Jimma University

School of Graduate Studies

Jimma Institute of Technology

School of civil and environmental engineering

Hydraulic Engineering Stream

Performance evaluation of community Based small scale irrigation schemes at Estie woreda, Amhara region, Ethiopia

A thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Master of Science in Hydraulic Engineering

By

Wendmagegn Bantie

November, 2015

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Adviser: Dr.Ing Kassa Tadele

Co-adviser: Andualem Shegutie (MSc)

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Abstract

This study was conducted with the general objective of the performance evaluation of community based small-Scale Irrigation schemes at Estie woreda. In addition to water application, agronomic and economic performance evaluation, the study also assesses irrigation water management strategies adopted by the communities and identify the major challenges of community owned irrigation systems on selected three modern SSI structures namely Gomit, Gumara and Chena in the study area. Systematic sampling technique has used in sample size determination. Actual field investigation and measurements or survey works including simple observations of scheme at the sites were required to collect the necessary data to know the present condition of the scheme. These Primary data were collected from February to April. In addition, the collection of primary data which require questionnaires, Interview, Discussions with irrigation water users and other secondary data were carried out in June and July. Comparative analysis, use of software, Actual observation and onsite field evaluation of the sites were methods of analysis and evaluation used by this paper. Software like GIS Software, Ms-Excel, cropwat, surface irrigation software (SURDEV), Data collection instruments like GPS and Video camera, Soil data, Meteorological and Hydrological data for a site and basin, Design and feasibility documents of a site Flow Measuring Equipments were some of the materials used in this study. The flow discharges along canals in the study area were measured with floating method with 10cm width interval and the flow discharge at the field inlets were measured with buckets. After measurement of discharge at canal head and canal outlet, Conveyance efficiency of Gomit, Gumara and Chena were 63.83, 29.5 and 56.5 respectively. The application efficiency of Gomit, Chena and Gumara are 86.2%, 83.37% and 66.85%. Although those values of application efficiency are high enough, achievement of irrigation to the minimum infiltrated depth is poor in all schemes i.e. under irrigation is observed. Output per cropped area of Gumara, Gomit and Chena are 3.087, 4.68 and 3.95 respectively. The respective values output per command area of Gumara, Gomit and Chena are 3.19, 1.51 and 1.57 and the respective values output per irrigation supply are 10.05, 5.51 and 6.05 while output per unit water consumed of Gomit ,Gumara and Chena are 12.42, 7.69 and 9.99 respectively. Gomit irrigation project has highest output per cropped area (4.68) followed by Chena (3.95). The values of relative irrigation supply in Gumara, Gomit and Chena were 1.52, 2.68 and 1.96 respectively. The respective values of relative water supply of Gumara, Gomit and Chena were 2.08, 3.17 and 2.53. Gomit has highest value of relative water supply and relative irrigation supply. The water delivery capacity of the scheme shows the capacity of the main canal to convey the maximum peak consumptive demand. The water delivery capacity of Chena, Gomit and Gumara is 1.03, 1.46 and 0.54 respectively. The output of this paper shows that, without the water users association, the efficient irrigation scheme management is impossible. By strengthening the management capacity of water users association, legal and smooth handover of schemes after the construction, frequent evaluation and follow-up are critical to maintain sustainable performances of schemes.

***Key words**: efficiency, comparative analysis, small scale irrigation, performance evaluation, irrigation water management, sustainable performance, water users association.*

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Tab of Contents Page

List of tables

List of figures

Acronyms

ADLI	Agricultural Development Led Industrialization
AET	Actual evapotranspiration
DA	Development Agent
DPR	Delivery Performance Ratio
E.C	Ethiopian Calendar
FAO	Food and Agriculture Organization
FBR	Free Board Ratio
GIS	Geographical Information System
GPS	Geographical Positioning System
IWMI	International Water Management Institute
MoA	Ministry of Agriculture
NCWR	Net Crop Water Requirement
NIR	Net Irrigation Requirement
O&M	Operation and Maintenance
PET	Potential Evapotranspiration
RAM	Readily Available Moisture
SGVP	Standard Gross Value Production
SSI	Small Scale Irrigation
SURDEV	surface irrigation design operation and evaluation software
TAM	Total Available Moisture
USDA	United States Department of Agriculture
WUA	Water Users Association
WUE	Water Use Efficiency

CHAPTER ONE

1. Introduction

1.1 Background

Irrigation can be defined as the science of artificial application of water to the land, in accordance with the crop requirements throughout the crop period for full-fledged nourishment of the crops (Garg, 2005). With increasing population and demand for food, sustainable production increases from irrigated agriculture must be achieved. With limited freshwater and land resources, and increasing competition for these resources, irrigated agriculture worldwide must improve its utilization of these resources (Molden et al, 1998).

Irrigation is one means by which agricultural production can be increased to meet the growing food demands of the fast growing population of the country (MoA, 2011).The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climactic volatility in any country. An effective irrigation scheme serves as reservoir during floods and a dependable source of water in drought. This enhances continuous farming all year round and boosts food availability and opportunities for employment and general well being. Consequently governments are severally introducing citizens to irrigation worldwide (Bagson and Wuleka, 2013).

Irrigated agriculture requires intensive management as compared with rain fed agriculture and the land holding size per household has significant impact on effectively managing the land in a more productive manner (MoA, 2011). Due to this, increased attention has recently been given to technical efficiency of small-scale irrigation to achieve food security and increase agricultural development. This is because only rain fed agriculture cannot bring sustainable agricultural development due to seasonal variation in the country. To achieve sustainable production from irrigated agriculture it is apparent that the management of important resources in irrigated agriculture, water and land is to be improved (Dananto and Alemu, 2014).

Irrigation structures differ from place to place for different reasons like topography, geology, availability of water resources etc. Besides this, each structure has created a challenge for the operation and maintenance. Most irrigation schemes, which professional's design approach starting from the site selection are considerably less demand driven. Schemes site selection and designs are based on location of potential sites from maps and geographic information system rather than explicit demand from the communities. This is not in a way that it accommodates the beneficiaries' idea. This results in poor design and reduction of irrigated farm land. Designs like deep canals make maintenance more difficult for the farmers. Irrigation structure designs that do not considers the sedimentation, debris and log problems, challenges the sustainability of the schemes (MoA, 2011).

An evaluation of a surface irrigation system will identify various management practices and field layouts that can be implemented to improve the irrigation efficiency and/or uniformity. The evaluation may show, for example, that achieving better performance requires a reduction in the flow and duration of flow at the field inlet, or it may indicate that improvements require changes in the field size and topography. Perhaps a combination of several improvements will be necessary. Thus, the most important objective of the irrigation scheme evaluation is to improve surface irrigation performance. The effectiveness of irrigation can be described by its efficiency and uniformity. Because an irrigation system applies water for evapotranspiration and leaching needs, as well as occasionally seed bed preparation, germination, or cooling, there have emerged a number of different efficiencies and ratios to give specific measures of performance. Adopting some form of irrigation scheduling is another recognized "best" management practice (Solomon, 1988).

Small-scale and community irrigation systems have been widely introduced in southern Africa to promote irrigated agriculture for small-scale farmers. Systems may vary in size from 5 to 200 hectares and may include river diversion, small dams or pump schemes. Results have not always been positive due to lack of ownership and inadequate involvement of the community in planning. Operation and maintenance have proved a major challenge, and operational costs were often too high for the cultivation of food crops by small-scale farmers (FAO, 2006).

In the lowlands of Lesotho outside Maseru, the Food and Agriculture Organization of the United Nations (FAO) has been assisting communities through implementation of small-scale irrigation projects. FAO promotes affordable small-scale irrigation methods that can be maintained easily and can improve the availability of food and earning capacity of households. FAO conducted an evaluation of its small-scale irrigation projects in southern Africa in July 2006. While numerous Challenges were outlined in the report; the evaluation found that there was a general increase in 1) the area under irrigation, 2) Food security, and 3) income (FAO, 2006)

In our country Ethiopia, the overall objective of the small-scale Irrigation (SSI) capacity building strategy is to undertake Infrastructural, institutional and human resource capacity building which will help the country to optimize the efficient use of water resources with improved land management of small holder Irrigated agriculture development and contribute to improve food security and alleviate poverty (*MoA*, 2011). The country's Agricultural Development Led Industrialization (ADLI) strategy considers irrigation development as a key input for sustainable development (Getaneh, 2011).

According to Yilma Silesh (2003) community based small scale irrigation structures are: irrigation systems that are reproducible and affordable, people centered, managed and owned by the community and covers irrigation area less than 200ha. The objective of the study related to this paper is to assess and evaluate the experiences with respect to community based small-scale irrigation techniques and overall irrigation water management situation at Estie. The paper also deals with the assessment of awareness of the people about SSI use and management as well as irrigation water application throughout the study area.

1.2 Problem statement

The performance of a surface irrigation event is influenced by a number of design and management factors. Each of these factors has a different amount of influence over the performance of an irrigation event **(**Wigginton**,** 2008). Those design and management factors affect surface irrigation variables at different impact level on irrigation performance.

In case of our country Ethiopia, according to MoA (2011), Lack of proper consultation of beneficiaries and all stakeholders at each stages of project implementation is the critical problem which affects operational efficiency and sustainability. However, the most pressing challenge is the poor water management practice, which is very common in most irrigation schemes, The major causes for such poor practices include: poor land preparation and leveling, improperly designed main and field canals, absence of water level measuring devices, poor maintenance of main and field channels, and limited know-how and inadequate practical skills of farmers on crop water needs, soil types and climatic conditions which are instrumental in choosing the more appropriate irrigation methods (M oA, 2011).

In the study area, Estie, these problems mentioned above, which can be summarized as guess water allocation, luck of awareness and poor irrigation water management affect the efficiency of the water application, and which has an impact on crop production. In addition, the water diverted from the source is lost through the canals. There for some of those problems are investigated particularly to selected modern SSI samples and evaluation of the performance and sustainability of small scale irrigation scheme in the study area were carried out.

1.3 Objectives

1.3.1 General objective

The general objective of this study is to evaluate the performance of community based small-Scale Irrigation schemes at Estie

1.3.2 Specific objective

The specific objectives of this study are

1. To evaluate the water application, agronomic and economic performance of small-scale Irrigation systems based on comparative performance indicators at Estie
2. To assess irrigation water management strategies adopted by the communities and identify the major challenges of community owned irrigation systems at the study area
3. To suggest possible options/strategies/ for rehabilitation and management of irrigation systems which will insure the sustainability of the schemes.

1.4 Scope of the study

The aim of this paper is mainly focused on the evaluation of surface irrigation performance with the help of SURDEV software simulation and comparative performance indicators. For this software the influencing factor is assumed to be slope rather than crop type. The study was not conducted on pre-construction structural design problems and catchment characteristics. In this paper the flow rate of irrigation water during investigation is assumed to be uniform throughout the irrigation season and the water loss along the canal accounts to be both evaporative and seepage losses.

CHAPTER TWO

2. Literature review

2.1 Overview of small scale irrigation

Small-scale and community irrigation systems have been widely introduced in southern Africa to promote irrigated agriculture for small-scale farmers. Systems may vary in size from 5 to 200 hectares and may include river diversion, small dams or pump schemes. Results have not always been positive due to lack of ownership and inadequate involvement of the community in planning. Operation and maintenance have proved a major challenge, and operational costs were often too high for the cultivation of food crops by small-scale farmers (FAO, 2006)

Small-scale irrigation can be defined as irrigation, usually on small plots, in which small farmers have the controlling influence, using a level of technology which they can operate and maintain effectively. Small-scale irrigation is, therefore, farmer-managed: farmers must be involved in the design process and, in particular, with decisions about boundaries, the layout of the canals, and the position of outlets and bridges**.** The small-scale irrigation schemes in Ethiopia are understood to include traditional small scale up to 100 ha and modern communal schemes up to 200 ha (MoA, 2011). Traditionally farmers have built small-scale schemes on their own initiative, sometimes with government technical and material support. They manage them through their own users' association or committees (MoA, 2011).Such associations handle construction, water allocation, and operation and maintenance functions.

2.2 Irrigation water management

Proper management of irrigation water is essential for conservation of water resources (Arora, 2011). In most areas of the country, existing small-scale irrigation infrastructures are not being managed as effectively and efficiently as they are supposed to be and the scheme performance is low and un profitable. Therefore, the major focus areas under this strategic direction are improving the capacity of extension services in irrigated agriculture, which includes improving on-farm water and crop management and improving farmers' know-how and practical skills in operation and maintenance of irrigation systems (MoA, 2011). Surface irrigation systems can be as efficient as most other methods. This requires improving the management and control of water, knowing how much water is applied and scheduling applications according to soil water levels and crop needs (Leib, 2003)

Surface irrigation is difficult to manage at consistently high levels of performance (efficiency and uniformity) because the basic field characteristics change from irrigation to irrigation, crop to crop, and year to year (USDA, 2006). Strengthening improvements in irrigation management and operation techniques, repairing and improving the existing old irrigation system facilities, adopting water-saving techniques are measures for raising the effective use of water resources (Sakthivadivel, *et al* 2001). By improving the operation and management of the irrigation water by the farmers, not only water can be saved, by reducing the seepage losses, but also a better production can be achieved by improving the irrigation management practices and related practices. (Margot, 1997)

An evaluation of a surface irrigation system will identify various management practices and field layouts that can be implemented to improve the irrigation efficiency and/or uniformity. The evaluation may show, for example, that achieving better performance requires a reduction in the flow and duration of flow at the field inlet, or it may indicate that improvements require changes in the field size and topography. Perhaps a combination of several improvements will be necessary. Thus, the most important objective of the evaluation is to improve surface irrigation performance. The effectiveness of irrigation can be described by its efficiency and uniformity. Because an irrigation system applies water for evapotranspiration and leaching needs, as well as occasionally seed bed preparation, germination, or cooling, there have emerged a number of different efficiencies and ratios to give specific measures of performance Surface irrigation is difficult to manage at consistently high levels of performance (efficiency and uniformity) because the basic field characteristics change from irrigation to irrigation, crop to crop, and year to year. Adopting some form of irrigation scheduling is another recognized "best" management practice (Solomon, 1988).

2.3 Surface irrigation

The term "surface irrigation" refers to a broad class of irrigation methods in which water is distributed over the field by a free-surface, gravity flow (Walker, 2003). Following the pull of gravity, the water flows over the fields from one end to the other, infiltrating into the soil as it goes. The most common surface irrigation techniques are level basins (with or without level furrows), sloping borders and sloping furrows to distribute irrigation water (Feyen et al, 2001) Surface irrigation performance is determined by furrow inflow rate, the soil infiltration characteristic, field slope and field length, surface roughness and furrow geometry (Raine and Montagu, 2006).

Surface irrigation systems can be as efficient as most other methods. This requires improving the management and control of water, knowing how much water is applied and scheduling applications according to soil water levels and crop needs (Leib, 2003).

Surface irrigation has evolved into an extensive array of configurations that can broadly be classified as: Basin irrigation, Border irrigation, furrow irrigation and wild flooding. The distinction between the various classifications is often subjective. For example, a basin or border system may be furrowed. Wild flooding is a catchall category for the situations where water is simply allowed to flow onto an area without any attempt to regulate the application or its uniformity (USDA, 2006).

According to (Orang *et al*, 2008) surface irrigation includes wild flood, border, basin, furrow irrigation without sprinklers, wheel-line sprinklers followed by furrow irrigation, and hand move sprinklers followed by furrow irrigation. In addition (walker, 2003) stated that surface irrigation as the oldest and most common method of applying water to croplands, surface irrigation has evolved into an extensive array of configurations. Efforts to classify surface systems differ substantially, but generally include the following: (1) basin irrigation, (2) border irrigation, (3) furrow irrigation, and (4) wild flooding

2.4 Challenges and Problems of SSI

Small-scale irrigation has improved the incomes of poor households in study area, but it is never free from problems. The problems of small-scale irrigation technology development range from individual households biased attitudes to institutional arrangements (Getaneh, 2005).

Modern water development schemes have often become arenas of multiple conflicts, of which the following are worth noting. a) There is conflict among water users over water allocation, land rights, or maintenance issues. b) Conflict may arise between users and the authority responsible for the project over inappropriate design of infrastructure, peasant relocations, water charges, or management issues. c) Conflict between project beneficiaries and non-beneficiaries is often inevitable. The latter often question the justice of being excluded from the benefits of water projects. d) Finally, there is conflict between donor agencies and the recipient country over design, management, environmental impact, and financial issues (Rahmato, 1999).

2.5 Efficiency

In general, the term efficiency is used to quantify the relative output obtainable from a given input. Referring to the use of water in irrigation, efficiency may be defined in various ways, depending on the nature of the inputs and outputs to be considered. Efficiency is the ratio of water output to the water input, and is usually expressed as percentage (Garg, 2005). An evaluation of a surface irrigation system will identify various management practices and field layouts that can be implemented to improve the irrigation efficiency and/or uniformity (USDA, 2006). Efficiency is expressed in (%) or fraction and is defined as output of a specific operation in relation to the input (Machibya *et al*, 2004). Irrigation efficiency is a critical measure of irrigation performance in terms of the water required to irrigate a field, farm, basin, irrigation district, or an entire watershed. The value of irrigation efficiency and its definition are important to the societal views of irrigated agriculture and its benefit in supplying the high quality, abundant food supply required to meet our growing world's population (Howell, 2003).

Irrigation efficiency can be mentioned as the most important parameter for the desirability of an irrigation system performance. Improvement of water management in an agricultural project requires assessment and evaluation of the efficiency of an irrigation system (Azmi *et al*, 2012). The term "evaluation" stands for assessment of irrigation performance, the performance indicators being adequacy, efficiency and uniformity (Feyen *et al*.2001)

2.5.1 Conveyance efficiency

Conveyance efficiency is defined as the net amount of water delivered to a farm, as a fraction of the amount taken from some source. The difference between the two amounts represents the seepage and evaporative losses incurred en route from source to field. Not generally considered in the term conveyance efficiency is the possible loss of water quality through pollution - such as that caused by wading animals or by human use of the canal water for washing and waste disposal. The conveyance efficiency (ec) mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals (FAO, 1989).

Table2. 1Indicative values of the conveyance efficiency (ec) for adequately maintained canals

	Earthen canals			
soil type	Sand	loam	Clay	lined canals
canal length				
long(>2000m)	60%	70%	80%	95%
medium(200-2000)	70%	75%	85%	95%
short(<200)	80%	85%	90%	95%

Source : FAO (1989)

$$\text{water conveyance efficiency}(\eta_c) = \frac{\text{water delivered to the fields}}{\text{water supplied in to the canal at the head}} \times 100 \quad \ldots\ldots\ldots (2.3)$$

2.5.2 Storage efficiency/Adequacy/

We express the adequacy of an irrigation turn in terms of storage efficiency (Es), which is defined by Hart et al. (1980) as the ratio between the storage depth and the required depth, or

$$E_s = \frac{D_s}{D_{req}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

D_S =Average depth stored in the crop root zone, Dreq= Required depth, ES= storage efficiency

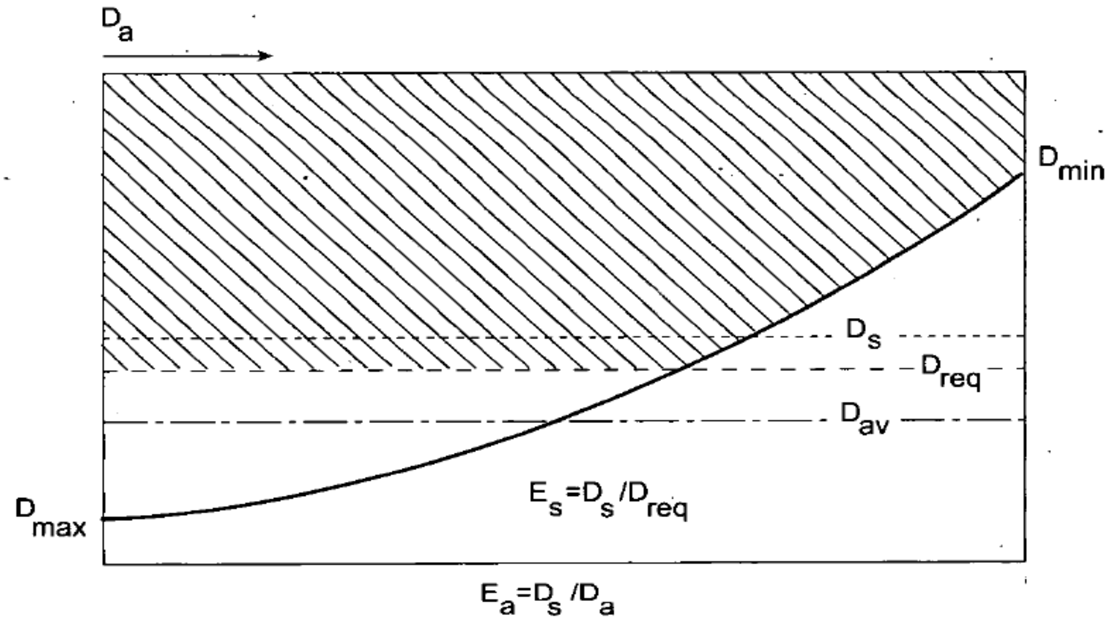

Figure2. 1 Storage efficiency

2.5.3 **Application efficiency**

The application efficiency (Ea) is a common yardstick of relative irrigation Losses. Hart et al. (1980) define it as the depth added to the target zone divided by the applied depth, or

$$E_a = \frac{D_S}{D_a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.5)$$

Where Ea= Application efficiency, Da= Applied depth, DS= Average depth stored in the crop root zone. The field application efficiency (ea) mainly depends on the irrigation method and the level of farmer discipline. In fact, 1 -E_a , indicates the fraction of the applied water that is "lost" (i.e., the fraction that is not actually stored in the target zone). Such losses can be due to surface runoff and deep percolation, for which we use the indicators below. In borders and furrows without reuse, the surface runoff ratio (SRR) equals the surface runoff depth divided by the applied depth, or

$$SRR = \frac{D_{sr}}{D_a} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.6)$$

The fraction of water that is lost to deep percolation is expressed by the deep percolation ratio (DPR), which is defined as the deep percolation depth divided by the applied depth, or

$$DPR = \frac{D_{dp}}{D_a} \quad (2.7)$$

Where Ddp= deep percolation depth. Da= applied depth

Table2. 2indicative values of field application efficiency (ea)

	Irrigation methods	Field application efficiency
1	Surface irrigation(border, furrow, basin)	60%
2	Sprinkler irrigation	75%
3	Drip irrigation	90%

(Source: FAO, 1989):

Attainable water application efficiencies vary greatly with irrigation system type and management but the following ranges give some idea of the efficiencies that may be achieved with reasonable design management (Solomon, 1988)

Table2. 3 attainable values of field application efficiency (ea)

Surface irrigation	Attainable efficiencies
Basin	80-90%
Border	70-85%
Furrow	60-75%

Source: Solomon, 1988

Application efficiency relates to the actual storage of water in the root zone to meet the crop water needs in relation to the water applied to the field (Howell, 2003, USDA, 1997). Irrigation systems are generally rated with respect to application efficiency (Ea), which is the fraction of the water that has been applied by the irrigation system and that is available to the plant for use (Dukes *et al*, 2015, Margôt, 1997).Water application efficiency is an irrigation concept that is very important both in system selection and design and in irrigation management. The ability of an irrigation system to apply water uniformly and efficiently to the irrigated area is a major factor influencing the agronomic and economic viability of the farming enterprise. Application efficiency is the most important in terms of design and management since it reflects the overall beneficial use of irrigation water (walker, 2003)

According to Fairweather *et al*, (1999).Worldwide, average application efficiencies of different systems are reported as being the following: Surface: 60 to 90%, Sprinkler: 65 to 90%, Drip: 75 to 90%. However, these efficiencies can be misleading and depend on soil type, moisture conditions before irrigation, depth to groundwater, the crop being grown, management practices, and quality of irrigation water.

2.5.4 Scheme irrigation efficiency (e)

Once the conveyance and field application efficiency have been determined, the scheme irrigation efficiency **(e)** can be calculated, using the following formula (FAO, 1971):

$$e = \frac{ec*ea}{100} \quad \text{……(.2.8)}$$

Where e = scheme irrigation efficiency (%), ec = conveyance efficiency (%), ea = field application efficiency (%).

A scheme irrigation efficiency of 50-60% is good; 40% is reasonable, while a scheme Irrigation efficiency of 20-30% is poor.

2.5.5 Distribution Uniformity

Although different cases might produce the same results for Es and Ea, their distribution patterns could differ. One indicator used to represent the pattern of the infiltrated depths along the field length is the distribution uniformity (DU) which is defined as the minimum infiltrated depth divided by the average infiltrated depth, or

$$DU = \frac{D_{min}}{D_{av}} \quad \text{…… (2.9)}$$

Where, DU= distribution uniformity, D_{min}= Minimum infiltrated depth, D_{av}= Average infiltrated depth Distribution uniformity (DU) is a measure of how evenly water is applied during an irrigation event. This uniformity of application can have a big effect on crop yield and optimum water application (Fairweather *et al*, 1999).

According to Rain Bird Corporation (2010), DU is expressed as a percentage between 0 and 100%, although it is virtually impossible to attain 100% in practice. DUs of less than 70% are considered poor, DUs of 70 - 90% are good, and DUs greater than 90% are excellent. In short, bad DU means that either too much water is applied, costing unnecessary expense, or too little water is applied, causing stress to crops. To improve the performance of a surface irrigation system, the measures of uniformity and efficiency may need to be more qualitative. DU gives minimal information about the magnitudes of losses or under-irrigation (walker, 2003).

2.5.6 Christiansen's uniformity coefficient

Christiansen's uniformity coefficient (UC), which is defined as (Feyen *et al*, 2001)

$$UC=1-\sum\left(\frac{|D_i - D_{av}|}{nD_{av}}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.10)$$

For n points along the length of the field, UC gives the average of all differences between the infiltrated depths and the average depth.

2.6 Estimation of crop water requirements

2.6.1 Water requirements and Irrigable area

The amount of water required by a crop depends on the local environment, the climate, the crop and its stage of growth, and the degree to which the crop may be stressed. This requirement may be expressed as a uniform depth of water over the area in millimeters per day (mm/d). Providing the crop with irrigation at the appropriate time and in the appropriate quantity requires experience and will depend on climate, rainfall, soil and crops stage, as well as the field irrigation system and irrigation technology used (FAO, 2014). Special computerized irrigation programmes such as the FAO CROPWAT8.0 programme were used to advise farmers about efficient water supply and schedule for the given climatic conditions, crop, soil and field irrigation method. According to (FAO, 2014), CropWat 8.0 Windows is a program that uses the FAO (2004) Pen-man-Monteith method for calculating reference crop evapo-transpiration (ETo).

2.6.2 Irrigation requirements

It is reasonable to assume that 70 per cent of average rainfall is available to the crop; the net irrigation requirement (In mm/d) can be estimated as (FAO, 1989):

$$I_n = ET_O - (0.70 \times P) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.11)$$

Where P (mm/d) is the average rainfall.

Additional water has to be supplied to take account of field application losses which, with surface irrigation, are typically about 40 per cent, giving an application efficiency of 0.60.

The field irrigation requirement (I_f) can be estimated as:

$$\text{If} = \frac{\text{In}}{0.60} = \frac{\text{ETo} - (0.70 \text{ x P})}{0.60} \quad \ldots\ldots (2.12)$$

2.6.3 Irrigation scheduling

Irrigation scheduling is the term used to describe the procedure by which an irrigator determines the timing and quantity of water application. Accordingly, the two classical questions of irrigation scheduling are: - when to irrigate? How much water to apply?

2.6.4 Design command area

The required canal discharge depends on the field area to be irrigated (known as the 'command area'), and the water losses from the canal. For a design command area A (m2), the design discharge required Q (l/s) for irrigation hours (H) every day, is given by the field-irrigation requirement multiplied by the area, divided by the time (in seconds) (FAO, 1984).: :

$$Q = \frac{\text{If x A}}{\text{H x 60 x 60}} \text{ plus canal losses} \quad \ldots\ldots (2.13)$$

2.6.5 Irrigation-canal losses

Water is lost from canals by seepage through the bed and banks of the canal, leakage through holes, cracks and poor structures, and overflowing low sections of bank. The canal losses depend on the type of canal, materials, standard of construction and other factors, but are typically about 3 to 8 (l/s) per 100 meters for an unlined earthen canal carrying 20 to 60 l/s (FAO, 1984). Losses often account for a large proportion of water requirements in small-scale irrigation, and may be estimated by 'ponding' water in a trial length of canal, and then measuring the drop-of-water level. When the water-surface width in the canal is W meters, a drop of S millimeters per hour corresponds to;

$$\text{average canal loss} = \frac{\text{W x S}}{60\text{x}60} \text{ L/s per meters length} \quad \ldots\ldots (2.14)$$

2.7 Performance indicators

The performance evaluation of an irrigation project can be examined in two major components, i.e. the on-farm system, and supply and distribution (off-farm) system. It is obvious that, the off-farm system should be capable of delivering water to farms with sound adequacy, efficiency, dependability, and equity. These parameters are commonly used for controlling an irrigation system performance. The performance of a system can be defined as the measurement of the degree/level of fulfillment of the established objectives (Ait Kadi, 1994). Such a degree/level is expressed by one or several parameters chosen as evaluation criteria or as indicators of the considered objectives. In other words, the definition implies that performance is a relative rather than an absolute concept. It is relative to some objectives which should be defined in advance.

According to Murray-Rust and W. Bart Snellen (1993) "The performance of a system is represented by its measured levels of achievement in terms of one, or several, parameters which are chosen as indicators of the system's goals". Nine indicators are developed related to the irrigation and irrigated agricultural system. The main output considered is crop production, while the major inputs are water, land, and finances (Molden et *al*, 1998).

2.7.1 Indicators of Irrigated Agricultural Output

The four basic comparative performance indicators relate output to unit land and water. These "External" indicators provide the basis for comparison of irrigated agriculture performance. 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. Output per unit of irrigation water supplied and output per unit of water consumed are derived from a general water accounting framework (Molden et al, 1998).

- $\text{out putper croped area}(\frac{\text{USD}}{\text{ha}}) = \frac{\text{production}}{\text{irrigated croped area}}$ ……………………………(2.15)
- $\text{out putper unit command}\left(\frac{\text{USD}}{\text{ha}}\right) = \frac{\text{production}}{\text{command area}}$ ……………….…………… (2.16)
- $\text{out putper irrigation supply}(\frac{\text{USD}}{\text{ha}}) = \frac{\text{production}}{\text{diverted irrigation supply}}$ ……..…………...(2.17)
- $\text{out putper unit water consumed}(\frac{\text{USD}}{\text{ha}}) = \frac{\text{production}}{\text{volume of water consumed by ET}}$………...(2.18)

2.7.2 Indicators of water supply

Molden et al. (1998) define several supply indicators for comparative purposes. Three below characterize the individual irrigation system with respect to water supply.

- Relative water supply (RWS) $= \frac{\text{Total water supply}}{\text{Crop demand}}$………………..……………….... (2.19)
- Relative irrigation supply (RIS) $= \frac{\text{Irrigation supply}}{\text{Irngation demand}}$……………………………..(2.20)
- Water delivery capacity (%) $= \frac{\text{Canal capacity to deliver water at system head}}{\text{Peak consumptive demand}} \times 100$………………...(2.21)

Total water supply =Surface diversions plus net groundwater draft plus rainfall

Crop demand =Potential crop ET, or the ET under well-watered conditions.

Irrigation supply = only the surface diversions and net groundwater draft for irrigation this does not include rainfal1 and does not include any recirculation internal project drainage water. Irrigation demand = the crop ET less effective rainfall,

Peak consumptive demand =the peak crop irrigation requirements for a monthly period expressed as a flow rate at the head of the irrigation system

2.7.3 Financial Indicators

The two financial indicators are:

- Gross return on investment(%) $= \frac{\text{production}}{\text{cost of irrigation infrastructure}}$ ……………....(2.22)
- financial self sufficiency(%) $= \frac{\text{revenue from irrigation}}{\text{total O\&}Mexpenditure}$ ………………………....(2.23)

Where,

- Cost of irrigation infrastructure considers the cost of the irrigation water delivery system referenced to the same year as the SGVP,
- Revenue from irrigation, is the revenue generated, either from fees, or other locally generated income, and
- Total O & M expenditure is the amount expended locally through operation and management

We are interested in the measurement of production from irrigated agriculture that can be used to compare across systems. The Standardized Gross Value of Production (SGVP) was developed for cross system comparison as obviously there are differences in local prices at different locations throughout the world. To obtain SGVP, equivalent yield is calculated based on local prices of the crops grown, compared to the local price of the predominant, locally grown, internationally traded base crop. The second step is to value this equivalent production at world prices. However When only one irrigation system is considered, or irrigation systems in a region where prices are similar, production can be measured as net value of production and gross value of production using local values (Molden *et al*. 1998).

2.7.4 Limitations of the Indicators

First, the major difficulty of using the indicators is the uncertainty involved in many of the estimates. Two major types of uncertainties exist: uncertainties in the source of data and uncertainties in the estimates. Many of the data come from secondary sources, not directly measured by the researchers. There is a wide variety in the quality of data obtained from these sources. Second, means of estimating leads to errors. For example, there are large uncertainties in estimates of actual crop evapotranspiration and effective precipitation related to the methodology of estimating these values (Molden et al, 1998).

CHAPTER THREE

3. Materials and Methodology

3. 1 Description of the study area

3.1.1 General

Ethiopia is situated in the East Africa and lies between 3°30´ and 14°50´ North latitudes and 32°42´ and 48°12´ East longitudes. Ethiopia is a landlocked country consisting of nine independent regions and two city councils divided along ethnic lines (Getaneh, 2005).

Amhara Region is one of the regional states of the Federal Republic of Ethiopia. Amhara region has a geographical area of about 153,000 Km2. Ethiopia's largest inland body of water, Lake Tana, as well as the Semen Mountains National Park, which includes the highest point in Ethiopia; Ras Dashan is located in Amhara region. The study was conducted in Estie woreda, which is one of the 106 woredas of the Amhara Regional State and found in South Gondar Zone. The climatic zone is classified as dega, weyna dega and kola It has common borders with Dera in the south, Andabet in the west, Simada in the North West, and Farta in the North East and Gaynt in the north. It is situated at 11^0 40N latitude and 38^0 10' E longitude. Mekane Eyesus is the capital of the woreda. It is found 653 km from Addis Ababa and 114 km from the Regional city, Bahir Dar. The woreda is districted with 36 rural kebeles and 6 urban administrative distinct.

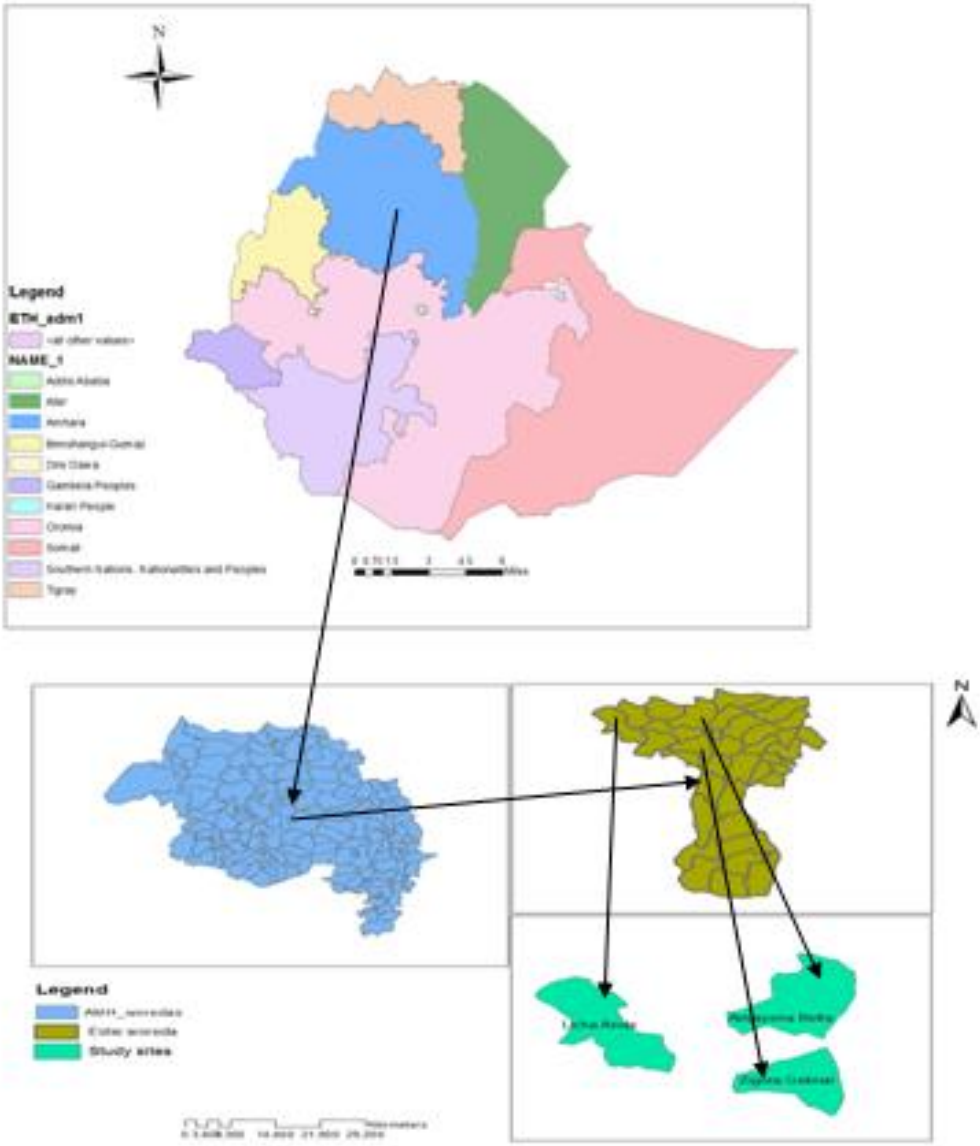

Figure3. 1 map of study area

Figure3. 1 Map of study area and study sites

3.1.2 Irrigation practice

The irrigation practice in Estie is not recent but it is ancient phenomena. Farmers have traditionally erected small stone or pole and brush weirs in the riverbed to make simple diversions in rivers and streams. Groups of farmers sharing an inlet excavate the gravity canals and construct the simple river water diversion structures. The inlet canals run over several kilometers even crossing gorges and small rivers over bore woods before reaching the sites where the irrigated lands are situated. These traditional structures require significant maintenance, and they are easily destroyed by floods, needing partial or full reconstruction almost annually. In addition, water control is difficult, resulting in large fluctuations of river water supply at the inlet and through canals.

According to Alvarez et al, (2014) Replacement of traditional weirs with a proper intake structure constructed of durable materials is a first step towards enhancing water control, reducing annual reconstruction and water losses, and allowing larger areas to be irrigated. Due to this the Government and donors as well as private sectors are involved in improvement of traditional small-scale irrigation construction with concrete or masonry weirs and other inlet structures. The government of Ethiopia in collaboration with non-Governmental organizations has built seven different SSI structures in Estie.

The irrigation agricultural production of Estie woreda is increased from year to year as shown in table 3.1

Table3. 1 irrigated land of Estie woreda (2003-2007)

Year	2003	2004	2005	2006	2007
Irrigated land(ha)	6654	8754.5	9694.5	11165	13700

Source: Estie woreda agricultural and rural development office annual reports (2003-2007)

For this increment the communities of the woreda used different irrigation technologies. As shown in table 3.2.below use of motor pumps and traditional river diversions accounts majority of irrigated land.

Table3. 2 irrigated land and irrigation technologies in the study area (Estie**)**

No	Scheme type	Modern					Traditional				
		Scheme no	Irrigated land	No of beneficiaries			Scheme no	Irrigated land	No of beneficiaries		
				M	F	T			M	F	T
1	river diversion	5	405	1167	133	1300	219	7846.86	26631	1526	28157
2	earthen dam	1	29	588	47	635					
3	pedal pump	99	2.5	5	1	6					
4	Pond	2	4.2	12	2	14					
5	Spring development						623	503	1054		7293
6	hand dug well						2828	91	2037	395	2432
7	motor pump	782	4251.5	11527	2191	13718					
8	drip irrigation	2	0.5	2	-	2					

Source: Estie woreda agricultural and rural development office annual reports (2007)

The methods of irrigation in the study area are mostly furrow irrigation and to some extent wild flooding. In case of wild flooding water is distributed over the farm land without any restricted boundary as shown in fig 3.3. This method of irrigation may result poor distribution uniformity whether they may be deep percolation loss or runoff loss, mostly runoff may occur.

Figure3. 2 practice of water distribution over the farm land

3.1.3 Description of study sites

3.1.3.1 Gomit irrigation project

Gomit irrigation project is found in South Gondar zone, Estie woreda 9km to the North direction of the woreda capital, Mekane Eyesus. It is micro earthen dam constructed by Co -S A E R A R in 2004. The climatic condition of the project area is w/dega with annual rainfall ranging from 1020-1900mm and mean monthly temperature 17.4^0 which are taken from Bahir dar meteorology agency of mekane Eyesus meteorology station. The dominant soil type of the command area is deep heavy clay and the infrastructure of this project is designed to irrigate about 90ha of land.

3.1.3.2 Gumara irrigation project

This irrigation project is located mainly at LichaMeskel Kebele of Este woreda in South Gondar Zone of Amhara Region. The project is constructed in 2004 and is located about 24kms away from Este (Mekane Eyesus). This irrigation project is undertaken on Gumara River to irrigate command area of 60ha and the headwork structures are specifically located at an altitude of about 2280 masl and geographical coordinates of $11^o37'$ N latitude & $37^o55'$E Longitude.

3.1.3.3 Chena irrigation project

Chena irrigation project is situated in Belta-Amjaye kebele of Estie woreda, South Gondar zone of the Amhara region. This project is constructed to irrigate a total command area of 90ha and is located to the North 6km far from Mekane Eyesus Town (district of Estie woreda), 52km from Zonal capital (Debretabor), and 114 km from Bahir Dar (Regional main town). Traditional irrigation practice was common around this project area by using Chena River. Potato and onion are the major crops grown by irrigation.

3.2 Sample size

It may not be necessary or possible to include the whole small scale irrigation structures due to time and resource limitations. Therefore a sample may be drawn to represent the total. There are seven modern SSI structures in the study area (Estie) which are owned by the community. These schemes are Gomit (SS earthen dam), upper Gumara (weir), lower Gumara (weir; new); Chena (new, 2006 diversion weir), Mebreg (weir with steel metal), tiritrat (weir) and licha (weir, 2007). Out of these, three schemes and three plots from each were selected for this study.

3.3 Sampling technique

Systematic sampling technique has used in sample size determination. Out of seven modern SSI schemes constructed in the study area, three schemes were selected systematically based on their geographical location. For example upper Gumara, lower Gumara, licha and Mebreg are found in the same territorial class, Gomit and tirtriat in another territory as well as Chena which is found alone in a new territory. Therefore upper Gumara (oldest), Gomit (earthen dam) and Chena were selected for the study.

3.4 Data collection

3.4.1 Primary data collection

Actual field investigation and measurements or survey works including simple observations of scheme at the sites is required to collect the necessary data to know the present condition of the scheme. These Primary data were collected from February to April includes Daily field observation of practices related to water delivery and application, Photograph and video of the site and structure, Flow measurement (discharge) along the canal and at field inlet, Field dimensions like width, length, slope and shape, Cutoff time, flow resistance, furrow spacing, Geographical coordinates (longitude & latitudes) of the scheme. In addition the primary data which require questionnaires, Interview of technical experts like DAs and WUA members as well as sample beneficiaries and Discussions with irrigation water users, water use association committees and development agents (DAs) were carried out in June and July. The flow discharges along canals in the study area were measured with floating method with 10cm width interval and the flow discharge at the field inlets were measured with buckets.

After measuring the discharge at a certain intervals of canal, the average discharge was estimated and this discharge was used to estimate the amount of water diverted in the year 2015. Mostly the season of irrigation cropping goes from January to end of May, and the amount of water diverted in these months were estimated as

Total diverted discharge = canal discharge *total days of irrigation season

Gumara 0.0147m^3/s*150day*24hour/day*60min/hr*60sec/min = 190512m3

Chena 0.018m^3/s*150day*24hour/day*60min/hr*60sec/min = 233280 m3

Gomit 0.019m^3/s*150day*24hour/day*60min/hr*60sec/min =246240 m3

There for Total amount of water diverted for the year 2015 = 190512 m3, 233280 m3 and 246240m3 for Gumara, Chena and Gomit respectively

3.4.2 Secondary data

The important secondary data were collected in June and July and these data includes: Annual irrigation reports of the sites, Meteorological and Hydrological data, Soil and Crop data, Design documents of a scheme, irrigated land and area to be irrigated, Operation and Maintenance costs, water management rules, regulations and standards set by the community.

Irrigated land Crop production output*:* Based on the collected data of Annual irrigation reports of the sites and of planting and harvest of each crop for the year of 2015, the agricultural out puts of each scheme are tabulated as follows.

Table3. 3 Total output of GUMARA for the year 2015

Crop	Area (ha)	Production in Qt/ha	Production in Qt.	Unit price(birr/Qt)	Total output in birr
Onion	5	60	300	900	270,000
Garlic	4	22	88	5400	475,200
Potato	47	210	9870	110	1,085,700
Barley	4	20	80	700	56,000
Maize	2	30	60	450	27,000
Total	62	486	17046	……	1,913,900

Source: kebele development agent (DA)

Table3. 4 Total output of CHENA for the year 2015

Crop	Area (ha)	Production in Qt/ha.	Production in Qt.	Unit price(birr/Qt)	Total output in birr
Potato	28	200	560	150	840,000
Onion	3.28	68	223	900	200700
Garlic	2.23	23	51.29	5400	276966
Cabbage	1.92	194	372.48	140	52147.2
Tomato	0.16	104	16.64	1200	19968
Beet root	0.16	134	21.44	1000	21440
Total	35.75	723	1244.85		1,411,221

Source: kebele development agent (DA)

Table3. 5 Total output of GOMIT for the year 2015

Crop	Area (ha)	Production in Qt/ha	Production in Qt.	Unit price (birr/Qt)	Total output in birr
Onion	15.25	50	762.5	900	686,250.00
Garlic	6.5	11	72	7000	504,000.00
Potato	5	110	550	170	93,500.00
Rup seed	0.25	15	3.75	3500	13125
Vetch	2	31	62	960	59520
Total	29	202.5	1446.125	……	1,356,395.00

Source: kebele development agent (DA)

Meteorological data which were collected from Bahirdar Meteorology Agency were tabulated as follows.

Table 3.6 Meteorological data of different station

Station	Year	Coordinates			Meteorological Variables
		X	Y	Z	
Debretabor	2004-2014	37.98°	11.89°	2612masl	Humidity,Sunshine,Wind speed
Mekane Eyesus	2004-2014	38.054°	11.61°	2374masl	Tmax,Tmin,Rainfall
Licha	2013-2014	37.885°	11.65°	2308masl	Rainfall

3.5 Materials used

The important materials used in this study are:

- Software like GIS Software ,Ms-Excel, cropwat, surface irrigation software (SURDEV)
- Data collection instruments like GPS and Video camera
- Soil data, Meteorological and Hydrological data for a site and basin, Design and feasibility documents of a site
- Flow Measuring Equipments Floater, stopwatch, water level, meter, note book, rope

3.6 Data sources

In addition to field measurement and actual field observation, the data available for this study were obtained from the past reports & files kept by responsible organizations or offices for further interpretation and analyses. Those data sources were:-Ministry of water and energy, Bahirdar meteorology agency, Amhara water works Design and supervision enterprise, Amhara water and energy bureau, Estie woreda agricultural and rural development bureau, Estie woreda cooperative promotion office, Kebele administrative of study sites, development agents of study sites, Administrative committees of sites, local communities of the study sites, Different literatures like FAO papers 56, FAO, 33 and internet etc.

3.7 Data analysis

The data obtained from primary and secondary sources were analyzed compared with standard and relative analyses of the schemes were carried out. In addition, those data were used as the input for the software to calculate performance indicators (efficiency and uniformity). Actual observation and onsite field evaluation of the sites were another method of analysis and evaluation.

3.7.1 Performance indicators

3.7.1.1 Agricultural output indicators

In the study area the four minimal comparative performance indicators developed by IWMI were used and determined by using the following formula (3.1-3.4).

- $o\text{ut putper croped area}(\frac{\text{birr}}{\text{m2}}) = \frac{\text{production}}{\text{irrigated croped area}}.$ ……..………………(3.1)
- $\text{out putper unit command}\left(\frac{\text{birr}}{\text{m2}}\right) = \frac{\text{production}}{\text{command area}}$ ……………………....(3.2)
- $\text{out putper irrigation supply}(\frac{\text{birr}}{\text{m3}}) = \frac{\text{production}}{\text{diverted irrigation supply}}$ ………………...(3.3)
- $\text{out putper unit water consumed}(\frac{\text{birr}}{\text{m3}}) = \frac{\text{production}}{\text{volume of water consumed by ET}}$ ………...(3.4)

Where:-

Production is the output of the irrigated area in terms of gross or net value of production measured at local or world prices,

Irrigated cropped area is the sum of the areas under crops during the time period of analysis,

Command area is the nominal or design area to be irrigated, diverted irrigation supply is the volume of surface irrigation water diverted to the command area, plus net removals from groundwater,

3.7.1.2 Water supply indicators

According to Molden *et al.* (1998) define several supply indicators were established for comparative purposes. Three below characterize the individual irrigation system with respect to water supply in the study area.

- Relative water supply (RWS) = $\frac{\text{Total water supply}}{\text{Crop demand}}$ …………………….………… (3.5)

- Relative irrigation supply (RIS) $= \frac{\text{Irrigation supply}}{\text{Irngation demand}}$………………………………(3.6)
- Water delivery capacity (%) $= \frac{\text{Canal capacity to deliver water at system head}}{\text{Peak consumptive demand}} \times 100$ …………. (3.7)

Where;

Total water supply = Surface diversions plus net ground water draft plus rainfall

Crop demand = Potential crop ET, or the ET under well-watered conditions (NCWR).

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

Both RWS and RIS relate supply to demand, and give some indication as the condition of water abundance or scarcity, and how tightly supply and demand are matched (Molden *et al.* 1998) Relative irrigation supply indicator is appropriate to characterize the irrigation system performance with respect to water supply since it informs managers whether sufficient water is being supplied to meet the total crop water demand or not (Kharrou *et al*, 2013).

3.7.1.3 Financial indicators

In addition to agricultural and water supply indicators Molden et al. (1998) developed two financial indicators which can be described as follows.

Gross return on investment $= \frac{\text{Production}}{\text{cost of irrigation infrastructure}}$ ………. ……….................. (3.8)

From the design documents of the schemes the grand total cost of the whole infrastructure system and its cost per hectare of Gomit, Chena and Gumara irrigation projects were estimated to be 551324.95(6125.84), 1961279.21(21791.99) and 245040(4084) respectively. The cost of the distribution system (irrigation infrastructure) can either be estimated from original costs, or estimated by using present costs of similar types of infrastructure development (Abdu and Sileshi ,2005).

$\text{PNW} = \text{initial}\frac{\text{cost}}{\text{ha}} * (1 + \text{r})^{n}$………………………………….. …………………...... (3.9)

Where PNW=present net worth, r=interest rate and it is taken from design document of Gomit irrigation project (0.13), n=years from construction.

Then cost of delivery system (cost of infrastructure) =PNW*command area

Financial self sufficiency $= \frac{\text{Revenue from irrigation}}{\text{Total O\&}M\ expenditure}$ …………………………….......... (3.10)

Revenue from irrigation is the revenue generated, either from fees, or other locally generated income, and Total O & M expenditure is the amount expended locally through operation and management. These costs in the study sites were collected through interview of irrigation experts of sites and local administrator (WUA) as well as Estie woreda cooperative promotion office audit reports and are tabulated as follows.

Table3. 6 Revenue from irrigation, operation and maintenance costs of each irrigation scheme

Scheme name	Expenditures for				Total income from			
	Operation (birr)	Maintenance (birr)	Administration (birr)	Total	Water fees (birr)	Farmers contributions (birr)	Out sanding dept payment (birr)	total
Gumara	140	720	170	1030	…..	880	3866.7	4746.7
Chena	400	……	366	766	1460	310	56.48	1826.5
Gomit	1200	…..	……	1200	……	……..	1031.37	1031.4

Source: Estie woreda cooperative promotion office audit report 2015 E.c

3.7.2 Surface irrigation Design, and Evaluation software description and application

The SURDEV package consists of three software programs for surface irrigation: BASDEV for irrigation of basins; BORDEV for irrigation of borders; and FURDEV for irrigation of furrows.

BASDEV, BORDEV and FURDEV can solve many problems of surface irrigation design, operation and evaluation, and can compare the options of a single irrigation method and of several different methods. We have categorized the many variables involved in surface irrigation according to whether they are field parameters, decision variables or evaluation variables (Feyen et al, 2001)

3.7.2.1 Field parameters

Field parameters are situational data (i.e. data that describe the field situation) and are not variables in the true sense of the word, because a design engineer or farmer cannot assign them another value. Field parameters always include the infiltration characteristics, the surface Roughness or flow resistance and the required irrigation depth. In border and Furrow irrigation, the gradient in the downstream direction is also a field parameter, in furrow irrigation; the shape and spacing of the furrow are limited-choice field parameters.

Flow resistance (n) is a basic input parameter in simulations of surface irrigation, which has a direct effect on flow velocity and, consequently, on advance time, infiltration pattern and total irrigation performance. The higher the flow resistance the longer the advance time, the longer the advance time the more non-uniform the infiltrated-depth distribution. Manning's roughness coefficient n meant for steady uniform flow in canals is also commonly used for surface irrigation. When investigating furrow infiltration, Fangmeier and Ramsey (1978) found n-values that ranged between 0.02 and 0.04.

Table3. 7 Recommended values of n (Manning's roughness coefficient) for basins and borders

n value	Conditions
0.04	Smooth, bare soil surface; row crops
0.10	Drilled, small-grain crops, drill rows in flow direction
0.15	alfalfa, mint, broadcast small grains
0.20	dense alfalfa or alfalfa on long fields without secondary ditches
0.25	dense sod crops and small grains, drilled perpendicular to flow direction

Source: Feyen et al 2001

Required depth (Drq): is another; ask input parameter in simulations of surface irrigation. The maximum required depth can be determined from the total soil-moisture holding capacity, i.e., the total moisture available between field capacity and wilting point (TAM) and the allowable depletion fraction, called the readily available moisture content (RAM)**.**Together with an assumed rooting depth, this gives the maximum depth to which the soil can dry out and the depth the irrigation water supply must reach by the end of an irrigation interval. For a given or estimated evapotranspiration rate, this maximum depth fixes the maximum irrigation interval (Feyen et al 2001).

Field slope and non-erosive velocity*:* For graded borders and furrows, the field slope *(So)* should not be too high (to prevent erosion) or too low (to prevent slow advance). The flow velocity in graded furrows should not exceed a maximum non-erosive value (Vmax,). The value of Vmax depends on the soil type. Usually, it ranges between about 8-10m/min in erosive silt soils and about 13-15 m/min in more stable clay and sand soils, with the highest values occurring in the first part of the furrow, down the inlet (Walker and Skogerboe 1987**).**

In simulations of flow in furrows, the furrow slope and the maximum non-erosive flow velocity are related to the maximum permissible inflow (q_{max}) with the equation.

$$q_{max} = (V_{max} C_1 \left(\frac{n}{So^{0.5}}\right) C_2)^{\frac{1}{1-C_2}} \dots \quad (3.11)$$

Where n is the flow resistance and *So* is the furrow slope. The coefficients C1 and *C2* depend on the furrow geometry. For triangular geometry

$C_1 = \delta_1 \, (\tau_1^{0.67}/\delta 1^{1.67})^{c2}$, $c_2 = 3\,\delta_2/5\,\delta_2 - 2\,\tau_2$, where $\delta_1 = z$, $\delta_2 = 2$, $\tau_1 = 2\sqrt{z^2}+1$, $\tau_2 = 1$

Furrow spacing (W,): The distance from centre to centre of two adjacent furrows, is in fact a dual-purpose parameter. It is clearly a field dimension used primarily to convert volumes to depths (D = Q / [LW,]), but it is also an input that assists in the modeling of the infiltration process. In simulations of flow in furrows, it is assumed that infiltration from the furrow spreads out over the width of the furrow spacing and then is entirely vertical below a certain depth. W, is used to convert the A and k values corresponding to the modified SCS intake families.

Furrow geometry: To simulate surface flow, there must be a means to relate the flow rate to the flow cross-section. For basins and borders the situation is fairly simple, flow is assumed to be uniform over the field width, therefore it is a two-dimensional process: only the head-to-tail direction and the flow depth are involved. Infiltration happens only in a vertical direction and so can be calculated per unit of width. Furrows are a bit more complicated. Furrows are miniature channels in which the relation between the top width of the flow section and the flow depth varies with the flow size and with the various shapes the furrow channel can have. Moreover, infiltration takes place along the wetted perimeter, which varies with the flow depth. Consequently, the geometric (or cross-sectional) parameters of furrows require further scrutiny. In simulations of flow in furrows, it is common practice to use Manning's equation to describe surface flow. Manning's equation reads

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \dots \quad (3.12)$$

In which Q is the furrow flow rate, S is the furrow slope, n is the flow resistance, **A** is the wet cross-section, and R is the hydraulic radius.

3.3.6.2 Decision variables

Design can be focused on the determination of one or more of the decision variables: flow rate, field length, field width and/or cutoff time. Available computer programs one can calculate field dimension and cutoff time, or the field dimensions are fixed and the computer programs can calculate the flow rate and cutoff time. Performance indicators are always obtained as a result. Surface irrigation mostly furrow irrigation is the main irrigation practiced in the study area (Estie). FURDEV is a modular, menu-driven computer program developed to solve problems in the design, operation and evaluation of furrow irrigation systems. FURDEV deals with the flow in one furrow and does not provide suggestions for field layout design.

Decision variables are those parameters or variables that a design engineer can manipulate to find the best irrigation performance for given or selected field parameters. The decision variables in surface irrigation are normally the field dimensions (length and width), the flow rate and the cutoff time. The main design consideration in surface irrigation is usually the choice of the appropriate combination of field dimensions, flow rate, and cutoff time. (Feyen et al, 2001)

Field dimensions: For basins and borders, the field dimensions are width (W) and length (L). For furrows, there is only one field dimension: the furrow length. Furrow spacing is important only in the context of field parameters. In simulations, field dimensions can be either the input to determine the required flow rate, or the output of such a simulation, to assist a designed evaluator who needs to know the best field dimensions for a given flow rate.

Flow rate: For basins and borders, there is a total flow rate *(Q,)* for the field. The flow rate is divided by the field width to obtain a unit flow rate (q_o,) per meter of width, and the result is used in the theoretical analysis. For furrows, q is the rate of inflow into one furrow, which is the unit flow rate per width of one furrow spacing. Flow rate is a key variable that affects the outcome of an irrigation event because it influences the advance time of the inflow and, consequently, the irrigation uniformity, efficiency, and adequacy. In simulations, flow rate can be either an input (chosen by the designer/ evaluator or dictated by the existing supply conditions) or the outcome of one or more simulations that the designer/evaluator makes while searching for the best flow rate.

Cutoff time: Cutoff time (Tco) is the amount of time that elapses from the start of irrigation to the cutoff of the inflow. In simulations, cutoff time can be either input or output, as with the other decision variables. If cutoff time is substantially later than advance time, this will have a clear effect on the deep percolation and surface runoff losses. If cutoff occurs too early, infiltration to the required depth will often not happen at the end of the field. So, clearly, there are limits to the value that you can choose for the cutoff time, to achieve good irrigation performance (Feyen *et al*, 2001)

Cutback ratio, advance time ratio and tailwater reuse ratio: The cutback ratio, advance time ratio, and tailwater reuse ratio enter the simulation picture when you reduce inflow after some time or when you reuse tail water runoff. This means that the three ratios are not relevant to basin irrigation.

The cutback ratio (CBR), which is defined as the ratio of reduced flow rate or cutback flow rate (Qcb) to initial flow rate (Q,), must be such that the reduced flow is sufficient to keep the entire field length wetted for the required time, while reducing the surface runoff. For ease of simulation, the usual assumption is that cutback occurs when the water has reached the end of the field. In simulations, the CBR is always input.

The advance time ratio (ATR) is defined as the ratio of advance time (Ta) to cutoff time (Tco). ATR is of special interest in cutback furrow or border systems. **A** small advance ratio means a fast advance, denoting a high flow rate. In simulations, ATR can be either input or output.

The tail water reuse ratio (TRR) is defined as the portion of the surface runoff that is reused. With the TRR, one can calculate the application efficiency directly. A TRR, of 1.0 though ideal may not always be possible to achieve because the costs involved may be too high. In simulations, the TRR is always input.

3.3.6.3 Evaluation variables

Evaluation variables are basically yardsticks for determining the combination of decision variables and field parameters that will produce the best irrigation performance. In most cases, the quality of an irrigation application is judged in terms of adequacy (i.e., whether sufficient water was supplied to the field), efficiency (i.e., a relative measure of how much water is "lost" during irrigation), and uniformity (i.e., the distribution of infiltrated water depths over the length of the field). The primary irrigation performance indicators are: Storage efficiency, application efficiency and distribution uniformity.

3.3.6.4 Calculation modes in SURDEV

The four modes appear when you select the Calculation menu. Calculation Modes **3** and **4** are the most essential modes for all three programs, BORDEV, BASDAV and SURDEV

Calculation Mode **1:** Flow Rate

Calculation Mode 1 is primarily for design purposes, when you know the length of the furrow and want to know the approximate flow rate that is needed to achieve a reasonable performance. The program will also give you the required cutoff time and the primary performance indicators as well as various depth and time parameters. Although the result obtained inMode 1 is close to these targets, it is advisable to continue running in Modes 3 and or 4, because in most cases refinements will still be necessary.

Calculation Mode 2: Furrow Length

Calculation Mode *2* is the reverse of Calculation Mode 1: the flow rate is now known and you want to know the approximate furrow length that is needed to achieve a reasonable performance. The program will also give you the required cutoff time and the primary performance indicators as well as various depth and time parameters. Here too it is necessary to continue in Modes 3 and/or 4 to get the final result.

Calculation Mode 3**:** Cutoff Time

Here, both the flow rate and furrow length are input. The required cutoff time is the resulting design variable, while also the application efficiency and secondary output parameters are given. Note, in this mode the advance ratio is an output. This is because it is impossible to **fix** advance ratio, length, and flow rate and at the same time satisfy the requirement that the minimum infiltrated depth equals the required depth.

Calculation Mode 4**:** Minimum Depth

Here, the cutoff time is also specified as input, in addition to the furrow length and the flow rate. Thus, all design variables are now input, which means that the required depth at the end of the field will usually not be achieved (ie, that under and/or over-irrigation can occur). The minimum infiltrated depth that occurs at the far end of the field is the determining factor of whether there is under or over-irrigation. It is therefore given as first output, followed by the primary performance indicators: application efficiency, storage efficiency and distribution uniformity. This mode is most suitable for a performance evaluation of an existing furrow irrigation system and for testing the performance sensitivity to a change in the field parameters.

CHAPTER FOUR

4. Result and discussion

4.1 Crop water and Irrigation requirement

According to (FAO, 2014), CropWat 8.0 Windows is a program that uses the FAO (2004) Pen-man-Monteith method for calculating reference crop evapo-transpiration (ETo). For the computation of ETo and effective rainfall, Daily rainfall and temperature (maximum and minimum) data of Mekane Eyesus and licha (2013 and 2014) meteorological station from 2004 to 2014 and also the same year daily Relative humidity, wind speed and sunshine hour data of Debre Tabor meteorological station were collected from Bahir dar meteorological agency. These estimates (ETo and Pe see appendix 3) were used in crop water requirement calculations.

Crop Water Requirement (CWR) = $ET_0 \times Kc - Pe$, where, Kc is the crop coefficient, ETo is reference crop evapo-transpiration and Pe, is the effective rainfall calculated by USDA soil conservation service method (T. A. Obreza and D. J. Pitts, 2002).

Total net crop demand for season =CWR c_1* (area a_1 / area total) + CWRc_2* (area a_2/ area total) + etc. =

Where c_1=crop type$_1$ grown at area$_1$, c_2=crop type$_2$ grown at area $_2$… in that season

After collecting the information on the various crop characteristics such as length of the growth cycle, crop factors, rooting depth, etc., crop water requirements and irrigation requirement of each crop for each scheme was calculated using CROPWAT 8.0

Table4. 1 CWR and IR of Gumara irrigation project for each crop

Crop	Area (ha)	Crop water requirement (mm/season)	Ne irrigation requirement (mm/season)
Onion	5	354.6	264.3
Garlic	4	354.6	264.3
Potato	47	399.4	172.6
Barley	4	419.1	305.8
Maize	2	626	425.6
Total	62	2153.7	1432.6

Table4. 2 CWR and IR of Chena irrigation project for each crop

Crop	Area (ha)	Crop water requirement (mm/season)	Ne irrigation requirement (mm/season)
Potato	28	397.5	333.1
Onion	3.28	426.4	362
Garlic	2.23	354.6	301.7
Cabbage	1.92	354.6	301.7
Tomato	0.16	420.7	356.2
Beetroot	0.16	363.8	316.5
Total	35.75	2318	1971.2

Table4. 3 CWR and IR of Gomit irrigation project for each crop

Crop	Area (ha)	Crop water requirement (mm/season)	Net irrigation requirement (mm/season)
Onion	15.25	354.6	301.7
Garlic	6.5	354.6	301.7
Potato	5	464.3	378.2
Rup seed	0.25	363.8	316.5
Vetch	2	399.4	334.9
Total	29	1937	1331.3

4.2 Scheme Irrigation requirement

FAO CROPWAT is a computerized irrigation management program for the calculation of crop water consumption and irrigation requirements based on soil, climate and crop data. The program allows the development of irrigation schedules for different management and water stress conditions and the calculation of water supply for varying cropping patterns ((FAO, 2014). Scheduling involves the application of irrigation water based on a systematic monitoring of crop soil-moisture requirements. Using climate data, cropping pattern, planting dates and area covered by each crop (%), the scheme irrigation requirement was calculated with CROPWAT8.0 for the year 2015.

Table4. 4 result of net scheme irrigation requirement for each scheme in l/s/h

Gumara

Net scheme irr.req.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
in l/s/h	0.23	0.29	0.44	0.16	0	0	0	0	0	0	0	0

Chena

Net scheme irr.req.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
in l/s/h	0.22	0.39	0.49	0.17	0	0	0	0	0	0	0	0

Gomit

Net scheme irr.req.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
in l/s/h	0.27	0.38	0.45	0.13	0	0	0	0	0	0	0	0

This result shows that the peak irrigation requirement for each scheme occurs on March and has values in (l/s/ha) 0.44, 0.49 and0.45 for Gumara, Chena and Gomit respectively. In order to calculate water delivery capacity (%) of the schemes, canal capacity at system head (l/s) were obtained from the field measurement and peak irrigation requirement (l/s/ha) is the result of CROPWAT8. Therefore the peak demand for each scheme is estimated as follows.

Peak consumptive demand (l/s) = peak irrigation requirement (l/s/ha)* Irrigated area (ha) at that season

Table4. 5 peak consumptive demand of each scheme

Scheme	peak flow(l/s/ha)	area(ha)	peak demand(l/s)	canal capacity(l/s)	WDC	WDC (%)
Gumara	0.44	62	27.28	14.7	0.538856305	53.8856305
Gomit	0.45	29	13.05	19	1.455938697	145.5938697
Chena	0.49	35.75	17.5175	18	1.027543885	102.7543885

4.3 Comparative performance indicators

The four basic comparative performance indicators relate output to unit land and water. These "external" indicators provide the basis for comparison of irrigated agriculture performance. To calculate those performance indicators, diverted irrigation supply and Volume of water consumed by ET has to be calculated as follows.

Diverted irrigation supply (in mm) =total diverted discharge/total irrigated area

Diverted irrigation supply (in mm) for: Gumara=190512m3/620000m2=0.3073m=307.3mm

Gomit =246240m3/290000m2=0.8491m=849.1mm

Chena =233280m3/357500m2=0.65253m=652.53mm

Volume of water consumed by ET is the actual evapotranspiration of crops =NCWR*Irrigated area. The calculated results are shown below.

Gumara = (401.48/1000)*62*10000=248917.6m3

Gomit = (376.68/10000)*29*10000=109237.2m3

Chena = (395.12/1000)*35.75*10000=141255.4m3

Using the data of production collected from tables 3.3to 3.5 those indicators were calculated as follows.

Table4. 6 result of Irrigated agricultural output indicators

Indicators	Equation	Result with respect to scheme		
		Chena	Gomit	Gumara
out putper croped area$\left(\frac{\text{birr}}{\text{m2}}\right)$	$\frac{production(P)}{irrigated\ croped\ area}$	3.95	4.68	3.087
out putper unit command $\left(\frac{\text{birr}}{\text{m2}}\right)$	$\frac{\text{production(P)}}{\text{command area}}$	1.57	1.51	3.19
out putper irrigation supply$\left(\frac{\text{birr}}{\text{m3}}\right)$	$\frac{\text{production(P)}}{\text{diverted irrigation supply}}$	6.05	5.51	10.05
out putper unit water consumed$\left(\frac{\text{birr}}{\text{m3}}\right)$	$\frac{\text{production(P)}}{\text{volume of water consumed by ET}}$	9.99	12.42	7.69

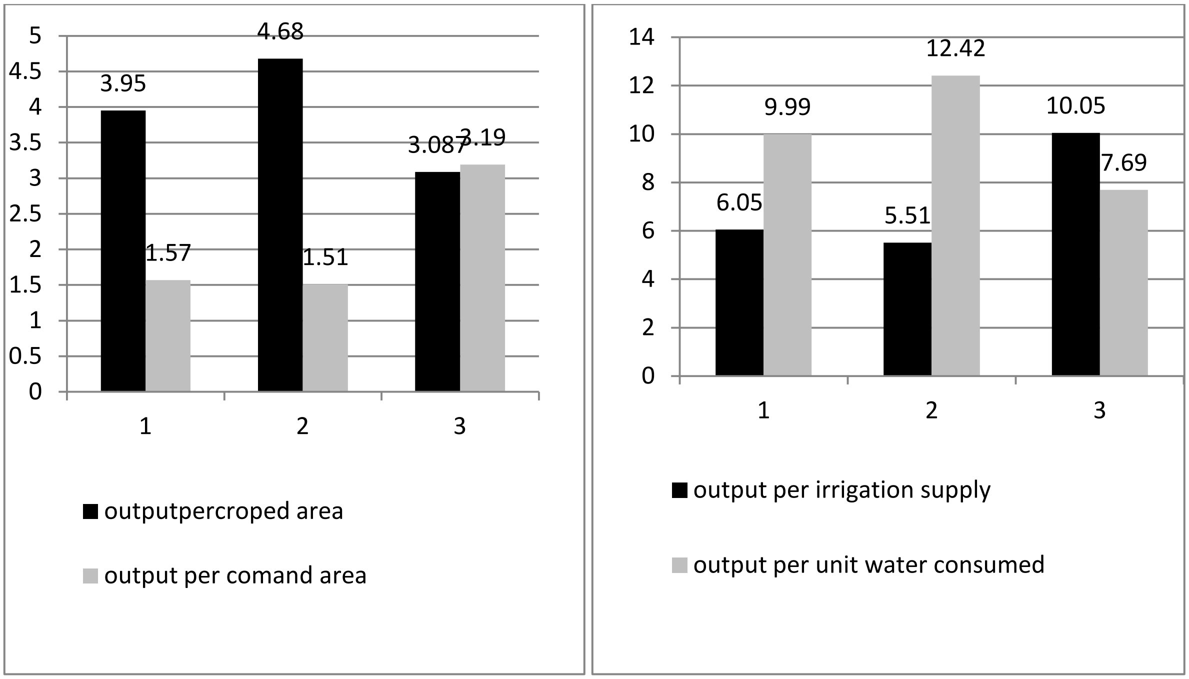

Figure4. 1 diagram of agricultural output indicators

As it is observed from the table and from the chart Gomit irrigation project has highest output per cropped area (4.68) followed by Chena (3.95). This highest value of Gomit is attained due to great attitude of farmers in producing market oriented crops and their well experience of irrigation practice. In addition to this both projects (Gomit and Chena) are located near the town (Mekane-Eyesus) to put on goods on the market rather Gumara is located too far from the town (Mekane Eyesus). However Gumara has highest output per command area.

In the case of output per irrigation supply Gumara has the highest value (10.05) implying that Gumara is better in effective utilization of water. That means the return per meter cub of water is highest in Gumara compared to other two schemes. But as the indicators are comparative we can’t say that Gumara achieved the required performance. Using the rainfall in a better way than Gomit and Chena, Gumara contributes for this higher value of output per irrigation.

Water supply indicators: Assuming no ground water contribution and Based on the data obtained from CROPWAT output and data collected from primary and secondary sources, these supply indicators were calculated and tabulated as follows.

Table4. 7 result of water supply indicators

Scheme	Total water supply (mm) Irrigation supply + pp*	Crop demand	Irrigation Demand	Irrigation supply	Water Supply indicators		
					RWS	RIS	WDC (%)
Gumara	834.3	401.48mm	202.67mm	307.3mm	2.08	1.52	0.54
Gomit	1194.4	395.12mm	317.31mm	849.1mm	3.17	2.68	1.46
Chena	998	376.68mm	332.13mm	652.53mm	2.53	1.96	1.03

Pp* = precipitation

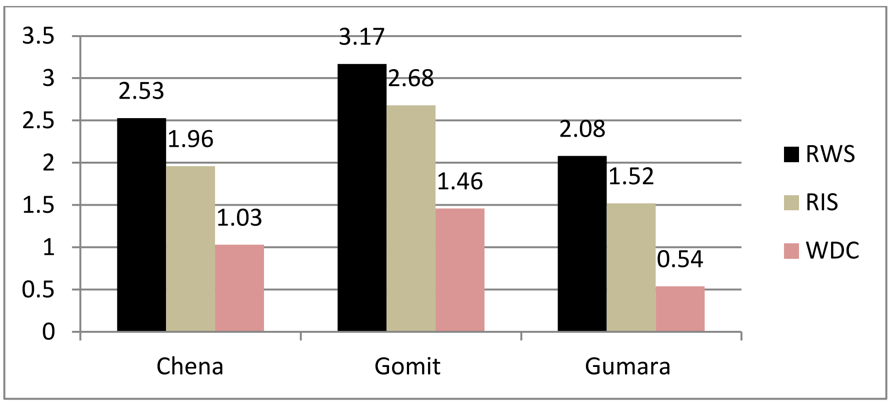

Figure4. 2 diagram of water supply indicators

Relative irrigation supply indicator is appropriate to characterize the irrigation system performance with respect to water supply since it informs managers whether sufficient water is being supplied to meet the total crop water demand or not (Kharrou *et al*, 2013). It is defined as the ratio between the irrigation water applied to a specific crop (IWS, mm) and the net irrigation water requirements of that crop (IWR, mm) (Sanchez *et al*, 2014). In the study area the values of RIS in Gumara, Gomit and Chena were 1.52, 2.68 and 1.96 respectively as shown in the table and chart below. The respective values of RWS of Gumara, Gomit and Chena were 2.08, 3.17 and 2.53. Gomit has highest value of RWS (3.17) and RIS (2.68) which are greater than 2 indicates that, there was a generous supply of irrigation water.

As it is observed from the table and from the chart, those values are greater than 1 which indicates that irrigation supply exceeds net irrigation requirement. To compare each irrigation scheme with respect to RIS Gomit irrigation project has higher irrigation supply while Gumara irrigation project has lowest irrigation supply but higher net irrigation demand. The lowest value of RWS and RIS in Gumara is not mainly the result of poor management rather the decreasing capacity of water supply from the source and losses through the canals.

The water delivery capacity of the scheme shows the capacity of the main canal to convey the maximum peak consumptive demand i.e. the ratio of canal capacity at system head to maximum consumptive demand. The water delivery capacity of Chena, Gomit and Gumara is 1.03, 1.46 and 0.54 respectively. This result shows that Gomit irrigation project is better in delivery of water followed by Chena rather Gumara is poor in this case. The lowest value of WDC (0.54) which is less than 1 in Gumara is an indication of canal capacity at peak time of crop demand is below the requirements while in the other two schemes canal capacity at peak time of crop demand is beyond the requirement.

Financial indicators: before we calculate the two financial indicators, PNW of each scheme has to be calculated using equation (3.9).

- Gross return on investment (GRI) =production/cost of irrigation infrastructure

Gomit PNW = 6125.84birr/ha*(1+0.13) ^11=23497.84
Gomit cost of delivery system=23497.84birr/ha*90ha=2114805.96birr
Gomit GRI =1,356,395.00birr/2114805.96birr= 0.64138=64.14%
Gumara PNW = 4048birr/ha*(1+0.13) ^11= 15665.66birr/ha
Gumara cost of delivery system=15665.66 birr/ha*60ha=939939.416birr
Gumara GRI =1,913,900birr/939939.416birr= 2.036195=203.6%
GRI for Chena =1,411,221/1961279.21 = 0.72=72%

- Financial self-sufficiency = Revenue from irrigation/Total O&M expenditure

Using the data from table 3.6 FSS can be calculated as
For Gumara = 4746.7birr/ 1030birr = 4.61
For Chena =1826.48/766 birr =2.38
For Gomit =1031.37/1200= 0.86

Table4. 8 financial indicators output

Financial indicators	Gomit	Gumara	Chena
FSS	0.64138	2.0362	0.72
GRI	0.86	4.61	2.38

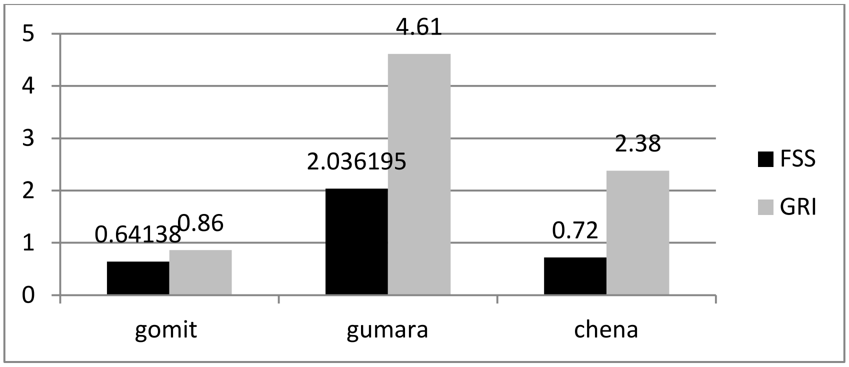

Figure4. 3 diagram of financial indicators

As it is observed from the above table the GRI of Gomit is lowest showing that its cost of irrigation infrastructure is high. The highest value of GRI in Gumara indicates its highest rate of return on investment. The calculated value of FSS in Gomit is least indicating that it expends much money to O&M and FSS in Gumara is highest which indicates that sufficient revenue from irrigation have been collected.

4.4 Existing condition of irrigation efficiency

Gomit irrigation project*:* Three samples were taken having 60 m, 110m and 80m long furrows in Gomit irrigation scheme. Since The soil type is clay which can be classified by the soil intake family # 0.25. The net irrigation requirement found by CROPWAT8 is 41 mm for onion crop. The furrows have a triangular side slope of 1:1, a respective slope of 0.02, 0.03 and 0.008 with spacing of 60 cm. The data obtained from the field is tabulated below.

Table4. 9 field data of Gomit irrigation project

No.	Furrow characteristics	Plot 1=adisu wale	Plot 2= Kindu Enyew	Plot3=Dubale Asmamew
1	furrow length	60	110	80
2	Flow rate	0.36	0.42	0.44
3	Cutoff time (min)	30	40	35
4	Furrow spacing	0.6	0.6	0.6
5	Furrow slope	0.02	0.03	0.008
6	Soil type	Clay	Clay	Clay
7	Required depth	41	41	41
8	Side slope	1:1	1:1	1:1

Source: field survey (2015)

Calculation mode 4 is most suitable for a performance evaluation of an existing furrow irrigation system and for testing the performance sensitivity to a change in the field parameters (Feyen et al 2001). There for to know the existing efficiency of plot1 Select Mode 4 *(*Minimum infiltrated depth*)*. Then put the cutoff time, furrow length and the flow rate. Thus, all design variables are now input, which means that the required depth at the end of the field will usually not be achieved (i.e., that under and/or over-irrigation can occur). The minimum infiltrated depth that occurs at the far end of the field is the determining factor of whether there is under or over-irrigation. It is therefore given as first output, followed by the primary performance indicators: application efficiency, storage efficiency and distribution uniformity. The result of software for this plot (1) owned by Mr.Addisu Wale shows that Ea=77.8%, SRR=22.2%, DPR=0%, DPR+SRR=22.2%, E_a=100-22.2=77.8%, D_u=90.5%, Es=34.1%, Uc=96%, D_a=14mm, D_{min}=13mm, D_{max}=15mm (appendix 1 run no.4 and Fig 4.4)
Where Ea=application efficiency, SRR=surface runoff ratio, DPR=deep percolation ratio, Du= distribution uniformity, Es=storage efficiency, Uc=uniformity coefficient, Da=average applied depth, Dmin=minimum infiltrated depth, Dmax=maximum infiltrated depth

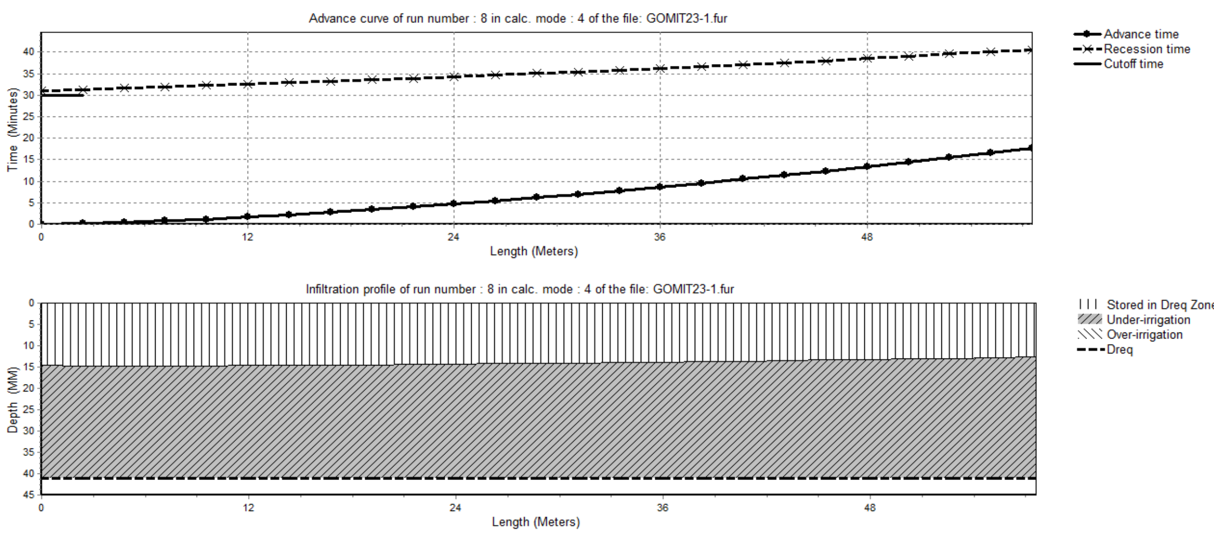

Figure4. 4 existing output graph of Gomit irrigation project plot1

As in the case of plot1 existing efficiency of plot 2 can be calculated. Then put the cutoff time, furrow length and the flow rate to the software. Result of software for this plot (2) owned by Mr.Kindu Enyew shows that Ea=95.1%, SRR=4.9%, DPR=0%, DPR+SRR=4.9%, Ea=100-4.9=95.1%, D_u=66.8%, Es=35.4%, Uc=87.3%, D_a=15mm, D_{min}=10mm, D_{max}=17mm. (appendix 1 run no.4 and Fig 4.5)

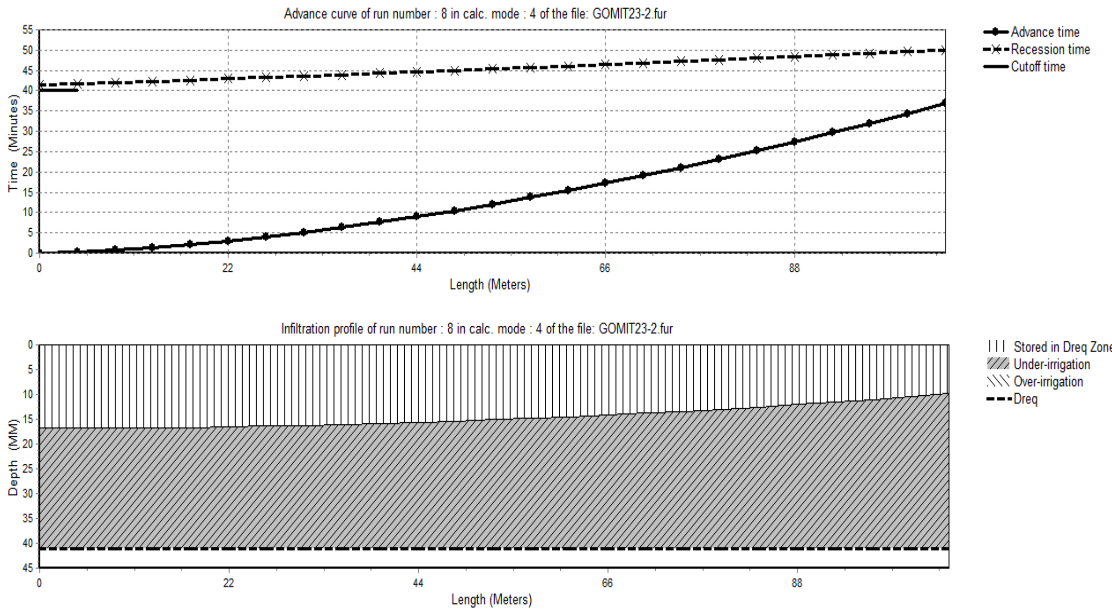

Figure4. 5 existing output graph of Gomit irrigation project plot2

The existing efficiency of plot 3 can also be calculated with the same procedure as in plot 1and 2. Put the cutoff time, furrow length and the flow rate obtained from the field to the software and run the program. Result of software for this plot (3) owned by Mr. Dubale Asmamew shows that Ea=85.7%, SRR=14.3%, DPR=0%, DPR+SRR=14.3%, Ea=100-14.3=85.7%, D_u=87.2%, Es=40.2%, Uc=99.4%, D_a=16mm, D_{min}=14mm, D_{max}=18mm (appendix 1 .run no.4 and Fig 4.6)

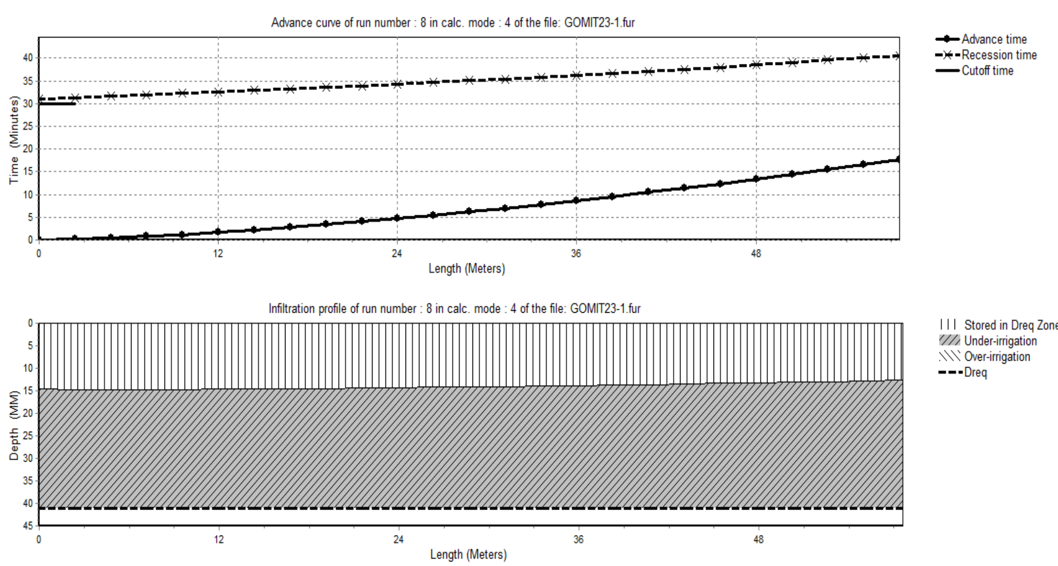

Figure4. 6 existing output graph of Gomit irrigation project plot3

Chena irrigation project*:* Three samples were taken having 75 m, 60m and 50m long furrows in Chena irrigation scheme. Since The soil type command area of the project is clay which can be classified by the soil intake family # 0.25. The net irrigation requirement found by CROPWAT8 is 41 mm for onion crop. The furrows have a triangular side slope of 1:1, a respective slope of 0.003, 0.008 and 0.02 with spacing of 60 cm. The data obtained from the field is tabulated below.

Table4. 10 field data of Chena irrigation project

No.	Furrow characteristics	Plot 1=Addisu Gebeyehu	Plot 2= Gulma Fenta	Plot 3=Desalegn Worku
1	furrow length	75	60	50
2	Flow rate	0.42	0.31	0.36
3	Cutoff time (min)	35	30	25
4	Furrow spacing	0.6	0.6	0.6
5	Furrow slope	0.003	0.008	0.02
6	Soil type	Clay	Clay	Clay
7	Required depth	41	41	41
8	Side slope	1:1	1:1	1:1

Source: field survey (2015)

Select Calculation mode 4 *(*Minimum infiltrated depth*)* to know the existing efficiency of plots. . Then put field parameters and decision variables, the cutoff time, furrow length and the flow rate to plot1. Thus, all design variables are now input, which means that the required depth at the end of the field will usually not be achieved (i.e., that under and/or over-irrigation can occur). The minimum infiltrated depth that occurs at the far end of the field is the determining factor of whether there is under or over-irrigation. It is therefore given as first output, followed by the primary performance indicators: application efficiency, storage efficiency and distribution uniformity. The result of software for this plot (1) owned by Mr.Addisu Gebeyehu shows that Ea=88.6%, SRR=11.4%, DPR=0%, DPR+SRR=11.4%, E_a=100-11.4=88.6%, D_u=81.7%, Es=42.4%, Uc=92.5%, D_a=17mm, D_{min}=14mm, D_{max}=19mm (appendix 1 run no.4 and Fig 4.7)

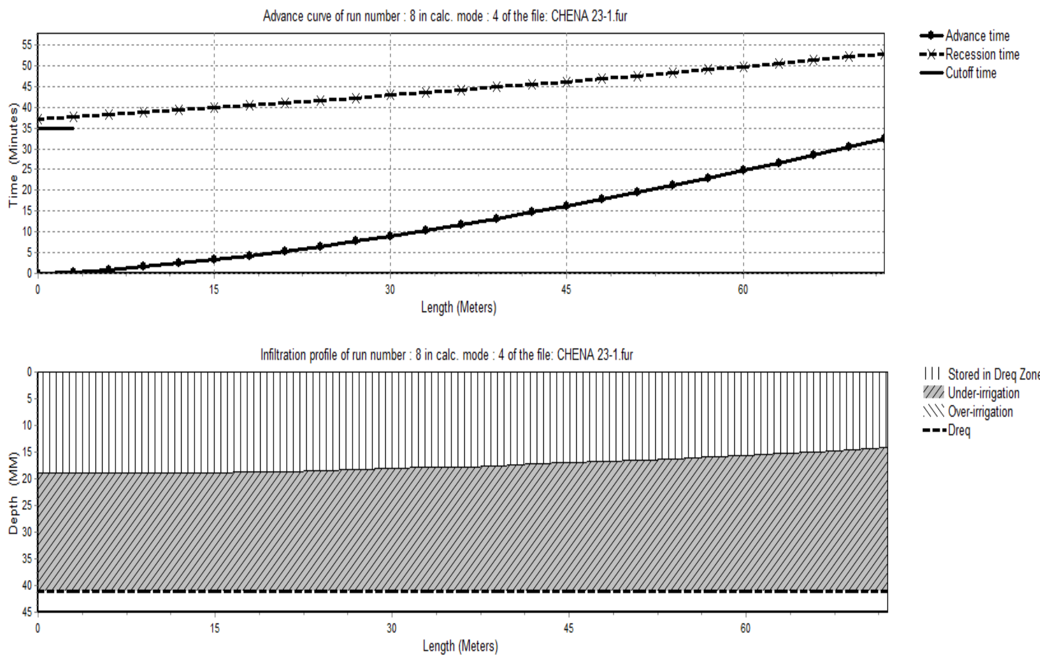

Figure4. 7 existing output graph of Chena irrigation project plot1

As in the case of plot1 existing efficiency of plot 2 can be calculated. Then put the cutoff time, furrow length and the flow rate obtained from the field to the software and run the program. Result of software for this plot (2) owned by Mr. Gulma Fenta shows that Ea=90.5%, SRR=9.5%, DPR=0%, DPR+SRR=9.5%, Ea=100-9.5=90.5%, D_u=80.4%, Es=34.2%, Uc=92.1%, D_a=14mm, D_{min}=11mm, D_{max}=15mm. (appendix 1 run no.4 and Fig 4.8)

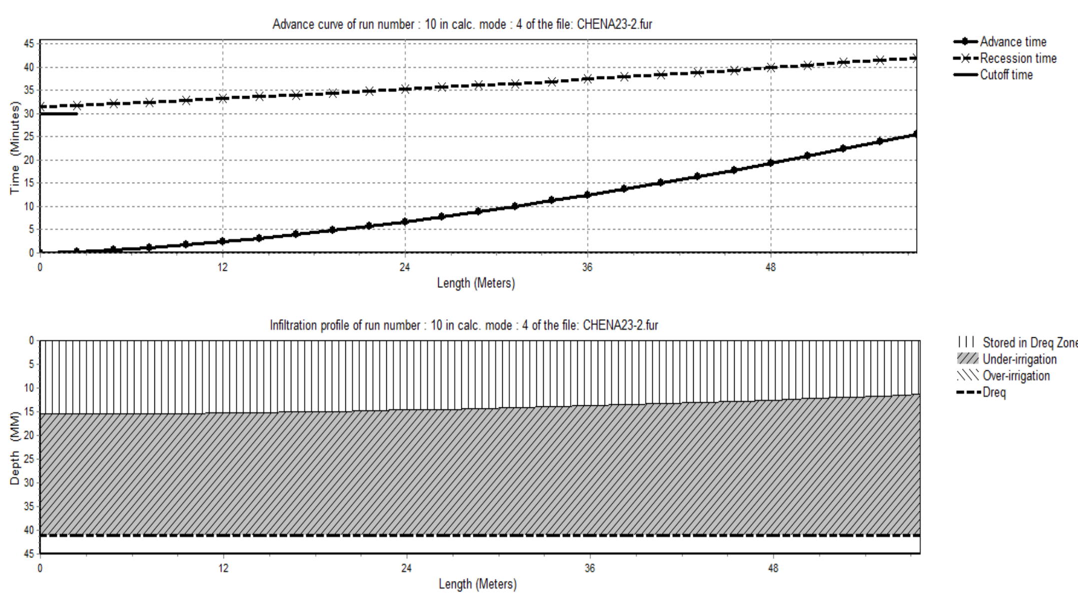

Figure4. 8 existing output graph of Chena irrigation project plot2

The existing efficiency of plot 3 can also be calculated with the same procedure as in plot 1and 2. Put the cutoff time, furrow length and the flow rate obtained from the field to the software and run the program. Result of software for this plot (3) owned by Mr. Desalegn Worku shows that Ea=71%, SRR=29%, DPR=0%, DPR+SRR=29%, Ea=100-29=71%, D_u=94.2%, Es=32.4%, Uc=97.4%, D_a=13mm, D_{min}=13mm, D_{max}=14mm (appendix 1 run no.4 and Fig 4.9)

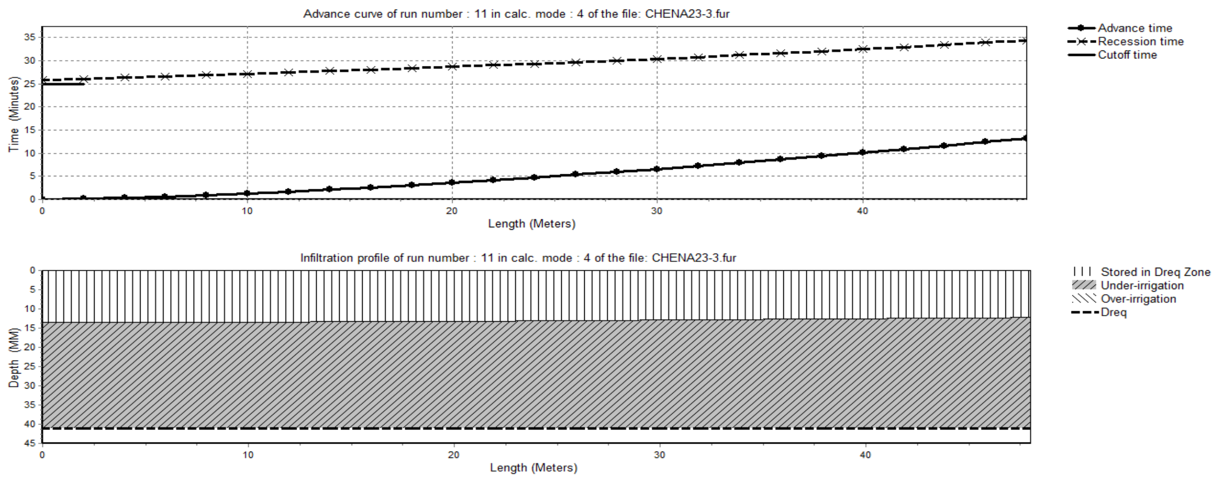

Figure4. 9 existing output graph of Chena irrigation project plot3

Gumara irrigation project: Two samples were taken having 65m and 90m long furrows in Gumara irrigation scheme. Since The soil type is clay which can be classified by the soil intake family # 0.25. The net irrigation requirement found by CROPWAT8 is 36 mm for onion crop. The furrows have a triangular side slope of 1:1, a respective slope of 0.005, and 0.001 with spacing of 60 cm. The data obtained from the field is tabulated below.

Table4. 11 field data of Gumara irrigation project

No.	Furrow characteristics	Plot 1=Getahun Asefa	Plot 2= Sale Alemu
1	furrow length	65	90
2	Flow rate	0.54	0.54
3	Cutoff time (min)	40	45
4	Furrow spacing	0.6	0.6
5	Furrow slope	0.005	0.001
6	Soil type	Clay	Clay
7	Required depth	36	36
8	Side slope	1:1	1:1

Source: field survey (2015)

To calculate the existing efficiency of plot1, we have to use the same procedure Gomit and Chena projects. Put the cutoff time, furrow length and the flow rate obtained from the field to the software and run the program. After doing the software run (run No 4) for this plot (1) owned by Mr. Getahun Asefa the following results were obtained. I.e. Ea=61%, SRR=39%, DPR=0%, DPR+SRR=39%, Ea=100-39=61%, D_u=99.1%, Es=56.3%, Uc=99.8%, D_a=20mm, D_{min}=20mm, D_{max}=20mm (appendix 1 run no.4 and Fig 4.10)

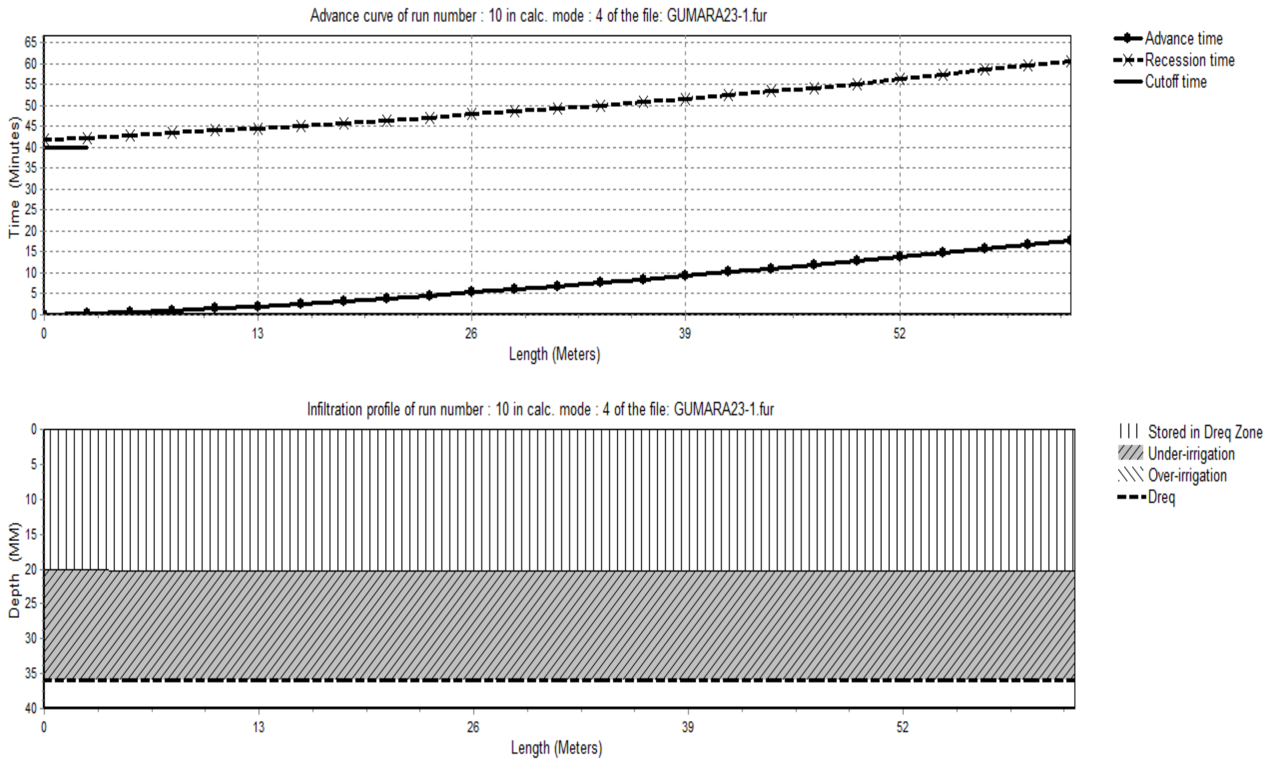

Figure4. 10 existing output graph of Gumara irrigation project plot1

To calculate the existing efficiency of plot2, we have to use the same procedure as plot 1. Then put the cutoff time, furrow length and the flow rate obtained from the field to the software and run the program. After doing the software run (run No 4) for this plot (2) owned by Mr. Sale Alemu, the following results were obtained. I.e. Ea=72.7%, SRR=27.3%, DPR=0%, DPR+SRR=27.3%, Ea=100-27.3=72.7%, D_u=94.6%, Es=54.5%, Uc=97.6%, D_a=20mm, D_{min}=19mm, D_{max}=20mm (appendix 1 run no.4 and Fig 4.11)

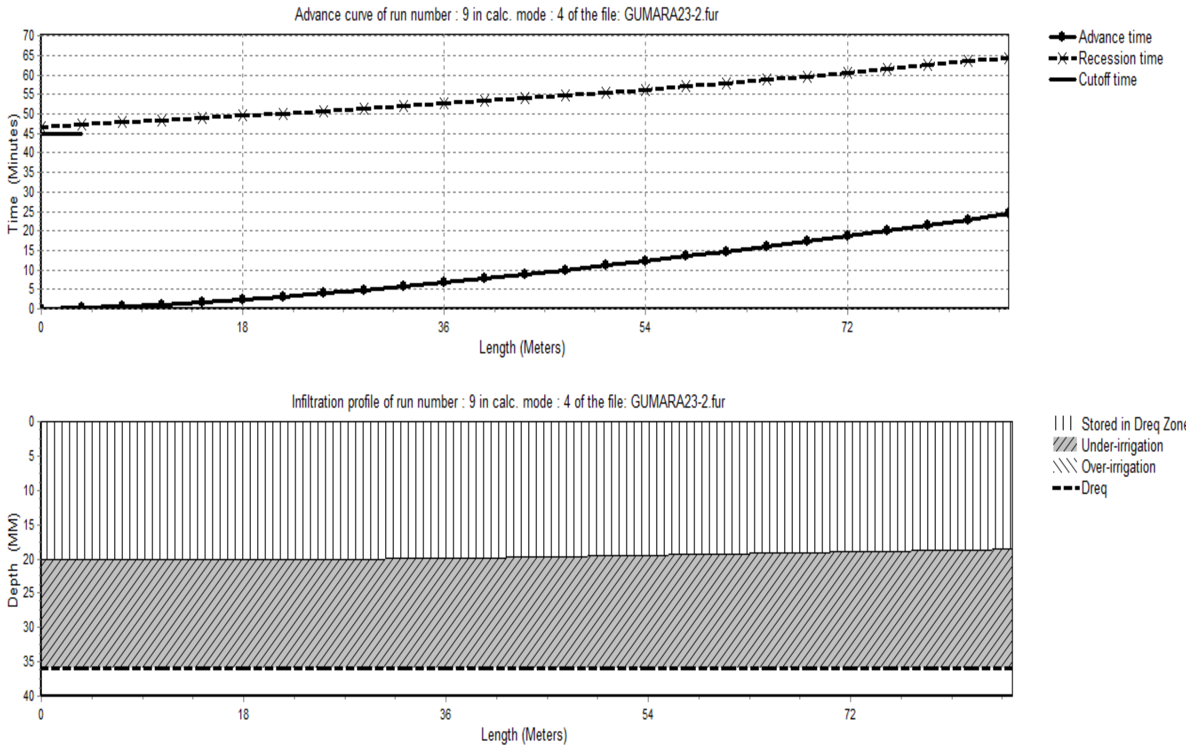

Figure4. 11 existing output graph of Gumara irrigation project plot2

4.5 Suitabl*e* design of decision variables

Decision variables are those parameters or variables that a design engineer can manipulate to find the best irrigation performance for given or selected field parameters. The decision variables in surface irrigation are normally the field dimensions (length and width), the flow rate and the cutoff time. The main design consideration in surface irrigation is usually the choice of the appropriate combination of field dimensions, flow rate, and cutoff time (Feyen et al, 2001). The combination of those variables in the above samples (sub portion 4.4) results poor performance in maintaining fulfillment of required depth. There for suitable design must be done by increasing or decreasing of those decision variables until the optimum result is obtained.

Gomit irrigation project*:* The combination decision variables, field dimensions, flow rate and cutoff time results an application efficiency of 77.8%, 95% and 85.7% for plots 1, 2, and 3 respectively. Even though those efficiencies are high enough they cannot attain in fulfillment of the required depth as shown in fig 4.4, 4.5, and 4.6 for respective plots (appendix1.run No 4). There for appropriate design of decision variables to attain sufficient irrigation has to be done.

Plot1: Run No 5(appendix1) shows that although application efficiency has slightly increased from 77.8% to 78.1%, there is under irrigation: a minimum infiltrated depth is 24mm instead of 41mm. In run No 6 there is slight increment of application efficiency to 78.4%, DU=84%, Uc=93.5%. Over the 70m of furrow, the average depth infiltrated would be 3mm less than that required. The upper 50m furrow would receive an average depth of 40mm.This is acceptable design and the graph is shown below.

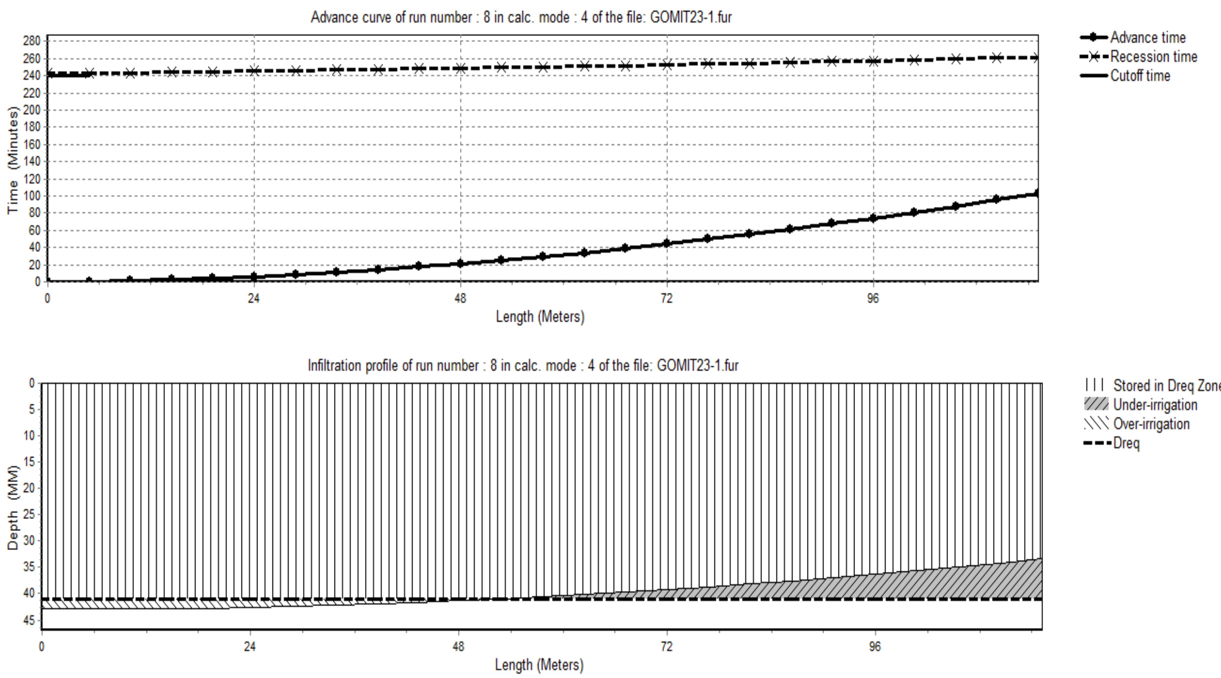

Figure4. 12 designed output graph of Gomit irrigation project plot1

Plot2: plot2 is also poor in achievement of irrigation to the required depth but high application efficiency as shown in appendix1 from run No 5 to 7. After analysis of those run results, a combination of decision variables in run No 6 gives appropriate result of Ea=70.2%, SRR=28.5%, DPR=1.2%, D_u=88.4%, Es=97.3%, Uc=95.3%, D_a=41mm, D_{min}=36mm, D_{max}=43mm, under irrigation depth=2mm, over irrigation depth=1mm, under irrigation length=55m, over irrigation length=55 (fig 4.13)

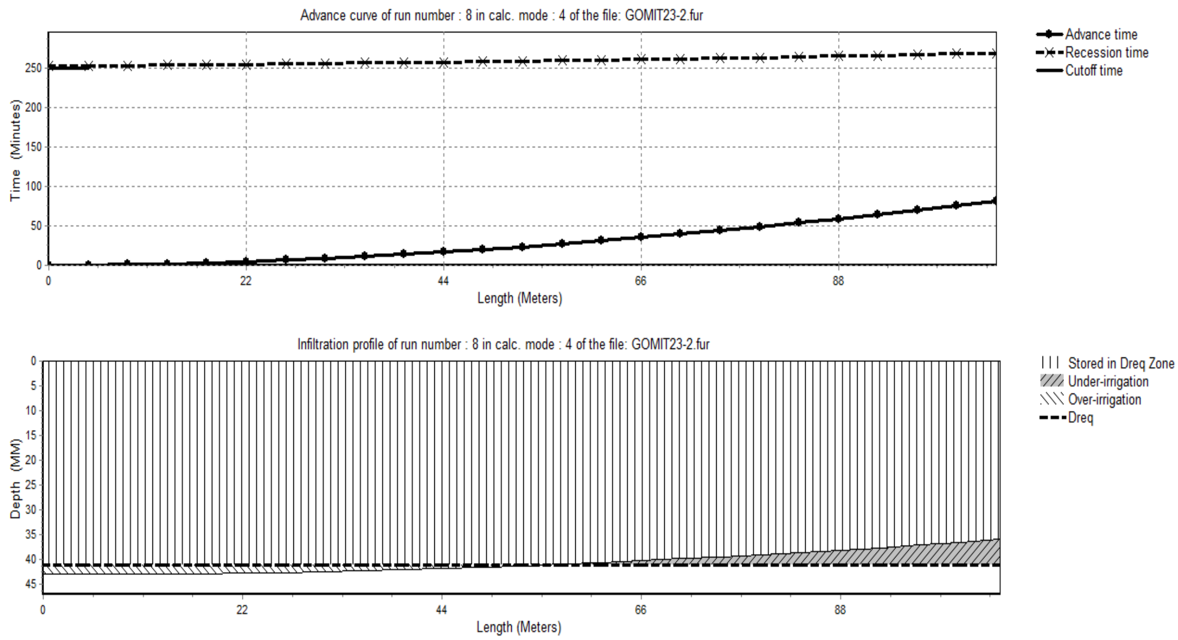

Figure4. 13 designed output graph of Gomit irrigation project plot2

Plot3: application efficiency of this plot is 85.7% without attaining required depth. a consecutive run from run No 5 to 6 gives also poor application efficiency. An optimum primary performance indicators, required depth, Ea, Du, and adequacy can be obtained in run No 7. The output results and the graph of the plot is shown below. Ea=73.2%, SRR=24.1%, DPR=2.7%, D_u=87.2%, Es=98.1%, Uc=94.8%, D_a=42mm, D_{min}=36mm, D_{max}=44mm, under irrigation depth=2mm, over irrigation depth=2mm, under irrigation length=45m, over irrigation length=75 (fig 4.14)

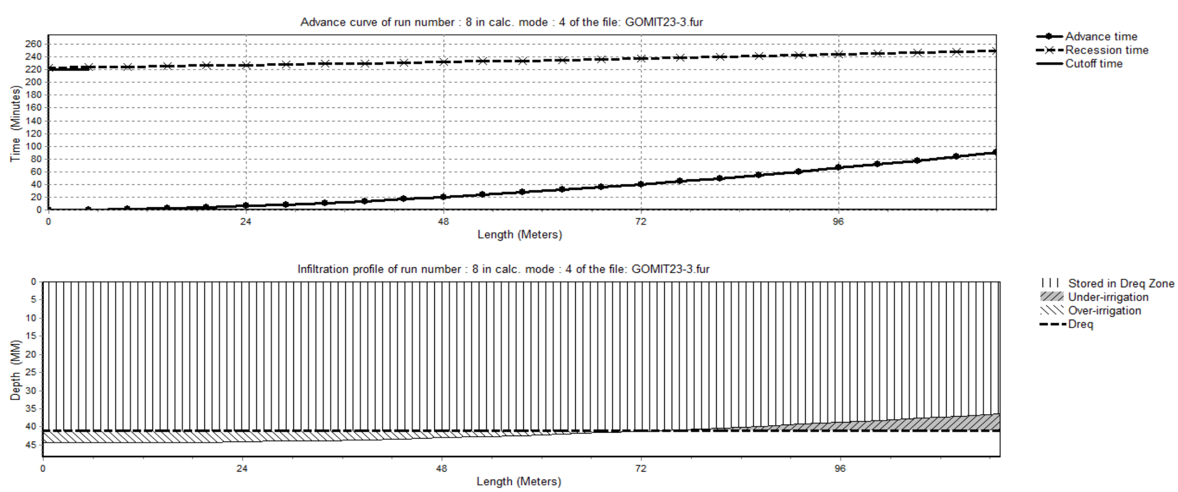

Figure4. 14 designed output graph of Gomit irrigation project plot3

Chena irrigation project: Chena irrigation project plot 1 shows under irrigation in which 24mm depth is suffered with shortage of water (appendix 1 run no.4 and Fig 4.7). Decreasing the flow rate by half and increasing the cutoff time three times results a slight increment of average applied depth from 17to 27 and slight decrement of under irrigation depth from 24to 14 (appendix 1.run No5). But still the plot is faced under irrigation. A suitable combination of decision variables were obtained in run No 6 of this table by doubling the furrow length and increasing the cutoff time to 180. The result of this run with those decision variables shows that, Ea=79.4%, SRR=16.6%, DPR=3.8%, DPR+SRR=20.4%, D_u=84.3%, Es=97.7%, Uc=93.6%, D_a=42mm, D_{min}=35mm, D_{max}=45mm. 56m of furrow falls 2mm under irrigated depth, while 3mm over irrigated depth is resulted with 94m of the upper furrow. This is acceptable design.

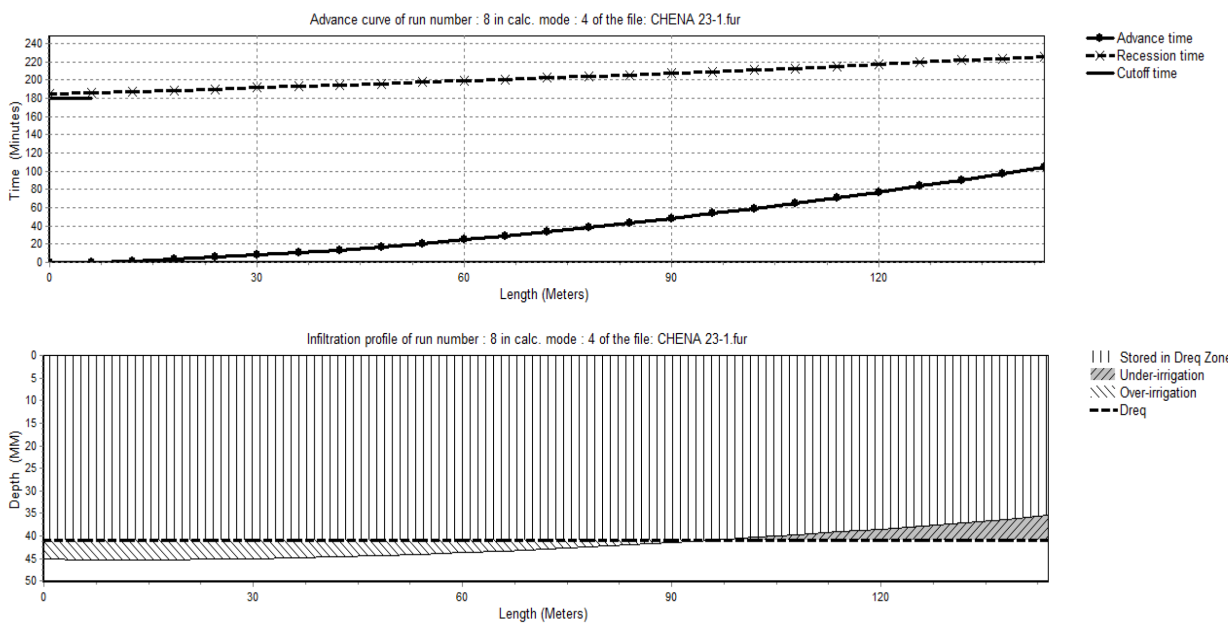

Figure4. 15 designed output graph of Chena irrigation project plot1

90.5% application efficiency is obtained in Chena irrigation project plot 2 with maximum, minimum and average applied depths of 15mm, 11mm and14mm respectively which shows under irrigation (appendix 1 run No4 Fig 4.8). By varying input parameters of decision variables as shown in appendix1 run No4 to 7 optimum required depth cannot be irrigated. But the combination of decision variables in run No 8 is best results of this plot which gives the following results (appendix1 run No 8). Ea=85.5%, SRR=11.5%, DPR=2.9%, D_u=76.7%, Es=94.8%, Uc=90.9%, D_a=40mm, D_{min}=31mm, D_{max}=45mm. This is an acceptable design.

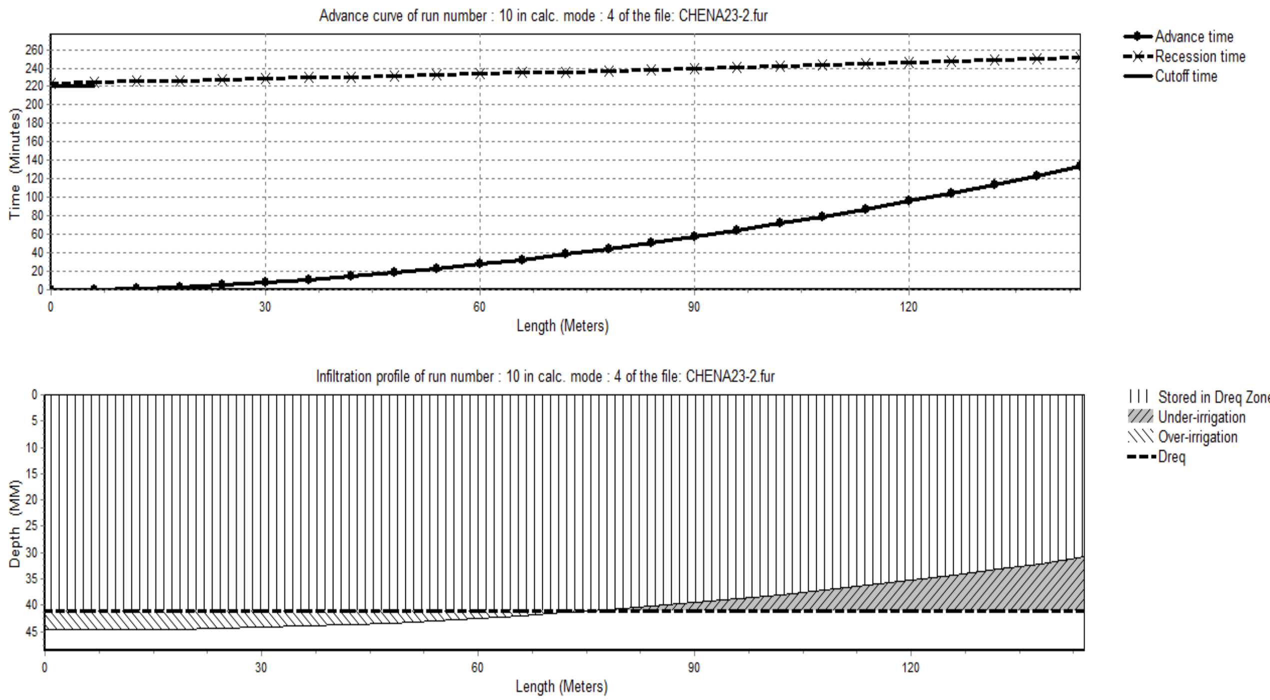

Figure4. 16 designed output graph of Chena irrigation project plot2

A similar procedure is done to plot3. After analyzing the results of run no 5 to 10 a combination of decision variables in run no 10 gives optimum result of (appendix 1 run No 10). Ea=81.6%, SRR=16.2%, DPR=2.2%, D_u=80.1%, Es=95.5%, Uc=92.4%, D_a=40mm, D_{min}=32mm, D_{max}=44mm, O_{id}=2mm, U_{id}= 4mm, O_{il}= 75m, U_{il} =75m.This is an acceptable design.

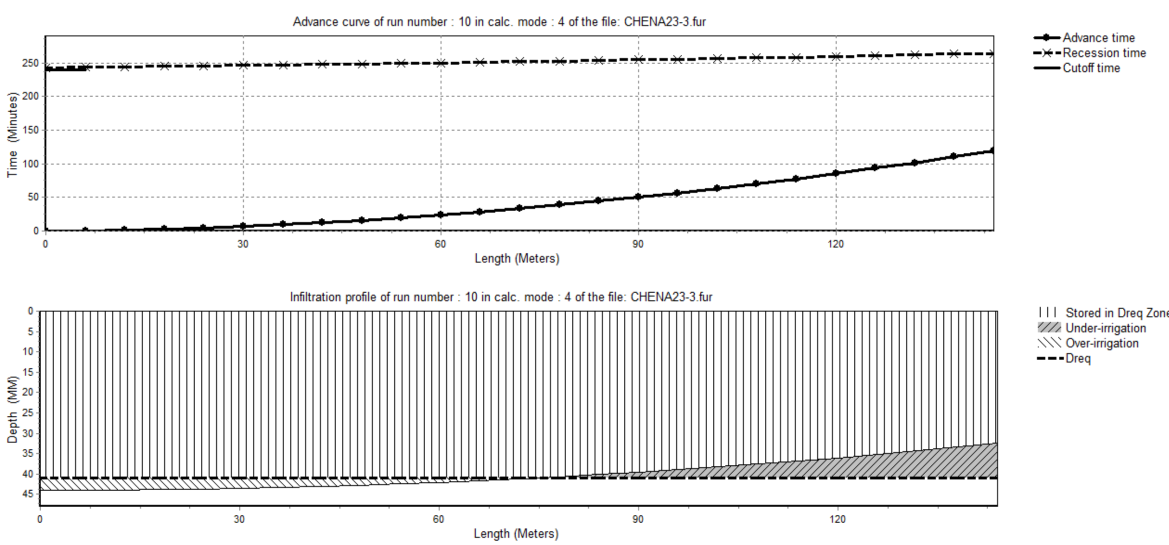

Figure4. 17 designed output graph of Chena irrigation project plot3

Gumara*:* There is also under irrigation in Gumara irrigation samples as shown in fig4.10 and 4.11 of plot1and plot2 respectively. The minimum infiltrated depth is 20mm instead of 36mm for plot 1and 19mm instead of 36mm for plot2. After analyzing the results of run no 5 to 9 of plot1 and run no 5 to 8 of plot2 a combination of decision variables in run no 9 run no 7 gives an optimum result (appendix 1 run No 9 plot1 and run No 7 plot2 Gumara). plot1 results are Ea=80.8%, SRR=16.2%, DPR=3%, D_u=83%, Es=96.7%, Uc=93.2%, D_a=36mm, D_{min}=30mm, D_{max}=39mm. Plot 2 results are Ea=72%, SRR=25.5%, DPR=2.5%, D_u=88%, Es=98%, Uc=95%, D_a=35mm, D_{min}=30mm, D_{max}=38mm.the following figure shows designed graph of those plots.

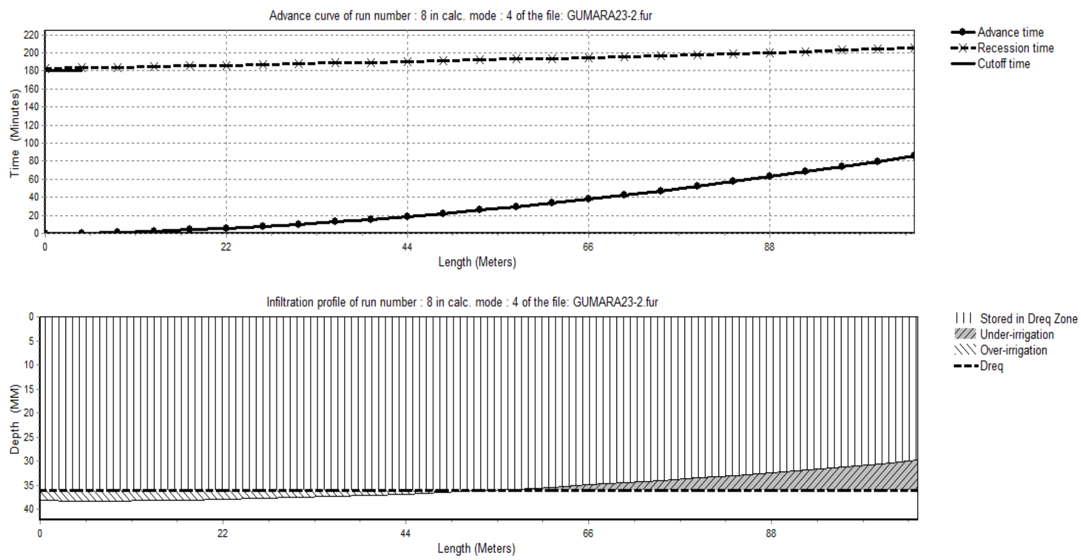

Figure4. 18 designed output graph of Gumara irrigation project plot1

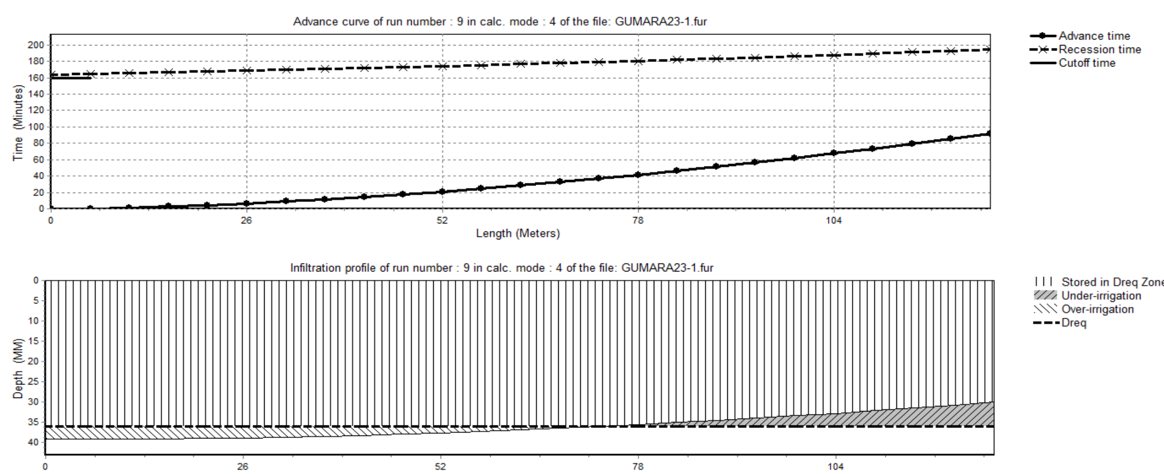

Figure4. 19 designed output graph of Gumara irrigation project plot2

4.6 Summary of the SURDAV results

Evaluation can be extended to cover quality of design and method of operation. We also use the term to denote analysis of an existing situation for all known data: field parameters, field dimensions, flow rate and cutoff time. Then, evaluation indicates the measure of the appropriateness of that situation and the modifications that could improve irrigation performance (Feyen *et al*, 2001). In the study area it can be summarized that, slope class 0.008-0.03% in Gomit scheme 110m-120m furrow length with flow rate 0.25-0.30 l/s and appropriate cut of time ranging between 220-250min is a suitable combination of decision variables to attain better performance. While in Chena slope class 0.003-0.02%, 150m furrow length, 0.3-0.42 l/s flow rate, 180-240min cut of time and in Gumara slope class 0.005-0.01%,110- 130m furrow length, 0.3-0.35 l/s flow rate and 160-180min cut of time are suitable decision variables to attain more than 70.% application efficiency.

4.7 Conveyance efficiency

After measuring the discharge at the head and at the outlet of the canals, conveyance efficiency of each scheme for the year 2015 were estimated. As the result of this, conveyance efficiency of Gomit, Gumara and Chena were 63.83, 29.5 and 56.5 respectively. As shown in the following diagram, Gomit irrigation scheme is more efficient in conveying water followed by Chena. But Gumara irrigation scheme is poor in this case.

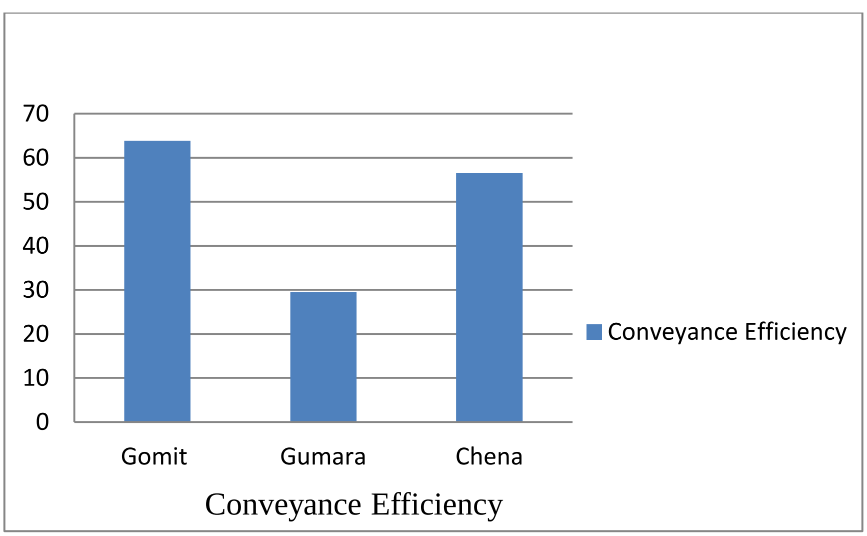

Figure4. 20 Conveyance efficiency

4.8 Comparison of schemes with efficiency

The conveyance efficiency (%) of Gomit, Chena and Gumara is 63.83, 56.5 and 29.5 respectively. This result shows that Gomit conveys much water the field than others and most of water diverted in Gumara is lost through seepage while Chena is intermediate. Application efficiency of Gomit (86.2%) is the greatest value followed by Chena (83.37%). Even if application efficiency of Gumara is poorest (66.85%), this scheme accounts highest value of storage efficiency (55.4%). Chena and Gomit have almost similar storage efficiency about 36.5%. Although the application efficiency is high enough in all irrigation schemes, the performance of schemes in irrigating minimum infiltrated depth is poor. Gumara is better in this case by irrigating about 20mm minimum infiltrated depth instead of 36mm required depth while in the other two schemes a minimum infiltrated depth is not greater than 13mm instead of 41mm.

4.9 Management system of the study sites

4.9.1 Irrigation water management system of Gomit irrigation project

In order to maintain the scheme sustainability and fair water use, water committee members were selected by the irrigation water user communities in meeting. Those committee members called administrative committees are five in number and are assigned for three years duration. They may be rejected from the member even before three years if their performance is poor. However looking their activity (participation), if they are performing their tasks well, the community may vote them for the next three years. But the rule and regulation of the community govern maximum working duration of the committee to be six years with two round elections.

In addition to administrative committees, there are three audit committees assigned by the community. The major functions of them are follow-up and evaluate activities and performance of administrative committees, financial settlement of the cooperative, participation of the community and water distribution system. Like that of administrative committees, the working duration of audit committees is restricted to be six years with two round election.

Water distribution to the farmer's farm land is carried out with organized groups of members. To do so members are organized into eleven groups having a member from 15 to 20. Each group has their group leaders and groups are organized on the basis of farmer's farm land topographic settlement for the simplicity of water distribution. Group leaders are responsible to administrative committees and they can regulate water to members on the basis of farm land size and type of crop. The type of crop which requires much water frequently is given priority by the decision of group leaders.

A brief discussion with chair man of the cooperative ato Admasu Tarekegn and secretariat ato Yaregal Abebe said, although there were 11 groups, only three groups are using irrigation water now. This is because reservoir water is decreasing from year to year resulting shortage of water to downstream irrigation users. As a result of this the participation of downstream communities in canal maintenance and administrative support as well as in decision making is decreased.

The bylaw of the community states that every member has to pay water fee on the basis of farm land size. For example a farmer who has 0.25ha (one timad) pays 12birr per irrigation year. If the farmer has one hectare farmland he must pay 48birr per irrigation year. Group leaders have responsibilities to collect payment before the farmers water their farm land. In this case if the farmers water their farmland before paying and refusing to pay, group leaders must take measures according to the rule they had.

To address technical and potential gaps in the sustainable management of water resources, a short training was given to administrative committees on December 2014. Even though they were trained, carelessness and poor participation of the committees in leadership of the community is observed. This is because a decrease of reservoir water with sedimentation causes a decrease in irrigation water user members at downstream end. It is there for a collaboration of government with NGO's on developing skill and awareness with training is very necessary.

4.9.2 Irrigation water management system of Gumara irrigation project

As in the case of Gomit irrigation project, Gumara irrigation project has organized water users' associations. The total number of WUA members are 142 which are grouped into ten groups each has group leaders. Those leaders are responsible for administrative committees and can regulate water for their group members. But the distribution of water is not restricted rather farmers' water in anticipation of their farm land is completely filled with water. This may cause improper use of water and may result wastage of water.

In addition to water distribution, group leaders have responsibility to collect water fee from their members. If the members refuse in paying fee after watering their land, leaders must pay with five birr additional punishment. This is stated by the rule and regulation but not applied due to lack of commitment of the community and committees as well.

4.9.3 Irrigation water management system of Chena irrigation project

Chena irrigation project construction is completed in 2014 by AWWE. At the completion of this project WUA were organized with the aid of woreda cooperative promotion office. The association has its own leadership (chairman, secretary, treasure) and produced their workable bi-laws to which they stick in the course of the development. This association has elected a committee members assigned by the water user communities in meeting. The numbers of committee members are seven in number and as in the case of Gomit irrigation project the maximum duration of the committees is six years with two round elections.

This association is not organized with groups for the simplicity of water allocation; rather Water distribution to farmer's field is carried out for one day and night without restriction of farm land size. In this project, farmers are not well organized in water usage and have not water fee contribution. This poor management structural system is a result of no handover (rather temporary) of the community with contractors due to design and construction problem on the canal.

4.9.4 Comparison of management systems

All three schemes have organized water users association and water committees. However Management system of each scheme is different. Management Division of Gomit irrigation scheme makes simplicity of water distribution, water fee collection, water planning and scheduling. There for it is better compared to the other two schemes. Even if there is no planned water distribution in Gumara, the water fee contribution of communities is better rather Chena is poor in irrigation water management. This is because no handover is carried out between contractor and local community.

4.10 Challenges and Problems of *SSI* in the study area

A field survey with focus group discussion and key informant interviews indicates that small-scale irrigation's great benefit is accompanied with multidimensional problems. The major problems encountered in small-scale irrigation in the study area are problems related to design, construction and management problems.

***Loss of water through seepage*:** It is the main problem in small-scale irrigation systems in the study area. Seepage from irrigation canals is the main causes for water losses in Gomit irrigation project. This is because canals are covered with grass as shown in fig 4.21

Figure4. 21 canal condition of Gomit irrigation project

In addition to the grass cover, non-durability of the physical structure of irrigation schemes and the poor canal clearance in this project causes high water seepage through canals. The canals were constructed in 2001, and the canal's service length and poor leadership of water use association cause the canal to be non-functional. Therefore, seepage causes water shortage in the study area in addition to evaporation and transpiration.

Seepage loss is also the main problem in Chena irrigation project. In addition to loss of water through canals, the problem faced in this irrigation activity is the water loss through seepage from the delivery hose at the end of head work. This is mainly caused due to poor construction of the structure. Those water losses through canals and at head work structure causes water shortage to downstream users. In this irrigation project canals are constructed with slope which is approach to zero. Due to this water to downstream users cannot reach as shown in fig4.22 below.

Figure4. 22 canal condition of Chena irrigation project

As it is observed from the figure water is not properly applied to the farm rather it is lost to uncultivated land during flow on earthen canals.

Gumara irrigation project is also faced with this problem. Canal of this scheme is constructed on deep gorge topography which results water to seep down the ground. As a result of this the downstream communities are suffered with shortage of water.

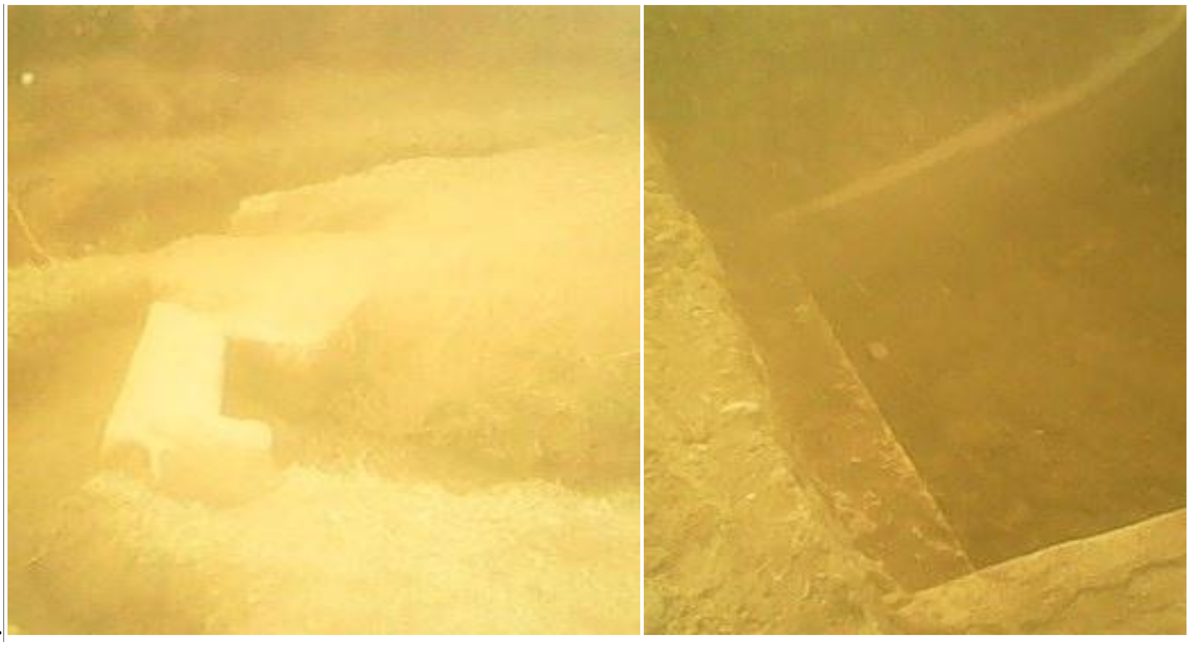

Figure4. 23 canal condition of Gumara irrigation project

Irrigation water distribution problem*:* It is also another problem in the study area. Irrigation water use depends only on spatial location of the farm plot; it does not consider the amount of water required for the type of cultivated crop, time interval of water application and the size of irrigated land sizes. Even if there are Water distributions and water use principles are regulated by the users in meeting in all irrigation schemes, there exists a problem in settlement of these rules and regulations. In this case Gomit irrigation project is better compared to others followed by Gumara. But performance of Chena irrigation project poor in this case.

Conflict between beneficiaries: This problem exists only in Gumara irrigation project. The scheme is unable to generate the required amount of water to the scheme beneficiaries. This is because upstream traditional river diversion water user farmers and farmers those use motor pumps for irrigation from the river is increased from year to year. This results conflict between upstream and downstream water users

Shortage of surface water*:* *It* is another problem in the study area. All rivers of each scheme are perennial flowing throughout the year. But the flow of the rivers decreases in driest months. Especially Gumara irrigation users are seriously affected by this problem due to the traditional river diversion and treadle pump irrigation users are using upstream water. In Gomit irrigation project this problem is encountered due to sedimentation in the reservoir.

Management problems: Lack of awareness and skill of farmers on irrigation water management and their perceptions on scheme owner ship are poor and canals are not properly functioning. Especially Chena irrigation project is seriously faced with this problem. In order to undertake canal maintenance, water distribution, ownership status and long term use of schemes water users associations are organized. But they are not suffered to undertake these activities. Even though there are legal documents of the associations (articles of incorporation, bylaws, and rules of procedure), they have some deficiencies and are poor in settlement.

Lack of inputs and infrastructures: The organized interview of some beneficiaries and group discussion with committee members in each scheme states that, Inputs like fertilizers and filtered seeds are not available and are not able to arrive at a proper time. This may cause farmers to delay in cultivation of crops with specified period. Poor infrastructure like road, transportation vehicle in all irrigation schemes are another problems in the study area. Due to this farmers cannot put-on goods to the market at appropriate time.

Poor capacity building: Beneficiaries and committee members are not well skilled on maintenance and management of schemes. This is due to lack of training and poor capacity building is carried out.

CHAPTER FIVE

5. Conclusion and recommendation

5.1 Conclusions

Surface irrigation mostly furrow irrigation is the main irrigation practiced in the study area (Estie). Design issues in furrow irrigation have to do with finding an optimum combination of design variables, notably, furrow length, flow rate and cutoff time.

- Application efficiency and secondary output parameters are always obtained as a result. The maximum application efficiency is obtained when the surface runoff ratio equals the deep percolation ratio. The average values of Application efficiency (%) were 86, 83.37 and 66.85 for Gomit, Chena and Gumara respectively. and the respective values of storage efficiency and distribution uniformity of Gomit were 81.5 and 36.57. In Gumara 96.85% distribution uniformity and 55.4% storage efficiency while in Chena 36.26% storage efficiency and 85.43% distribution uniformity were obtained. Even though Application efficiency is high enough which is more than 66.85%, all schemes cannot achieve irrigation to the minimum required depth. In this case Gumara is better than the other two schemes.
- Gomit irrigation project has highest output per cropped area (4.68) followed by Chena (3.95). This highest value of Gomit is attained due to great attitude of farmers in producing market oriented crops and their well experience of irrigation practice. In addition to this both projects (Gomit and Chena) are located near the town (Mekane-Eyesus) to put on goods on the market rather Gumara is located too far from the town (Mekane Eyesus). In the case of output per irrigation supply Gumara has the highest value (10.05) implying that Gumara is better in effective utilization of water. But as the indicators are comparative we can't say that Gumara achieved the required performance. Using the rainfall in a better way than Gomit and Chena, Gumara contributes for this higher value of output per irrigation.
- The three water supply indicators, RWS, RIS and WDC were used for comparison of schemes performance in the study area. Both RWS and RIS relate supply to demand, and give some indication as the condition of water abundance or scarcity, and how

tightly supply and demand are matched. Relative irrigation supply indicator is appropriate to characterize the irrigation system performance with respect to water supply since it informs managers whether sufficient water is being supplied to meet the total crop water demand or not. In the study area the values of RIS in Gumara, Gomit and Chena were 1.52, 2.68 and 1.96 respectively. The respective values of RWS of Gumara, Gomit and Chena were 2.08, 3.17 and 2.53. Gomit has highest value of RWS and RIS. The water delivery capacity of the scheme shows the capacity of the main canal to convey the maximum peak consumptive demand. The WDC of Chena, Gomit and Gumara is 1.03, 1.46 and 0.54 respectively. This result shows that Gomit irrigation project is better in delivery of water followed by Chena rather Gumara is poor in this case.

- In addition to agricultural and water supply indicators Molden et al. (1998) developed two financial indicators which are Gross return on investment and Financial self-sufficiency. The calculated values of Gross return on investment for Gumara Chena and Gomit were 2.036, 0.72 and 0.64 respectively and respective financial self-sufficiency values of Gumara Chena and Gomit were 4.61, 2.38 and 0.86. Those FSS result shows that Gumara collects sufficient revenue from irrigation while Gomit expends much money to O&M.
- The responsibility for running management of the irrigation systems was delegated to "WUA" in the hope of enhancing effectiveness, equity and responsiveness in irrigation management and to ensure sustainability. WUA" are in charge of water allocation, distribution, observing the water rights of members, conflict management and coordination of maintenance activities. In the study area water users associations in all irrigation systems have established their own management structures and constructed internal bylaws that contribute to efficient and better irrigation management systems. In general, Executive committees, sub-committees and water user teams (WUTs) or Water user association (WUA) were formed at irrigation systems and distribution levels with the aim to facilitate water control and coordination of maintenance activities. The committees are one of the essential factors that are responsible for efficient management of irrigation schemes. However, in the study area committees lacks transparency, accountability and commitment to irrigation water users; and hence they were not able

to ensure equity in water distribution. They did not practice the overall management activities according to the established internal bylaws. In this case Gomit irrigation project is better followed by Gumara rather Chena is poor.

- Although the development of SSI holds significant role to improve productivity and reduces poverty in any country, field survey with focus group discussion and key informant interviews indicates that small-scale irrigation's great benefit is accompanied with multidimensional problems. The major problems encountered in small-scale irrigation in the study area are; Loss of water through seepage, Irrigation water distribution problem, Conflict between beneficiaries, Shortage of surface water, Management problems, Lack of inputs and infrastructures and Poor capacity building

5.1 Recommendation

- Effective organizational structure of the Water Users Association in irrigation schemes creates the ability to facilitate working relationships between various entities and to improve the working efficiency within the organizational units. Without the WUA, the efficient irrigation scheme management is impossible. By strengthening the management capacity of WUA, legal and smooth handover of schemes after the construction are critical to sustain performances.
- To address potential gaps in technical assistance provided to farmers, collaboration among government, technical agencies and NGOs can be beneficial, and build on complementary expertise. Training supporting government staffs like DA,s is essential in order to establish the necessary capacity to successfully carry out the farmers training and demonstration programmes
- Conveyance efficiency of Gomit, Chena and Gumara were 63.83, 56.5 and 29.5 respectively. Those values shows that almost all schemes are faced with conveyance losses specially Gumara. Unlined of main canal is the cause of poor conveyance efficiency in this scheme (Gumara). There for Lining of irrigation canals is very important to reduce conveyance losses.
- Measurement of flow into the field and into the furrows, limiting the time of application and field layouts is very important for increasing efficiency of the system and water saving.
- To maintain better production, application efficiency and sustainability, frequent performance evaluation, Training of farmers for operation and maintenance, and other managerial activities of the irrigation systems as well as to obey their bylaws is very crucial.
- Water application (Distribution) and management system of each scheme is somewhat different. Experience sharing between beneficiaries is very important by visiting their sites one another.

Reference

Abdu Beshir and Sileshi Bekele (2005). Analysis of irrigation systems using comparative performance indicators. A case study of two large scale irrigation systems in the upper awash basin

Bellingham B. K. (2009). Method for Irrigation Scheduling Based on Soil Moisture Data Acquisition Paper originally submitted to and published by the United States Committee on Irrigation and Drainage, for the 2009 Irrigation District Conference. Stevens Water Monitoring Systems, Inc.

David H. Manz (1993). performance evaluation of irrigation conveyance systems using dynamic simulation models Canadian Water Resources Journal / Revue canadienne des ressources hydrique. University of Calgary, Calgary

David Molden, R. Sakthivadivel Christopher J. Perry, Charlotte de Fraiture and WimH. Kloezen (1998). Indicators for comparing performance of irrigated Agricultural systems. Research report *20*. International Water Management Institute. Sri Lanka

David Wigginton (2008). Evaluating surface irrigation performance**,** Cotton Catchment Communities, the Australian cotton grower-21,

Dessalegn Rahmato (1999). Water resources development in Ethiopia: Issues of Sustainability and Participation, forum for social studies Addis Ababa.

Dr.K.R.Arora(2011). irrigation, water power and water resources engineering,Kota ,Raji

Ernest Bagson and Conrad-J.Wuleka Kuuder (2013). Assessment of a Smallscale Irrigation Scheme on Household Food Security and Leisure in Kokoligu; Ghana

Food and Agriculture organization (1998). Crop evapotranspiration-guidelines for computing crop water requirements. FAO irrigation and drainage paper 56, Rome

Food and Agriculture Organization (1989). Guidelines for designing and evaluating surface irrigation systems, FAO Irrigation and drainage paper no 45.Rome

Food and Agriculture Organization, (2014). Guidelines for Planning Irrigation and Drainage Investments available at, http://www.fao.org/docrep/007/w1037e/ w1037e00.HTM).

Food and Agriculture Organization (1971). irrigation and drainage papers: Irrigation practice and water management, http://www.fao.org/docrep/t0231e/t0231e0c.htm#TopOfPage

Food and Agriculture Organization (1984). irrigation and drainage papers Rev.1. Irrigation practice and water management, http://www.fao.org/docrep/t0231e/t0231e0c.htm#TopOfPage

Food and Agriculture organization (1986). yield response to water.FAO irrigation and drainage paper 33, Rome

Francisco Mojarro Dávila, Carlos Francisco Bautista Capetillo, José Gumaro Ortiz Valdez and Ernesto Vázquez Fernández (2012). Comparing Water Performance by Two Different Surface Irrigation Methods, Irrigation - Water Management

Getaneh, K. (2011). The impact of selected small scale irrigation schemes on the house hold income and livelihood of poverty in the Lake Tana basin of Ethiopia. A Project Paper Presented to the Faculty of the Graduate School of Cornell University

Helen Fairweather, Nick Austin and Meredith Hope (1999). NSW Agriculture Water use efficiency, an information package, Irrigation Insights Number 5 Australia

Ineke Margôt Kalwij, (1997). irrigation methods and practices, field evaluation of irrigation processes for selected basin irrigation systems during Rabi 1995-96 season, Punjab, Pakistan

Marcel Aillery, (202) 694-5511 [maillery@ers.usda.gov]; and Noel Gollehon, (202) 694-5539 Agricultural Resources and Environmental Indicators

Jose A. Sanchez, Juan Reca and Juan Martinez (2014). irrigation water management in Mediterranean greenhouse district: irrigation adequacy assessment, Department of Engineering, University of Almeria, Almeria, Spain.

Magayane Machibya, Makarius Mdemu and Bruce Lankford (2004). irrigation efficiency and productivity manual, Raising Irrigation Productivity And Releasing Water for Intersectoral Needs Overseas Development Group**,** University of East Anglia, Norwich.

M. D. Dukes, L. Zotarelli, G. D. Liu, and E. H. Simonne June (1995). reviewed march 2015 Principles and Practices of Irrigation Management for Vegetables, IFAS extension University of Florida

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

Ministry of agriculture, natural resource Directorate October (2011). Small scale irrigation situation analysis and capacity needs assessment (A Tripartite Cooperation between Germany, Israel and Ethiopia), Addis Ababa, Ethiopia

Ministry of agriculture, natural resource sector October (2011). Small scale irrigation capacity building strategy for Ethiopia, Addis Ababa, Ethiopia

M. Jurriëns ,D. Zerihun, J. Boonstra, J. Feyen (2001). Design, Operation, and Evaluation of Basin, Border,and Furrow Irrigation, SURDEV: Surface Irrigation Software, ILRI Publication 59, Wageningen University, Netherland

Mohammad Azmi & Abdolmajid Liaghat & Fahimeh Sarmadi(2012). Evaluation of surface irrigation system performance using System Dynamics (SD) approach, International University of Ghazvin, Ghazvin, Iran

Mohamed Hakim Kharrou. Michel Le Page. Ahmed Chehbouni. Vincent Simonneaux. Salah Er-Raki. Lionel Jarlan. Lahcen Ouzine. Said Khabba. Ghani Chehbouni (2013). Assessment of Equity and Adequacy of Water Delivery in Irrigation Systems Using Remote Sensing-Based Indicators in Semi-Arid Region, Morocco

Morteza N. Orang; J. Scott Matyac; and Richard L. Snyder (2008). Survey of Irrigation Methods in California in 2001, technical notes, Journal of irrigation and drainage engineering © asce / January/February 2008

Murray-Rust, D. H. and W. B. Snellen (1993). Irrigation System Performance Assessment and Diagnosis. IWMI. Colombo Sri Lanka

Rain Bird Corporation (2010). Distribution Uniformity for Sprinkler Irrigation, The Intelligent Use of Water, **www.rainbird.com**

R.J.Oosterbaan (1988). Effectiveness and Social/Environmental Impacts of Irrigation Projects: a critical Review The paper presented at the 3rd National Irrigation and Drainage Symposium, 20 to 23 September, Izmir, Turkey

Santosh Kumar Garg (2005). Irrigation engineering and hydraulic structures, Delhi University. Delhi

Seleshi Bekele Awulachew (2010). Irrigation potential in Ethiopia, Constraints and opportunities for enhancing the system, International Water Management Institute

Steven Raine and Kelvin Montagu,(2006). improving surface irrigation application performance CRC for irrigation futures, University of southern Queensland

Tahar Boutraa, Abdellah Akhkha, Abdulkhaliq Alshuaibi, Ragheid Atta (2011). Evaluation of the effectiveness of an automated irrigation system using wheat crops Saudi Arabia.

Terry A. Howell, (2003). Irrigation Efficiency, United States Department of Agriculture (USDA), Bushland, Texas, U.S.A.

Thomas W. Ley (1914). reviewed by Brian Leib (2003) Surface Irrigation Systems

United States Department of Agriculture (2006). Natural Resources Conservation Service Irrigation National Engineering Handbook Part 623.

Kenneth H. Solomon (1988). Irrigation Systems and Water Application Efficiencies Center for Irrigation Technology, Irrigation Notes, California State University, Fresno, California

Wynn R. Walker (Professor) (2003). Surface Irrigation Simulation, Evaluation and Design Guide and Technical Documentation, SIRMODlll, Biological and Irrigation Engineering Utah State University.

Yilma Silesh (2003). Community based small scale irrigation types and importance in poverty alleviation. Addis Ababa University, ILRI, A.A Ethiopia

Appendixes

Appendix1: SURDEV program output result tables of each scheme and each plot

SURDEV program output results of furrow irrigation of Chena irrigation plot1

Run nr.		1	2	3	4	5	6
Type of system		1	1	1	1	1	1
Calculation Mode		1	2	3	4	4	4
INPUT PARAMETERS	units						
Flow rate	l/s	-	0.42	0.42	0.42	0.21	0.42
Length	M	75	-	75	75	75	150
Cutoff time	Min	-	-	-	35	105	180
Advance ratio	-	-	-	-	-	-	-
Cut-back ratio	-	-	-	-	-	-	-
Recovery ratio	-	-	-	-	-	-	-
Required depth	Mm	41	41	41	41	41	41
Flow resistance	-	0.04	0.04	0.04	0.04	0.04	0.04
Slope	m/m	0.003	0	0	0.003	0.003	0.003
Spacing	M	0.6	0.6	0.6	0.6	0.6	0.6
Maximum Velocity	m/min	13	13	13	13	13	13
Sigma1	m^(2-Sig2)	-	-	-	-	-	-
Sigma2	-	-	-	-	-	-	-
Tau 1	m^(1-Tau2)	-	-	-	-	-	-
Tau 2	-	-	-	-	-	-	-
Side Slope	m/m	1	1	1	1	1	1
BedWidth	m	-	-	-	-	-	-
MaxDepth	m	-	-	-	-	-	-
MaxWidth	m	-	-	-	-	-	-
SCS #	-	0.25	0.25	0.25	0.25	0.25	0.25
Infiltration parameter A	-	-	-	-	-	-	-
Infiltration parameter k	mm/min^A	-	-	-	-	-	-
Infiltration parameter Fo	mm/min	-	-	-	-	-	-
Trial Flowrate	l/s	-	-	-	-	-	-
Stable Runoffrate	l/s	-	-	-	-	-	-
Adv. Time L.	min	-	-	-	-	-	-
Adv. Time HalfL.	min	-	-	-	-	-	-
Trial Length	m	-	-	-	-	-	-
Trial Slope	m/m	-	-	-	-	-	-
OUTPUT PARAMETERS							
Flow rate	l/s	0.12	-	-	-	-	-
Cutback flow	l/s	-	-	-	-	-	-
Length	m	-	185	-	-	-	-

Cutoff time	min	374	260	157	-	-	-
Advance ratio	-	-	-	-	-	-	-
Application efficiency	%	67.2	69.3	46.6	88.6	90.6	79.4
Storage efficiency	%	100	100	100	42.4	65	97.7
Uniformity coefficient	%	91.4	92	99.6	92.5	90.6	93.6
Distribution uniformity	%	77.6	79.8	99.4	81.7	76.2	84.3
Deep percolation ratio	%	19.5	17.6	0.5	0	0	3.8
Runoff Ratio	%	13.3	13.1	52.9	11.4	9.4	16.6
Average applied depth	mm	53	51	41	17	27	42
Minimum infiltrated depth	mm	41	41	41	14	20	35
Maximum infiltrated depth	mm	58	56	42	19	30	45
Surface runoff	mm	8	8	47	2	3	8
Over irrigation depth	mm	12	10	0	0	0	3
Under irrigation depth	mm	0	0	0	24	14	2
Over irrigation length	m	75	185	75	0	0	94
Under irrigation length	m	0	0	0	75	75	56
Advance time	min	189	156	32	32	77	104
Depletion time	min	377	266	160	37	108	185
Recession time	min	403	313	190	53	130	225
Opportunity time	min	215	157	158	20	53	121

SURDEV program output results of furrow irrigation of Chena irrigation plot2

Run nr.		1	2	3	4	5	6	7	8	9
Type of system		1	1	1	1	1	1	1	1	1
Calculation Mode		1	2	3	4	4	4	4	4	4
INPUT PARAMETERS	units									
Flow rate	l/s	-	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.25
Length	m	60	-	60	60	150	150	150	150	120
Cutoff time	min	-	-	-	30	150	180	200	220	240
Advance ratio	-	-	-	-	-	-	-	-	-	-
Cut-back ratio	-	-	-	-	-	-	-	-	-	-
Recovery ratio	-	-	-	-	-	-	-	-	-	-
Required depth	mm	41	41	41	41	41	41	41	41	41
Flow resistance	-	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Slope	m/m	0.008	0.008	0.008	0.01	0.01	0.008	0.008	0.008	0.008
Spacing	m	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Maximum Velocity	m/min	13	13	13	13	13	13	13	13	13
Sigma1	m^(2-Sig2)	-	-	-	-	-	-	-	-	-
Sigma2	-	-	-	-	-	-	-	-	-	-
Tau 1	m^(1-Tau2)	-	-	-	-	-	-	-	-	-

Tau 2	-	-	-	-	-	-	-	-	-	-
Side Slope	m/m	1	1	1	1	1	1	1	1	1
BedWidth	m	-	-	-	-	-	-	-	-	-
MaxDepth	m	-	-	-	-	-	-	-	-	-
MaxWidth	m	-	-	-	-	-	-	-	-	-
SCS #	-	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Infiltration parameter A	-	-	-	-	-	-	-	-	-	-
Infiltration parameter k	mm/min^A	-	-	-	-	-	-	-	-	-
Infiltration parameter Fo	mm/min	-	-	-	-	-	-	-	-	-
Trial Flowrate	l/s	-	-	-	-	-	-	-	-	-
Stable Runoffrate	l/s	-	-	-	-	-	-	-	-	-
Adv. Time L.	min	-	-	-	-	-	-	-	-	-
Adv. Time HalfL.	min	-	-	-	-	-	-	-	-	-
Trial Length	m	-	-	-	-	-	-	-	-	-
Trial Slope	m/m	-	-	-	-	-	-	-	-	-
OUTPUT PARAMETERS										
Flow rate	l/s	0.1	-	-	-	-	-	-	-	-
Cutback flow	l/s	-	-	-	-	-	-	-	-	-
Length	m	-	168	-	-	-	-	-	-	-
Cutoff time	min	368	327	199	-	-	-	-	-	-
Advance ratio	-	-	-	-	-	-	-	-	-	-
Application efficiency	%	66.5	67.9	39.8	90.5	97.1	93.4	90.1	85.5	79.6
Storage efficiency	%	100	100	100	34.2	73.4	84.8	90.8	94.8	97.1
Uniformity coefficient	%	93.2	91.9	99.4	92.1	84.5	88.3	89.8	90.9	92.6
Distribution uniformity	%	82.7	79.2	98.7	80.4	58.2	69.4	73.6	76.7	81.2
Deep percolation ratio	%	13.9	17.9	0.5	0	0	0	0.6	2.9	4
Runoff Ratio	%	19.6	14.2	59.6	9.5	2.9	6.6	9.1	11.5	16.4
Average applied depth	mm	50	52	42	14	30	35	38	40	42
Minimum infiltrated depth	mm	41	41	41	11	18	24	28	31	34
Maximum infiltrated depth	mm	54	57	42	15	36	40	42	45	46
Surface runoff	mm	12	9	61	1	1	2	4	5	8
Over irrigation depth	mm	9	11	1	0	0	0	1	3	3
Under irrigation depth	mm	0	0	0	27	11	6	5	4	3
Over irrigation length	m	60	168	60	0	0	0	44	75	75
Under irrigation length	m	0	0	0	60	150	150	106	75	45
Advance time	min	145	168	25	25	133	133	133	133	121
Depletion time	min	370	331	201	31	153	184	204	224	243
Recession time	min	386	363	220	42	174	209	231	252	269
Opportunity time	min	241	195	195	16	41	76	97	119	148

SURDEV program output results of furrow irrigation of Chena irrigation plot3

Run nr.		1	2	3	4	5	6	7	8	9	10
Type of system		1	1	1	1	1	1	1	1	1	1
Calculation Mode		1	2	3	4	4	4	4	4	4	4
INPUT PARAMETERS	Units										
Flow rate	l/s	-	0.36	0.36	0.36	0.36	0.36	0.25	0.25	0.36	0.3
Length	M	50	-	50	50	50	100	150	150	150	150
Cutoff time	Min	-	-	-	25	25	125	225	250	240	240
Advance ratio	-	-	-	-	-	-	-	-	-	-	-
Cut-back ratio	-	-	-	-	-	-	-	-	-	-	-
Recovery ratio	-	-	-	-	-	-	-	-	-	-	-
Required depth	Mm	41	41	41	41	41	41	41	41	41	41
Flow resistance	-	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Slope	m/m	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Spacing	M	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Maximum Velocity	m/min	13	13	13	13	13	13	13	13	13	13
Sigma1	m^(2-Sig2)	-	-	-	-	-	-	-	-	-	-
Sigma2	-	-	-	-	-	-	-	-	-	-	-
Tau 1	m^(1-Tau2)	-	-	-	-	-	-	-	-	-	-
Tau 2	-	-	-	-	-	-	-	-	-	-	-
Side Slope	m/m	1	1	1	1	1	1	1	1	1	1
BedWidth	m	-	-	-	-	-	-	-	-	-	-
MaxDepth	m	-	-	-	-	-	-	-	-	-	-
MaxWidth	m	-	-	-	-	-	-	-	-	-	-
SCS #	-	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Infiltration parameter A	-	-	-	-	-	-	-	-	-	-	-
Infiltration parameter k	mm/min^A	-	-	-	-	-	-	-	-	-	-
Infiltration parameter Fo	mm/min	-	-	-	-	-	-	-	-	-	-
Trial Flowrate	l/s	-	-	-	-	-	-	-	-	-	-
Stable Runoffrate	l/s	-	-	-	-	-	-	-	-	-	-
Adv. Time L.	min	-	-	-	-	-	-	-	-	-	-
Adv. Time HalfL.	min	-	-	-	-	-	-	-	-	-	-
Trial Length	m	-	-	-	-	-	-	-	-	-	-
Trial Slope	m/m	-	-	-	-	-	-	-	-	-	-
OUTPUT PARAMETERS											
Flow rate	l/s	0.07	-	-	-	-	-	-	-	-	-
Cutback flow	l/s	-	-	-	-	-	-	-	-	-	-
Length	m	-	208	-	-	-	-	-	-	-	-
Cutoff time	min	414	350	209	-	-	-	-	-	-	-

Advance ratio	-	-	-	-	-	-	-	-	-	-	-
Application efficiency	%	66.5	67.5	27.3	71	72.3	65.7	94.9	90.7	70.4	81.6
Storage efficiency	%	100	100	100	32.4	31.7	72.1	86.8	92.2	99	95.5
Uniformity coefficient	%	91.6	91.9	99.9	97.4	97.3	96.8	86.5	88.2	95.1	92.4
Distribution uniformity	%	78.1	79.1	99.8	94.2	93.8	92.3	64.1	68.9	88	80.6
Deep percolation ratio	%	18.7	17.9	0.1	0	0	0	0.1	2.3	3.3	2.2
Runoff Ratio	%	14.8	14.6	72.7	29	27.7	34.3	5	7.3	26.3	16.2
Average applied depth	mm	53	52	41	13	13	30	36	39	42	40
Minimum infiltrated depth	mm	41	41	41	13	12	27	23	27	37	32
Maximum infiltrated depth	mm	58	57	41	14	13	31	41	44	45	44
Surface runoff	mm	9	9	109	5	5	15	2	3	15	8
Over irrigation depth	mm	12	11	0	0	0	0	0	2	3	2
Under irrigation depth	mm	0	0	0	28	28	11	6	6	2	4
Over irrigation length	m	50	208	50	0	0	0	25	63	106	75
Under irrigation length	m	0	0	0	50	50	100	125	88	44	75
Advance time	min	184	172	13	13	13	42	166	166	88	119
Depletion time	min	415	354	210	27	26	127	228	253	243	243
Recession time	min	425	381	222	36	34	144	246	272	266	264
Opportunity time	min	241	209	209	22	21	103	80	107	178	145

SURDEV program output results of furrow irrigation of Gomit irrigation plot1

Run nr.		1	2	3	4	5	6	7
Type of system		1	1	1	1	1	1	1
Calculation Mode		1	2	3	4	4	4	4
INPUT PARAMETERS	units							
Flow rate	l/s	-	0.36	0.36	0.36	0.36	0.25	0.28
Length	m	60	-	60	60	120	120	120
Cutoff time	min	-	-	-	30	120	240	240
Advance ratio	-	-	-	-	-	-	-	-
Cut-back ratio	-	-	-	-	-	-	-	-
Recovery ratio	-	-	-	-	-	-	-	-
Required depth	mm	41	41	41	41	41	41	41
Flow resistance	-	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Slope	m/m	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Spacing	m	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Maximum Velocity	m/min	13.8	13.8	13.8	13.8	13.8	13.8	13.8
Sigma1	m^(2-Sig2)	-	-	-	-	-	-	-
Sigma2	-	-	-	-	-	-	-	-
Tau 1	m^(1-	-	-	-	-	-	-	-

	Tau2)							
Tau 2	-	-	-	-	-	-	-	-
Side Slope	m/m	1	1	1	1	1	1	1
BedWidth	m	-	-	-	-	-	-	-
MaxDepth	m	-	-	-	-	-	-	-
MaxWidth	m	-	-	-	-	-	-	-
SCS #	-	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Infiltration parameter A	-	-	-	-	-	-	-	-
Infiltration parameter k	mm/min^A	-	-	-	-	-	-	-
Infiltration parameter Fo	mm/min	-	-	-	-	-	-	-
Trial Flowrate	l/s	-	-	-	-	-	-	-
Stable Runoffrate	l/s	-	-	-	-	-	-	-
Adv. Time L.	min	-	-	-	-	-	-	-
Adv. Time HalfL.	min	-	-	-	-	-	-	-
Trial Length	m	-	-	-	-	-	-	-
Trial Slope	m/m	-	-	-	-	-	-	-
OUTPUT PARAMETERS								
Flow rate	l/s	0.09	-	-	-	-	-	-
Cutback flow	l/s	-	-	-	-	-	-	-
Length	m	-	208	-	-	-	-	-
Cutoff time	min	413	350	211	-	-	-	-
Advance ratio	-	-	-	-	-	-	-	-
Application efficiency	%	66.6	67.5	32.3	77.8	78.1	78.4	71.5
Storage efficiency	%	100	100	100	34.1	68.6	95.6	97.7
Uniformity coefficient	%	91.6	91.9	99.7	96	94.4	93.5	95.1
Distribution uniformity	%	78.2	79.1	99.4	90.5	86.2	83.7	87.8
Deep percolation ratio	%	18.7	17.9	0.2	0	0	1.2	1.8
Runoff Ratio	%	14.8	14.6	67.4	22.2	21.9	20.4	26.7
Average applied depth	mm	52	52	41	14	28	40	41
Minimum infiltrated depth	mm	41	41	41	13	24	33	36
Maximum infiltrated depth	mm	58	57	41	15	30	43	44
Surface runoff	mm	9	9	85	4	8	10	15
Over irrigation depth	mm	11	11	0	0	0	1	2
Under irrigation depth	mm	0	0	0	27	13	3	2
Over irrigation length	m	60	208	60	0	0	50	65
Under irrigation length	m	0	0	0	60	120	70	55
Advance time	min	184	172	18	18	58	103	85
Depletion time	min	414	354	212	31	122	242	242
Recession time	min	426	381	227	41	140	261	262
Opportunity time	min	241	209	209	23	83	158	177

SURDEV program output results of furrow irrigation of Gomit irrigation plot2

Run nr.		1	2	3	4	5	6	7
Type of system		1	1	1	1	1	1	1
Calculation Mode		1	2	3	4	4	4	4
INPUT PARAMETERS	units							
Flow rate	l/s	-	0.42	0.42	0.42	0.2	0.25	0.2
Length	m	110	-	110	110	110	110	110
Cutoff time	min	-	-	-	40	240	250	250
Advance ratio	-	-	-	-	-	-	-	-
Cut-back ratio	-	-	-	-	-	-	-	-
Recovery ratio	-	-	-	-	-	-	-	-
Required depth	mm	41	41	41	41	41	41	41
Flow resistance	-	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Slope	m/m	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Spacing	m	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Maximum Velocity	m/min	13	13	13	13	13	13	13
Sigma1	m^(2-Sig2)	-	-	-	-	-	-	-
Sigma2	-	-	-	-	-	-	-	-
Tau 1	m^(1-Tau2)	-	-	-	-	-	-	-
Tau 2	-	-	-	-	-	-	-	-
Side Slope	m/m	1	1	1	1	1	1	1
BedWidth	m	-	-	-	-	-	-	-
MaxDepth	m	-	-	-	-	-	-	-
MaxWidth	m	-	-	-	-	-	-	-
SCS #	-	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Infiltration parameter A	-	-	-	-	-	-	-	-
Infiltration parameter k	mm/min^A	-	-	-	-	-	-	-
Infiltration parameter Fo	mm/min	-	-	-	-	-	-	-
Trial Flowrate	l/s	-	-	-	-	-	-	-
Stable Runoffrate	l/s	-	-	-	-	-	-	-
Adv. Time L.	min	-	-	-	-	-	-	-
Adv. Time HalfL.	min	-	-	-	-	-	-	-
Trial Length	m	-	-	-	-	-	-	-
Trial Slope	m/m	-	-	-	-	-	-	-
OUTPUT PARAMETERS								
Flow rate	l/s	0.16	-	-	-	-	-	-
Cutback flow	l/s	-	-	-	-	-	-	-
Length	m	-	245	-	-	-	-	-
Cutoff time	min	412	355	228	-	-	-	-
Advance ratio	-	-	-	-	-	-	-	-
Application efficiency	%	66.8	67.5	47.1	95.1	85.2	70.2	83.9

Storage efficiency	%	100	100	100	35.4	90.7	97.3	93
Uniformity coefficient	%	91.6	91.9	98.6	87.3	91.5	95.3	91.9
Distribution uniformity	%	78.2	79.1	96.6	66.8	78.2	88.4	79.2
Deep percolation ratio	%	18.7	18	1.7	0	0	1.2	0.6
Runoff Ratio	%	14.5	14.6	51.2	4.9	14.6	28.5	15.6
Average applied depth	mm	52	52	42	15	37	41	38
Minimum infiltrated depth	mm	41	41	41	10	29	36	30
Maximum infiltrated depth	mm	58	57	43	17	41	43	42
Surface runoff	mm	9	9	45	1	6	16	7
Over irrigation depth	mm	11	11	1	0	0	1	1
Under irrigation depth	mm	0	0	0	26	4	2	4
Over irrigation length	m	110	245	110	0	14	55	32
Under irrigation length	m	0	0	0	110	96	55	78
Advance time	min	188	174	37	37	122	81	122
Depletion time	min	414	358	230	41	242	252	252
Recession time	min	429	385	248	50	257	268	267
Opportunity time	min	241	211	211	13	135	187	145

SURDEV program output results of furrow irrigation of Gomit irrigation plot3

Run nr.		1	2	3	4	5	6	7
Type of system		1	1	1	1	1	1	1
Calculation Mode		1	2	3	4	4	4	4
INPUT PARAMETERS	units							
Flow rate	l/s	-	0.44	0.44	0.44	0.44	0.44	0.3
Length	m	80	-	80	80	80	80	120
Cutoff time	min	-	-	-	35	140	175	220
Advance ratio	-	-	-	-	-	-	-	-
Cut-back ratio	-	-	-	-	-	-	-	-
Recovery ratio	-	-	-	-	-	-	-	-
Required depth	mm	41	41	41	41	41	41	41
Flow resistance	-	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Slope	m/m	0.008	0.008	0.008	0.01	0.01	0.01	0.01
Spacing	m	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Maximum Velocity	m/min	13	13	13	13	13	13	13
Sigma1	m^(2-Sig2)	-	-	-	-	-	-	-
Sigma2	-	-	-	-	-	-	-	-
Tau 1	m^(1-Tau2)	-	-	-	-	-	-	-
Tau 2	-	-	-	-	-	-	-	-
Side Slope	m/m	1	1	1	1	1	1	1

BedWidth	m	-	-	-	-	-	-	-
MaxDepth	m	-	-	-	-	-	-	-
MaxWidth	m	-	-	-	-	-	-	-
SCS #	-	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Infiltration parameter A	-	-	-	-	-	-	-	-
Infiltration parameter k	mm/min^A	-	-	-	-	-	-	-
Infiltration parameter Fo	mm/min	-	-	-	-	-	-	-
Trial Flowrate	l/s	-	-	-	-	-	-	-
Stable Runoffrate	l/s	-	-	-	-	-	-	-
Adv. Time L.	min	-	-	-	-	-	-	-
Adv. Time HalfL.	min	-	-	-	-	-	-	-
Trial Length	m	-	-	-	-	-	-	-
Trial Slope	m/m	-	-	-	-	-	-	-
OUTPUT PARAMETERS								
Flow rate	l/s	0.12	-	-	-	-	-	-
Cutback flow	l/s	-	-	-	-	-	-	-
Length	m	-	218	-	-	-	-	-
Cutoff time	min	408	297	180	-	-	-	-
Advance ratio	-	-	-	-	-	-	-	-
Application efficiency	%	67	68.4	41.5	85.7	46.5	42.3	73.2
Storage efficiency	%	100	100	100	40.2	87.3	99.3	98.1
Uniformity coefficient	%	91.5	91.9	99.6	94.7	99.4	99.5	94.8
Distribution uniformity	%	77.9	79.5	99.2	87.2	98.7	99.1	87.2
Deep percolation ratio	%	19.1	17.8	0.4	0	0	0	2.7
Runoff Ratio	%	13.9	13.8	58.2	14.3	53.5	57.7	24.1
Average applied depth	mm	53	52	41	16	36	41	42
Minimum infiltrated depth	mm	41	41	41	14	35	40	36
Maximum infiltrated depth	mm	58	57	42	18	36	41	44
Surface runoff	mm	9	8	58	3	41	56	13
Over irrigation depth	mm	12	11	0	0	0	0	2
Under irrigation depth	mm	0	0	0	25	5	0	2
Over irrigation length	m	80	218	80	0	0	0	75
Under irrigation length	m	0	0	0	80	80	80	45
Advance time	min	193	162	27	27	27	27	90
Depletion time	min	410	302	182	37	142	177	223
Recession time	min	430	340	205	51	164	200	250
Opportunity time	min	237	178	178	25	138	173	160

SURDEV program output results of furrow irrigation of Gumara irrigation plot1

Run nr.		1	2	3	4	5	6	7	8	9
Type of system		1	1	1	1	1	1	1	1	1
Calculation Mode		1	2	3	4	4	4	4	4	4
INPUT PARAMETERS	units									
Flow rate	l/s	-	0.54	0.54	0.54	0.27	0.27	0.27	0.3	0.35
Length	m	65	-	65	65	65	65	130	130	130
Cutoff time	min	-	-	-	40	40	120	160	160	160
Required depth	mm	36	36	36	36	36	36	36	36	36
Flow resistance	-	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Slope	m/m	0.005	0.01	0.01	0.005	0.005	0.005	0.005	0.01	0.005
Spacing	m	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Maximum Velocity	m/min	13	13	13	13	13	13	13	13	13
Side Slope	m/m	1	1	1	1	1	1	1	1	1
SCS #	-	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Flow rate	l/s	0.11	-	-	-	-	-	-	-	-
Length	m	-	219	-	-	-	-	-	-	-
Cutoff time	min	326	210	125	-	-	-	-	-	-
Application efficiency	%	67	69.6	34.6	61	93.4	62.1	95.3	90.2	80.8
Storage efficiency	%	100	100	100	56.3	43.1	86	87.9	92.5	96.7
Uniformity coefficient	%	91.5	92	99.5	99.8	87.5	97.7	85.5	89.5	93.2
Distribution uniformity	%	77.9	79.9	99	99.1	67.7	94.5	61.5	73.1	83
Deep percolation ratio	%	19	17.7	0.7	0	0	0	1.1	1.8	3
Runoff Ratio	%	14	12.6	64.7	39	6.6	37.9	3.6	8.1	16.1
Average applied depth	mm	46	45	37	20	16	31	32	34	36
Minimum infiltrated depth	mm	36	36	36	20	11	29	20	25	30
Maximum infiltrated depth	mm	51	50	37	20	18	32	38	38	39
Surface runoff	mm	8	7	67	13	1	19	1	3	7
Over irrigation depth	mm	10	9	1	0	0	0	1	2	2
Under irrigation depth	mm	0	0	0	16	20	5	6	5	3
Over irrigation length	M	65	219	65	0	0	0	38	54	76
Under irrigation length	M	0	0	0	65	65	65	92	76	54
Advance time	min	162	133	18	18	38	38	137	116	92
Depletion time	min	329	215	127	42	42	122	164	164	164
Recession time	min	348	258	150	61	52	143	187	191	194
Opportunity time	min	186	125	133	43	14	105	50	75	102

SURDEV program output results of furrow irrigation of Gumara irrigation plot2

Run nr.		1	2	3	4	5	6	7	8
Type of system		1	1	1	1	1	1	1	1
Calculation Mode		1	2	3	4	4	4	4	4
INPUT PARAMETERS	units								
Flow rate	l/s	-	0.54	0.54	0.54	0.27	0.25	0.3	0.27
Length	m	90	-	90	90	90	90	110	110
Cutoff time	min	-	-	-	45	135	180	180	180
Required depth	mm	36	36	36	36	36	36	36	36
Flow resistance	-	0.04	0.04	0.04	0.04	0.04	0.04	0	0.04
Slope	m/m	0.01	0.01	0.01	0.01	0.01	0.01	0	0.01
Spacing	m	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Maximum Velocity	m/min	13	13	13	13	13	13	13	13
Side Slope	m/m	1	1	1	1	1	1	1	1
SCS #	-	0.25	0.25	0.25	0.25	0.25	0.25	0.3	0.25
Flow rate	l/s	0.15	-	-	-	-	-	-	-
Length	m	-	242	-	-	-	-	-	-
Cutoff time	min	327	234	139	-	-	-	-	-
Application efficiency	%	66.9	68.8	43.2	72.7	75.3	70.1	72	78.5
Storage efficiency	%	100	100	100	54.5	84.7	97.4	98	96.3
Uniformity coefficient	%	91.5	91.9	99.7	97.6	95	95.6	95	93.6
Distribution uniformity	%	78	79.6	99.5	94.6	87.8	89.2	88	84.2
Deep percolation ratio	%	19	17.8	0.3	0	0	1.3	2.5	1.8
Runoff Ratio	%	14.1	13.4	56.4	27.3	24.7	28.3	26	19.7
Average applied depth	mm	46	45	36	20	31	36	37	35
Minimum infiltrated depth	mm	36	36	36	19	27	32	32	30
Maximum infiltrated depth	mm	51	50	36	20	32	38	39	38
Surface runoff	mm	8	7	47	7	10	14	13	9
Over irrigation depth	mm	10	9	0	0	0	1	2	2
Under irrigation depth	mm	0	0	0	16	5	2	2	3
Over irrigation length	m	90	242	90	0	0	49	69	55
Under irrigation length	m	0	0	0	90	90	41	41	55
Advance time	min	161	137	24	24	59	66	73	86
Depletion time	min	329	239	141	47	137	182	183	183
Recession time	min	349	276	163	64	157	203	206	205
Opportunity time	min	187	139	139	40	98	137	133	119

Appendix 2

Questionnaires developed with respect to

1. **Land and Crops**

- Total command area (ha) ………………………………………..
- Cropping pattern of irrigated crops (Planting/harvesting/ dates, growth length in days) …
- Area per crop, per season, or per year (ha) ……………………………..
- Yields, per season or per year (tons/ha) (Kul/ha) ………………………………….

No	Crop name	Area (ha)	Production in Qt.	Unit price(birr/Qt)	Total output in birr
1					
2					
3					
4					

2. **Market**

- Local prices, per season, or per year (local Currency/ton) (L.C/Kul) …………………
- World market prices for main crop (USDollars/ton) or $/Kul if necessary……………

3. **Finance and maintenance**

- Expenditures for operation, maintenance, and administration, i.e., all costs to run the system (in local currency/year)…………………………………………
- Total income from water fees, farmers' contributions, outstanding debt payments, etc., excluding all government Subsidies (local currency/year) ………………….
- Investment cost of irrigation infrastructure (Local currency/ha) ………………….
- Does the irrigation scheme annually maintained by the beneficiaries? 1. Yes: 2. No
- If yes how many times do you maintained/participated in irrigation scheme maintenance in this year?

- If no, why not possible to maintain annually? 1. No need of maintenance: 2. Some parts of the scheme maintenance are beyond the capacity of the farmers: 3. Lack of maintenance skill: 4. Others
- Are you paying water fee and maintenance fee every year? 1. Yes: 2. No
- If no, why you are no paying water and maintenance fee? 1. The collected cash is not properly use in the scheme work: 2. Nobody asks for fee: 3. No interest to pay any type of payment
- Are volunteer to pay water and maintenance fees in the future? 1. Yes: 2. No

Scheme name	Expenditures for			Total income from		
	Operation (birr)	Maintenance (birr)	Administration (birr)	Water fees(birr)	Farmers contributions (birr)	Out sanding dept payment (birr)
Chena						
Gomit						
Gumara						

4. <u>Management</u>

- Who and how does committee members are assigned?

  ……………………………………………………..
- How many members and for how long do those committee members are assigned?

  ………………………………………………………..
- How do those committee members manage the scheme and run the business?

  ………………………………………………………………………………
- What types of problems encountered in the process of irrigation scheme management?

  ………………………………………………………………………………
- What types of administrative support given by the kebele administration to the scheme beneficiaries/committee members?

……………………………………………………………

- What types of administrative support given by the woreda irrigation experts to the scheme beneficiaries/committee members?

  ………………………………………….

- How do you see the perceptions of farmers on the irrigation scheme?

  …………………………………………………..

- What type of support do you expect from technical support providers?

  …………………………………………………………….

5. Challenges and problems in the scheme

- Does the scheme positively contribute to the area? 1. Yes : 2. No
- What are the weaknesses of the scheme?

  ………………………………………..

- What types of problems occurred in the scheme utilization and management? (including upstream and downstream users)

  ………………………………………………..

- Do individuals/ beneficiaries misuse the irrigation scheme? 1. Yes : 2. No
- If yes what are the reasons? 1. No responsible body for the scheme : 2. Un fair distribution of water : 3. Shortage of water : 4. Others
- Is there downstream and upstream conflicts in the scheme? 1. Yes : 2. No
- If yes what are the reasons for the conflict? 1. The existence of another upstream diversion on the source of the scheme water : 2. Shortage of water: 3. Plantation of different types of crop which require different watering frequency: 4. Others
- Who is responsible body for the scheme? 1. Kebele administration: 2. Irrigation users cooperative: 3. Traditional water users association: 4. Yewha abat: 5. Others
- What type of infrastructures and services do you lack in the scheme? 1. Road: 2. Farm or hand tools: 3. Storage facilities: 4. Transportation facilities: 5. Canals are not properly functioning: 6. Others
- What measures should be taken to maximize the benefits of the community?

  ………………………………………………………………………………….

6. Irrigation practice

- How long do you have irrigated agriculture practices?

  ………………………………………….

- How many times do you produce using irrigation in a year- round?

  ………………………………….

- Why do you select this irrigation method rather than others?

  ……………………………………………..

- Do you practice in developing annual plan in irrigated agriculture?

  ………………………………………………………………

- Does the irrigable area of the scheme properly cultivated every year? 1. Yes: 2. No
- If no, what are the main reasons? 1. Lack of labor: 2. Shortage of water: 3. Damage of the land: 4. Others
- Do you use your land at its full capacity for crop production? 1. Yes : 2. No
- If no what are the main reasons? 1. Lack of knowledge and skill: 2. Due to marketing problem of the products: 3. Lack of labour: 4. Others
- Does your and your family life improved/changed due the irrigation scheme? 1. Yes : 2.No
- Do you think the capacity of the scheme/volume of water become decrease from year to year? 1. Yes: 2. No
- If yes what are the reasons? 1. The upper stream users of the scheme become increased: 2. Canals are not properly functioning: 3. There is frequent siltation problem: 4. Others
- What types of measures should be taken o utilize the scheme at its full capacity?

  ……………………………………………………..

  ………………………………………………………..

Appendix 3

Meteorological Data

Table 3.1 average Tmin(°C), Tmax(°C), Humidity (%),Wind (km/day), Sun(hrs) data

month	Tmin(°C)	Tmax(°C)	Humidity (%)	Wind (km/day)	Sun(hrs)
Jan	5.2	27.8	41.4	86.4	8.1
Feb	6.6	29.3	37.7	103.68	8.3
Mar	8.6	28.3	38.2	103.68	7.4
Apr	10.2	28.9	44.1	112.32	7.3
May	10.4	27.4	49.7	103.68	5.7
Jun	10.2	23.6	69.6	103.68	6.5
Jul	11	21.9	81.1	86.4	4.8
Aug	11.2	22.2	90.7	95.04	5.3
Sep	9.4	24	74.3	86.4	6.5
Oct	8.1	26.1	61.9	69.12	7.5
Nov	7.4	26.6	53.4	69.12	7.6
Dec	5.5	26.6	47	77.76	8.4

Table 3.2 ETo data of mekane Eyesus station

Month	Min Temp°C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	5.2	27.8	41	86	8.1	18.8	3.72
February	6.6	29.3	38	104	8.3	20.5	4.38
March	8.6	28.3	38	104	7.4	20.5	4.49
April	10.2	28.9	44	112	7.3	20.8	4.71
May	10.4	27.4	50	104	5.7	18.1	4.19
June	10.2	23.6	70	104	6.5	19	3.78
July	11	21.9	81	86	4.8	16.5	3.16
August	11.2	22.2	91	95	5.3	17.5	3.19
September	9.4	24	74	86	6.5	19.1	3.64
October	8.1	26.1	62	69	7.5	19.6	3.73
November	7.4	26.6	63	89	7.6	18.4	3.59
December	5.5	26.6	47	78	8.4	18.7	3.52
Average	8.7	26.1	58	93	7	19	3.84

Table 3.3 effective RF

Effective RF of M/Eyesus

	Rain	Eff rain
	Mm	mm
January	6.1	6
February	15.3	14.9
March	27.3	26.1
April	41.4	38.7
May	77.7	68
June	177.5	127.1
July	354.4	160.4
August	299	154.9
September	141.5	109.5
October	98.9	83.3
November	76.3	67
December	52.5	48.1
Total	1367.9	904

Effective RF of Licha

	Rain	Eff rain
	mm	mm
January	0.9	0.9
February	43	40
March	45	41.8
April	57.8	52.5
May	134.4	105.5
June	246	149.2
July	700.9	195.1
August	442.7	169.3
September	219.6	142.4
October	84.3	72.9
November	170.3	123.9
December	85.6	73.9
Total	2230.5	1167.3

Appendix 4

Net crop water and irrigation requirement

Table 3.4 Net crop water and irrigation requirement for each crop in each scheme

GUMARA

Crop	Etc	Irr. Req.	Area	Ncwr	NIR
Onion	354.6	264.3	5	28.59677	21.31452
Garlic	354.6	264.3	4	22.87742	17.05161
Potato	399.4	172.6	47	302.771	130.8419
Barley	419.1	305.8	4	27.03871	19.72903
Maize	626	425.6	2	20.19355	13.72903
Total	2154	1432.6	62	401.4774	202.6661

Chena

Crop	Etc	Irr. Req.	Area	Ncwr	NIR
Potato	397.5	333.1	28	311.3287	260.8895
Cabbage	426.4	362	3.28	39.12145	33.21287
Garlic	354.6	301.7	2.23	22.1191	18.81933
Onion	354.6	301.7	1.92	19.04425	16.20319
Tomato	420.7	356.2	0.16	1.882853	1.594182
Beet root	363.8	316.5	0.16	1.628196	1.416503
Total	2318	1971.2	35.75	395.1245	332.1356

gomit

crop	Etc	Irr. Req.	Area	Ncwr	NIR	
Onion	354.6	301.7	15.25	186.4707	158.6526	
Garlic	354.6	301.7	6.5	79.47931	67.62241	
Potato	464.3	378.2	5	80.05172	65.2069	
Rup seed	363.8	316.5	0.25	3.136207	2.728448	
Vetch	399.4	334.9	2	27.54483	23.09655	
Total	1937	1331.3	29	376.6828	317.3069	