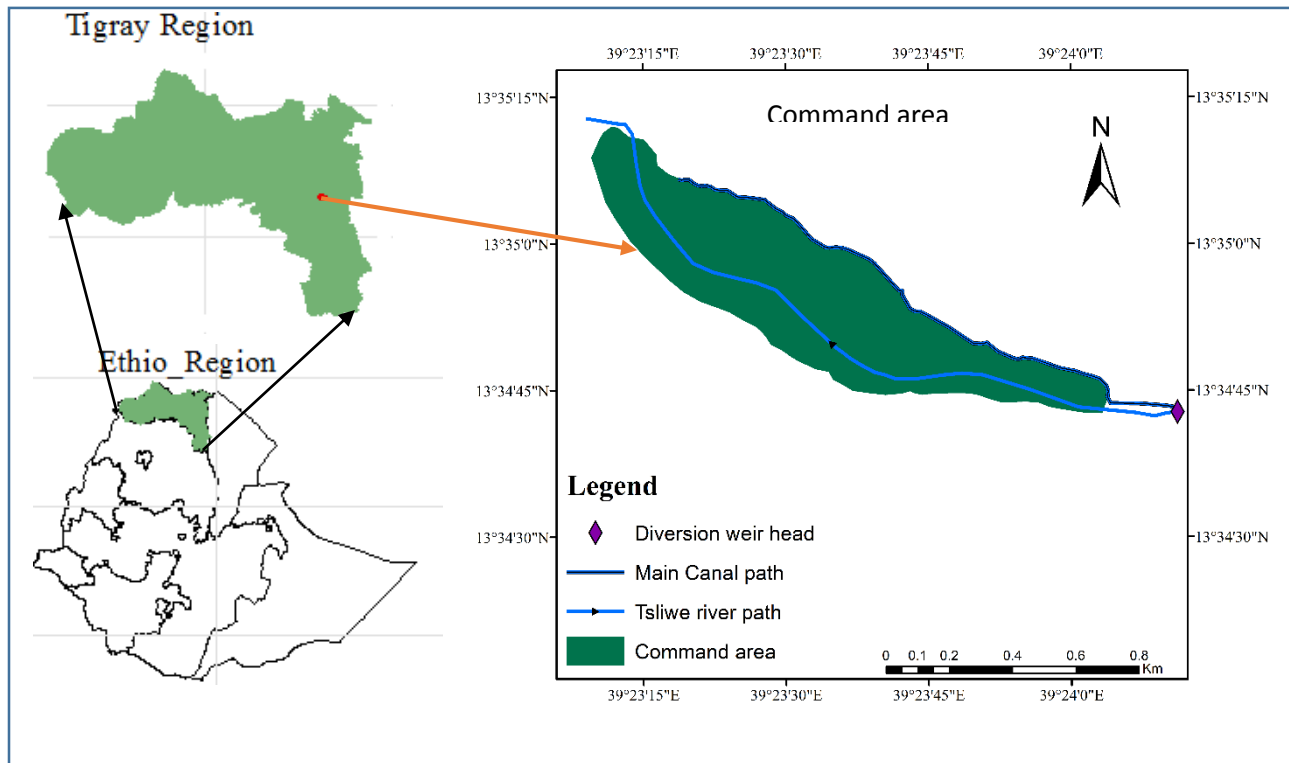


Figure 3. 1: Location map of the study area

##### 3.1.2. Tsilwe Small Scale Irrigation Scheme

The study area is selected a command area of, Gereb Geba irrigation scheme which is located in the north-eastern part of the Tekeze River Basin. The Tsilwe SSIS is found at Mahber Genet Kebelle in Enderta District in the Tigray regional State. Tsilwe SSIS is located about 14 km to

north western of Mekelle which is the Capital city of Tigray regional state along the Tenbien Adwa road. Geographical location of the scheme is lied between 13°34'35" to 13° 35'0"North and 39°23'30" to 39°24'0" East. The average elevation of the irrigation scheme is 1758 m.a.sl with peaks reaching 1782 m.a.s.l.

**Climate:** based on the climatological data of Mekelle meteorological station, which is the nearest weather station of the irrigation scheme, the rainfall at the study site can be estimated to vary between 324 mm to 769 mm mainly received from June to mid-September followed by a distinct dry spell season up to the first week of May.

The average monthly minimum and maximum temperature in the project area is in the order of 10°C and 28 °C respectively. Generally the area is belonging to semi-arid drought prone area of the Region.

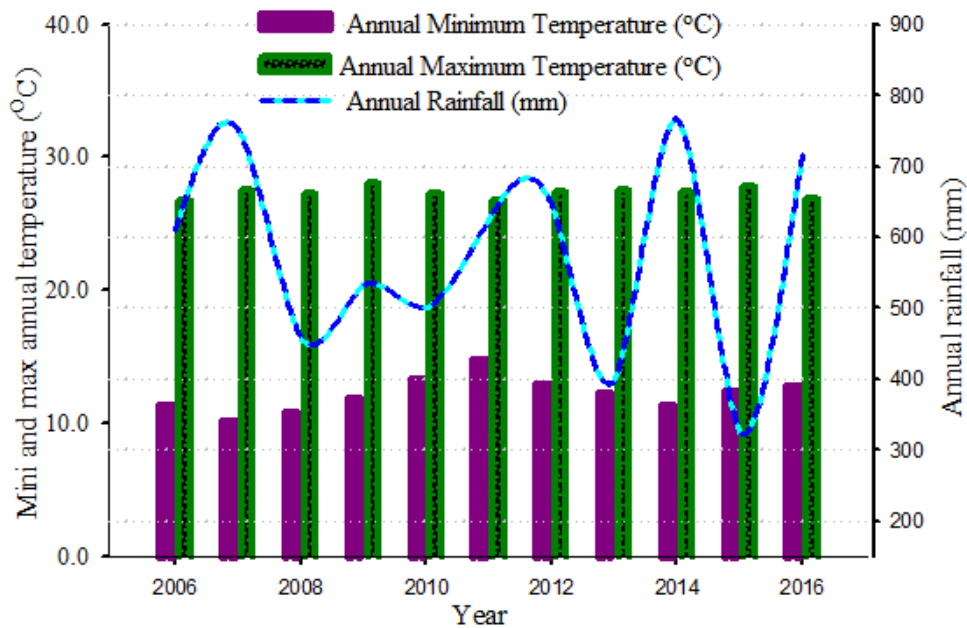


Figure 3. 2: Annual maximum and minimum temperature and rainfall of the study area for the period of 2006-2016

**Soil Characteristics:** The soils distribution at the study site are sandy soil 43.3%, silt soil 34.15% and clay soil 22.55% from the laboratory result.

**Water source:** The irrigation water is diverted from a weir constructed across the Tsilwe River into a Rectangular lined canal which consists of 1.6 km long from the diversion point to the field distributions (from GPS measurement). The discharge delivered to the farmers usually ranges

between 2.2 and 4.2 l/s. The concrete-lined canal with a top width of 0.4 m and a depth of 0.6 m is designed to convey approximately 0.043 m<sup>3</sup>/s (EWMEo 2013). The scheme is divided into three blocks of different sizes for management and ease of water distribution as depicted in figure 3.4.

The actual year the scheme was established is not clear but farmers highlighted that the scheme started in the 1991 E.C. with a budget of Catholic Church. The scheme was intended to provide food and to create jobs to the local people. The intended command area was 53 ha but the current irrigated command is about 33 ha (from GIS delineation) as depicted in Figure 3.4. The farmers own approximately 0.0625 ha each in size. However, some farmers own or use more than one plot with about 0.5 ha on average. There are 144 beneficiaries in the irrigation scheme.

The scheme is managed through block committees which are responsible for water distribution within each specific block, among other responsibilities. The overall scheme is managed by an irrigation management committee (IMC) which is comprised of the chairpersons and secretaries of the overall irrigation scheme. The irrigation management committee ensures equitable water distribution among the blocks, inspection of irrigation infrastructure and sourcing funds for repairs and conflict resolutions.

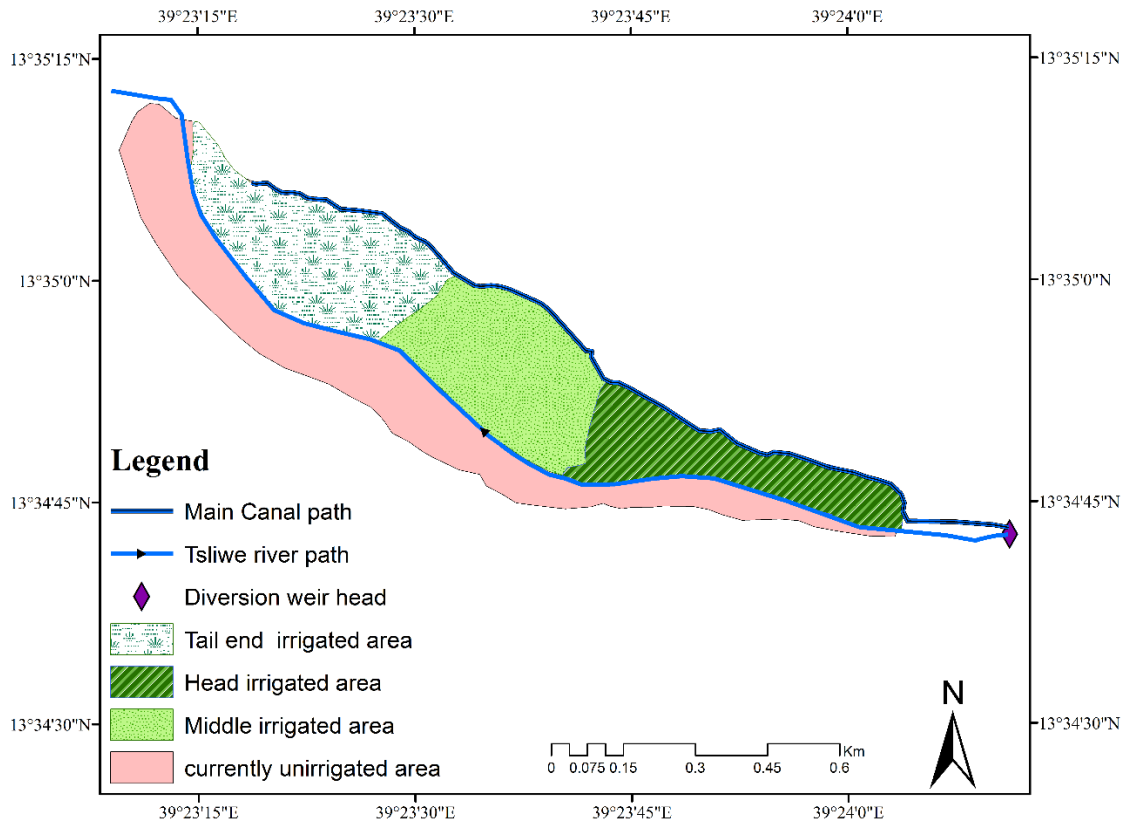


Figure 3. 3: Map of the current irrigated area of the scheme

### 3.2. Materials

Field measurements were carried out to assess irrigation performance in the study scheme. Data that needed field measurements were flow rates, soil moisture content, infiltration rate, yield in the study scheme, irrigation schedules and soil depths were needed physically measurement. materials used to measure data's at field were Double ring infiltrometer, Core sampler, auger, Plastic bag, Oven dry, GPS, Parshall flume, Meter tape, Stopwatch, Floating material and Weight balance. And also the following software's were used arc GIS 10.3 and CROPWAT model. The arc GIS was used to delineate command area and to locate the sample points.

### 3.3. Data Collection Methods

For the study all the necessary data were collected using primary and secondary sources. The primary and secondary data were utilized by employed quantitative and qualitative methods.

Quantitative data collection methods rely on random sampling and structured data collection instrument that lists in section (3.2). Typically quantitative data gathering strategies was included

surveying with closed ended questionnaire interviews, experiments, observing and recording and any measuring procedure yields numerically. Qualitative data were gathering through sketches and photographs.

### **3.3.1. Secondary Data Collection**

For the irrigation schemes secondary data collection was used. for data's like feasibility study of the irrigation scheme, production cost, irrigation productivity of the irrigation scheme, income generated by the irrigation scheme, yield per hectare, farm gate prices of irrigated crops, total yields and description of the study area were obtained from the Wereda Enderta Agriculture and rural development office and water mining and Energy office report documents and other. The eleven (11) years climatic data of near the irrigation scheme was obtained from Mekelle metrological stations. The data's for the major crops grown in the study area their growth stage, crop coefficient (kc) rooting depth ( $Z_r$ ) depletion level (P) yield response factor (Ky) such data were obtained from FAO paper No 56, 33 and 66 guide lines as presented in appendix table C-1.

### **3.3.2. Primary Data Collection**

In this study the primary data was obtained through field measurements and/or observations and laboratory tests which include field topography, soil data, irrigation water discharge delivery and field irrigation method. To collect primary data both closed and open ended questionnaires on crop type, cropping pattern, total yield of the scheme, production cost per season or per year, such data's were collected from a sampled of irrigator farmers using structured interview questionnaires.

#### **3.3.2. 1. Data Collection by Field Observation**

To locate the boundary of the command area and location of canal structure network, transverse survey was made with GPS. This was done by walking around the boundary of the command area, and canals network.

#### **3.3.2.2. Field Measurements and Laboratory Experiments**

For the study area the data's such as soil characteristics, water discharge at the main canals, and field applied irrigation water flows, was gathered at field by measurements and laboratory experiments.

### **3.3.2.3. Soil Characterization**

To know the particle size distribution, bulk density, field capacity and permanent wilting point, soil moisture content soil samples were taken from three field locations ( head, medium and tail irrigations) each three sample points at two depths 0-30cm and 30-60 cm using core sampler for undisturbed soil and plastic bag for disturbed soil samples.

### **Soil Particle Size Distribution**

Particle size distribution was determined using the Bouyoucos Hydrometer method (Bouyoucos, 1951). The percentage of sand, silt and clay of the composite soil sample were determined by sieve analysis and hydrometer method. After the percentage of sand, silt, and clay was measured, the soil may be assigned a textural class using the USDA textural triangle.

**Bulk density:** - Soil bulk density ( $\text{gm}/\text{cm}^3$ ) was determined using the methodology described in Walker (1989). Undisturbed soil samples were taken at two depths, 0-30 and 30-60 cm, which is the maximum root depth of the crops grown at the irrigation scheme using core samplers of known volume and the samples were weighed and placed in an oven at  $105^\circ\text{C}$  for 24 hrs. After 24 hrs, the oven dried soil was weighed, and then bulk density was calculated by equation 3.5.

### **3.3.2.4. Field Capacity, Permanent Wilting Point and Moisture Content Determination**

To test the moisture content of the soil at field capacity (FC) and permanent wilting point (PWP) disturbed soil samples were taken with plastic bag from the selected profiles pit excavated at three locations (head, middle and tail end of the scheme) which have different soil textures at two depths of 0-30cm and 30-60cm which is the maximum effective root depth of the common crop of the scheme. And the samples were taken to Addis Ababa water works design and supervision Enterprise soil laboratory to analyses using the pressure plate apparatus.

First the soil samples were saturated, a state where all pore spaces are filled with water, and a pressure of 0.33 bars and 15 bars were applied for field capacity and permanent wilting point respectively. Then, the values were determine experimentally in terms of gravimetric moisture content held in the soil at FC and PWP. The gravimetric soil moisture was finally multiplied by its bulk density to get the corresponding volumetric value (Warner 2002).

**Soil Moisture:** Bilskie (2001) pointed that the soil water content is expressed on a gravimetric water content ( $\theta_g$ ) or on volumetric water content ( $\theta_v$ ) basis. The gravimetric water content ( $\theta_g$ ) is the result of mass of water over mass of dry soil.

The soil moisture content measurements before and two days after irrigation were made by gravimetric method which randomly collected three undisturbed soil sample from each Head, middle and tail end of the irrigated land with auger and weighing the wet soil samples, removing the water by drying in an oven at 105 °C for 24 hours and re-weighing the sample to determine the amount of water was removed.

### 3.3.2.5. Infiltration Rate

To determine infiltration rate of the soil in the scheme, double ring infiltrometer of 30 cm and 60 cm inner and outer ring diameters respectively was used at the selected representative of the scheme which have different soil textures. Double ring infiltrometer was driven up to 15 cm depth depending the soil depth of the site by hammer. A minimum head of 12 cm was maintained in both rings during measurement. Depths to water levels were measured at increasing time intervals from the datum establishes on the edge of each cylinder (Johnson, 1991).

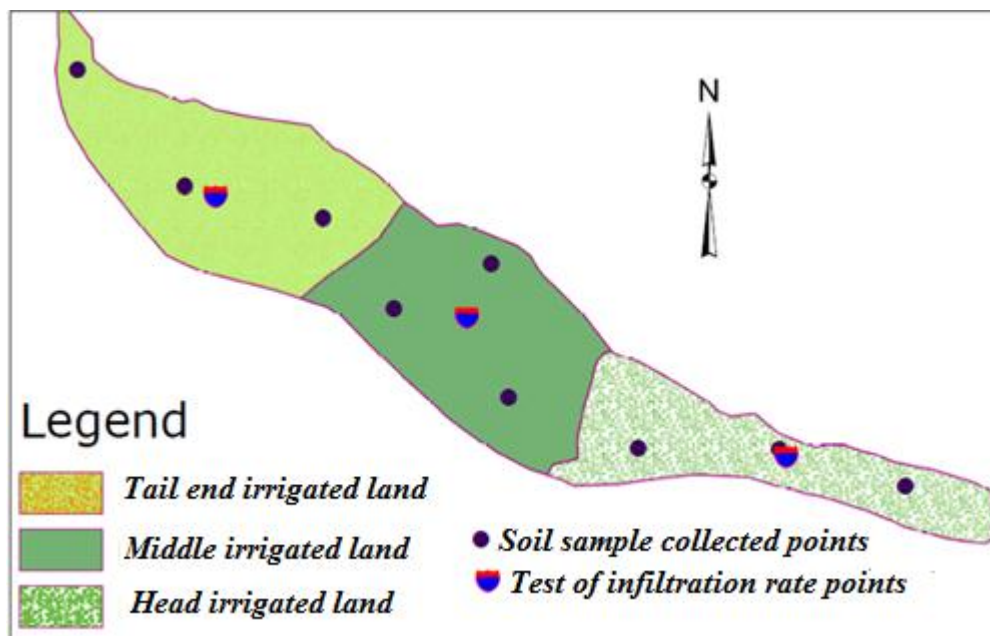


Figure 3. 4: Location points where soil sample collected and infiltration test measured

### 3.3.2.6. Discharge Measurement

The discharges of irrigation water diverted from Tslive river diversion at the irrigation scheme was determined by float method for main canal and parshal flume for field (farmer's field).

#### Float method to determine discharge at main canal

According to Joy and Marlies, (2005) floating methods is the inexpensive and simple method for measurements of an open channel discharge. The discharge at an open channel is a function of the cross-section area and flow velocity. Thus requires the measurement and calculation of the cross-section area of the canal as well as the time it takes a float object to a designated distance. Three times (at mid of February, end February and mid of march) flow measurement have been taken starting from intake to reference of main canal using float material as depicted in figure 3.6 and 3.7.

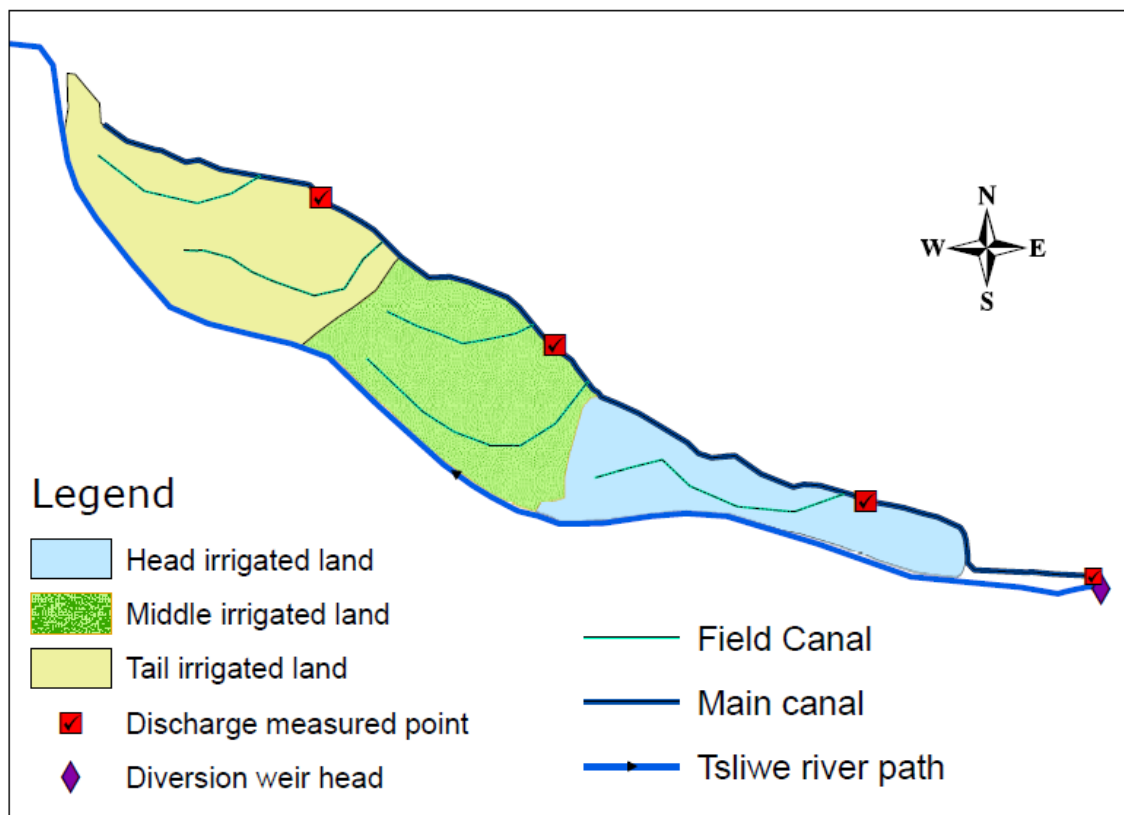


Figure 3. 5: Layouts for water flow rate measurement points

The procedures of discharge measurement at the main canal using floating material: first along straight line and uniform section was selected has a 5m long with an average top width of 0.4m

and in the length of canal in which the float object traveled the average depth of flow water was measured. The floating object was released slightly in to the center of the beginning section of canal and start timing and stopped when the floating object reached at end section and recorded the amount of time it was taken the float to reach the end marked section This measurement was repeated for five times to be more accurate. The measuring procedure and the canal section is depicted in figure3.7.

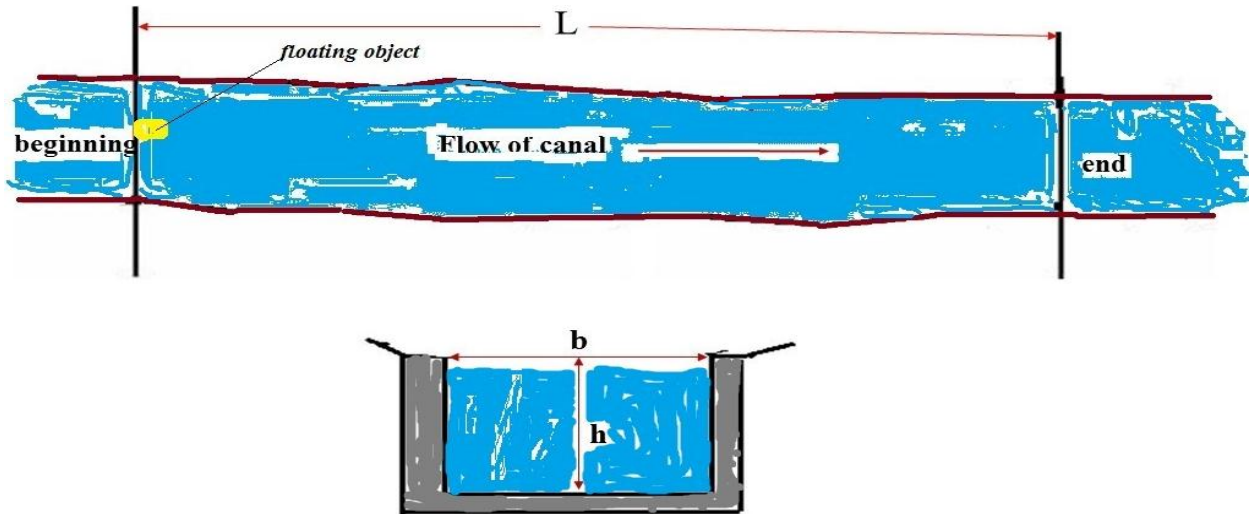


Figure 3. 6: Measurement of flow by floating methods at the cross sectional canal

The average area was calculated using the equation described by (Yoder 1999)

$$A = b \cdot h \dots\dots\dots (3.1)$$

Where **A** is area of canal, **b** top width of the canal and **h** is the depth of water in the canal.

The average flow velocity (**V**) was calculated as

$$V = \frac{L}{T} \dots\dots\dots (3.2)$$

Where **L** is the length of float material traveled and **T** is the time taken for the floating material to reach the end section.

The flow discharge, (**Q**) (m<sup>3</sup>/s) in the canal, was calculated using the formula below:

$$Q = V \cdot A \dots\dots\dots (3.3)$$

**Determination of the amount of water applied to the fields using Parshal flume**

To determine the amount of water applied in the fields, a 2 inches Parshal flume was installed at the entrance of three selected sample plot field locations head, middle and tail parts of the irrigation scheme during the farmers applied irrigation water for three times frequent readings was taken at

three farmers each head, middle and tail end irrigation. During the determination of the amount of water applied to the field, the average water depth irrigation water passed through the flume to the field and respective time intervals was recorded with the sizes of the fields being irrigated. The flow discharge through flume was calculated by the formulae for free flow conditions the level to flow equation for the parshal flume (USDA-II, 1994).

$$Q = kH_a^n \dots\dots\dots (3.4)$$

Where **Q** is free flow rate (l/s), **k** is flume discharge constant coefficient varies by flume size, **H<sub>a</sub>** is depth at the point of measurement (m) and **n** is discharge exponent depends upon flume size. The values for **k** and **n** are presented in appendix table 10.

**3.4. Data Analysis Methods**

The collected data was first summarized for analysis and for the performance analysis the internal and the external indicators were used.

**3.4.1. Soil Characterization**

**Bulk density**

The samples were weighed and placed in an oven at 105<sup>0</sup>C for 24 hrs. After 24 hrs the oven dried soil was weighed, and then bulk density was calculated using the equation:-

$$\rho_b = \frac{M_{dry}}{V_s} \dots\dots\dots (3.5)$$

Where **ρ<sub>b</sub>** = bulk density, **M<sub>dry</sub>** = mass of dry soil and **V<sub>s</sub>** = Volume of soil sample

**Soil moisture content determination**

For every plots, in the selected section of the irrigation scheme soil samples were taken before irrigation and two days after irrigation at two depths 0-30cm and 30-60cm of the average root depths of the crops which grown at the scheme per test pit. Soil moisture content in each sample was determined on gravimetric basis using the equation (De Angelis, 2007).

Water in the soil was calculated on weight /gravimetric/ basis: however it was not very useful without converting it to a volumetric measurement by multiplying the gravimetric value by soil bulk density using equation (Bilskie, 2001).

$$\theta_g = \frac{M_w}{M_s} = \frac{M_{wet}-M_s}{M_s} \dots\dots\dots (3.6)$$

Where  $\theta_g$  is the soil moisture content on gravimetric basis (%),  $M_w$  is weight of water,  $M_{wet}$  is the weight of the wet soil sample (gm) and  $M_s$  is the weight of the soil sample after oven drying (gm)

According to Bilskie, (2001) the gravimetric soil water content were converted to the volumetric water content using the equation below.

$$\text{Therefore } \theta_v = \theta_g * \rho_b \dots\dots\dots (3.7)$$

The soil moisture content also expressed in terms mm/m and was converted as:

$$\theta_v = (\theta_{vol} \%) * 10 \dots\dots\dots (3.8)$$

**Where**  $\theta_v$  (mm/m) is the volumetric soil water content in equivalent depth (mm)

The depth of water stored in the root zone of selected field was determined from the soil moisture content before and two days after irrigation by both gravimetric and volumetric methods. The depth of stored in the root zone was computed (Allen, 1998).

$$W_s = \sum_{i=0}^n \frac{(\theta_{vai} - \theta_{vbi})i}{100} * di \dots\dots\dots (3.9)$$

Where  $W_s$  = depth of water stored in to root zone of the soil (mm),  $\theta_{vai}$  = moisture content of the soil layer two days after irrigation ( $\% \theta_v$ ),  $\theta_{vbi}$  = moisture content of the soil layer before irrigation ( $\% \theta_v$ ),  $di$  = the thickness of  $i^{th}$  soil layer of the root zone (mm) and  $n$  = Number of layers in the root zone.

The actual moisture storage or retention (AMS) after irrigation in mm/m was computed using the equation (Allen 1998).

$$AMS = [\theta_{ai} - \theta_{bi}] * 10 \dots\dots\dots (3.10)$$

**Total available of water (TAW):** According to Allen (1998) affirms that 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 rooting depth. TAW was computed using the equation:

$$TAW = 1000 (\theta_{fc} - \theta_{pw})z_r \dots\dots\dots (3.11)$$

Where  $\theta_{fc}$  is water content at field capacity ( $m^3/m^3$ ),  $\theta_{pw}$  is the water content at wilting point ( $m^3/m^3$ ) and  $Z_r$  the rooting depth (m).

Readily available water content /RAW/: according to Allen (1998) RAW is represents the amount of water that a crop can extract from the root zone without suffering water stress. RAW was calculated using the equation (FAO, 1998).

$$RAW = p \text{ TAW} \dots\dots\dots (3.12)$$

**RAW** is the readily available soil water in the root zone [mm/m], **p** is average fraction of Total Available Soil Water (TAW) that can be depleted from the root zone before moisture stress.

The value P was taken from table (FAO 1998). The value that was taken from the table can be adjusted for different ET<sub>c</sub> using the equation (Allen, 1998).

$$p = p_{table} + 0.04(5 - ET_c) \dots\dots\dots (3.13)$$

Where P is the adjusted depletion fraction; ET<sub>c</sub> is the crop evapotranspiration (mm/day)

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

$$SMD = [\theta_{FC} - \theta_{bi}] * 10 \dots\dots\dots (3.14)$$

Where **SMD** is the 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 at the moment of irrigation without deep percolation loss (mm/m),  $\theta_{FC}$  soil moisture contents in percent volume at FC and  $\theta_{bi}$  is soil moisture contents in percent volume before irrigation.

### **3.4.2. Reference Evapotranspiration, Crop water Requirement, Crop Irrigation Requirement**

The potential evapotranspiration of the area, the net crop water requirements, the net irrigation requirements and the effective rainfall were calculate using the CROPWAT 8.0 computer program model (FAO, 2009). The CROPWAT model requires an inputs such as climatic, crop and soil data for determination of crop water and irrigation requirements. To determine ETo values the model needs climatic data i.e. minimum and maximum monthly temperature ( $^{\circ}C$ ), relative humidity (%),

wind speed (km/day) and sunshine hours (hr). The governing equation of Penman-Montieth was used for determination of ETo in CROPWAT model, because of the Penman-Montieth method is better to overcome the shortcomings of all other empirical methods and provides ETo values that are more consistent with actual crop water use data in all regions and climates and now is the sole recommended method (Tesfa-alem et al., 2014). There are various approaches that can be used to estimate the effective rainfall from the total monthly rainfall. For this study the dependable rain [FAO/AGLW] was used based on analysis carried out for different arid and sub-humid climates thus is more suitable for our condition (Tesa-alem et al., 2014). Crop Water demand: the total Crop water demand and the total irrigation requirement for the irrigation scheme was determine by the equation (De Fraiture and Garces-Restrepo 1997).

$$\text{Total crop water demand} = \frac{\text{CWR}_O * A_O}{A_T} + \frac{\text{CWR}_P * A_P}{A_T} + \frac{\text{CWR}_M * A_M}{A_T} + \frac{\text{CWR}_T * A_t}{A_T} \dots\dots (3.15)$$

Where  $\text{CWR}_O$ ,  $\text{CWR}_P$ ,  $\text{CWR}_M$  and  $\text{CWR}_T$  are crop water requirement for onion, pepper, maize and tomato crops respectively;  $A_O$ ,  $A_P$ ,  $A_M$  and  $A_T$  are field areas for onion, pepper, maize and tomato crops respectively and  $A_T$  is total area of the scheme. For calculation total irrigation requirement the same procedure was used.

### **3.4.3. The Performance Indicators**

#### **3.4.3.1. Internal Process Indicators**

The internal performance indicators for irrigation scheme was compute based on field measurement data. The internal performance indicators used to evaluate were:

#### **Source of Water for the Irrigation Scheme**

As figure 3.7 indicated that the water need to supply the irrigation scheme was taken from Tsilwe river diversion averagely supplied a discharge of 19.3 l/s at the intake gate the diversion weir as measured during study period (mid-February and March months).



Figure 3. 7: Tsilwe diversion weir structure

**Water Conveyance efficiency ( $E_c$ ):** This term is used to measure the efficiency of water conveyance system associated with the main canal (pipe) network, secondary and tertiary and field channels. The conveyance efficiency was calculated as (Ramulu, 1998).

$$E_c = \frac{W_f}{W_d} * 100 \dots\dots\dots (3.16)$$

Where  $E_c$  = water conveyance efficiency (%),  $W_f$ = Water delivered to the irrigated plot (At the field supply channel) and  $W_d$  = Water diverted from the source.

**Water application Efficiency ( $E_a$ ):** Application efficiency ( $E_a$ ) was measured by calculating the ratio of the depth of water stored in the root zone during irrigation to the depth of water diverted into the field (Michal, 2008). Water application efficiency is describe as a percentage of water delivered to the field that is consumed by the crop, computed as follows: (Mati, 2011).

$$E_a = \frac{W_s}{W_f} * 100 \dots\dots\dots (3.17)$$

**Where**  $E_a$  is application efficiency (%),  $W_s$  is water stored in the root zone of the plants and  $W_f$  is Water delivered to the irrigated plot (At the field supply channel).

**Water storage efficiency (E<sub>s</sub>):** It is defined as the ratio of the water stored in the root depth by irrigation to the water needed in the root depth to bring it to the field capacity. Also termed as water storage factor. This was determined by the formula (Allen et al., 1998).

$$E_s = \frac{W_s}{W_n} * 100 \dots\dots\dots (3.18)$$

Where, **E<sub>s</sub>** = Water storage efficiency (%), **W<sub>s</sub>** = water stored in the root zone of the plants

**W<sub>n</sub>** = Water needed in the root zone prior to irrigation

**Water distribution uniformity (D<sub>u</sub>):** This shows how uniformly water is applied to the field along the irrigation run. DU is defined as the percent of the smallest accumulated soil moisture depth to the average soil moisture depth. This was calculated by the formula (Burt, 1997).

$$D_u = \left(\frac{D_{min}}{D_{av}}\right)*100 \dots\dots\dots (3.19)$$

Where, **D<sub>u</sub>** = water distribution uniformity (%), **D<sub>min</sub>**= minimum accumulated soil moisture depth this is determined from soil moisture after irrigation and **D<sub>av</sub>**= the average accumulated soil moisture depth (mm).

**Determination of deep percolation ratio (DPR):** The loss of water through drainage beyond the root zone is reflected only in the deep percolation ratio that expresses the ratio between the percolated water beyond the root zone to the volume of water applied to the field. Deep percolation ratio was calculated using the formula (Feyen and Zerihun, 1999).

$$DPR = 100 - E_a \dots\dots\dots (3.20)$$

Where, **DPR** = Deep percolation ratio and **E<sub>a</sub>** = application efficiency in percent

**Overall Irrigation efficiency (E<sub>o</sub>):** The overall scheme efficiency was calculate as the product of conveyance and application efficiency (Ramulu, 1998).

$$E_o = E_c * E_a \dots\dots\dots (3.21)$$

Where **E<sub>o</sub>** is overall scheme efficiency (%), **E<sub>c</sub>** is conveyance efficiency (%) and **E<sub>a</sub>** is application efficiency (%).

### 3.4.3.2. External Performance Indicators

Generally different groups of performance indicators; Water related indicator, Agriculture indicators and physical sustainability indicators; have been used in this study to assess and compare the performance of the Tsilwe small scale irrigation schemes at system levels. Under each group a number of minimum performance indicators have been used during evaluation.

#### Water related indicators:

##### a) Relative water supply (RWS)

Bases on the relative water supply described by Levine (1982) and relative irrigation which is set by Perry (1996) are the basic water supply indicators. It is the ratio of total water supplied by irrigation and rainfall to total water demanded by crop (i.e. actual crop evapotranspiration (*ETc*)). determine using the formulas below:

$$RWS = \frac{\text{Total water supply (TWS)}}{\text{Total crop water demand}} \dots\dots\dots (3.22)$$

##### b) Relative irrigation supply (RIS)

This is the second water supply indicator and described as the ratio of irrigation supply to irrigation demand. Irrigation water is a scarce resource in many irrigation schemes and it is a major constraint for production. This indicator is useful to assess the degree of irrigation water stress/abundance/ in relation to irrigation demand and was calculated using the formulas (Molden et al., 1998)

$$RIS = \frac{\text{irrigation supply}}{\text{irrigation demand}} \dots\dots\dots (3.23)$$

##### c) Water delivery capacity (WDC)

The water delivery capacity ratio indicates whether the system design is in anyway a constraint to meet the maximum crop water requirement. WDC was estimated using equation below (Molden et al., 1998).

$$WDC = \frac{\text{Actual canal capacity}}{\text{Schemepeak demand}} \dots\dots\dots (3.24)$$

Actual canal capacity was measured at the diversion outlet and the scheme irrigation water requirement was calculated with CROPWAT 8.0.

### **Agricultural output indicators (water-land productivity)**

A number of indicators are developed regard to irrigated agricultural systems. Water, land and finance are the main inputs for output of crop production. Five of them are relating to output to land and water were selected, i.e., two from land productivity and three from water productivity. These external indicators provide the basis for the evaluation of irrigated agricultural performances. Where water is a constraining resource, output per unit water may be more important, whereas if land is a constraint relative to water, output per unit land may be more important (De Fraiture and Garces-Restrepo 1997).

#### **a) Output per unit command area (birr/ha):**

This indicator quantifies the value of production that obtained per unit command irrigable area. The computed value indicates the level of utilization or number of cropping frequency of the given command area in the production year and the productivity of the command area. High value result shows there is good intensive irrigation. Meanwhile small values are not pertinent from land productivity point of view; less intensity of irrigation could not increase the production amount per unit of land. Furthermore this is more relevant for land is the major constraint factor for production. Command area is the nominal or design area to be irrigated.

$$\text{Output per unit command area} = \frac{\text{value of production}}{\text{command area}} \dots\dots\dots 3.25$$

#### **b) Output per unit irrigated cropped area (birr/ha)**

It is computed as the total value of production per harvested area in the irrigation seasons. The harvested /Irrigated / area includes the areas that were irrigated in the irrigation seasons.

$$\text{Output per irrigated area (birr / ha)} = \frac{\text{Value production}}{\text{irrigation cropped area (A}_{\text{cropped}})} \dots\dots\dots (3.26)$$

#### **c) Output per unit water consumed (birr / m<sup>3</sup> )**

This indicator derived from the general water accounting frame work (Molden, 1998). Consumed water is the actual evapotranspiration or process consumption from only irrigated crops (ET); it excludes other losses and water depletion from the hydrological cycle. The computed value does not affected by water losses through the system but only affected by the climatic feature of the

area. It used to observe water consumption of crops at scheme level through evapotranspiration relative to the diverted and delivered amount of irrigation water. It has a contribution for irrigation management aspects; to take measurements those minimize evapotranspiration losses.

$$\text{Output per unit water consumed (birr / m}^3\text{)} = \frac{\text{income value}}{\text{volume of water consumed by ETc}} \dots (3.27)$$

**d) Output per unit irrigation supply (birr/m<sup>3</sup>)**

This is one of the water productivity indicators and calculated as the total value of production per unit water diverted from the headwork to the command area throughout the irrigation seasons; it includes the conveyance losses in the irrigation systems. It illustrates the productivity of diverted water from the source. It is an important parameter where water is a scarce resource. Diverted/supplied irrigation water is the volume of surface irrigation water diverted to the command area.

$$\text{Output per unit irrigation supply (kg/m}^3\text{)} = \frac{\text{Value Production}}{\text{diverted irrigation supply}} \dots\dots\dots (3.28)$$

**Physical performance indicators**

Under this, two important physical performance indicators were selected to measure the sustainability and irrigation intensities of the systems.

**a) Irrigation Ratio**

The intensity with which the irrigated area is cropped traditionally is a function of the number of crops per year grown on an irrigated area.

$$IR = \frac{\text{Irrigated area}}{\text{Command /Nominal/irrigable area}} \dots\dots\dots (3.29)$$

**b) Sustainability of irrigated area**

According to Bos (1997) sustainability of irrigated area is the ratio of currently irrigable area to initially irrigated area.

$$SIA = \frac{\text{Currently irrigable area}}{\text{Initially irrigated area}} \dots\dots\dots (3.3)$$

## 4. Result and Discussion

Tsilwe SSIS characterization and performance evaluation was carried out using different resources characterization and efficiency indices and the results are presented and discussed in this chapter.

### 4.1. Physical Soil Characteristics

**Texture:** table 4.1 shows that the mean values of textural class for sand, silt and clay were 47%, 32% and 21% respectively. This is within the ranged of 23 to 52 % for sand, this is followed by silt in the range of 28 to 50% and clay 7 to 27 %. This indicated that the soils in the study area were mainly dominant to loam soil.

Table 4. 1: physical Soil characteristics of the study area

field code	Depth cm	Bulk density gm/cm <sup>3</sup>	Sand%	Silt%	Clay%	Texture Class (USDA)
H <sub>1</sub>	0-30	1.33	39	29	32	clay loam
	30-60	1.34	29	41	30	clay loam
H <sub>2</sub>	0-30	1.41	75	19	6	sandy loam
	30-60	1.44	57	25	18	sandy loam
H <sub>3</sub>	0-30	1.12	81	13	6	sandy loam
	30-60	1.37	80	12	8	sandy loam
Head Average	0-30	1.29	65	20	15	sandy loam
	30-60	1.38	55	26	19	sandy loam
	0-60	1.34	60	23	17	sandy loam
M <sub>1</sub>	0-30	1.35	58	30	12	sandy loam
	30-60	1.43	59	23	18	sandy loam
M <sub>2</sub>	0-30	1.34	67	13	20	sandy loam
	30-60	1.43	55	35	10	sandy loam
M <sub>3</sub>	0-30	1.38	55	35	10	sandy loam
	30-60	1.41	57	25	18	sandy loam
Medium Average	0-30	1.36	60	26	14	sandy loam
	30-60	1.42	57	28	15	sandy loam
	0-60	1.39	59	27	15	sandy loam
T <sub>1</sub>	0-30	1.37	18	53	29	silt clay loam
	30-60	1.39	19	51	30	silt clay loam
T <sub>2</sub>	0-30	1.36	13	55	32	silt clay loam
	30-60	1.49	15	56	29	silt clay loam
T <sub>3</sub>	0-30	1.25	36	27	37	clay loam
	30-60	1.43	33	29	38	clay loam
Tail Average	0-30	1.33	22	45	33	clay loam
	30-60	1.44	22	45	32	clay loam
	0-60	1.38	22	45	33	clay loam
Grand average	0-30	1.32	49	30	20	loam
	30-60	1.40	45	33	22	loam
	0-60	1.37	47	32	21	loam

H<sub>1</sub>, H<sub>2</sub> and H<sub>3</sub> are code of fields selected from head irrigated area, M<sub>1</sub>, M<sub>2</sub> and M<sub>3</sub> are code of fields selected from middle scheme irrigated area, and T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> are code of fields selected from tail irrigated area.

**Soil bulk density:** as shown in appendix table B-1 in the study area the average bulk density values ranged at 1.29, 1.36 and 1.33 gm/cm<sup>3</sup> at the top layer depth 0-30 cm of the soil For head, medium and tail end of irrigated area respectively and 1.38, 1.42 and 1.44 gm/cm<sup>3</sup> at the lower layer depth 30-60 cm of the soil for head, medium and tail end of irrigation area respectively. The weighted average soil bulk density of the study area was obtained 1.32gm/cm<sup>3</sup> for 0-30cm and 1.41gm/cm<sup>3</sup> for 30-60 cm soil depth. the lower layer of the soil bulk density had larger than the top soil this indicated that the subsurface soil might have lower organic matters content and compacted due to the overlaying by the upper soil materials . Generally this revealed that the subsurface soils have lower soil porosity than surface soil. The overall results of the bulk density of the study area was in the interval for the ideal bulk density for plant growth which is less than or equal to 1.4 gm/cm<sup>3</sup> for the same soil texture reported by (USDA-NRCS 2014).

#### **Field capacity, permanent wilting point and total available water**

The soil in the study area has an average moisture content of FC about 42.5% and PWP about 26.3% on volume basis. These values are larger than the values recommended as 27% for FC and 12% for PWP conducted by IAEA (International Atomic Energy Agency) (2008) for the same loam soils this revealed that the soil has high moisture holding capacity. The TAW of the soil was computed using equation 3.11 described in section 3.4.1 and obtained as 161.5 mm/m. this indicated that the values were within the range 140-190 mm/m reported by Israelsen and Hansen (1987) for the same loam soil. The soil water contents at field capacity and wilting point and the TAW of all 3 samples are presented in Table 4.2

**Table 4. 2:** Bulk density, field capacity, Permanent wilting point and total water available

Field	Soil depth (cm)	$\rho_b$ (gm/cm <sup>3</sup> )	FC (g %)	FC (vol %)	PWP (g %)	PWP (vol %)	TAW (mm/m)	TAW (mm)
H	0-30	1.33	30.36	40.38	18	23.94	164.4	49.32
	30-60	1.34	36.27	48.6	24.21	32.44	161.6	48.48
M	0-30	1.38	28.26	39	16.88	23.29	157.1	47.13
	30-60	1.41	28.12	39.65	16.57	23.36	162.9	48.87
T	0-30	1.36	28.91	39.32	17.49	23.79	155.3	46.59
	30-60	1.49	32.24	48.04	20.98	31.26	167.8	50.34
Average	0-30	1.36	29.18	39.57	17.46	23.67	158.93	47.68
	30-60	1.41	32.21	45.43	20.59	29.02	164.1	49.23
Total	0-60	1.39		42.5		26.3	161.5	96.91

H, M and T are location of Field for Head Middle and Tail respectively. FC (g %) is a field capacity in weight, FC (vol %) field capacity in volumetric and PWP (g %) and PWP (vol %) is permanent wilting point for gravimetric and volumetric respectively.

### Soil Infiltration Rate

The infiltration rate of the soil was measured at the soil which have different soil textures (sandy loam, silt clay loam and clay loam). The basic infiltration rate values were obtained 42 mm/hr, 43 mm/hr and 14 mm/hr for sandy loam, silt clay loam and clay loam respectively of the study area. These results indicated that higher than the recommended ranged values for the same soil texture reported 20-30 mm/hr for sandy, 10-20 mm/hr for silt loam and 1-5 mm/hr for clay loam by FAO (2002). These values were above the recommended value might be resulted from the soil was disturbed (ploughed) during the measurement and other possible reasons might be the soil at depth have cracks and fissures due to its nature and vegetation rooting.

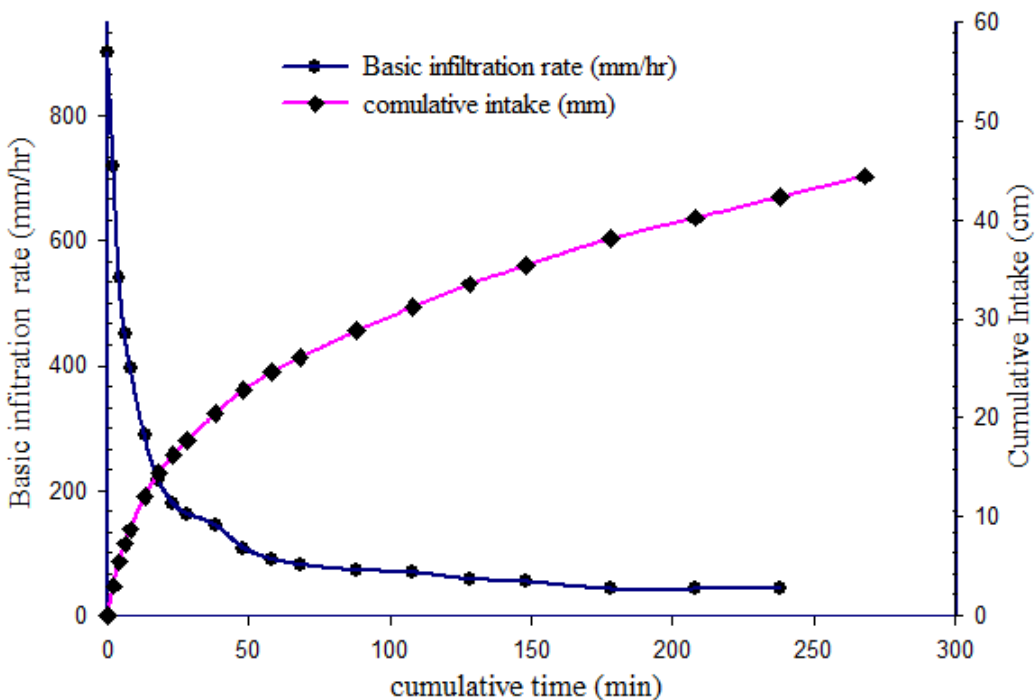


Figure 4. 1: Average infiltration rate (mm/hr) and cumulated intake (cm) vs. Time (min)

The plot in figure 4.1 illustrates the trend of the basic infiltration rate line shows decreasing and lastly becoming constant as the cumulative time increase while the cumulative intake is increasing and become constant as the cumulative time increasing.

## 4.2. Reference Evapotranspiration, Effective Rainfall

**Reference evapotranspiration:** The average daily reference evapotranspiration of the study area was determined using CROPWAT 8.0 model based on the climatic data that indicated in table 4.3. The ETo varied from 2.92 to 4.2 mm/day with an average value of 3.47 mm/day. The highest ETo occurs during February while the lowest occurs during December. From figure 4.2 can be elaborated that the rainfall was lower than the ETo for about ten months from September to mid-June.

**Table 4. 3:** The 11 year (2006 -2016) mean monthly climatic data and reference crop

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m <sup>2</sup> /day	ETo mm/day	Rain mm	Eff rain mm
Jan	8.6	26.5	59	1	9.3	20.2	3	1.4	0
Feb	10.3	28	55	1	9.8	22.5	3.52	1.9	0
Mar	12.8	28.7	55	2	8.9	22.6	3.84	22	3.2
Apr	14.7	28.9	53	2	9.4	24	4.2	45.9	17.5
May	14.8	29.8	51	1	8.9	23	4.1	22.5	3.5
June	14.8	29.9	52	1	6.5	19.1	3.58	29.3	7.6
July	14.2	25.9	70	1	5.1	17.1	3.26	178.9	119.1
August	13.7	24.9	76	1	4.6	16.5	3.09	219.4	151.5
September	12.1	28	61	1	6.7	19.4	3.46	44.9	16.9
October	11.3	26.7	52	1	9.2	21.9	3.54	3.2	0
November	10.2	25.7	58	1	9.3	20.4	3.15	5.6	0
December	8.7	25.3	61	1	9.5	19.9	2.92	0.6	0
Average	12.2	27.4	58	1	8.1	20.5	3.47	575.6	319.4

**Effective rainfall:** the total average effective rainfall was 319.4 mm which is 55.5% of the total annual rainfall (575.6 mm). The average effective rainfall was maximum in August 151.5 mm and the minimum effective rainfall was in five months (October, November, December, January and February) 0 mm as presented in table 4.3 and figure 4.2.

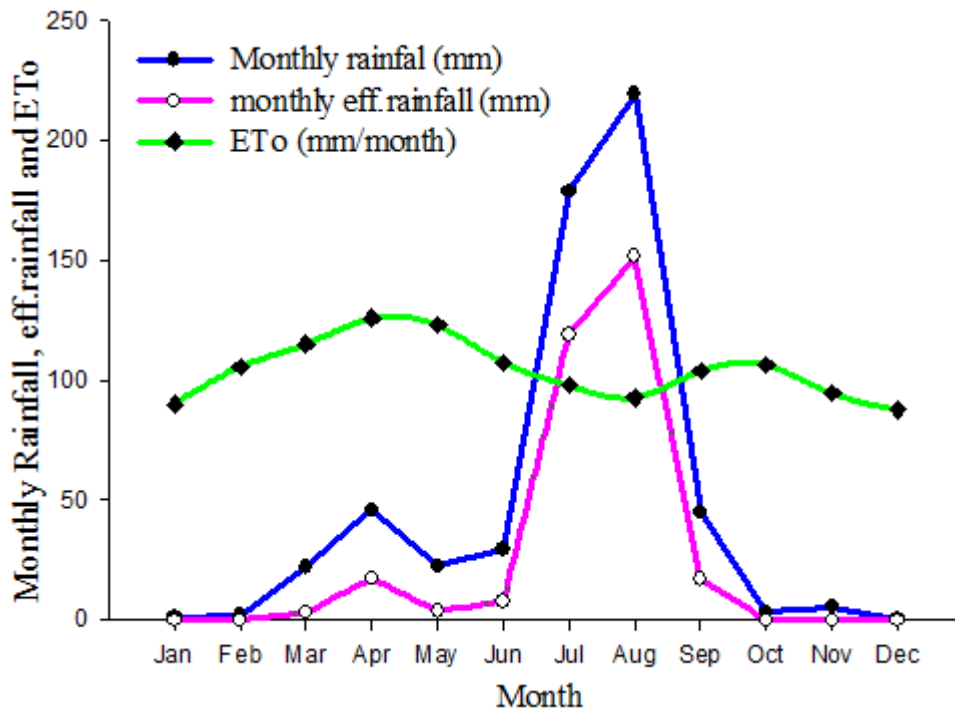


Figure 4. 2: Mean monthly rainfall, effective rainfall and reference evapotranspiration rate in the study area

#### Net Crop water requirement (CWR) and net irrigation requirement (IR)

The net CWR and net IR were calculated for each crop for 2016/2017 irrigation season by CROPWAT 8.0 model based on the ETo a shown Table 11 and the crop data's as indicated in appendix Table C-1. The Cumulative CWR and IR were estimated using equation 3.15 described in section 3.4.2 and obtained the total values of 304.13 and 301.9 mm per growing season (November- April) respectively. The summary results of the net CWR and net IR for the four major crops (Onion, Pepper, Maize and Tomato) of the study area are presented in Table 4.4.

**Table 4. 4:** The crop water requirement and irrigation requirement

crop	area (ha)	Total Precipitation (mm/season)	Effective rainfall (mm/season)	Net irrigation Requirement (mm/season)	Net CWR (mm/season)	Total net IR (mm/season)	Total net CWR (mm/season)
Onion	11.55	8.9	0.4	244.3	244.7	85.505	85.645
Pepper	9.57	15.3	0.7	310.4	311.1	90.016	90.219
Tomato	4.62	34.8	4.9	367.1	372	51.394	52.08
Maize	7.26	33.3	5.4	340.9	346.3	74.998	76.186
Total	33					301.913	304.13

## The scheme irrigation requirement

The scheme irrigation requirement was calculated with CROPWAT 8.0 using the climate data presented in table 4.3, cropping data and area coverage of individual crop for the cropping season of 2016/2017 presented in appendix table C-1 for the purpose of determining peak irrigation requirement and the peak demand of irrigation water supply. Peak irrigation requirements was occurred in February which is 0.43 l/s/ha. The peak demand calculated for that month which was obtained by multiplying the peak irrigation requirement by the cropped area for that month was 13.86 l/s.

### 4.3. Performance Evaluation Indicators

#### 4.3.1. Performance Evaluation with Internal Indicators

##### 4.3.1.1. Conveyance Efficiency ( $E_c$ )

Table 4. 5: Computed conveyance efficiency and losses rate

Canal type	Segments	Distance between two points	Inflow	Outflow	Conveyance loss		Conveyance efficiency
		m	L/s	L/s	l/s	l/s/m	%
Lined canal	A-B	200	19.3	17.8	1.52	0.008	92.13
	B-C	310	17.8	16.3	1.46	0.005	91.78
	C-D	390	16.3	15.8	0.56	0.001	96.56
Average conveyance efficiency loses					1.18	0.005	93.49

**A** is upper inlet, **B** is the outlet for section **A** and inlet for section **C**, **C** is the inlet for outlet **D**.

As presented in table 4.5 the conveyance efficiency of the irrigation scheme was found 93.5 % this revealed that below the recommended standard of 95 % for lined canal as FAO (1989). Whereas it is in the interval range values for conveyance efficiency 95% for lined canal by Mati (2011). The amount of water lost in the main canal was estimated to be 1.18 l/s and 0.005 l/s/m. this large loses is caused by the badly maintained canal and improper design of division boxes as observed at the field.



Figure 4. 3: The badly managed main canal at the study area

#### 4.3.1.2. Application Efficiency ( $E_a$ )

Table 4. 6: Field application discharge measurement

Field location	Time Concentration (sec)	Fluem height (cm)	Respective discharge (L/s)	Area (m <sup>2</sup> )	Total volume (m <sup>3</sup> )	Applied depth (mm)	Soil moisture storage mm	Application efficiency %
<b>H</b>	3540.0	11.43	4.188	369.44	14.826	40.13	30.77	76.7
<b>M</b>	3198.0	9.13	2.894	249.26	9.255	37.13	27.4	73.8
<b>T</b>	3300.0	9.00	2.889	250.00	9.534	38.13	24.1	63.2
<b>Average application efficiency</b>								71.23

H, M and T are field locations for Head, middle and tail respectively for the irrigation scheme

The application efficiency was estimated using equation 3.17 and presented in table 4.6. The value for the three locations (head, middle and tail) of the irrigation scheme were in the ranges of 63.2 to 76.7 % with an average of 71.23 %. The application efficiencies were vary from field to field. The head and the middle irrigation schemes were more efficient than the tail end irrigation scheme due to short furrow length, short application time and proper water management. While at the tail end irrigation scheme the furrows were long, improper furrow layout and excess application time were used and due to this the tail end irrigation field was less efficient relatively to the head and middle irrigation fields. As FAO (1989) water application efficiency for furrow irrigation method is ranged 60-70%. Whereas according Rogers et al. (1997) revealed that furrow irrigation method have wider range of application efficiency i.e. 50-90%. The study carried out by Yusuf, (2004) at

Awash River valley the water application efficiency for furrow irrigation method was obtained within the ranges 31.5 to 64.3% this shows the lower value of application efficiency. On over all basis of the values of application efficiency for the study area was indicates more efficient. This is due to the shortage of water availability from the source the farmers were tried to apply the less water wisely to their fields.

#### 4.3.1.3. Storage Efficiency ( $E_s$ )

Table 4. 7: Storage efficiency of the irrigation scheme

Field location	Soil moisture storage	Moisture desired in root zone	Storage efficiency
	mm	mm	%
H	30.77	45.97	66.9
M	27.4	45.12	60.7
T	24.1	45.54	52.9
Average values of storage efficiency			60.17

The storage efficiency was computed using equation 3.18 described in section 3.4.3.1 and result is displayed in table 4.7. The storage efficiency varied from 52.9 to 66.9% with an average value of 60.17%. This indicated that the storage efficiency at Tsilwe SSIS is lower than the values 78 to 89 % founded in semi-arid regions of Ethiopia by Mulubrhan et al., (2007) and also 90.2 to 96.8% for West Hararge Zone, Oromia Region, Ethiopia by Worku, (2013). But higher than the values 40 to 56.2% founded in Central Rift Valley of Ethiopia by Eticha, (2011).

#### 4.3.1.4. The Distribution Uniformity (DU)

The DU of the scheme was calculated using equation 3.19 described in section 3.4.3.1. The average results were found 81.5%, 90.7% and 89.5 % for the Head, Middle and Tail location of the irrigation scheme respectively. From the result observed, there was a poor distribution uniformity at head location of the irrigation scheme, at the middle and tail location of the irrigation scheme was similar and better distribution uniformity relatively. These result indicated that acceptable according the typical recommended values by FAO (1989) ranged greater than 80%.

Deep percolation ratio was calculated using equation 3.20 the average deep percolation ratio at Tsilwe irrigation scheme was found to be 28.77%.

#### **4.3.1.5. The overall Scheme efficiency ( $E_p$ )**

The overall scheme efficiency at the study area was obtained to be 66.6%. This result indicated that the overall irrigation efficiency is efficient as compared with values ranged 50 -60% stated by FAO, (1989) for surface irrigation. This large value is due to no secondary and tertiary canals at the irrigation scheme therefore no losses from secondary and tertiary canals.

### **4.3.2. Performance Evaluation of Tsilwe SSIS with External Indicators**

#### **4.3.2.1 Water Related Indicators**

The analysis of water related indicators RWS, RIS and WDC were calculated using equations 3.26, 3.27 and 3.28 respectively as described in section 3.4.3.2. And the values are presented in table 4.8.

**RWS:** the values for RWS at the study area was found a ratio of 0.88. This value is less than one. As Molden (1998) justification the value is indicated that the water supply is insufficient /or is not getting enough water for the irrigation scheme. Previous studies at different Regions different Values of RWS were founded. For instance 3.13 to 5.96 ration for Tekeze basin, Tigray North Ethiopia by Mintesinot et al., (2004); 2.49 ratio values of RWS for Kalwande minor irrigation in Maharashtra state, India for the year 2013/14, ( Ingle, 2015). According Molden et al., (1998) investigation varied values of RWS were found to be between 0.8 and 4.1, from 18 different irrigation schemes in 11 countries of the world.

**RIS:** from table 4.8 the values for RIS at the study area was found 0.82 which is less than one as Molden (1998) justification the values are indicated that the irrigation water supply by the canal system is not getting enough for the irrigation scheme. Previously RIS values were founded for different irrigation schemes for instance 3.33 to 6.68 ratio for Tekeze basin, Tigray North Ethiopia (Mintesinot et al., 2004); 1.55 for Hayrabola irrigation scheme in Turkey (Molden et al., 1998); 0.77 for Wonji sugar estate in the upper Awash basin, Ethiopia (Beshir and Bekele, 2007). As Molden et al., (1998) reported that large variation of RIS values indicated between 0.4 and 4.8, among the studies of 18 different irrigation schemes in 11 countries of the world.

**WDC:** The result shows that the river diversion infrastructure is not delivering the necessary peak water demand. The WDC ratio was 0.7 this is below one this indicated that the canals may not meet the peak demands that may occur in some particular time.

Table 4. 8: Water related indicators for Tsilwe SSIS

Parameters	Values
Irrigation supply (mm)	248.2
Total rainfall (mm)	19.75
Total water supply (mm)	267.95
Total crop water demand (CWD) (mm)	304.1
Total irrigation demand (mm)	301.9
Canal capacity to deliver water at system head (l/s)	19.3
Peak consumptive demand (l/s)	27.7
RWS	0.88
RIS	0.82
WDC	0.7

#### 4.3.2.2. Agricultural Performance Indicators

Four main crops are common at Tsilwe irrigation scheme were taken into account. Onion, pepper, maize and tomato was taken as the base crop, respectively because they were the most tradable and cultivated crop. The irrigated area in Tsilwe is 33 ha and total command area is 53 ha. The area allocation for each crop, intensity, productivity values were calculated for the scheme for the year 2016/17 by local prices as presented in Table 4.9.

**Output per unit command area (OPPUCA):** the OPPUCA in terms of monetary was calculated using equation [3.25] in section 3.4.3.2 the output per unit command area for the period 2016/17 was obtained 95860.99 Birr/ha. This result obtained was higher than the values 1277.7 – 29360.8 and 65423.67 Birr/ha which was obtained by Mintosnot et al. (2005) and Dessalew et al. (2016) (2015) for tekeze basin, Bedene Alemtena irrigation.

**Output per unit of irrigated area (OPPIUA):** as the OPPIUA was calculated in terms of monetary using equation [3.26] and presented in table 10 the result was obtained 153958.6 birr/ha for the 2016/17 cropping year. This result is higher than when compared with values 2000-41291.7 and 58940.24 Birr/ha obtained by Mintosnot et al. (2005) and Dessalew et al. (2016) for May Nigus irrigation scheme in tekeze basin and Bedene Alemtena irrigation irrigation schemes respectively. This is might be because of the irrigators of the study area was covered with high value cash crops

around 78% of the irrigated land were covered with the high value cash crops (onion, pepper and tomato) the remain only about 22% of the irrigated land was covered by maize which has relatively low local price in the study area as presented in table 4.9. And also the reason to be varied this result is the fluctuation of crops price over time.

Table 4. 9: Total crop yield, total income and area coverage by each crops at the irrigation scheme

Crop type	Area		production qtl/ha			Total production qtl	Income birr/ctl			Total price in birr	OPPIUA birr/ha
	ha	%	Mini	max	mean		Min	max	mean		
Maize	7.26	22	16	40	32.6	236.5	300	450	335.7	79381.4	10934.1
onion	11.6	35	120	381	244.9	2828.6	600	1500	1065	3012453.7	259694.3
pepper	9.57	29	20	80	57.8	553.0	800	2000	1648	911269.2	95221.4
Tomato	4.62	14	90.7	240	177.7	821.0	1200	1400	1313	1077528.4	233231.3
total	33									5080632.6	<b>153958.6</b>

Where qtl is for quintal and OPPIUA is for output per unit irrigated area

**Output per unit water consumed:** The average values of water productivity with respect to CWR was calculated using equation [3.27] described in section 3.4.3.2. the average result in terms of monetary was found to be 44.2 birr/m<sup>3</sup>. This result is larger when comparable to 14.59 birr/m<sup>3</sup> conducted by Dessalew et al., (2016) in Hallaba Sepecial woreda Southern Ethiopia. This might be attributed to good management practices of farmers. The detail results are presented in table 4.10.

**Output per unit irrigation supply:** the output per unit irrigation supply was calculated using the equation [3.28] described in section 3.4.3.2. As presented in table 4.10 the calculated result was obtained in the range of 0.13 – 3.18 birr /m<sup>3</sup>. The average value of output, per unit of irrigation supply for the TSILWE SSIS was obtained 1.83 birr/m<sup>3</sup>. This result is relatively similar to 0.77 to 1.53 birr/m<sup>3</sup> conducted by Mintesinot et al., (2005) in Tekeze basin, Tigray North Ethiopia.

Table 4. 10: Output per unit actual water consumed of the irrigation scheme

Crop type	Area	production	income	CWR	CWR	irrigation supply	OPUWC	OPUWC	OPUIS	OPUIS
	ha	Qtl/ha	birr/ha	mm/s	m <sup>3</sup>	m <sup>3</sup> /sea	kg/m <sup>3</sup>	birr/m <sup>3</sup>	kg/m <sup>3</sup>	birr/m <sup>3</sup>
Maize	7.3	32.6	10934.1	244.4	2444	81907.2	1.3	4.5	0.04	0.13
onion	11.6	244.9	260818.5	310.7	3107	81907.2	7.9	83.9	0.30	3.18
pepper	9.6	57.8	95221.4	370.7	3707	81907.2	1.6	25.7	0.07	1.16
Tomato	4.6	177.7	233231.3	371.6	3716	81907.2	4.8	62.8	0.22	2.85
total	33					81907.2	3.9	44.2	0.16	1.83

OPUWC, output per unit water consumed; and OPUIS, output per unit irrigation supply

### 4.3.2.3. Physical performance indicators

Two basic physical indicators of irrigation ratio (IR) and sustainability of irrigated areas (SIA) were selected and computed, based on equations [3.29] and [3.30], to evaluate the status of both irrigation schemes. The result is indicated in table 4.11.

Table 4. 11: Physical performance indicators computed values

Command area (ha)	Initially irrigated area (ha)	Currently irrigated area (ha)	IR (%)	SIA (%)
53	37	33	62.3	89.2

IR is for irrigation Ratio SIA is for Sustainable of irrigated area

### Irrigation Ratio

The irrigation ratio shows the level of utilization of a given irrigable area in the specific production season. As calculated using equation 3.29 the irrigation ratio of Tsilwe was found to be 0.62 this elaborates that about 0.38 (38%) of the command area of the irrigation scheme was not under irrigation during the study period. The current irrigated area was under irrigated below the proposed command area due to insufficient water available from the source and lack of proper designed irrigation infrastructure.

### Sustainability of irrigated area

As shown in table 4.12 the computed values of sustainability of irrigated area at the study scheme was found to be 0.89 this is below one, which is indicates the current irrigable area is below the irrigable area at the initial period of the irrigation scheme. Thus the irrigable area in Tsilwe irrigation scheme showed decreasing trend; about 10.8% of initial irrigated area has not been irrigated. The main reasons as the farmers raised and as observed at the irrigation scheme were water shortage i.e. the design area is so large relative to the water source and illegal water abstraction at the upstream of the diversion weir through pumps and this reduced the discharge at the diversion weir so due to those factors the initial irrigated land was decreased.

#### **4.3.2.3. Financial indicators**

The data which are used to calculate the financial indicators such as design documents and feasible studies were not available in the study area. Therefore the researcher is not possible to compute the financial indicators i.e. self-sufficiency indicator and gross return on investment.

## 5. Conclusion and Recommendations

### 5.1. Conclusion

From this performance evaluation study can conclude that:

- ❖ As RWS, RIS and WDC values were 0.88, 0.85 and 0.7 respectively and since this is below one which is the standard which indicates a deficiency of water supply at the irrigation system. Generally the RWS and RIS values indicated that the water demand by the crops at the irrigation scheme is not satisfied and water availability is a main constraint in Tsilwe SSIS.
- ❖ The agriculture production shows that there is satisfactory result compared to previous study results. The Production of all crops were not agreeable in to international market of single crop, for this reason agricultural production performance indicators were not compared with other countries worldwide.
- ❖ Although the amount of irrigation water supplied with respect to demanded is bit lower at this irrigation scheme the water productivity values were still relatively similar with previous studies.
- ❖ Farmers located at the upstream of the irrigation scheme used more water through pump as a result there is water scarcity at downstream users this is a source of conflict among the users.
- ❖ There is low participation of irrigation beneficiary's in the Tsilwe irrigation scheme in irrigation system maintenance for efficient water application.
- ❖ Due to shortage of water availability at Tsilwe SSIS there is big difference between the proposed and the actual current irrigated command area.
- ❖ The Tsilwe SSIS water use association have not filed and organized bylaw and weak water committee. As a result it attributed to illegal water abstractions and unfair water distribution at the irrigation scheme. The water allocation and distribution has not supported technically by kebele DAs and irrigation experts.

## **5.2. Recommendation**

To enhance sound irrigation management practices and maximize the output of the Tsilwe irrigation scheme the following recommendations are provided.

- ◆ For fair water distribution there must be a clear rule and regulation that water user enforces.
- ◆ Use of Water saving technologies such as drip irrigation, selecting of crops that has moisture stress resistance and light irrigation water requiring.
- ◆ For sustainability of the irrigation scheme periodic maintenance that reduce the leakage and seepage losses in the division boxes and expansion (cracking) of the cemented.
- ◆ Continuous monitoring and evaluation of irrigation scheme is necessary to know the performance of the irrigation scheme and important for the future planning and management of new scheme and maintenance of the old scheme.
- ◆ For sustainability of the irrigation scheme introducing of water tariff to curb carelessness in water use and can be used for maintenance tasks.
- ◆ Besides no water fee the beneficiaries of irrigation were not willing and responsible for the overall water management such as maintenance of the headwork diversion, main canals and monitoring and evaluation of the bylaw.
- ◆ For protecting further conflicts among the users by illegal water abstraction should need a strong water user associations.
- ◆ Environmental protection such as soil and water conservation and afforestation mitigation measurements should be taken to protect the rapid deficiency of water availability from the source.

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## 7. Appendices

### 7.1. Tables in the Appendices I:

#### Appendix tables A: Indicative value ranges from previous studies

Country	Irrigation System	year	output per unit cropped land (\$/ha)	output per unit command area (\$/ha)	output per unit irrigation supply (\$/m <sup>3</sup> )	output per unit water consumed (\$/m <sup>3</sup> )	Gross return investment (%)	Financial self-sufficiency (%)	RWS (Ratio)	RIS (Ratio)	WDC (Ratio)
Burkina Faso	Gorgo	1992/93	1025	1065	0.1	0.91	9	42	1.6	3.5	3.5
	Mogtedo	1992/93	1204	2499	0.09	0.14	21	79	1.4	2.7	2.1
	Savili	1992/93	3085	2652	0.37	0.8	33	—	2.5	2.6	2.9
	Gorgo	1994/95	771	679	0.08	0.12	6	35	1.9	2.7	3.5
	Mogtedo	1994/95	1403	2384	0.11	0.15	20	78	1.4	2.5	2.1
	Savili	1994/95	2348	2281	0.28	0.62	29	28	2.5	2.6	2.9
Colombia	Coella	1993	1290	1303	0.14	0.2	24	114	1.8	1.8	2.2
	Saldana	1993	1125	1811	0.12	0.17	33	127	2.2	2.9	3.2
	Samaca	1993	1472	2462	0.63	0.34	36	109	1.2	1.1	1.7
Egypt	Nile Delta	1993/94	1510	2594	0.12	0.11	26	—	1.6	1.6	1.3
India	Mahi Kadana	1991/92	605	515	0.04	0.03	30	—	3.9	3	2.9
	Mahi Kadana	1995/96	916	893	0.07	0.06	52	53	2.7	2.5	2.6
Malaysia	Muda	1994/95	1021	1041	0.38	0.1	59	—	0.8	0.4	—
Mexico	Alto Rio Lerma	1994/95	2227	1464	0.18	0.24	28	80	2.2	3.3	5.1
	Cortazar Module	1994/95	2615	1827	0.22	0.25	33	133	2.1	2.3	1.2
	Salvatierra Module	1994/95	2117	974	0.1	0.27	27	101	4.1	4.8	2.4
Morocco	Triffa Scheme	1994/95	1087	1358	0.27	0.34	47	—	1.3	1.1	—
Niger	Saga	1993/94	1389	2592	0.12	0.13	—	139	2.2	1.8	—
	Kourani Baria I	1994	827	1460	0.05	0.17	—	—	2.9	2.4	—
	Kourani Baria II	1994	1107	1879	0.06	0.11	43	—	2.2	1.7	—
Pakistan	Chishtian	1993/94	384	477	0.04	0.05	—	40	1.3	1.2	0.8
Sri Lanka	Nachchaduwa	1994/95	826	1544	0.04	0.08	34	—	2	2.2	—
	Rajangana	1994/95	967	1934	0.06	0.11	43	—	—	—	3.3
Turkey	Seyhan	1996/97	2167	2526	0.21	0.19	108	88	2.07	2.15	2.62

Tables in Appendix A- 1: Performance indicators computed for 18 irrigation systems in 11 countries (adopted from Molden et al., 1998)

Tables in Appendix A- 2: Some performance Indicators computed different irrigation schemes in Ethiopia

Author	year	irrigation System	Technical performance indicators				Agricultural performance indicators				Water related performance indicators		
			Ec	Ea	Es	Du	Output per unit irrigated land (Br/ha)	Output per unit command area (Br/ha)	Output per unit irrigation supply	Output per unit water consumed (Br/m <sup>3</sup> )	RWS (Ratio)	RIS (Ratio)	WDC (Ratio)
Mintosnot et al.	1997/98 - 2001/02	May Nigus micro dam irrigation scheme	-	-	-	-	2000-41291.68	1274.7-29360.76	0.77 – 1.53	4.41 – 8.89	0.8 – 1.2	3.13 - 5.96	3.33- 6.68
Dessalew et al.	2016	Bedene Alemtena	-	54.9		90.2	58940.24	65423.67	4.31\$/m <sup>3</sup>	14.58 \$/m <sup>3</sup>	-	-	-
Abebe	2012/13	Shina Hamusit	-	-	-	-	6349 \$/ha	8704 \$/ha	0.95 \$/m <sup>3</sup>	1.46 \$/m <sup>3</sup>	1.55	1.87	-
	2012/13	Selamko	-	-	-	-	4446 \$/ha	4746 \$/ha	0.62 \$/m <sup>3</sup>	1.15 \$/m <sup>3</sup>	1.31	0.81	-
Yusuf	2004	Batu Degaga	-	31.5-64.3	80.4-104.7	100	5027.25	6625.83	1.14	2.45	2.32	2.57	0.77
	2004	Doni	-	-	-	-	5018.9	7590	0.67	1.14	2.24	2.76	1.83

Tables in Appendix A- 3: Indicative standard values of the conveyance and application efficiency (Ec) for various canals adopted from(Mati,2011).

Canal length	Conveyance efficiency in %				Application efficiency	
	Earthen canal for different soil type			Lined canal	Irrigation system	Efficiency in %
	Sand	Loam	Clay			
Long > 2000 m	60	70	80	95	Basin	60- 95
Medium 200-2000 m	70	75	85	95	border	60-90
Short < 200 m	80	85	90	95	furrow	50-90

Tables in Appendix A- 4: Range for some soil characteristics parameters

Soil type	FC	PWP	Available water per unit depth of soil (mm/m)
Fine sand	3-5	1-3	20-40
Sandy soil	5-15	3-8	40-110
Soil loam	12-18	6-10	60-130
Clay loam	15-30	7-16	100-180
clay	25-40	12-20	160-300

### 7.1.2. Tables Appendix B: for soil characteristics

Tables in Appendix B- 1: Soil moisture before and two day after irrigation

Field code	Soil depth (cm)	BD (gm/ cm <sup>3</sup> )	Moisture before irrigation (%)	Moisture after irrigation ( g %)	Moisture before irrigation (vol %)	Moisture after irrigation ( vol %)	Moisture stored (mm/m)	Moisture stored (mm)
H <sub>1</sub>	0-30	1.33	15.7	20.6	20.9	27.4	65.1	19.52
	30-60	1.34	14.4	15.3	19.3	20.4	11.0	3.30
H <sub>2</sub>	0-30	1.41	18.1	21.3	25.5	30.0	45.1	13.54
	30-60	1.44	20.1	22.3	28.9	32.1	31.7	9.50
H <sub>3</sub>	0-30	1.12	12.6	20.4	14.1	22.8	87.4	26.21
	30-60	1.37	14.3	19.3	19.6	26.5	69.0	20.69
Head Average	0-30	1.29	15.5	20.8	20.2	26.8	65.9	19.76
	30-60	1.38	16.3	19.0	22.6	26.4	37.2	11.16
	0-60	1.34	15.9	19.9	21.4	26.6	51.5	30.92
M <sub>1</sub>	0-30	1.35	11.7	16.3	15.8	22.0	61.7	18.52
	30-60	1.43	13.2	16.3	18.9	23.3	44.3	13.30
M <sub>2</sub>	0-30	1.34	14.9	19.5	20.0	26.1	61.8	18.53
	30-60	1.43	18.3	22.4	26.2	32.0	58.6	17.59
M <sub>3</sub>	0-30	1.38	16.2	16.5	22.4	22.8	4.1	1.24
	30-60	1.41	13.5	16.4	19.0	23.1	40.9	12.27
Medium Average	0-30	1.36	14.3	17.4	19.4	23.6	42.6	12.8
	30-60	1.42	15.0	18.4	21.4	26.2	48.0	14.4
	0-60	1.39	14.6	17.9	20.4	24.9	45.3	27.2
T <sub>1</sub>	0-30	1.37	13.9	16.0	19.0	22.0	29.3	8.80
	30-60	1.39	12.8	18.6	17.8	25.9	80.6	24.19
T <sub>2</sub>	0-30	1.36	13.3	16.3	18.0	22.2	41.3	12.40
	30-60	1.49	20.6	21.3	30.7	31.7	10.4	3.13
T <sub>3</sub>	0-30	1.25	12.5	15.6	15.6	19.5	38.8	11.63
	30-60	1.43	19.2	22.0	27.5	31.5	40.0	12.01
Tail Average	0-30	1.33	13.2	16.0	17.6	21.2	36.5	10.9
	30-60	1.44	17.5	20.6	25.3	29.7	43.7	13.1
	0-60	1.38	15.4	18.3	21.4	25.4	40.1	24.1
Grand average	0-30	1.32	14.3	18.1	19.0	23.9	48.3	14.5
	30-60	1.41	16.3	19.3	23.1	27.4	43.0	12.9
	0-60	1.37	15.3	18.7	21.1	25.6	45.6	27.4

H<sub>1</sub>, H<sub>2</sub> and H<sub>3</sub> are code of fields selected from head irrigated area, M<sub>1</sub>, M<sub>2</sub> and M<sub>3</sub> are code of fields selected from middle scheme irrigated area, and T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> are code of fields selected from tail irrigated area; g % is for gravimetric in percent and vol % is for volumetric in percent.

Tables in Appendix B- 2: Infiltration measurement result

cumulative time (min)	time elapsed (min)	water level depth (cm)	water level reading difference (cm)	infiltration rate (cm/min)	cumulative infiltration rate (cm/min)	Infiltration rate (mm/hr)
<b>0</b>	0	0	0	0	0	0
<b>2</b>	2	3	3	1.5	1.5	900
<b>4</b>	2	5.4	2.4	1.2	2.7	720
<b>6</b>	2	7.2	1.8	0.9	3.6	540
<b>8</b>	2	8.7	1.5	0.75	4.35	450
<b>13</b>	5	12	3.3	0.66	5.01	396
<b>18</b>	5	14.4	2.4	0.48	5.49	288
<b>23</b>	5	16.2	1.8	0.36	5.85	216
<b>28</b>	5	17.7	1.5	0.3	6.15	180
<b>38</b>	10	20.4	2.7	0.27	6.42	162
<b>48</b>	10	22.8	2.4	0.24	6.66	144
<b>58</b>	10	24.6	1.8	0.18	6.84	108
<b>68</b>	10	26.1	1.5	0.15	6.99	90
<b>88</b>	20	28.8	2.7	0.135	7.13	81
<b>108</b>	20	31.2	2.4	0.12	7.25	72
<b>128</b>	20	33.48	2.28	0.11	7.36	68.4
<b>148</b>	20	35.4	1.92	0.10	7.46	57.6
<b>178</b>	30	38.1	2.7	0.09	7.55	54
<b>208</b>	30	40.2	2.1	0.07	7.62	42
<b>238</b>	30	42.3	2.1	0.07	7.69	42
<b>268</b>	30	44.4	2.1	0.07	7.76	42

**Tables Appendix C: For crop coefficients and crop water Requirements**

Table in Appendix C- 1: Crop input data for CROPWAT model for Tsilwe SSIS

Crop Type	Indicators	Growth stages					Sowing date	Harvesting date
		initial	Crop dev't	Mid stage	Late stage	total		
Onion	Length of growth stage (day)	20	45	20	10	95	Dec- 05	mar-09
	Kc	0.5	0.75	1.05	0.85	-		
	Ky	0.8	0.4	1.2	1	1.1		
	Rooting depth (m)	0.25		0.4	0.4			
	Depletion (p)	0.3	-	0.45	0.5	-		
Pepper	Length of growth stage	25	35	40	20	120	Nov-15	Mar-14
	Kc	0.35	0.7	1.05	0.90	-		
	Ky	1.4	0.6	1.2	0.6	1.1		
	Rooting depth (m)	0.25	-	0.6	0.6			
	Depletion (p)	0.2	-	0.3	0.5			
Tomato	Length of growth stage	30	40	40	25	135	Nov-20	Apr-03
	Kc	0.35	0.75	1.1	0.9	-		
	Ky	0.5	0.6	1.1	0.8	1.05		
	Rooting depth (m)	0.25		0.6	0.6			
	Depletion (p)	0.3		0.4	0.5			
Maize	Length of growth stage	20	35	40	30	125	Jan-01	Apr-04
	Kc	0.4	0.8	1.15	0.7	-		
	Ky	0.4	1.5	0.5	0.2	1.25		
	Rooting depth (m)	0.2		0.6	0.6			
	Depletion (p)	0.55	-	0.55	0.8			

Table in Appendix C- 2: Mean monthly meteorological data and ETo values of the study area

Country	Ethiopia	Station	Mekelle				
Altitude	1780 m.	Latitude	13.00 °N				
		Longitude	39.00 °E				
Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m <sup>2</sup> /day	mm/day
January	8.6	26.5	59	1	9.3	20.2	3.00
February	10.3	28.0	55	1	9.8	22.5	3.52
March	12.8	28.7	55	2	8.9	22.6	3.84
April	14.7	28.9	53	2	9.4	24.0	4.20
May	14.8	29.8	51	1	8.9	23.0	4.10
June	14.8	29.9	52	1	6.5	19.1	3.58
July	14.2	25.9	70	1	5.1	17.1	3.26
August	13.7	24.9	76	1	4.6	16.5	3.09
September	12.1	28.0	61	1	6.7	19.4	3.46
October	11.3	26.7	52	1	9.2	21.9	3.54
November	10.2	25.7	58	1	9.3	20.4	3.15
December	8.7	25.3	61	1	9.5	19.9	2.92
<b>Average</b>	<b>12.2</b>	<b>27.4</b>	<b>58</b>	<b>1</b>	<b>8.1</b>	<b>20.5</b>	<b>3.47</b>

Table in Appendix C- 3: For onion crop water irrigation requirement at Tsilwe SSIS

Planting date: Dec- 05

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.5	1.5	9	0.3	8.7
Dec	2	Init	0.5	1	14.6	0	14.6
Dec	3	Deve	0.53	2	17.2	0.2	17
Jan	1	Deve	0.65	2	19.3	0.4	18.9
Jan	2	Deve	0.77	2	23	0.5	22.5
Jan	3	Deve	0.89	3	31.1	0.5	30.6
Feb	1	Mid	1.01	3	33.8	0.1	33.6
Feb	2	Mid	1.03	4	36.4	0	36.4
Feb	3	Late	1.03	4	29.9	1.9	28.1
Mar	1	Late	0.91	3	30.5	4.4	25.6
					244.8	8.3	236.1

Table in Appendix C- 4: For Pepper crop water irrigation requirement at Tsilwe SSIS

Planting date: Nov-15

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.35	1.1	6.6	1.3	5.5
Nov	3	Init	0.35	1.08	10.8	1.5	9.3
Dec	1	Deve	0.35	1.06	10.6	0.6	10
Dec	2	Deve	0.48	1.4	14	0	14
Dec	3	Deve	0.69	2.03	22.4	0.2	22.2
Jan	1	Deve	0.9	2.68	26.8	0.4	26.4
Jan	2	Mid	1.04	3.13	31.3	0.5	30.9
Jan	3	Mid	1.05	3.33	36.7	0.5	36.2
Feb	1	Mid	1.05	3.52	35.2	0.1	35
Feb	2	Mid	1.05	3.7	37	0	37
Feb	3	Late	1.03	3.74	29.9	1.9	28.1
Mar	1	Late	0.96	3.6	36	4.9	31.1
Mar	2	Late	0.91	3.5	14	2.8	10.5
					311.2	14.6	296.1

Table in Appendix C- 5: For Tomato crop water irrigation requirement at Tsilwe SSIS

Planting date: Nov-20

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.35	1.1	1.1	0.2	1.1
Nov	3	Init	0.35	1.08	10.8	1.5	9.3
Dec	1	Init	0.35	1.05	10.5	0.6	9.9
Dec	2	Deve	0.35	1.03	10.3	0	10.3
Dec	3	Deve	0.48	1.42	15.6	0.2	15.4
Jan	1	Deve	0.68	2.02	20.2	0.4	19.8
Jan	2	Deve	0.87	2.6	26	0.5	25.5
Jan	3	Mid	1.05	3.34	36.8	0.5	36.2
Feb	1	Mid	1.1	3.68	36.8	0.1	36.7
Feb	2	Mid	1.1	3.88	38.8	0	38.8
Feb	3	Mid	1.1	3.99	31.9	1.9	30.1
Mar	1	Late	1.1	4.1	41	4.9	36.2
Mar	2	Late	1.05	4.02	40.2	7	33.2
Mar	3	Late	0.96	3.82	42	9.4	32.6
Apr	1	Late	0.91	3.71	11.1	3.9	4.6
				2.72	373.1	31.1	339.6

Table in Appendix C- 6: Net scheme irrigation requirement for Tsilwe SSIS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Tomato	82.9	108	120	8.6	0	0	0	0	0	0	11.9	36.4
2. Onion	73.4	100	30.3	0	0	0	0	0	0	0	0	40.8
3. pepper	94.8	102	49.3	0	0	0	0	0	0	0	17.4	46.9
4. Maize	91.2	112	113	9.2	0	0	0	0	0	0	0	40.8
Net scheme irr.req.												
in mm/day	2.7	3.7	2.1	0.1	0	0	0	0	0	0	0.2	1.4
in mm/month	84.9	104	66.6	3.2	0	0	0	0	0	0	6.7	42
in l/s/ha	0.32	0.43	0.25	0.01	0	0	0	0	0	0	0.03	0.16
Irrigated area (% of total area)	100	100	100	36	0	0	0	0	0	0	43	100
Irr.req. for actual area (l/s/ha)	0.32	0.43	0.25	0.03	0	0	0	0	0	0	0.06	0.16

Table in Appendix C- 7: For Maize crop water irrigation requirement at Tsilwe SSIS

Planting date: Jan-01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Initial	0.4	1.2	12	0.6	11.4
Dec	2	Initial	0.4	1.17	11.7	0	11.7
Dec	3	Development	0.53	1.56	17.1	0.2	17
Jan	1	Development	0.75	2.24	22.4	0.4	22
Jan	2	Development	0.97	2.9	29	0.5	28.6
Jan	3	Middle	1.14	3.61	39.8	0.5	39.2
Feb	1	Middle	1.15	3.85	38.5	0.1	38.4
Feb	2	Middle	1.15	4.05	40.5	0	40.5
Feb	3	Middle	1.15	4.17	33.4	1.9	31.5
Mar	1	Late	1.13	4.21	42.1	4.9	37.2
Mar	2	Late	0.99	3.81	38.1	7	31.1
Mar	3	Late	0.83	3.31	36.4	9.4	27
Apr	1	Late	0.72	2.95	11.8	5.2	5.2
		average		3.0	372.8	30.7	340.9

## Tables In Appendices D: Discharge Measurement

Table in appendix D- 1: Discharge calculation from floating method measurement

S.No	time in seconds	depth (m)	width (m)	length (m)	Velocity (m/sec)	Area (m <sup>2</sup> )	Q (m <sup>3</sup> /sec)	Q (L/sec)
1	17.21	0.17	0.4	5	0.291	0.068	0.0198	19.8
2	18.45	0.17	0.4	5	0.271	0.068	0.0184	18.4
3	17.5	0.17	0.4	5	0.286	0.068	0.0194	19.4
4	17.25	0.17	0.4	5	0.290	0.068	0.0197	19.7
5	17.6	0.17	0.4	5	0.284	0.068	0.0193	19.3
<b>Average</b>					0.284	0.068	0.0193	19.3

Table in appendix D- 2: Discharge characteristics and values of k flume constant coefficient and n flume exponent (adopted from Mekelle Agriculture Research Center).

Throat width, b	Discharge range		Equation $Q = kh_1^n$ ( $h_1$ is in m & Q is in m <sup>3</sup> /s)	Head range, m		Modular limit, $h_2/h_1$
	Minimum	Maximum		Minimum	Maximum	
	l/s					
1 in	0.09	5.4	$Q = 0.0604h_1^{1.55}$	0.015	0.21	0.5
2 in	0.18	13.2	$Q = 0.1207h_1^{1.55}$	0.015	0.24	0.5
3 in	0.77	32.1	$Q = 0.1771h_1^{1.55}$	0.03	0.33	0.5
	l/s					
6 in	1.5	111	$Q = 0.3812h_1^{1.58}$	0.03	0.45	0.6
9 in	2.5	251	$Q = 0.5354h_1^{1.53}$	0.03	0.61	0.6
1 ft	3.32	457	$Q = 0.6909h_1^{1.52}$	0.03	0.76	0.7
1.5 ft	4.8	695	$Q = 1.056h_1^{1.538}$	0.03	0.76	0.7
2 ft	12.1	937	$Q = 1.428h_1^{1.55}$	0.046	0.76	0.7
3 ft	17.6	1427	$Q = 2.184h_1^{1.556}$	0.046	0.76	0.7
4 ft	35.8	1923	$Q = 2.953h_1^{1.578}$	0.06	0.76	0.7
5 ft	44.1	2424	$Q = 3.732h_1^{1.587}$	0.06	0.76	0.7
6 ft	74.1	2929	$Q = 4.519h_1^{1.595}$	0.076	0.76	0.7
7 ft	85.8	3438	$Q = 5.312h_1^{1.601}$	0.076	0.76	0.7
8 ft	97.2	3949	$Q = 6.112h_1^{1.607}$	0.076	0.76	0.7
	m <sup>3</sup> /s					
10 ft	0.16	8.28	$Q = 7.463h_1^{1.6}$	0.09	1.07	0.8
12 ft	0.19	14.68	$Q = 8.859h_1^{1.6}$	0.09	1.37	0.8
15 ft	0.23	25.04	$Q = 10.96h_1^{1.6}$	0.09	1.67	0.8
20 ft	0.31	37.97	$Q = 14.45h_1^{1.6}$	0.09	1.83	0.8
25 ft	0.38	47.14	$Q = 17.94h_1^{1.6}$	0.09	1.83	0.8
30 ft	0.46	56.33	$Q = 21.44h_1^{1.6}$	0.09	1.83	0.8
40 ft	0.6	74.7	$Q = 28.43h_1^{1.6}$	0.09	1.83	0.8
50 ft	0.75	93.04	$Q = 35.41h_1^{1.6}$	0.09	1.83	0.8

Table in appendix D- 3: Parshall flume discharge & depth relation (Q = lit/sec)

height, (m)	Throat width of the Parshall flume, inches and fit									
	1 in	2 in	3 in	6 in	9 in	1 ft	1 ft 6in	2 ft	3 ft	4 ft
0.02	0.14	0.281								
0.03	0.263	0.526	0.772	1.496	2.504	3.347	4.803			
0.04	0.411	0.822	1.206	2.357	3.889	5.183	7.475			
0.05	0.581	1.162	1.705	3.354	5.471	7.275	10.536	13.745	20.037	
0.06	0.771	1.541	2.261	4.473	7.232	9.599	13.678	18.233	26.659	34.849
0.07	0.979	1.957	2.872	5.707	9.155	12.133	17.678	23.154	33.937	44.446
0.08	1.205	2.407	3.532	7.047	11.231	14.863	21.708	28.479	41.83	54.871
0.09	1.446	2.889	4.239	8.489	13.448	17.777	26.019	34.183	50.303	66.078
0.1	1.702	3.402	4.991	10.027	15.801	20.865	30.596	40.247	59.327	78.03
0.11	1.973	3.943	5.786	11.656	18.281	24.117	35.426	46.654	68.877	90.695
0.12	2.258	4.513	6.621	13.374	20.885	27.528	40.499	53.39	78.932	104.043
0.13	2.557	5.109	7.496	15.177	23.605	31.089	45.805	60.442	89.472	118.05
0.14	2.868	5.731	8.408	17.062	26.44	34.796	51.334	67.8	100.482	132.695
0.15	3.191	6.377	9.358	19.027	29.383	38.643	57.081	75.452	111.947	147.957
0.16	3.527	7.048	10.342	21.07	32.433	42.626	63.038	83.39	123.852	163.819
0.17	3.875	7.743	11.361	23.188	35.585	46.741	69.198	91.606	136.187	180.265
0.18	4.234	8.46	12.413	25.38	38.837	50.983	75.557	100.092	148.939	197.28
0.19	4.604	9.2	13.499	27.643	42.186	55.35	82.108	108.842	162.099	214.851
0.2	4.985	9.961	14.616	29.976	45.63	59.839	88.848	117.849	175.657	232.964
0.21	5.376	10.744	15.764	32.379	49.167	64.445	95.772	127.107	189.604	251.609
0.22		11.547	16.942	34.848	52.794	69.167	102.875	136.61	203.933	270.774
0.23			18.151	37.384	56.51	74.002	110.154	146.355	218.634	290.449
0.24			19.389	39.984	60.312	78.947	117.606	156.335	233.703	310.625
0.25			20.655	42.648	64.199	84.001	125.226	166.546	249.13	331.293
0.26			21.95	45.374	68.169	89.161	133.013	176.985	264.912	352.445
0.27			23.272	48.162	72.221	94.425	140.962	187.647	281.04	374.072
0.28			24.621	51.011	76.354	99.792	149.071	198.529	297.51	396.167

## 7.2. Figures in Appendices II



Figure in appendix 1: During the soil sample collection at field



Figure in appendix 2: During infiltration measurement at field

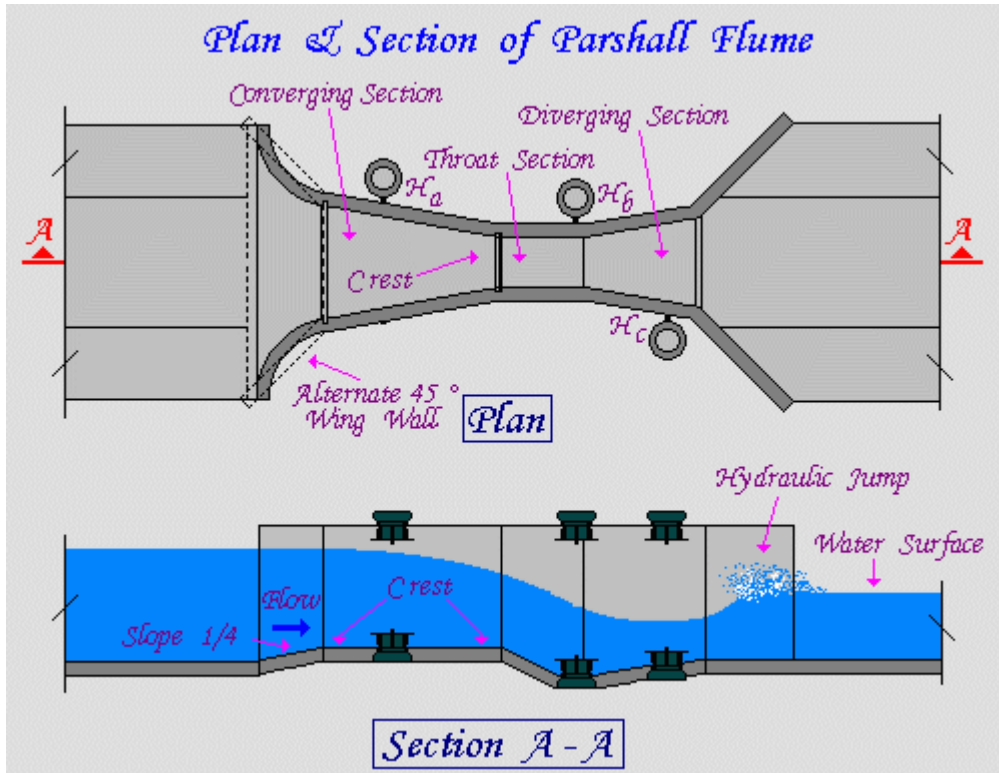


Figure in appendix 3: Plan view of sheet metal Parshall flume showing its component parts



Figure in appendix 4: Discharge measurement at field application using parsshall flume