TECHNICAL PERFORMANCE EVALUATION AND REDESIGNING OF SMALL SCALE IRRIGATION SCHEME: CASE OF GUDER IRRIGATION SCHEME AWI ZONE, AMHARA REGION

MSc. THESIS

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Technical Performance Evaluation and Redesigning of Small Scale Irrigation Scheme: Case of Guder Irrigation Scheme Awi Zone, Amhara Region

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I hereby certify that I have read and evaluated this thesis entitled **Technical Performance Evaluation and Redesigning of Small Scale Irrigation Scheme: Case of *Guder* Irrigation Scheme Awi Zone, Amhara Region** prepared under our guidance by Mr. Ayele Tebikew Ejigu. I recommend that it be submitted as fulfilling the thesis requirement.

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As member of the Board of Examiners of the Thesis Open Defense Examination, i certify that i have read, evaluated the Thesis prepared by Ayele Tebikew Ejigu and examined the candidate. I recommended the Thesis be accepted as fulfilling the Thesis requirements for the degree of Master of Science in Irrigation Engineering.

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DEDICATION

I dedicate this thesis manuscript to all my families for their love and dedicated partnership in the success of my life and to my father Tebikew Ejigu who passed away while I was in grade 11.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compliation of this Thesis. Any scholarly matter that is included in the Thesis has been given recognition through citation.

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BIOGRAPHICAL SKETCH

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ACRONYMS AND ABBREVIATIONS

ACSI	Amhara Saving and Credit Supply Institution
AMC	Actual Moisture Content
ARCPA	Amhara Regional Cooperative Promotion Agency
a.s.l	Above Sea Level
BoWRD	Bureau of Water Resource Development
CUC	Christianson's Uniformity Coefficient
DA	Development Agent
DAFF	Department of Agriculture, Forestry and Fisheries
DU	Distribution Uniformity
FAO	Food and Agricultural Organization
FC	Field Capacity
Ha	Hectare
ICID	International Commission on Irrigation and Drainage
IDP	Irrigation Development Plan
IWRM	Integrated Water Resource Management
IWMI	International Water Management Institute
LQ	Low Quarter
MoA	Ministry of Agriculture
MoWR	Ministry of Water Resource
WSDP	Water Sector Development Program
WUA	Water User Association
NGO	Non-Governmental Organization
PWP	Permanent Wilting Point
RAW	Readily Available Water
SCS	Soil Conservation Service
SGVP	Standardized Gross Value of Production
SJVDIP	San JoaquinValley Drainage Implementation Program
SSI	Small Scale Irrigation
TAW	Total Available Water
USBR	United States Bureau of Reclamation

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ABSTRACT

The bulk of available land and water resources potential in Ethiopia is still underutilized. Even worse already developed irrigation schemes are not performing as desired. This study was made in an effort to contribute towards the betterment of the performance of irrigation schemes, using Guder small scale irrigation scheme as the case study site. Measurement of canal discharge, soil moisture and its physico-chemical properties were made to investigate the technical performance; and interview using structured questionnaires were made to identify potential social and inistitutional factors in the performance of the irrigation scheme. Internal and external technical performance indicators were used to evaluate the scheme for better performance in terms of water applied and water consumed for future improvements. The irrigation scheme has average conveyance, application, distribution, Christianson's uniformity coefficient and storage efficiency value of 88%, 49.74%, 82.3%, 90%, and 70% respectively. Absence of WUAs and irrigation expert, low institutional support service, inadequate input and credit supply were the major social and inistitutional factors of the scheme. The irrigation project was over designed. This was due to unmeasured river base flow and diversion weir, main canal, division boxes and drop structures were redesigned. Large amount of water lost was measured from the system before reaching the target fields due to spillage and seepage from unlined main canal. It is also recommended that the pimary section of canal be lined with stone masonry or concrete and the remaining earthen canal should be compacted properly for which the support of institutions may be important.

1. INTRODUCTION

1.1. Background

Day by day the world's population is increasing at the alarming rate resulting in increasing demand of food and fiber. On the other hand, per capita land and water resources are decreasing at alarming rate (Ingle *et al.,* 2015). Land and water resources and the way they are used are central to the challenge of improving food security across the world. Demographic pressures, climate change, and the increased competition for land and water are likely to increase vulnerability to food insecurity in Africa and Asia. The challenges of providing sufficient food for everyone worldwide has never been greater (FAO, 2011).

In 2006, the global area equipped with irrigation stood at 301 Mha. Irrigation has developed rapidly in recent decades, particularly in developing countries, in response to the need to ensure controlled water sources for optimal crop productivity. As the global population grew, the area equipped for irrigation more than doubled from 139 Mha to 301 Mha and water withdrawals for irrigation almost doubled from about 1540 km^3 to 2710 km^3. Over the same period, the proportion of total cultivated land that is irrigated grew from 10 to 20 percent (FAO, 2011). Many major land and water systems are globally important and present substantial levels of risk, in terms of sustainability, productivity and capacity to address poverty and food security (FAO, 2011).

Production value of different crops grown in command area were lower than that of the recommended package of practices (Ingle *et al.,* 2015). Ethiopia has 12 river basins with an annual runoff volume of 122 billion m^3 of water and an estimated 2.6 - 6.5 billion m^3 of groundwater potential, which makes an average of 1575 m^3 of physically available water per person per year, a relatively large volume (Awulachew *et al.,* 2007). With all this potential, however, it fails to produce enough food to feed its population (Awulachew *et al.,* 2006). The country puissant dependence on food aid has been attributed largely to an over-reliance on rain-fed smallholder agriculture. Moreover, ample rainfall is available to be tapped through rainwater harvesting technology at household level for small-scale irrigation. Nonetheless, the developed irrigation from all these sources is so far, not more than 0.86 Mha (GTP II, 2016).

Irrigation is one means by which agricultural production can be increased to meet the growing demands in Ethiopia (Awulachew *et al*., 2005). One of the best alternatives to consider for reliable and sustainable food security development is expanding irrigation development on various scales, through river diversion, constructing micro dams, water harvesting structures, etc (Robel, 2005).

Currently, the government is giving more emphasis to the sub-sector by way of enhancing the raw materials, importing and exporting (foreign currency) systems and food security situation in the country. Efforts are being made to involve farmers progressively in various aspects of management of small-scale irrigation systems, starting from planning, implementation and management aspects, particularly, in water distribution and operation and maintenance to improve the performance of irrigated agriculture (Awulachew *et al*., 2007).

Understanding the challenges is crucial to improving the effectiveness of Small Scale Irrigation (SSI) projects. Moreover, it is crucial to understand the different challenges that emerge at different levels of SSI development. The challenges compromise the effectiveness of SSI projects in generating income for farmers and improving livelihood (Mastewal, 2015).

Poor understanding of the local contexts towards irrigation coupled by the mere focus on technical aspects of SSI schemes limits the success of past interventions in Ethiopia and elsewhere in Africa (Merrey and Cook, 2012).

1.2. Statement of the Problem

The intensity of recurrent drought affects the livelihood of agricultural communities and the whole economy. Even with good harvests in normal times, both acute and chronic hunger and malnutrition occur among many Ethiopians (Catterson *et al*., 1999). Thus, irrigated agriculture is thought to be one of the solutions to bring food security in the country.

Even if Ethiopia has a substantial potential for irrigated agriculture assessed both from available land and water resource view point, the bulk of this potential is still underutilized. Most farmers produce once in a year due to the erratic and seasonal nature of rainfall and this phenomenon imposes crucial antagonistic impact on livelihoods of the smallholder farmers.

Special attention is given to small scale irrigation development for their low capital requirement. In spite of this, the attention paid for this sector, the development of irrigation has not picked up. Even though some efforts have been underway to develop small scale irrigation (SSI) schemes; yet, Ethiopia has developed only 12% of the irrigable land (Zeleke, 2015). Furthermore, it is noticed that the existing irrigation farms are operating at sub-optimal levels and many of the SSI projects have been performing below the required economic efficiency (Getaneh, 2011).

The World Bank, other development banks and numerous countries have invested in large irrigation projects. There have been conflicting opinions about the wisdom of investing further in new irrigation projects, primarily due to the questions about the performance of existing projects (Burt and Styles, 1999).

However, there is a concerted effort that underway by the government of Ethiopia to expand irrigation of all categories including rain-water harvesting with the prime purpose of overcoming the problem of food insecurity, extreme rural poverty, and to promote economic dynamism.

Therefore it is important to undertake performance assessment of existing irrigation schemes to increase the farmer’s frequency of production and improve the productivity of scarce resources that are available in rural areas.

One of the small scale irrigation projects that this research seeks to investigate is *Guder* irrigation scheme which is located in Awi Zone Amhara Region. The irrigation scheme is known to suffer a number of shortcomings such as seepage and sedimentation but, there has not been a systematic study to evaluate. Hence, the project is proposed to investigate those shortcomings for better performance.

1.3. Objective

The overall objective of this study was to undertake a comprehensive evaluation of *Guder* irrigation scheme and come up with a recommendation to enhance the performance of the scheme to improve efficiencies, increase water productivity and increase crop yield.

The specific objectives of this study are:

- To evaluate the technical performance of the scheme using internal and external indicator;
- To analyze social and inistitutional factors; and
- To re-design the scheme for better scheme performance

2. LITERATURE REVIEW

2.1. Irrigation Development Overview

Over the last forty years, the irrigation has been a major contributor to the growth of food and fiber supply for a global population that has more than doubled, from 3 to over 7.3 billion people. Global irrigated area increased by around 2% a year in the 1960s and 1970s, slowing down to around 1% in the 1980s, and lower still in the 1990s. Between 1965 and 1995 the world's irrigated land grew from 150 to 260 million ha. Nowadays it is increasing at a very slow rate because of the significant slowdown in new investments, combined with the loss of irrigated areas due to salination and urban encroachment (De Wrachien and Goli, 2015).

At present irrigation covers 270 million ha, *i.e*. 18% of the world's arable land. Overall, irrigated land contributes to 40% of agricultural output and employs about 30% of population in rural areas. It uses about 70% of water withdrawn from global river systems. About 60% of this water is used consumptively, the rest returning to the river systems (De Wrachien and Goli, 2015).

In the face of soaring global food prices, importing agricultural products is becoming more challenging. This entails a substantial increase in water and land productivity through investment in both rainfed and irrigated agriculture (Tilahun *et al.*, 2011).

2.2. Irrigation Development Profile in Ethiopia

Irrigation practices were long been in use during ancient times with unspecified beginning period. However, irrigation was not likely a driving force for the initiation of ancient civilization in Ethiopia. Since 1950's modern irrigation was introduced at the Rift Valley basin for production of commercial crops. Government, donors and NGOs are investing in developing irrigation systems, especially on small-scale irrigations. As a result, irrigation is developing rapidly. However, its contribution to the national economy is not significant when compared to rain-fed agriculture (Haile and Kasa, 2015).

The water resources of Ethiopia are enormous; amounting to about 125 BCM of annual surface water potential and an estimated annual groundwater potential of 2.6 BCM. Total irrigable land potential in Ethiopia is estimated to be 5.3 million ha, including from surface water, groundwater and rain water harvesting. Equipped irrigated area to date covers only 700,000 ha, including schemes of all scales. The irrigated area covers only 12% of the potential and 5% of the cultivated land (Zeleke, 2015).

Irrigation in Ethiopia plays a vital role to ensure food security and remains a high priority consideration in development strategy and prevention of food shortage. The availability of water confers opportunities to individuals and communities to boost food production, both in quantity and diversity, to satisfy their own needs and to generate income from surpluses. Improper irrigation management practices do not only waste scarce and precious water resources but also decrease marketable yield and economy (Dessalew *et al.*, 2016).

Nowadays, the policies and strategies of Ethiopia strongly supports the irrigation developments especially the small scale irrigation (SSI) through the Water Sector Development Programs (WSDP) and Ethiopian Irrigation Development Plan (IDP). This irrigation development is mainly expressed in the development of small scale irrigation (SSI) schemes by governments, donors and NGOs. Irrigation is believed as a key for food security and poverty reduction in Ethiopia. As a result, developments in the Ethiopian irrigation system have shown great advancements so as to assure Ethiopian livelihoods especially in the rural areas (Haile and Kasa, 2015). Irrigation development helps to increase household income and reduces the incidence of poverty at the household level. It can benefit the poor through raising yields and production and nonfarm employment (Adugna *et al.*, 2014).

However, the contribution of irrigation to the national economy as compared to its potentials is non-negligible. This indicates more investments on the area have paramount importance for the development of the country. Therefore, intensive investments should be operated in the sector by governmental, non-governmental and privates investors (Haile and Kasa, 2015).

Well-managed irrigation development is key in helping Ethiopia to overcome major challenges including population pressure; soil and land degradation; high climate variability, and low agricultural productivity (Awulachew and Ayana, 2010). Irrigation can have adverse effects on environment and public health, if it is not properly managed (Abraham *et al*., 2011).

According to MoA (2011) agriculture still remains to be the leading sector in the national economy of Ethiopia. The country is endowed with a wide range of natural resources such as land, irrigation potential and agro ecological diversities favorable for the growing of various crops. However, these natural resource bases are not getting sufficient attention for the wise use and sustainable utilization in order to bring a sound change and sustainable development in the overall economic development of the country.

The government of Ethiopia is giving emphasis to the irrigation sub- sector in order to enhance the capacity and increase its contribution in the overall economic development of the country. But this needs to be strengthened further and enhance irrigated agriculture, particularly giving emphasis to small-scale irrigation development to increase production and productivity and improve food security and reduce poverty. This is basically based on the fact that small-scale irrigation has a comparative advantage as compared with medium and large irrigation schemes, where SSI has lower investment cost, easier to construct and maintain, end users can be actively involved and have more control over the water resources, requires less management capacity, has less environmental impact and can be more fairly distributed to benefit more users (MoA, 2011).

2.3. Small Scale Irrigation

According to Ministry of Water Resources of Ethiopia (MoWR, 2002), irrigation development in Ethiopia is classified based on the size of the command area, in three types: Small-scale irrigation systems (less than 200 ha), Medium-scale irrigation systems (200 - 3000 ha) and Large-scale irrigation systems (greater than 3000 ha). This classification system is the most common in Ethiopia. Accordingly, 46% of proposed irrigation developments are in the small-scale irrigation category (Makombe *et al*., 2011). Small scale irrigation has a positive effect on farm production, income, asset endowment, and employment opportunity and poverty reduction (Adugna *et al.,* 2014).

According to Lam (1996) the definition of “small-scale irrigation systems” varies, depending on the way that specific countries define it. On another view, various criteria are used in referring to small scale irrigation (FAO, 1998) and defining as the process of introducing effective water control technique to schemes with an independent water supply and a command area not exceeding 500 ha, which are to be planned, developed and managed by farmers through the establishment of viable water use association (WUA) linked to existing social structure.

Large-scale irrigation schemes are economically more efficient than the small-scale irrigation. Productivity of SSI is impeded by the minimal use of improved technologies such as fertilizers, improved seed and the management practices such as planting and irrigation. However, SSI is more efficient than the rain fed system (Tilahun *et al,*. 2011).

According to FAO (1998), small-scale irrigation can be highly cost effective when simple locally adapted technique are used and that quick return can be expected as planning and design are implemented at local level with farmers directly contributing towards the construction. And this also plays a vital role in poverty alleviation and improving the nutritional conditions of the rural poor who often do not receive the common benefits of economic growth.

Investment in small scale irrigation (SSI) is crucial to sustain food security and livelihoods of smallholders. In Ethiopia, the government and development partners show a growing interest in developing irrigation projects. The success of irrigation projects is determined by governance and socio-cultural contexts. Yet the lack of thorough understanding of the challenging contexts undermines the efforts to achieve sustainability outcomes in irrigation projects (Mastewal, 2015).

2.4. Technical Performance Evaluation of Irrigation Systems

In order to conserve water resources, close attention has to be paid to the performance of irrigation systems. Irrigation systems should be evaluated on a regular basis to ensure that the systems are well maintained and are performing according to design. The irrigation system must also be managed correctly and effectively (Ascough and Kiker, 2004). Much of the work to date in irrigation performance assessment has been focused on internal processes of irrigation systems. Many internal process indicators relate performance to management targets such as timing, duration, and flow rate of water, area irrigated, and cropping patterns (Kloezen and Garce, 1999).

Effective irrigation management requires reliable performance assessment. Good farm irrigation management assures correct frequency of irrigations, correct application depth, uniform irrigation, minimum runoff, and minimum deep percolation except for that required for salt management, minimum erosion, and optimal return on irrigation investment (Renault, 1999).

According to Molden *et al*. (1998), performance is assessed for a variety of reasons: to improve system operations; to assess progress against strategic goals; as an integral part of performance-oriented management, to assess the general health of a system; to assess impacts of interventions; to diagnose constraints; to better understand determinants of performance; and to compare the performance of a system with others or with the same system over time. The type of performance measures chosen depends on the purpose of the performance assessment activity.

A comprehensive performance evaluations can provide answers to the following questions (LeRoy *et al*., 1994):

- Is the system properly designed? In other words, are lengths, widths, flow rates, properly designed?
- Pressures, slopes, and other design factors within acceptable ranges to permit good irrigation when the system is properly managed?

- Are the irrigations conducted at the right time and in the right amount? If not,
- What is the proper timing and amounts of typical irrigation applications?
- Are the irrigations acceptably uniform? If not, how do we improve them?
- Are runoff losses acceptable? If not, how do we lower these losses?
- Is soil erosion a problem? If so, then how can the problem are eliminated?

Performance of any irrigation system is the degree to which it achieves the desired objectives. As many irrigation systems do not perform as much as they should, due to considerable constraints and setbacks, identifying the areas in which they fall short of potentials is essential (Gashaye, 2007).

2.4.1. Performance gaps existing in irrigation management

So-called durable structures (weirs, intakes, dams, canals) do not always last as long as their design life. Failure of such structures (because of poor construction quality, inadequate design, earth tremors, floods) can have severe implications for sustainability as repair can be beyond the means of the community. In contrast, structures built from local materials, although also regularly damaged, and so requiring significant labor inputs for maintenance, can often be repaired by communities themselves. The relative merits and ease of maintenance of structures, 'modern' or 'traditional', need to be assessed on a case-by-case basis. Continued soil erosion and poor catchment management prevalent in Ethiopia are likely to increase the incidence of failure of structures, both 'durable' and locally made (Richard *et al*., 2006).

According to Douglas and Juan (1999), There are four potential kinds of performance gaps that can occur with irrigation systems. The first is a technological performance gap. This is when the infrastructure of an irrigation system lacks the capacity to deliver a given hydraulic performance standard. The second kind of performance gap is when a difference arises between how management procedures are supposed to be implemented and how they are actually implemented. The third kind of performance gap is a difference between management targets and actual achievements. Examples of management targets are the size of area served by irrigation in a given season, cropping intensity, irrigation efficiency, water delivery schedules and water fee collection rates. This can be called a gap in achievement. Such problems are generally addressed either by changing the objectives or increasing the capacity of management to achieve them - such as through increasing the resources available or reforming organizations. The fourth type of performance problem concerns impacts of management. This is a difference between what people think should be the ultimate effects of irrigation and what actually results. These are gaps in impact performance and include such measures as agricultural and economic profitability of irrigated agriculture, productivity per unit of water, poverty alleviation and environmental problems such as water logging and salinity. If management procedures are being followed and targets are being achieved, but ultimate impacts are not as intended, then the problem is not that the managing organization has performed badly, since these effects are generally beyond its direct control. The problem is that the objectives of the organization do not produce the desired impacts. This is more a problem of policy than management.

2.4.2. Technical internal and external performance indicators

Performance indicators can be broadly categorized into internal and external indicators to describe the above mentioned aspects. Internal indicators are used to assess the performance of the internal processes and irrigation services. They are concerned with operational procedures of the systems, institutional setups for management, irrigation infrastructure and water delivery services. Internal indicators enable comprehensive understanding of the processes that influence water delivery service and the overall performance of a system (Renault and Wahaj, 2007). Hence, they are useful to show what would have to be done to improve the internal and hence the external performance. They relate the performance to internal management targets (equity, adequacy and reliability). Internal irrigation performance is linked to farmers' level of satisfaction by some authors (Ghosh *et al*., 2005 and Kuscu *et al*., 2008).

External indicators on the other hand evaluate inputs and outputs to and from irrigation schemes. They are generally meant to evaluate the efficiency of resource use (land, water, finance) in irrigated agriculture. External indicators can be best used as part of a strategic performance assessment and benchmarking performance of schemes (Burt and Styles, 2004). They are those indicators based on outputs and inputs from and to an irrigated agricultural system (Molden *et al*., 1998).

2.4.2.1. Conveyance efficiency

Conveyance efficiency is defined as the ratio of the amount of water delivered at the turnouts of the main irrigation conveyance network to the total amount of water diverted into the irrigation system. It is one of several closely related and commonly used output measures of performance that focus on the physical efficiency of water conveyance by the irrigation system (Bos, 1997).

Bos *et al*. (1994) stated that the change of the ratio is an indicator for the need of maintenance. Quantifying the outflow over inflow ratio for only one month gives information to the system manager provided that a target value of the ratio is known.

Most irrigation water comes from diversions from streams or reservoirs. Losses that occur while conveying the water are often excessive. 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, 2002).

Water conveyance loss consists mainly of operation losses, evaporation and seepage into the soil from the sloping surfaces and bed of the canal. The most important of these is seepage. Evaporation loss in irrigation networks is generally not taken into consideration (Xie *et al.*, 1993). The seepage loss in the irrigation canals accounts for the major portion of water conveyance loss (98.37%) while approximately 0.3 per cent of the total stream is lost due to evaporation (Badenhorst *et al.*, 2002). The lining of an irrigation canal has the advantages of reduction in seepage losses from canals reaching water table and raising it resulting in waterlogging and reduction in yield, reduction in losses thereby making more water available for extension of irrigation to new areas and improvement of irrigation facilities in the areas already under irrigation (Kumar *et al.*, 2008).

According to FAO (2002), canal seepage varies with the nature of the canal lining; hydraulic conductivity, the hydraulic gradient between the canal and the surrounding land, resistance layer at the canal perimeter, water depth, flow velocity, and sediment load. Excessive seepage can occur due to poor canal maintenance. In large irrigation schemes more water is lost than in small schemes, due to a longer canal system. From canals in sandy soils more water is lost than from canals in heavy clay soils, when canals are lined, with bricks, plastic or concrete, only very little water is lost. If canals are badly maintained, bund breaks are not repaired properly and rats dig holes, a lot of water is lost

Once losses are better understood, technique to increase the conveyance efficiencies can be more intelligently proposed. The research result of FAO (2002) in Egypt reached to a conclusion that water losses from canals were estimated to account for 25-50% of the total water loss. In most canal systems, due to their continuous use, the large majority of the total conveyance loss is steady state seepage.

With proper soil compaction techniques, steady-states loss rates in earthen channels can be reduced even more than 50%. Overall conveyance efficiency of the lined, unlined section of the main canal and field channel was observed as 75, 52 and 34 percent respectively (Jadhav *et al.*, 2014). Conveyance losses from unlined canal and field channels have contributed to more losses. Management interventions of converting the unlined canal network sections into lined sections can improve conveyance efficiency by up to 75%.

The choice of water saving channel improvement techniques should be based on an economic analysis of the costs of the improvement vs. the benefits derived from the saved water. Once losses are better understood, technique to increase the conveyance efficiencies can be more intelligently proposed. In another study conducted in Pakistan, the conveyance efficiencies of three unlined watercourses were found to be 72.89, 74.15 and 68.75% respectively (Zeb *et al.*, 2000). A figure of over 90% is normally considered acceptable for a lined canal, but a well-constructed canal on a small scheme should achieve better than 95% (Adrian, 2007).

2.4.2.2. Application efficiency

Water application efficiency provides a general indication of how well an irrigation system performs its primary task of delivering water from the conveyance system to the crop. The objective is to apply the water and to store it in the crop root zone to meet the crop water requirement (Odhiambo and Kranz, 2011). It is defined as a measure of the fraction the total volume of water delivered to the farm or field to that which is stored in the root zone to meet the crop evapotranspiration needs.

According to Roger *et al*. (1997) methods of determining application efficiency of a specific irrigation system is generally time consuming and often difficult because it may vary in time due to changing soil, crop and climatic condition.

Lesley (2002) explained and defined the situation of application efficiency with time and event specific and the equation could be used for a single irrigation event or more as a term reflecting seasonal performance. The difference in how it is used can be quite dramatic. For example, the first irrigation event using furrow irrigation can have a very low application efficiency if the length of run is long, furrows are freshly corrugated, stream size is wrong or for several other reasons. If irrigations are too close together, or the amount of water applied is too high, the application efficiency will be lower than it could be. This was indicate low irrigation efficiency, showing that water is being wasted as deep percolation.

Application efficiency does not show if the crop has been under-irrigated. According to Roger *et al*. (1997) it is possible to have high application efficiency and 50-90% can be used for general system type comparison. FAO (1989) reported that the attainable application efficiency according to the US (SCS) ranges from 55%-70% while in ICID/ILRI this value is about 57%. However, Lesley (2002) opined that it could be in the range of 50-80%. On a well-run scheme it could be as high as 80% (Adrien, 2007).

FAO (1989) suggested that 60% attainable water application efficiencies for surface irrigation system. Also Norman (1999) said that a minimum value of the ratio of crop water demand to the actual amount of water supplied to the field of 0.6 or irrigation efficiency of 60% is included in the design of most surface irrigation systems to accommodate crop water needs and anticipated losses. Value below this limit would normally be considered unacceptable.

2.4.2.3. Distribution uniformity

Although different cases might produce the same results for application and storage efficiencies, 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 (Jurriens *et al.*, 2001).

The uniformity of application is evaluated using the Christianson Uniformity Coefficient (Jurriens *et al.*, 2001). Distribution uniformity describes how evenly irrigation is applied to the crop. Distribution uniformity concerns the distribution of water over the actual field. Based on the analysis of nearly 1000 properly designed irrigation system evaluations, SJVDIP (1999) puts a distribution uniformity of furrow irrigation to be 80-90%.

2.4.2.4. Christianson's uniformity coefficient

The uniformity of application is evaluated using Christianson's uniformity coefficient (Jurriens *et al*., 2001). Little *et al.,* (1993) suggested a classification of .uniformity of a sprinkler irrigation system as very good, good, poor and worse if CU value equals 90%, between 80% and 89%, between 70% and 79% and < 69%, respectively. Classification of uniformity of a center pivot irrigation system was also suggested as Excellent (no changes required), good (no changes required unless a problem area is obvious), fair (no improvements needed but system should be monitored closely) and poor (improvements needed) if CUC value equals 90 to 100%, 85 to 90% , 80 to 85% and below 80%, respectively (Harrison and Perry. 2010). Merkley and Allen (2003) considered DU > 65% and CU > 78% to be the minimum acceptable performance level for economic system design.

2.4.2.5. Storage efficiency

Water storage efficiency is an index used to measure irrigation adequacy. It is the ratio of quantity of water stored in the root zone during irrigation event to that required to the field (Garg, 1989). The requirement efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone. The value of *Es* is important when either the irrigations tend to leave major portions of the field under-irrigated or where under-irrigation is purposely practiced to use precipitation as it occurs and storage efficiency become important when water supplies are limited (FAO, 1989).

Water storage efficiency has significant impact on the crop yields and thus on the economic return on water use. The Natural Resource Conservation Service of UK recommends water storage efficiency for homogeneous soil condition to be at least 87.5% (Raghuwanshi and Wallender, 1998).

2.4.2.6. Water delivery performance

The simplest, and yet probably the most important and short term, hydraulic performance indicator are those that compare actual discharge to an intended or target discharge at any given location in the system (Bos *et al*., 1994):

According to Bos *et al*. (2005), the numerator can be determined in two ways depending on the availability of data:

a) In systems where no structures are available to measure the flow rate, time is the only remaining parameter to quantify water delivery performance. For operational purposes it then is assumed that the flow rate is constant during a relatively long period.
b) With systems dependent on flow rates and volumes, flow rates must be measured (in m^3/s). Delivery performance of water then relates the actual delivered volume of water with

respect to the intended volume. The length of the period for which the volume is calculated depends on the process that needs to be assessed. It varies from one second (for flow rate), one irrigation rotation (for water availability) to one month or year (for water balance) studies.

2.4.2.7. Maintenance indicators

Proper maintenance enables to keep water control infrastructure in good working condition so that the designed water level could be achieved. Higher than designed water levels, increase seepage and result the danger of overtopping of the embankment. Lower than the designed water level, increases vegetal growth for earthen canals and result in shortage of irrigation water for the farm. Both lower and higher water levels alter the intended water division at canal bifurcation structures, if the canal has maintenance problem. The magnitude of this alteration of the water distribution depends on the hydraulic flexibility of the division structures (Bos *et al*., 1997). This change of head (level) over structures in irrigation canals is the single most important factor disrupting the intended delivery of irrigation water. This is explained by the following two hydraulic performance indicators.

a) The relative change of the water level (RCWL)

The relative change of water level will be determined by taking the actual water level depth from the canal and comparing it with design value at the same position in the main canal. Greater than zero value indicates that the intended water level in the main canal has not been achieved. Hence less discharge is delivered per unit time (Gashey, 2007).

b) Effectivity of infrastructure

The effectivity of infrastructure stands for the ratio of the number of functioning structures to the total number of structures initially installed (Gashaye, 2007). In order to determine the effectivity of the infrastructure of the irrigation system, all the infrastructures including the drop structures, the division boxes, farm bridges and human water supply points which are positioned on the main, secondary and tertiary canals are monitored.

c) Sustainability

According to Bos (1997), the sustainability of irrigation with respect to maintenance is best explained by the sustenance of the resources without compromising the environmental aspects and productivity. It is a useful indicator for assessing the sustainability of irrigated agriculture. Lower values of this indicator would mean abandonment of lands which were initially irrigated; and hence, indicate contraction of irrigated area over time. On the other hand, values higher than unity indicate expansion of irrigated area and would imply more sustainable irrigation (Zeleke, 2015).

2.4.2.8. External indicators of irrigation performance

According to Molden (1998), 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 cropped area: The output per unit irrigated cropped area (output per unit harvested area) quantifies the total value of agricultural production per unit of area harvested during the period of analysis. The annual harvested area depends on the intensity of cropping (irrigation intensity). The area is the sum of all the areas under crops during the year in this case. This indicator is not affected by the intensity of cropping (irrigation). However, it can also indirectly indicate the degree of irrigation water availability. In addition to water availability, soil type and fertility, land suitability, crop variety and agricultural inputs do have significant impact on output and hence on land productivity. It is given as (Molden *et al*., 1998 and Malano *et al*., 2004):

Output per unit command area: The output per unit command area is the value of agricultural production per unit of nominal area which can be irrigated. Smaller values of this indicator can also imply, although not necessarily, less intensive irrigation and vice versa. It is particularly important where land is a constraining resource for production (Molden *et al*., 1998).

Output per unit irrigation water supply: The output per unit irrigation water supply tells on how well the total annual diverted irrigation water from a source is productive. Irrigation water supply includes conveyance (seepage) losses in canals, and hence it is generally measured at the intake from the source or at diversion. In areas where water is scarce, water management aims to increase the output per drop of irrigation water (Zeleke, 2015).

Output per unit irrigation water delivered: The output per unit irrigation water delivered is meant for the value of production per unit volume of annual irrigation water delivered to the head of command area. It is different from irrigation supply as it does not include losses in conveyance systems. It is a useful comparative indicator because it addresses output per drop of irrigation water actually delivered to the user. Inefficient water use results in lower values of this indicator (Zeleke, 2015).

2.5. Social and Inistitutional Factors on Irrigation Schemes

Ethiopia has a policy and legislative framework that supports IWRM, but its implementation is poor; institutional roles are not sufficiently well articulated, nor are coordination mechanisms for water resource management (especially at sub-national level) (Beatrice *et al*., 2015). There is poor scheme management in terms of inadequacy and late maintenance of canals. Added to this, many of the water users associations are weakly functioning. Lack of effective coordination, inefficient control system, very weak linkage with relevant stakeholders; and lack of regular training is the peculiarity of many WUAs. Existing problems in operation and maintenance and weaknesses in the capacity of WUAs is challenging (MoA, 2011).

Among socio- institutional constraints MoA (2011) reported the following as major problem:

- At all levels, there exists low institutional capacity which is critical to enhance development of SSI with respect to development planning, design, implementation, and operation and maintenance including irrigation advisory services.
- Water theft, conflict on land, and water distribution are a common scenario in many schemes.
- WUAs have weak coordination skill to solve scheme related problems.
- Upper stream households were getting adequate water, whereas lower stream lower stream beneficiaries do not. As a result some sort of conflict and dissatisfaction was rising.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

Guder small scale irrigation scheme is situated specifically in Tana Basin *Ende Wuha Kebele* in *Fagita Lequma woreda* of *Awi* Zone, Amhara Region of Ethiopia. The *woreda* situated on about 464 km north west to Addis Ababa and 10 km from the *woreda* centre of *Addis Kidam* town in south west direction, and the scheme is located at a point Latitude: 11º01'14.2" North and Longitudes: 36º54'21.6" East. The altitude ranges from 2530 to 2556 m.a.s.l.

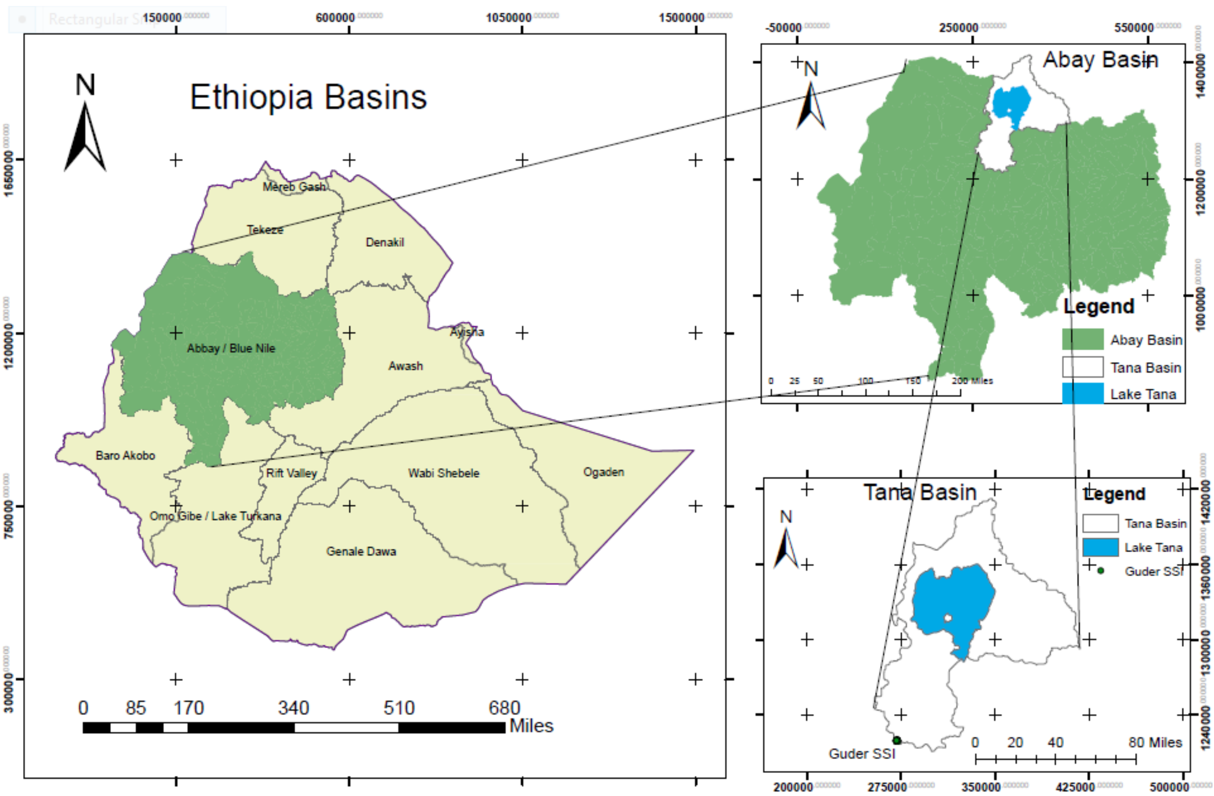


Figure 1. Location map of the study area

3.2. Soil and Topography

The dominant soil texture of the command area is silt clay. The effective soil depth ranges from 70 to 150 cm with undulating topography. Its slope ranges from 3 to 15% with slightly hilly mountains. The slope of the command area lies from slightly sloping to nearly level slopes. The catchments area above the irrigation scheme is vegetated by forest plantaion but soil erosion during rainy season is a major problem causing canal siltation and sedimentation. No soil and water conservation structures are observed in the upstream catchments (author's field observation).

3.3. Climate Characteristics

According to *Enjebra* and *Dangila* meteorological station, the average minimum rainfall 8.7 mm occurs in the months of February and the maximum 537 mm occurs during the month of August. The mean monthly relative humidity of the area varies between 28.3 to 66 % and the average is to be 50.1%. The mean daily wind velocity varies between 6.6 and 19.8 km/day in the months of October and June respectively. The mean daily sunshine hours varies from 2.7 in the month of August to 8.4 in April. The average of monthly minimum and maximum temperatures were observed as 5.8˚C and 28.9˚C occurring in the month of December and April respectively. Rainfall data was taken from *Enjebera* meteorological station, located at 8 km away from the study area, Based on ten years data from the station (2000 - 2015) mean annual precipitation in the area is 1614 mm.

3.4. Data Collection

3.4.1. Primary data

Field investigations were taken to assess both the structural integrity of system components and their fitness to control and/or convey flows. Observations have been made how farmers control and manage irrigation water during application/irrigation events. In order to evaluate constraints, Stratified randam sampling was used to select 60 respondents from 108 irrigation scheme users. Stratification of the scheme was based on groups of irrigators as head, middle and tail end users. A sampling frame was obtained from most commonly available membership list of scheme user using lottery method.

3.4.2. Secondary data

Secondary data was collected from Regional Bureau of Agriculture, Zonal Bureau of Agriculture, Zonal Bureau of Water Resources Development and *Fagita Lekoma* Office of Agriculture. Secondary data included necessary report, project documents, studies and other useful written materials. These data included design and layout of the scheme, design of conveyance and water control structures, annual production, irrigable area, total command area, area irrigated per crop per season/year, crop types, yields, cropping pattern, and intended canal flow and the role of irrigation water users association.

3.5. Overview of Irrigation Scheme

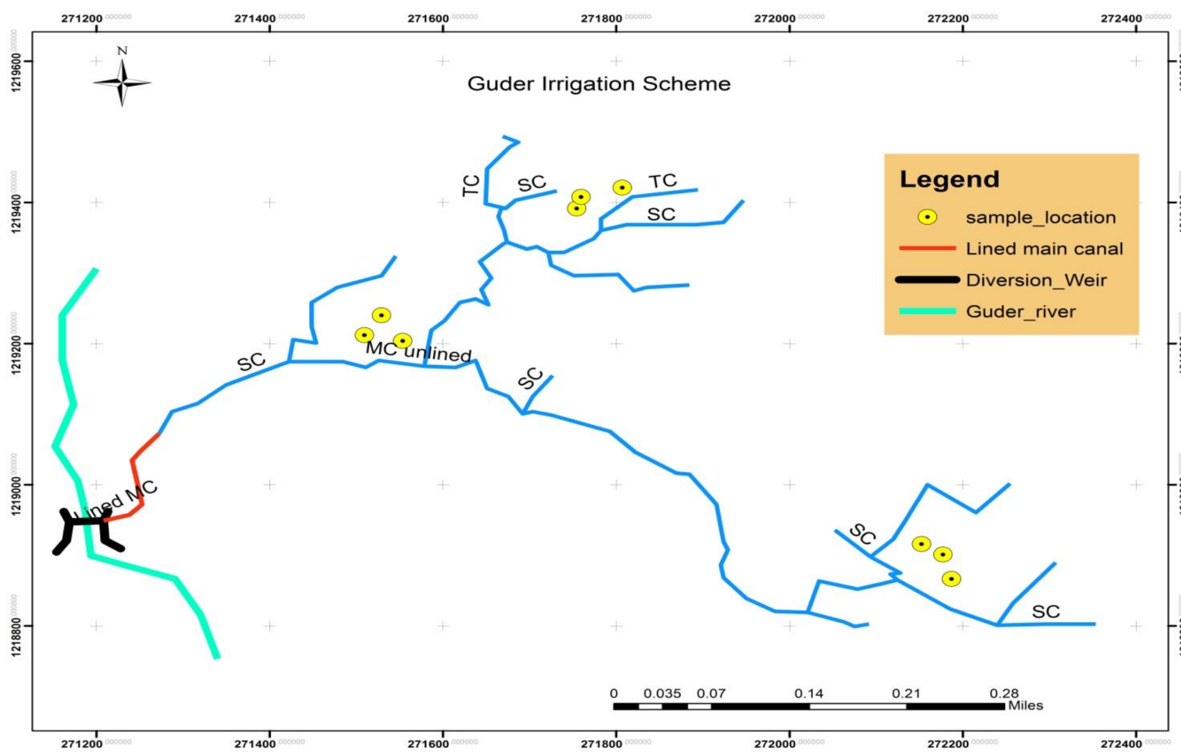
Before the establishment of the project, farmers were irrigating about 30 ha of land by using temporary diversion structures to produce crops and other vegetables. These temporary structures were laid at an angle to the river course and supply canals were extended to the field where irrigation was taking place.

Guder diversion is established on December 30/2014 which was originally designed to irrigate 90 ha of land.. The source of water for the scheme is *Guder* River. According to the design note, the river base flow which was taken as guss estimation from the local people information is 140 lit/sec and required amount of water per ha (water duty) was estimated to be 1.3 l/s/ha and the capacity of intake gate was 140 l/s (BoWRD, 2012). The main irrigation canal length was 1.85 km long. The project has four secondary canals and the sum of the length of these secondary canals was 2.6 km, while the tertiary canals total length is 2.1 km. The crest length of the weir is 8 m while the height is 1.6 m.

From the total 1.85 km length of main canal, about 0.15 km is lined and remaining 1.7 km is unlined or earthen canal. The entire earthen canal have critical seepage problem. According to the design document, the main canal which was proposed to be lined is 1.523 km.

The command area falls under *Dega* agro-climatic zone. Commonly grown and adopted crop and vegetables, during dry season, potato and barley which cover around 53.83% and 30.67% respectively of the irrigated area. There is no stated rule or restriction about the type of crop to be cultivated.

The average landholding of *Guder* irrigation water user's ranges from 0.125 ha to 0.75 ha, with majority of farmers own 0.25 ha of irrigable land. The total number of households in the Kebele is 1,073, out of which the projects intended (designed) for a total beneficiaries of 108 households disaggregated by gender facets (96 male and 12 female).



*MC - main canal *SC - secondary canal *TC - tertiary canal

Figure 2. *Guder* irrigation scheme layout

Table 1. Designed variables of *Guder* scheme

River base flow	Base flow: 140 lit/sec
Hydrology (Design variables)	Design rainfall: 111.3 mm Catchment area: 0.75 km^2 Time of concentration: 0.3 hr Design flood: 10.5 m^3/sec
Type of head work (Design parameters)	Diversion structure Crest length: 8 m Crest height: 1.6 m Cyclopean concret
Sill level of canal intake	2549.36 masl
Command area features	Dry season 90 ha Wet season 110 ha
Irrigation hours	18 hr a day
Maximum duty for irrigation	1.3 lit/sec/ha
Over all irrigation efficiency	50%
Main canal	On right side Rectangular masonery canal Design ddischarge: 140 lit/sec Length: 1523m

3.6. Technical Performance Evaluation

Three sample research farms which belong to three farmers were chosen systematically; from head, middle and tail ends users and all the necessary measurement. The sizes of each farm selected for evaluation were 205 m^2, 287 m^2 and 214 m^2 from the upper, middle and lower end respectively, but for the evaluation purpose, the size of the farmer's field was restricted to 205 m^2 for each. The middle and tail end farmer's field was getting water from the secondary canal and the upper farmer's field was getting water from the main canal. All the farmer's fields chosen for study were planted with potato.

The moisture status of the soil profile for each furrow was measured before and two days after irrigation. Soil samples from each furrow to a depth of at least that of the root penetration was collected using soil auger sampler. Samples were put into oven for 24 hours at a temperature of 105ºC to determine the moisture content gravimetrically. Using soil core samplers, nine undisturbed soil samples were collected and the bulk densities at different depths were determined. Pressures of 1/3 bar and 15 bar exerted on saturated soil samples to determine the field capacity (FC) and permanent wilting point (PWP) respectively. To determine the pH of each farmer's field, soil samples were collected from different depths and measured using pH meter. The analysis was done in Amhara Design and Supervision Works soil laboratory.

3.6.1. Conveyance efficiency

The conveyance efficiency was measured on the main canal and secondary canal using floating method; the first measurement of discharge was conducted in the upper position of the main canal. In this canal section, the channel was lined and uniform.

The canal section considered for discharge measurement had 18 m length for lined main canal, 20 m for unlined main canal and 17 m length for secondary canal. Floating material (Cow dung) was put on the upper end of this canal section and the time it took to travel the marked distance was registered. This test was repeated five times and the average time it took was taken to calculate the surface velocity. The surface velocity is known distance divided by the time it took to travel that distance.

Since the top of the stream flow is faster than bottom due to friction against the channel bed, surface velocity was converted to flow velocity multiplying by a correction factor 0.85 for rough or rocky bottoms and 0.9 for smooth, muddy, sandy or smooth bed rock conditions (Harrelson *et al*., 1994).

The cross sectional area of the canal was also estimated by measuring the average depth and width of the same canal section. Then continuity equation (Q = A x V) was used, where, Q is the discharge (m^3/sec), A, the cross sectional area of the canal (m^2) and V, the average flow velocity (m/sec).

The second measurement was taken at a fixed distance above the downstream end of the lined main canal, unlined main canal and unlined secondary canal. The same procedure was followed to that of the upper parts of the canal to estimate the discharge at the outlet (the downstream end) so that the amount of conveyance loss was known and the conveyance efficiency was determined. The measurements for both positions were taken twice in one measurement. The conveyance efficiency was calculated by using the following equation:

$$E_c = \frac{Total\ water\ supplied\ by\ the\ conveyance\ system}{Total\ inflow\ into\ the\ conveyance\ system}\ x\ 100 \quad (3.1)$$

The irrigation water discharge was also measured at the main canal intake during the study period to determine the actual discharge of intakes in the scheme. Measured data are taken monthly at head end when the main gate was opened. These flow data were utilized for computation of canal delivery performance indicators.

3.6.2. Application efficiency

The application efficiency was calculated from the fields of three farmers that were growing potato and situated in the upper, middle and lower end of the water source. For moisture content determination soil samples were taken to the laboratory three times at four growth stages of the potato (initial, developmental, mid-season and late stage) per farm. For every three farms, soil samples were taken before irrigation and two days after irrigation from (0-20 cm), (20–40 cm) and (40-60 cm) depths per test pit. Samples were initially weighed with sensitive balance immediately after sample collection on the field. Water content was then measured gravimetrically by weighing the sample after oven drying at 105^{o}C.

In all the four crop growth stages, immediately after soil samples before irrigation was taken, fields were irrigated and the amount of water applied to the field was measured by installing three inch parshall flume at entrance of selected farmer’s field when fields were being irrigated and the measured water depth was changed to its respective discharge by flume-discharge empirical formula recommended in USBR (2007):

$$Q = C_f \times {h_u}^{nf} \quad (3.2)$$

where: Q = Discharge rate (l sec^{-1})

hu = Flow depth or head (m), in the flume and Cf and nf are dimensionless constant values of 176.5 and 1.55 respectively.

Two days after irrigation (at field capacity), 36 soil samples were taken with similar procedure as above from three pits per farm. The depth of the water retained (d) in the root zone of the soil before and two days after irrigation was calculated using equation (3.3) recommended in Mishra and Ahmed (1990):

$$d = \sum_{i=1}^{n} \frac{(Q_f - Q_i)}{100} \; x \; A_{si} \; x \; D_i \qquad (3.3)$$

where: Qf is moisture content of the ith layer of soil after irrigation on oven dry weight basis in %

Qi is moisture content of the ith layer of soil before irrigation on oven dry weight basis in %

Asi is apparent specific gravity of the ith layer of soil (gm/cm^3)

Di is depth of ith layer and (cm)

n is no of layers in the root zone.

The apparent specific gravity of the soil (dry bulk density) was measured using the standard core sampler and weighing before and after drying the soil samples collected with core samplers in the Amhara Design and Supervision Works Soil Laboratory. The bulk density of the soil was determined by dividing the mass of the dry soil to the sample volume. The application efficiencies (Ea) in the selected fields were calculated using equation 3.4.

$$E_a = \frac{W_s}{W_f} \; x \; 100 \qquad (3.4)$$

where: Ea = water application efficiency [%]

Ws = water stored in the soil root zone during the irrigation [mm]

Wf = water delivered to the farm [mm]

3.6.3. Distribution uniformity

For calculating the Distribution uniformity, the effective root depth of the crop (*i.e.* up to 60 cm) was taken as the zone of distribution and three rows selected along each field. Auguring was done at three points starting from the beginning to the end of the three rows at regular interval. And at each selected points of the row, soil samples were collected at three depths (*i.e.* at 0-20 cm, 20-40 cm and 40-60 cm). Therefore, a total of 9 samples were collected before irrigation. The same was done after irrigation also. This procedure was repeated for each three farmer's field; and three times for each one of them.

After measuring the soil moisture contents of the soil samples gravimetrically, at the selected points in oven dried, the depth of water infiltration at that particular soil layer was calculated using the equation 3.5 (Walker, 2003).

$$X = \left(\frac{W_a - W_b}{100}\right) x\ AS\ x\ D \tag{3.5}$$

where: X is depth of water infiltrated in a particular soil layer (cm)

Wa is moisture content of the i^{th} layer of the soil after irrigation (at field capacity) on oven-dry weight basis, (%)

Wb is moisture content of the i^{th} layer of soil before irrigation on oven-dry weight basis, (%)

AS is apparent specific gravity of the i^{th} layer of soil

D is soil depth of i^{th} layer (D = 20 cm in this case)

Then, to determine the total depth of water stored at each sample point (X_1 to X_9), the values of $X_{(0\text{-}20)}$, $X_{(20\text{-}40)}$ and $X_{(40\text{-}60)}$ of that specific point were summed up.

$$X_1 = X_{(0\text{-}20)1} + X_{(20\text{-}40)1} + X_{(40\text{-}60)1} \tag{3.6a}$$

.

to

$$X_9 = X_{(0\text{-}20)9} + X_{(20\text{-}40)9} + X_{(40\text{-}60)9} \tag{3.6b}$$

After calculating the depth of water stored (as the difference between after and before moisture content) at each points of the rows, the distribution uniformity (DU) parameter was determined.

The DU is defined as the percentage of average application amount received in the least-watered quarter of the field. It is the ratio of the average depth infiltrated in the lower quarter of observations to the average depth of all observations (Roger, 1997).

$$DU = \frac{\overline{X}_{Lq}}{\overline{X}_{m}} \ x\ 100 \qquad (3.7)$$

where: $\overline{X}_{Lq}$ is the mean of lower-quarter depth of water infiltrated and

$\overline{X}_m$ is the mean depth of all water infiltrated (*i.e.* the average of all the nine points).

3.6.4. Christianson's uniformity coefficient (CUC)

In similar way to the distribution uniformity, uniformity of application was also evaluated by calculating Christianson Uniformity Coefficient using equation (3.8). The average depth of water infiltrated was obtained by finding the mean of the stored depths at different sections of the furrows.

The equation used to evaluate the uniformity of water redistribution below the soil surface was Christiansen's coefficient of uniformity (CUs). This equation is the most widely and accepted criterion used to define uniformity (Zoldoske *et al.*, 1994). The uniformity of water redistribution below the soil surface used a rewritten form of the non-weighted coefficient of uniformity:

$$CUs = 100\left(1 - \frac{\Sigma|\theta_i - \overline{\theta}|}{N\overline{\theta}}\right); \qquad \overline{\theta} = \frac{(\Sigma_{i=1}^{N} \theta_i)}{N} \qquad (3.8)$$

where; CUs = Christiansen's coefficient of uniformity of soil water content below soil surface,

θ_i = the measured gravimetric soil water content at depth i,`

$\overline{\theta}$ = the mean gravimetric soil water content, and N = number of measured points.

3.6.5. Storage efficiency

Using FC in volume basis, bulk density and volumetric soil moisture content of the soils before irrigation at different depth, water requirement of the root zone profile was computed. Assuming the density of water as unity the volumetric soil moisture content each field at different depths of test point was evaluated using equation (3.9) and the required water depth was calculated using equation (3.10) as recommended by (Allen *et al*., 1998).

$$\theta_v = \frac{\theta_w \ x \ \rho_d}{\rho_w} \tag{3.9}$$

where; $\theta v =$ Volumetric soil moisture content (%)

$\theta w =$ Soil water content on dry weight basis (%)

ρ_d= bulk density (gm/cm^3) $\rho_d = density\ of\ water$

$$Wn = \sum_{i=0}^{n}\left(\theta_{fc} - \theta_{before}\right) x \ Di \tag{3.10}$$

where: θ_{before} = i^{th}layer moisture content before irrigation in volume percent

θ_{fc} = i^{th}layer soil moisture content at field capacity in volume percent

Wn = required water depth (mm)

Di = i^{th} layer crop root depth (mm)

n = number of layers in the root zone

The depth of water retained in the root zone was calculated using equation (3.3). After determining the depth of water stored and required water depth in the root zone, the storage efficiency was calculated using equation (3.11) as recommended in Garg (1989).

$$E_s = \frac{\boldsymbol{I_s}}{\boldsymbol{I_r}} \ x \ 100 \tag{3.11}$$

where: E_s = storage efficiency (%)

I_s = stored water depth (mm)

I_r = required water depth (mm)

3.6.6. Water delivery performance

In order to evaluate how the water delivery performance is adequate, actually delivered volume of water was measured using area – velocity method repeatedly while the value of designed (intended) volume of water was taken from the design document. It is calculated using equation (3.12) as recommended in Bos *et al.*(1994):

$$Water\ Delivery\ Performance\ = \frac{\text{Actual Flow of Water}}{\text{Intended Flow of water}} \tag{3.12}$$

3.6.7. Maintenance indicators

In order to evaluate the hydraulic performance indicators such as relative change of water level and sustainability of irrigable area, the maximum actual water level (m) was measured repeatedly and the intended water level was taken from the design document. Current total irrigable area (ha) and initial total irrigable area (ha) was collected from secondary data sources. Relative change of water level and sustainability of irrigable area were calculated using equation (3.13) and (3.14) respectively as recommended in Bos *et al*. (1997):

$$Relative\ change\ of\ water\ level\ = \frac{Actual\ water\ level\ (m)}{Intended\ (Designed) water\ level\ (m)} \tag{3.13}$$

$$Sustainability\ of\ Irrigable\ Area\ = \frac{Current\ total\ irrigable\ area\ (\ ha)}{Initial\ total\ irrigable\ Area\ (\ ha\ )} \tag{3.14}$$

3.6.8. External indicators

To determine the external indicators of the scheme such as output per cropped area, output per unit command area, output per unit irrigation supply and output per unit water consumed data’s such as production, irrigable cropped area, commend area were collected. Production can be measured as gross value of production using local values. The first two parameters were calculated based on the crop productions of the year 2015/2016 (Oct to May) of the projects where as some data's, like the irrigation water supply, that can be used to calculate the last two parameters needs direct field measurements for each cropping seasons otherwise long-term recorded data must be available. So for this study these parameters were applied for 2015/2016 (Oct-May) cropping season only for the availability of these data through field measurements. The following equations were used to compute the external or comparative indicators (Molden, 1998).

$$\text{Output per cropped area} = \frac{Production(US\$)}{Irrigated\ cropped\ area(ha)} \tag{3.15}$$

$$\text{Output per unit command area} = \frac{Production(US\$)}{command\ area(ha)} \tag{3.16}$$

$$\text{Output per unit irrigation supply} = \frac{Production(US\$)}{Diverted\ irrigation\ supply(m^3)} \tag{3.17}$$

$$\text{Output per unit water consumed} = \frac{Production\ (US\$)}{Volume\ of\ water\ consumed\ by\ ET(m^3)} \tag{3.18}$$

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, and

Volume of water consumed by ET is the actual evapotranspiration of crops.

3.7. Social and Inistitutional Factors on Guder Irrigation Scheme

Data were collected using structured questionnairs and interviewing 60 scheme beneficiaries to analyze social and inistitutional factors. To select 60 respondents from 108 irrigation scheme users, stratified randam sampling was used.

Stratified random sampling consists in dividing the population into groups, or strata, and then taking a simple random sample from each stratum. This is done to improve the accuracy of estimates, to reduce cost, or to make it possible to compare strata (Shirley *et al*., 2004).

The irrigation scheme was stratified in three stratas such as head, middle and tail end users which has total beneficiaries of 38, 29 and 41 respectively. Users are grouped into egiht which of these 3, 2 and 3 are in the head, middle and tail positions respectively. These groups were used to classify the strata. Simple lottery method was used to select 20 respondents from each strata. Necessary informations on social and inistitutional (implementation, institutional supports, organizational supports and water management) factors of the scheme were collected and analyzed descriptively and simple report method.

3.8. Redesigning of the Scheme

To redesign, structural problems on the existed scheme was identified and all the necessary proceduers and formulas in design document was checked and compared. The following methodologies have been adopted.

Table 2. Methodologies used to redesign the project

Sr. No	Activities	Methodologies
1	Exact Weir site identification	By surveying the elevation difference to meet the command area (Using GPS)
2	Weir site and main canal geology investigation	By physical observation and taste pits (adopted from the design document)
3	Surveying work	By total station (adopted from the design document)
4	Command area features	By physical observation and taking soil samples
5	Soil test results and meteorological data of the surrounding areas	Taken from Amhara design and supervision works and *Engibara* and *Dangla* meteorological stations
6	Social response of the scheme users to wards the project	By interview and discussions held with the users
7	Flood mark declination	By looking features at the river bank and asking dwellers
8	Catchment area and collection of watershed characteristic data	Observation and Top maps (1:50,000) (adopted from the design document)

3.8.1. **Soil water availability**

The total available water in the root zone is the difference between the water content at field capacity and wilting point (Allen *et al.*, 1998):

$$TAW = 1000x(FC - PWP)xZr \tag{3.19}$$

where: TAW is the total available soil water in the root zone (mm),

FC is the field capacity of the soil volumetric in decimal

PWP is the permanent wilting point volumetric in decimal

Zr is the rooting depth (m)

Allen *et al*. (1998) stated that the fraction depletion (P) is a function of the evaporative power of the atmosphere. At low rates of *ETc*, the P values listed in the table are higher than at high rates of *ETc* and for hot dry weather conditions, where *ETc* is high; P is less than the values presented by Allen *et al*. (1998). The tabulated values for P apply for ETc$\neq$ 5 mm/day. The values for P were adjusted for different *ETc* using equation (3.20):

$$P_{adj} = P_{tab} + 0.04(5 - ETc) \quad (3.20)$$

where; P_{tab} is tabulated fraction (Allen *et al*., 1998) and *ETc* is in mm day(0-1).

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

$$RAW = P_{adj} \, x \, TAW \quad (3.21)$$

where: *RAW* = Readily Available Soil Water in the root zone (mm)

P_{adj} = average adjusted fraction of Total Available Soil Water (*TAW*) that can be depleted from the root zone before moisture stress (reduction in ET) occurs (0 - 1).

3.8.2. Cropping pattern

The cropping pattern, which should be dominated by annual food crops, is assumed to cover an annual cropping intensity of 200%. Cereals (Wheat, Barley and Maize) was cover the major part of the area followed by root crop (Potatoes), vegetables (Cabbage).

3.8.3. Base flow measurment

The major sources of water for *Guder* river are three spring sources and some contribution from a small watershed. The head work site whcich is far 400 m from the spring sources and at this range there is no modern and traditional irrigation practice. Due to this the redesigner expect all spring water at the head work site.

Guder is ungauged river. The only means of estimating base flow of the river is by local people's information and measuring the river flow in critical seasons. Base flow of the river is observed on 29 Novmber 2016. The base flow recorded using floating method was 99.36 lit/sec.

3.8.4. Hydrological data availability

Rainfall and other related hydrologicala data availability is core for any project that require hydrological analysis. In redesigning Guder diversion irrigation project, redesigner have adopted Dangila and Enjebara stations of meteorological data for different purposes. In deciding the possible sources of climate data, topographic features, distance and position of the area from the meteorological stations, and local information on the rainfall movement direction have been checked.

According to the local dwellers information, the rainfall coming from Enjebara area always drops to their farm area. Also the altitude difference and air distance of Enjebara is smaller than the nearby Dangilla meteorological station. Therefore, redesigner have adopted mean monthly rainfall data of Enjebara meteorological station. However, Enjebara meteorological station does not have other sufficient data, like minimum and maximum temperature, sunshine hour, Humidity, and wind speed. Hence, redesigner adopted these data from the next nearest station that is Dangila meteorological station. All these data are analyzed and used for crop water requirement purpose.

In addition to the crop-water requirement, rainfall data is needed for redesigning of drainage canals inside the command area. For the drainage canals design purpose, 24 hour heaviest rain fall data of Enjebara meteorological station is adopted.

At the proposed outlet point, Guder River has a catchment area of 0.75km^2. For peak flood analysis and crop water requirement calculation, the redesigner used nearest metrological station of 16 years data (Enjebara metrological station from 2000 - 2015).

Table 3. Rainfall analysis of Enjebara meteorological station

Year	Max. RF	Descending order(X)	Rank	Logarithm value (Y)
2000	67.2	90.4	1	1.956
2001	84.8	84.8	2	1.928
2002	56.3	80	3	1.903
2003	51.6	73.26	4	1.865
2004	80	72.4	5	1.860
2005	53.6	72.26	6	1.859
2006	68.7	68.7	7	1.837
2007	90.4	67.2	8	1.827
2008	64.1	64.1	9	1.807
2009	51.4	62.94	10	1.799
2010	72.4	62.24	11	1.794
2011	62.94	58.32	12	1.766
2012	73.26	56.3	13	1.751
2013	58.32	53.6	14	1.729
2014	62.24	51.6	15	1.713
2015	72.26	51.4	16	1.711
Sum	1069.52			29.104
Mean	66.845		$\overline{Y}$	1.82
Standard Deviation	12.34		Sy	0.07
Skewness coefficient			Cs	0.19
Number of Data	16			

3.8.5. Data Consistency Test

Sixteen years of daily heaviest rainfall records of Enjebara metrological station, from 2000 to 2015, has been used for the estimation of design rainfall. In spite of less number of rainfall data, the designer assumes an event that happens at every 50 years of return period to compute the design rainfall. These data should be checked for their consistency by the outlier test following the assurance of the reliability of the data. Those data, which had been missed, were abandoned and only fully recorded monthly highest one were used for computation.

3.8.5.1. Check the data reliability.

Number of data = 16

Standard deviation, $\delta_{n-1} = 12.34$

Mean, $\bar{X} = 66.845\ mm$

Standard error of mean, $\delta_n = \frac{\delta_{n-1}}{\sqrt{n}} = \frac{12.34}{\sqrt{16}} = 3.084$

Relative standard, $\frac{\delta_n}{\bar{X}} * 100 = \frac{3.084}{66.845} * 100 = 4.614$ which is less than 10%.

Therefore, the data shows no variability.

3.8.5.2. Data Outlier Test

Sometimes significant change may occur in and around a particular rain gauge station. Such a change occurring in a particular year might start affecting the rain gauge data being reported from that particular station. After a number of years, it may be felt that the data of that station is not giving consistent rainfall values. In order to detect such inconsistency, and to correct and adjust the reported rainfall values, technique, called outlier test is used.

Outliers are data points that depart significantly from the trend of the remaining data. The retention or deletion of these outliers can significantly affect the magnitude of statistical parameters computed form the data.

According to MoWR (1981),

If the $S_k > 0.4$ = test for high outlier

If the $S_k < 0.4$ = test for lower outlier

If the $0.4 < S_k < 0.4$ = test for both higher and lower outlier

For this data CS = 0.19, so the designer considered both lower and higher outlier test.

Input data: $\sum RF = 1069.52\ mm$

$\bar{X} = \frac{\sum RF}{N}, \frac{1069.52}{16} = 66.845$

$Y_m = 1.82$

Kn is outlier test value for a given sample size and level of significance

a. Tast for higher outlier

Higher outlier ; $Y_h = \bar{Y} + k_n S_y$

where: $\bar{Y}$ is mean of data in log unit

$K_n = -3.62201 + 6.28446N^{0.25} - 2.49835N^{0.75} - 0.037911N$

$K_n = 1.899$

From Table 2; N = 16, $\bar{Y} = 1.82, S_y = 0.07, K_n = 1.899$

Skewness coefficient $C_s = 0.19$

Higher outlier $Y_h = \bar{Y} + k_n S_y$ = 1.82+1.899*0.07 = 1.96

Higher outlier = $(10)^{1.96} = 91.32$ mm

Therefore, **90.4 < 91.32** it is ok. No higher outlier

b. Tast for lower outlier

Lower outlier, $Y_l = \bar{Y} - k_n S_y$

1.82 - 1.899*0.07 = 1.6774

Lower outlier, $(10)^{1.6774}$ = 47.584mm

Therefore, 51.4 mm > 47.584 mm**,** it is ok. No lower outlier

3.8.6. Design rainfall computation

The design storm of a certain project can be determined by using various computational methods. But the adoption of a particular method depends on the frequency distribution of the available data series. Thus, before applying one of the available computational methods, the data serious has to be tested for its good fitness to a particular frequency distribution.

For this project the outlier test is checked as shown above and the data is within the lower and higher outliers. Considering 50 years return period and using Gamble's EVI distribution method the design rainfall is determined using equation 3.22:
From the Gamble's EvI distribution method,

$$X_T = \overline{X} + K_T * \sigma_{n-1} \tag{3.22}$$

where: X_T is maximum storm for T years of return period in mm (T = 50 years)

$\overline{X}$ is mean daily heaviest rainfall in mm

σ_{n-1} = is the standard deviation

$K_T = \frac{Y_T - Y_n}{S_n}$; Where: Sn = reduced standard deviation $\overline{Y}$n = reduced mean

$Y_T = -\ln(\ln(\frac{T}{T-1}))$; T = 50 years

3.8.7. Design flood estimation

The peak discharge is a primary variable for the design of storm water runoff facilities such as pipe systems, storm inlets and culverts, and small open channels. It is also used for some hydrologic planning such as small detention facilities in urban areas. It is an acceptable design variable for designs where the time variation of storage is not a primary factor in the runoff process (Richard, 1998).

In design of hydraulic structures, sometimes the total volume of runoff is required, and sometimes the peak rate of runoff is required. This method helps us in evaluating the peak runoff rate.

If rainfall is applied to an impervious surface at a constant rate, the resultant run off from the surface runoff would finally reach a rate equal to the rate of rain fall. In the beginning only a certain amount of water may reach the outlet, but after some time, the water may start reaching the outlet from the entire area, and in that case, the runoff rate would become equal to the rainfall rate. The time required to reach the equilibrium condition is known as the time of concentration (Tc). For small impervious areas, the designer may assume that if a rain persists at a uniform rate of rainfall. In other words, the peak runoff rate occurring for an area having coefficient of runoff K, as caused by a rainfall of intensity of p, and continuing for a time more than Tc might be given by equation 3.23

$$Qp = K * P * A; \text{ for } t > Tc \quad (3.23a)$$

$$Qp = \frac{1}{36} * K * Pc * A \quad (3.23b)$$

Let P cm of rain has fallen in T hours during an individual storm. The mean rain fall intensity (P) be given by $P = \frac{P}{T}$ cm/hr =1.13/6 =1.855cm/hr. The intensity P' of the same storm during any other smaller time interval, say t hr., shall be more than the mean intensity over the whole period, because the intensity is not uniform throughout the storm.

The intensity of the severest storm of given frequency in particular region, during time interval of one hour, somewhere within the entire duration of the storm, is called one hour rain fall of the given frequency of the region, and is represented by Po. Thus,

$$\mathrm{Po} = \frac{\mathrm{P}}{\mathrm{T}} * \left[\frac{\mathrm{T}+1}{1+1}\right] = \frac{\mathrm{P}}{2} * \left(1 + \frac{1}{\mathrm{T}}\right) \quad (3.24)$$

The maximum value of Po, can be accepted as 'the one hour rainfall' of the region for a particular frequency for the design of hydraulic structures. After deciding the frequency of the design storm this value of point rainfall intensity is multiplied by the Areal distribution factor, so as to obtain Po. The areal dispersion factor may vary from 1.0 for small areas to 0.8 for very large areas of the order of 20,000 hectares or so. Since our catchment area is small therefore we take the area dispersion factor to be 1.0 The Po can then be reduced to Pc by using the equation 3.25:

$$\frac{\mathrm{Pc}}{\mathrm{Po}} = \frac{1+1}{\mathrm{Tc}+1} \quad (3.25)$$

Time of concentration (Tc)

It is the time at which the entire watershed begins to contribure to runoff; this is calculated as the time taken for runoff to flow from the most hydraulically remote point in the watershed to the outlet. This might be a number of possible paths to consider in detrmining the longest travel time. Hence the longest flow path which the longest travel time is likely to occur shoud be identified and used for Tc.

Time of concentration can be computed by Kirpich's equation (3.26) which is widely used to estimate Tc.

$$\mathrm{Tc} = \frac{1}{3000}\left(\frac{\mathrm{L}}{\sqrt{\mathrm{S}}}\right)^{0.77} \tag{3.26}$$

where; Tc is time of concentration (hr)

L is length of the min water course (m)

S is slope of the main water course (m/m)

3.8.8. Weir type and weir parameter determination

Weir type was selected by looking the availability of natural construction materials and considering the river features and expected flood amount. Weir parameters such as weir height, crest length, top and bottom width was determined using major factors; maximum command area elevation, sluice gate elevation and deriving head of the intake structure. The crest length of the weir was taken as the width of the river since the river bed is stabilized rock and boulder having defined bank.

Top and bottom width of the weir was determind using Bligh's formula;

$$\text{Top width, B} = \frac{\mathrm{He}}{\sqrt{\mathrm{p-1}}} \tag{3.27}$$

$$\text{Bottom width, B} = \frac{\mathrm{H + He}}{\sqrt{\mathrm{P-1}}} \tag{3.28}$$

where; H is Height of weir (m)

He is specific energy head (over flow depth + approaching velocity head (m))

ρ is specific weight of weir body (2.3 kn/m3 for concrete)

He is estimated using broad crested weir formula

Weir crest length = 8m

Coefficient of discharge for broad crested weir, C=1.7

Head over the weir crest,

$$He = \left(\frac{Q}{1.7 \times L}\right)^{2/3} \quad (3.29)$$

3.8.9. Hydraulics of weir

3.8.9.1. Water depth over the crest

The water depth over the crest was computed using broad crested weir formula:

$$Q = C \times L \times H_e^{3/2} \quad (3.30)$$

Approch velocity, $Va = \frac{Q}{L(Hd+P)}$

Specific energy head, $He = Hd + \frac{{V_a}^2}{2g}$

Note that: Design head over the weir (Hd) was computed by trial and error method.

$$Ha = He - Hd \quad (3.31)$$

Down stream TEL = $\text{HFL befor construction} + \text{Ha}$

Up stream TEL = $\text{Weir crest level} + \text{He}$

Up stream HFL = $\text{Up stream TEL} - \text{Ha}$

Afflux = $\text{Up stream HFL} - \text{Down stream HFL}$

3.8.9.2. Determination of the stilling basin level and down stream water surface

Guder river has stable bed rock, so that no need to construct apron because there is a negligable effect of uplift preasure on this structure and the bottom level of stilling basin was the same as river bed level.

Equating; $Eo = E1$

$Eo = He + Z$, where Z is weir height (m)

$$E_1 = D_1 + \left(\frac{V_1^2}{2g}\right) \quad (3.32a)$$

$$V_1 = \left(\frac{Q}{L \times D_1}\right) \quad (3.32b)$$

$$F_r = \frac{V_1}{\sqrt{gD_1}} \quad (3.32c)$$

$$D_2 = \frac{D_1}{2}\left(\sqrt{1 + 8F_r^2 - 1}\right) \quad (3.32d)$$

3.8.10. Design of canal outlet

The head regulator (off-take) is a structure at the head of a canal taking off water from a reservoir behind a dam or a weir. It is provided to

- regulate supply in the canal
- Control the entry of silt in the canal and
- shut out river floods

The crest level of the regulator/outlet level/ in this case is fixed to be at 2549.36 masl.

3.8.10.1. Capacity of the outlet canal

The water way of the head regulator should be sufficient to pass full supply discharge of the canal which was computed usin equation (3.33).

$$\text{Full supply discharge of the canal} = \text{Duty} * \text{command area} * 1.2 \quad (3.33)$$

N.B:-Correction factor helps to include the water which we get in the wet season

Outlet Size: -Adapting the weir discharge equation:

$$Q = CLH^{3/2} \quad (3.34a)$$

where C= Coefficient of discharge=1.7, L = Length of water way (m)

H = head (water depth) above crest level of regulator (m)

For pond level condition, H= weir crest level – crest level of regulator (3.34b)

$$L = \frac{Q}{CH^{3/2}} \quad (3.34c)$$

3.8.11. Hydraulics design of canal section

3.8.11.1. Main canal redesign

The canal section is redesigned using the Manning's formula as follows.

$$Q = \frac{AR^{\frac{2}{3}}S^{\frac{1}{2}}}{n} \quad (3.35)$$

where: Q = Design discharge (m^3/sec) n = Manning's roughness coefficient
S = Design bed slope R = Hydraulic radius = A/P
b = bed width d = Water depth
p = Wetted perimeter = b+ 2d

The hydraulic Parameters for each variable is calculated using Iteration excel program.

3.8.12. Redesigning of irrigation structures

3.8.12.1. Division box redesign

Division boxes are redesigned in order to attain fair water distribution and protect canals from unnecessary damages that would come by drawing water everywhere. Division boxes have their own sill height, width and total depth proportional to flow they planned to serve. In addition to the redesigned discharge capacity, workability and management problems are taken in to consideration.

3.8.12.2. Drop structure design

For irrigation canals vertical drop structure of U.S.B R type standard is selected to convey water from higher to lower elevation of the ground. The design procedures are shown below:

a. Critical hydraulic

Design discharge, Q (m3/s),

Height of drop, h (m),

Width of drop, bc $= \frac{0.734Q}{d^{\frac{3}{2}}}$, m

where d = water depth of the canal, m

Critical discharge, $q = Q/bc$

Critical depth, $dc = \left(\frac{q^2}{g}\right)^{\frac{1}{3}}$

Lip height, $a = dc/2,\ a \geq 0.15$

b. Stilling basin

Basin width, B $= \frac{18.46\sqrt{Q}}{Q + 9.91}$, m (3.36a)

Basin length, $L = 2.5 + \left[\frac{1.1d_c}{n} + 0.7\left(\frac{d_c}{n}\right)^3\right]\sqrt{hd_c}$, m (3.36b)

3.9. Data Analysis

The data collected to evaluate the technical performance of the scheme were analyzed descriptively. Data collected through questionnaires were analyzed descriptively using Statistical Package for Social Science (SPSS 16) for institutional performance evaluation. In addition, depending on the nature of the questionnaires some of the data are summarized as narrative reports.

Based on the field measurements taken, the internal indicators of the irrigation system were analyzed. FAO's computer program CROPWAT 8 package was used to calculate the crop water requirements (FAO, 1996). Data for major crops grown in the study areas including growing stages and stage lengths (days), crop coefficients (kc), rooting depths (Zr), depletion levels (P), as well as yield response factors (ky) were obtained from FAO irrigation and drainage paper No. 56 and 33.

4. RESULT AND DISCUSION

4.1. Overview of Irrigation Scheme

According to field assessment, *Guder* small scale irrigation scheme has only one drop structure which was constructed during the study period. The main canal lacks a number of distribution structures such as head regulator, drop structures, division boxes, pass ways, and aqueduct which was designed in the project document but not implemented.

There are a number of illegal water abstraction points and canal breaching. The earthen main, secondary and tertiary canals' water is partly flowing through the canal and partly seeped laterally since the embankment is not properly compacted. All the farmers use concept of furrow irrigation but only potato grower's use furrow irrigation.

In the irrigation project, there is no any rule or restriction on the farmers about what type of crop to produce. Any individual farmer has the right to choose type of crop to produce as long as he feels that the crop is profitable, household consumable and that the water allocation is adequate to produce the selected crop.

4.2. Technical Performance Evaluation of the Scheme

4.2.1. Conveyance efficiency

The result of conveyance efficiency measured on main canal and secondary canal is presented in Table 4. The conveyance efficiency of the system is decreasing from head to tail end users. As it can be seen in the Table 4, conveyance efficiency of head, middle and tail end users was 99%, 79% and 86%, respectively. The head Lined main canal has higher conveyance efficiency than the middle and tail end users.

Table 4. Canal conveyance efficiency

Canal location	Area (m^2)	Ave. surface velocity (m/sec)	Velocity coefficient (fraction)	flow velocity (m/sec)	Discharge (m^3/sec)	Ec (%)	Remark
	0.26	0.32	0.9	0.28	0.074		LMC
Head	0.25	0.33	0.9	0.29	0.073	99±0.00	LMC
	0.23	0.34	0.9	0.31	0.070		UMC
Middle	0.22	0.28	0.9	0.25	0.055	79±0.00	UMC
	0.12	0.35	0.9	0.32	0.038		USC
Tail	0.11	0.33	0.9	0.30	0.032	86±0.00	USC
Average						88±10.12	

*LMC - lined main canal *UMC - unlined main canal *USC - unlined secondary canal.

Source: author

From Table 5, it can be seen that 20.78 lit/sec water was lost due to conveyance efficiency from total canal length of 1523 m. This could have irrigated more than 11.54 ha of land (irrigation duty as 1.8 lit/sec/ha). Higher volume of water was lost in the middle stream than the two streams (Table 5). This may be due to unlined canal seepage loss but management intervention and or converting unlined canal to lined canal may reduce this loss.

Table 5. Water lost due to conveyance efficiency

Canal location	Canal length (m)	Conveyance efficiency (%)	Water duty (lit/sec/ha)	Water lost (m^3/24hrs)	Water lost (lit/sec)	Lost irrigable land(ha)
Head	0-150	99	1.8	69.98	0.81	0.45
Middle	150-830	79	1.8	1281.31	14.83	8.24
Tail	830-1523	86	1.8	444.09	5.14	2.86
Total	1523			**1795.39**	**20.78**	**11.54**

Source: author

4.2.2. Application efficiency

The measured amount of water applied to each filed is shown in Table 6. The result shows a decreasing trend from head to tail end users. It can be concluded that tail end farmer seems to have applied the smallest amount of water to his field. This may be the reason why the farmer around the tail end has scarcity of water due to different loses such as seepage loss at the head and middle location of the scheme.

Table 6. Average depth of water applied to farmer's field

Field location	Time (sec)	Flume height (cm)	Respective discharge (l/sec)	Area (m^2)	Total Volume (liter)	Applied depth (mm)
Head	18122.50	7.20	3.00	205	54367.50	265.00
Middle	22107.00	6.40	2.50	205	55267.50	270.00
Tail	25643.25	5.60	2.00	205	51286.50	250.00
Average						262.00

Source: author

The result of application efficiency calculated from the (Table 7) was 53%, 50% and 46% for head, middle and tail end farmer's respectively. According to FAO (1995), the expected application efficiency ranges between 40 and 60%. The result obtained in this research was in the range of these typical value. The probable reason for the low application efficiency values may be attributed due to low level of water management at field level.

Table 7. Application efficiency

Farm	Total depth moisture stored (mm)	Applied depth (mm)	Ea(%)
Head	140.00	265.00	53
Middle	135.00	270.00	50
Tail	116.00	250.00	46
Average			49.74

Source: author

4.2.3. Distribution uniformity

The distribution uniformity value are presented in Table (8) below. The water spreading uniformity of the head, middle and tail end user fields are 84.70%, 82.20% and 80.00% respectively with an average value of 82.30%. The result obtained in the selected farmer's field was sufficient which is in the acceptable range and it was almost similar to the research result of SJVDIP (1999) on nearly 1,000 irrigation systems (i.e. 80% - 90%). The distribution uniformities of all the three farms are by far higher than the value categorized as sufficient (i.e. 65%) by FAO (1992).

From this it can be concluded that much portion of the irrigation fields received and stored equal amount of water to their root zone depth. This was due to short furrow length and layout. This indicates that the higher the value of DU, the better the uniformity of application and the higher the distribution efficiency.

Table 8. Distribution Uniformity

Farm position	X_{Lq}	X_{av}	DU (%)
Head	33.08	39.06	84.70
Middle	27.59	33.56	82.20
Tail	33.86	42.32	80.00
Average			**82.30**

Source: author

4.2.4. Christianson's uniformity coefficient

The Christiansen's uniformity coefficient (CUC) was obtained using equation (3.8) of section 3.6.4. The results found were 93.34%, 89.36% and 87.89% for upstream, middle and downstream fields of the scheme respectively (Table 9). The reason for achieving higher values of CUC in this study might be due to the flatness of the test plot fields and uniformity of soil texture and bulk density.

Table 9. Christianson's uniformity coefficient

Farm position	N	$\sum_{i=1}^{N} \theta_i$	$\overline{\theta}$	$\sum_{i=1}^{N} \lvert \theta_i - \overline{\theta} \rvert$	CUC (%)
Head	9	351.56	39.06	23.41	93.34
Middle	9	302.07	33.56	32.12	89.36
Tail	9	380.84	42.32	46.09	87.89
Average					**90.2**

Source: author

4.2.5. Storage efficiency

Storage efficiency of the scheme varies between 74% and 73% with mean value of 63% (Table 10). According to Raghuwanshi and Wallender (1998), the recommended storage efficiency is 87.5%. Thus, the storage efficiency of the system is below the recommended value. It can be concluded that the irrigation system was not adequate in fulfilling the soil moisture. This was due to low frequency of water applied to the field and the water was infiltrated deeper.

Table 10. Irrigation storage efficiency

Farm position	Total depth moisture stored Ds, (mm)	Water needed Wd (mm)	Storage efficiency (%)
Head	140	188.00	74
Middle	135	184.00	73
Tail	116	190.00	63
Average			**70**

Source: author

4.2.6. Water delivery performance

Table 11 shows the water delivery performance of *Guder* irrigation scheme. The value was calculated as the ratio of actually delivered volume of water to the intended volume of water to be delivered. The mean actual delivered volume of water through the *Guder* irrigation system is 0.09936 m^3/sec while the intended amount based on the design document was 0.14 m^3/sec. Hence the delivery performance is in the order of 70.97%. The amount of water delivered was less than the intended amount. This might be due to sedimentation and seepage loss.

In this scheme, the shortage in water delivery has forced to develop limited area. The farmers over emphasize the water scarcity problem and the poor conveyance efficiency. This was observed while looking into the annually irrigated farms.

Table 11. Water delivery performance of *Guder* irrigation scheme

Actual discharge (m^3/sec)	Intended discharge (m^3/sec)	Water delivery performance (%)
0.09936	0.14	70.97

Source: author

4.2.7. Maintenance indicators

a) Relative change of water level

The design or intended value of the water level (H) when the main canal carries a maximum discharge of 140 lit/second was 0.4 m and the actual level (H) measured was 0.32 m during current maximum 74 lit/sec discharges. This makes the value of relative change of water level to be 20% (Table 12). This mean relative change of water level (%) greater than 0 values indicates that the intended water level in the main canal has not been achieved. Hence less discharge is delivered per unit time.

Table 12. Relative change of water level

Description	Discharge in m^3/sec	H (Depth of water in m)
Designed maximum value of the main canal	0.140	0.40
Current maximum value of the main canal	0.074	0.32
Change of value (0.4 – 0.32)	0.066	0.08
Water delivery performance		20%

Source: author

b) Sustainability

Guder irrigation scheme construction was completed for 110 ha and the actual irrigated area during the study season was only 46 ha. This gives sustainability of irrigation scheme as 41.8%. This figure shows that there is plenty of land to be developed with the scheme while the resulting achievement is far from satisfactory. The fact that the amount of irrigable area is decreasing from year to year while the discharge of the water source is the same clearly indicates that the sustainability of the irrigation scheme is threatened due to water shortage.

4.2.8. External indicators

SGVP values were calculated for the year 2016 using local prices Table 13. The cropped area was 46 ha in the winter season of 2016 in the study area. Five main cash crops were taken into account among which potato was taken as the base crop because it was the most cultivated crop in the area.

Table 13. Standardized gross values of production (SGVP) for different crops on 2016 local prices in *Guder* irrigation scheme

Crop	Copped Area (ha)	Yield (ton/ha)	Prices (US$/ton)	SGVP (SU$)
potato	24.84	4.00	147.42	14647.67
barely	14.26	2.00	245.70	7007.37
maize	3.68	2.60	196.56	1880.69
wheat	0.92	3.60	294.84	976.51
Cabbage	2.30	3.23	106.14	788.53
Sum	46	15.43	990.66	25300.77

Source: author

SGVP per unit of cropped area (US$/ha): The annual SGVP per unit command area was determined 550.02 US$/ha for 2016 (Table 14).

SGVP per command area (US$/ha): SGVP was determined 230.01 US$/ha. *Guder* irrigation scheme had a low value when we compared to other results, for instance it was 325.60 US$/ha for *Batu Degaga* irrigation scheme and 373 US$/ha for *Doni* irrigation scheme (Yusuf, 2004). This may be attributed to the low cropping intensity and the type of crops grown.

SGVP per unit irrigation supply (US$/$m^3$): Value for the year 2016 was 0.1 US$/$m^3$, Guder irrigation scheme has higher value when it was compared to Batu and Doni irrigation schemes 0.056 US$/$m^3$ 0.033 US$/$m^3$ respectively (Yusuf, 2004). SGVP per unit irrigation tends to be higher in humid regions where irrigation needs area generally lower. To increase the value of SGVP per unit irrigation supply, much more area cultivated with vegetable is needed.

SGVP per unit consumed water ($US\$/m^3$): Consumed water is the actual ET from irrigated crops. SGVP per unit consumed water value is calculated 0.17 US$/m^3 (Table 14). The result is below the SGVP per unit consumed value 0.19 US$/m^3 reported by Molden *et al.* (1998). The relatively low value is attributable to the cropping patterns and the abilities of farmers and system manager.

Table 14. External performance indicators *Guder* irrigation project area for 2016 year (SGVP: Standardized gross values of production)

SGVP per Cropped area (US$/ha)	SGVP per command area (US$/ha)	SGVP per Diverted irrigation supply (US$/$m^3$)	SGVP per volume of water consumed by ET (US$/$m^3$)
550.02	230.01	0.10	0.17

4.3. Social and Inistitutional Factors on Guder Irrigation Scheme

4.3.1. Socio-economic characterstics

Table 15 shows educational status of irrigation users. As it can be seen from the Table 15 below, more of users are primary educated. From this it can be concluded that it is possible to train and introduce modern small scale irrigation methods for users.

Table 15. Educational status of *Guder* irrigation scheme

Education status of irrigation users	Frequency	Percent
Illiterate	25	41.7
Informally educated	9	15.0
Primary education completed	26	43.3
Total	60	100

Source: author

All respondents confirmed that the irrigation scheme is very important for them to secure food self-sufficiency. This leads to the conclusion that community had awareness about advantages of irrigated agriculture. Moreover, 63.33% of the respondents confirmed that the scheme has increased their annual income while 36.67% of users annual income has no change. However, all of them corroborated the possibilities to increase the economic benefits of the irrigation system more than its current level. This might be possible using improved seed varities, protecting the scheme from upper catchment flooding through soil conservation works (e.g. cut off drain), removing sediments from head of the scheme regularly, and through compeleting the designed lined canal, water control structures and cross drainage works.

4.3.2. Organizational Status

There are eight teams organized in *Guder* irrigation scheme. The number of beneficiaries within each team ranges from 10-15 which has a leader.

Amhara Regional Cooperative Promotion Agency stated the bylaw clearly that WUA is responsible for water distribution, system maintenance, assessment and collection of irrigation water fees, input supplies, credit facilitation, planning and monitoring, etc. However during the study period *Guder* irrigation system has no WUA and it was administered by community representatives "*Yewuha abats"*. The WUA was established six years ago but now it is not functional. This might cause poor sense of ownership and improper irrigation water opration and management.

4.3.3. Operation and managment

As the scheme was constructed some 4 years ago, farmers were asked what they knew about the involvement of the community in planning and development of the scheme. Nearly 85% of the 60 respondents said that the project was initiated by the local people while 15% of respondents admitted that the project staff had initiated the project but later agreement was reached between the government and the local people. This might be due to the agreement on who was involved in planning and development of the scheme.

According to the survey conducted in this research, the respondents reported that they were involved in the construction of the diversion structure and irrigation canals (74.35%) mainly through by rule without payment (mass mobilization).

Although farmers had long experiences with traditional irrigation, they have little experiences in handling modern irrigation infrastructure and modern irrigation water management skills. They have skill gaps on crop type selection and growth stage during water allocation (every respondents). The water distribution is decided by water users' representatives *"Yewuha Abats"* with no predetermined schedule (without specifying the date and waiting line order of each beneficiary).

The no WUA its representatives of the community "*Yewuha abats*" that is not legally recognized and have lack of power to discharge its responsibilities (to enact regulations that are legally binding on its users) and maintenance obligation are impeding their effectiveness
Conflicts were rising due to the problem of water scarcity, unequal water distribution and water theft (71.6% respondents). Incomplete water control structures and seepage loss are possible reasons for water inadequacy. The major maintenance challenges of the scheme are seepage loss, sediment accumulation on reservoir and canal.

4.3.4. Inistitutional support service

All respondents need credit to purchase agricultural inputs (fertilizers, improved seed and insecticide), fattening and rearing of animals. But beneficiaries have only one institution that provides credit which is Amhara Saving and Credit Supply Institution (ACSI). *Meto Leqoma* cooperative is the only input supplier found in *Adis kidam* which has 10 km distance. It supplies only fertilizer and improved seeds (maize, wheat and barley).

However, farmers have critical problem due to lack of inputs (improved seeds and vegetables such as potato, cabbage, carrot, etc.) Due to shortage of credit, supply of inputs during the irrigation season is very small (87.9% respondents). Scheme beneficiaries have two main market centres (*Enjebera* and *Addis kiddam*). Producers sell their products to local dealers and it is for their subsistence food expense. All respondents confirmed that potato and barley are their main marketable products. There is no any market computation for their products and have limited market network

4.4. Re-designing of the Scheme

4.4.1. Irrigation agronomy

4.4.1.1. Soil moisture content before and after irrigation

Moisture contents of the three irrigation fields before and two days after irrigation is presented in Table 16. Average moisture content within the three soil layers were in an increasing trend down to the profile. This is typical of moisture characteristics after irrigation or rainfall. The bulk density of the area shows variation with depth. It varied between 1.22 to 1.33 gm cm^{-3}.

Table 16. Soil moisture content before and after irrigation

Farm location	Soil depth (cm)	Ave. bulk density (gm/cm^3)	Average moisture content by mass (%)		Moisture content within the root zone by volume basis (%)	
			BI	AI	BI	AI
Head	0-20	1.28 ± 0.02	30.79 ± 0.03	50.65 ± 0.03	39.41	64.83
	20-40	1.22 ± 0.02	33.71 ± 0.07	57.64 ± 0.03	41.13	70.32
	40-60	1.22 ± 0.00	40.86 ± 0.03	60.73 ± 0.02	49.85	74.09
	Average				**43.46**	**69.75**
Middle	0-20	1.24 ± 0.02	18.92 ± 0.03	38.09 ± 0.04	23.46	47.23
	20-40	1.26 ± 0.03	27.84 ± 0.03	44.78 ± 0.03	35.08	56.42
	40-60	1.33 ± 0.04	31.49 ± 0.04	48.37 ± 0.02	41.88	64.33
	Average				**33.47**	**56.00**
Tail	0-20	1.22 ± 0.02	34.92 ± 0.01	51.58 ± 0.02	42.60	62.93
	20-40	1.22 ± 0.03	49.13 ± 0.03	63.13 ± 0.00	59.94	77.02
	40-60	1.24 ± 0.01	41.85 ± 0.03	53.66 ± 0.02	51.89	66.54
	Average				**51.48**	**68.83**

**BI - before irrigation* ** AI - after irrigation*

Source: author

4.4.1.2. Cropping pattern

Different cropping systems are being practiced in the irrigation project. The major crops practiced in the project was analyzed (Table 17). The dominat crop during dry season was Potato which covers 55% of the command area while during wet season Barley was the dominat crop. This was due to Dega agro ecological zone.Using different cropping systems and cropping pattern has advanages on availability and duration of soil moisture during the cropping season, crops can be grown sequentially one after another so that time is used to obtain more production. The significant feature of multiple cropping system has a greater dependability of return compared with sole cropping.

Table 17. Cropping patern for major crops

Horticultural crops		Cereal crops	
Dry season	Area coverage (%)	Wet season	Area coverage (%)
Potato	55	Wheat	25
Cabbage	25	Barley	50
Maize (cereal crop)	20	Maize	25

4.4.1.3. Gross and net irrigation water requirement

The gross and net irrigation requirement of major crops of the project was analyzed (Table 18). The average reference evapotranspiration (ET_o) of the site was found to be 3.16 mm/day (Appendix Table 1). The total available water of the soil was 68.23 mm (Appendix Table 3). The mean actual depth of water applied to the Potato fields by the sample farmers was 262 mm (Table 18). This indicates that the farmers applied 6.2 mm (262.0 mm – 255.8 mm) of excess water to their fields than was required by the crop (255.8 mm).

Table 18. Gross and net irrigation requirement of crop

Crop	Total ETo (mm/period)	Total CWR (mm/period)	Total effective rain (mm/period)	Total irr. req (mm/period)
Potato	388.8	365.5	106.3	255.8
Barley	342.9	135.1	166.3	94.6
Maize	487.4	189.4	231.0	270.6
Cabbag	269.2	238.7	107.1	163.5
Wheat	368.1	275.1	75.6	192.5

Source: author

4.4.1.4. Irrigation scheduling

Water application depth and interval in days are the important elements in irrigation scheduling (Doorenbos *et al.*, 1986). The three farmers were using the same irrigation interval (20 days). This may causes inadequacy for better production. However, there is a problem in the scheme in applying the required depth of water at the proper time to optimize crop yield. Table 6 shows the irrigation interval computed using CROPWAT 8 Computer program.

Table 19. Computed irrigation interval for major crops

Crop	TAW (mm)	Zeff (m)	Ptab (fraction)	Padj (fraction)	RAW (mm)	ETo (mm/day)	Kc (fraction)	ETc (mm/day)	Dn (days)
Potato	45.6	0.4	0.35	0.44	20.06	3.95	0.80	3.16	7.00
Barley	57.0	0.5	0.60	0.71	40.47	3.95	0.56	2.21	18.00
Maize	68.4	0.6	0.55	0.64	43.78	3.95	0.70	2.76	16.00
Cabbag	45.6	0.4	0.35	0.45	20.52	3.95	0.90	3.56	7.00
Wheat	57.0	0.5	0.50	0.61	34.77	3.95	0.60	2.37	15.00

Source: author

4.4.1.5. Irrigation Duty

The maximum irrigation duty was 1.3 lit/sec/ha from the design document but due to less value of overall irrigation efficiency (36%) analyzed during the study, the maximum irrigation duty was found to be 1.8 lit/sec/ha. This might be due to the implementation problem on irrigation systems and improper water management during irrigation.

4.4.2. Hydrological analysis

4.4.2.1. River base flow

The river base flow was 99.36 lit/sec which was less than the design document. This might be due the reason that the base flow 140 lit/sec was taken from the local pepole's information which was not measured value.

4.4.2.2. Design flood

The structure of Guder irrigation project was over designed which was costy and problems found on the irrigation system during field observation and analysis. Design variables and parameters was checked and compared with the design document and has difference value (Table 20).

Hydrological design varaiables such as design rainfall and design flood have a slightly difference in magnitude. This might be due to the rainfall data difference due to a year difference during data collection.

Table 20. Checked design variables and parameters from design document.

Activities	Design variables and parameters from design document	Checked design variables and parameters from design document
Hydrology (Design variables)	Design rainfall: 111.3 mm Catchment area: 0.75 km^2 Time of concentration: 0.3 hr Design flood: 10.5 m^3/sec	Design rainfall: 107.36 mm Catchment area: 0.75 km^2 Time of concentration: 0.3 hr Design flood: 10.06 m^3/sec

4.4.3. Head work redesign

The crest length of the weir was taken as width of the river (Table 21). This was due to the reason that Guder river bed was stabilized rock and boulder having defined abutment (banks). The design and constructed weir crest length (8 m) was equal during study period. Due to this weir crest length was accepted .

The design and constructed weir crest height (1.6 m) was equal during study period. Due to this weir crest heigh was accepted.

The head work of Guder irrigation scheme was redesigned after determination of weir hydraulics (Table 21). The afflux height was 1.66 m which means after construction of the weir the water may raise by 1.66 m. The afflux height greater than 1 m is not recommended. To decrease this value to its allowable limit, it needs to increase the crest length of the weir. But in this proiect the increament of water height by 1.66 m after construction of the weir may not have any significant impact on upstream side.

The top and bottom width of the weir was constructed as per the design document but these were computed using unmeasured river base flow which was taken from local peoples information. The top width was compared and it was accepted but bottom width of the weir was computed and redesigned using design discharge of 99.36 lit/sec which was a measured value during the study period.

The existing condition of the weir was threatened with upstream and down stream siltation and sedmentatation (Appendix figure 1). This might be due to the reason that the run off coming from upper catchment of the watershed

Table 21. Redesign hydrualic parameters of weir profile

Description	Relation	Design	Constructed	Redesign
Crest length L, m	-	8	8	8
Discharge coefficient , C	-	1.7	1.7	1.7
Unit discharge q, m^3/sec	Q/L	1.3125	1.3125	1.2575
Head over the weir He, m	-	0.842	0.842	0.818
Design head Hd, m	Trial & error	0.79	0.79	0.804
Tail water depth , m	-	0.9	0.9	0.74
Weir crest level, masl	-	2549.76	2749.16	2549.76
River bed level, masl	-	2548.16	2548.16	2548.16
Weir crest height Hw, m	-	1.6	1.6	1.60
River bed slope, S	-	0.023	0.023	0.023
D/S HFL	-	2549.06	2549.06	2548.904
U/S TEL	-	2550.602	2550.602	2550.578
D/S TEL	-	2549.112	2549.112	2549.010
U/S HFL	-	2550.55	2550.55	2550.564
Afflux	-	1.438	1.438	1.660
Top width b, m	-	1	1	0.717 use 1
Bottom width B, m	-	2.5	2.5	2.121 use 2
Assuming the silt free depth, P	-	0.5	0.5	0.5
Eo, m	-	2.442	2.442	2.021
Pre jump depth D1, m	Trial and error	0.198	0.198	0.21
Post jump depth D2, m		1.23	1.23	1.24
Length of the stilling basin Ls, m	5 x (D2 – D1)	6	6	5
Length of retaining wall fixed to be, m	-	6	6	5

4.4.4. Outlet canal and main canal redesign

The capacity of outlet canal was constructed as per the design document (Table 22). It was provided a length (L) of 0.5 m and head (H) of 0.4 m and it was constructed in rectangular shape (Appendix figure 2. a) and lined only 0.15 km length from head. This was computed using the weir discharge formula. But the design discharge was unmeasured. Due to this the length of the outlet canal was computed and redesigned using the measured value of discharge (99.36 lit/sec)

The 99.15% of main canal was earthen and has high amount of seapage loss (Appendix figure 2. b). This was the reason that the earthen canal was not even compacted. The main canal runs almost along the contour and a have the capacity of 0.09936 m^3/sec and have rectangular shape. It was redesigned to be masonry lined canal due to topographic and geologic condition of their route. It has design discharge of 0.099 m^3/sec. The adopted depth and bed width was 0.6 m and 0.4 m respectively.

Table 22. Hydraulic redesign parameters of main canal

Chainage(m)	Symbol	Unit	Designed value	Constructed value	Redesigned value
Design discharge	Q	m^3/sec	0.140	0.140	0.099
Bed width to depth ratio			0.120	0.120	1.000
Side slope	Z	%	0.000	0.000	0.000
Manning's roughness	n		0.030	0.030	0.015
Longitudinal slope	S	%	0.001	0.001	0.001
Wet Area	A	m^2			0.184
Wetted perimeter	P	m			1.288
Hydraulic radius	R	m			0.143
Velocity	V	m/sec	0.800	0.800	0.537
Free board	FB	m	0.200	0.200	0.200
Water depth	D	m	0.400	0.400	0.429
Bed width	B	m	0.5	0.5	0.429
Total depth	D	m	0.6	0.6	0.629
Adopted, depth	**D**	**m**	**0.6**	**0.6**	**0.600**
Adopted, Bed width	**B**	**m**	**0.5**	**0.5**	**0.400**

4.4.5. Redesign of irrigation structures

4.4.5.1. Devision box

There were no any division box constructed in the canal section but there were four division boxes designed in the design document (Appendix Table 10). But these all were designed using unmeasuered value of design discharge (140 lit/sec) which might lead to over design.Due to this reason, the new design discharge was measured (99.36 lit/sec) and four division boxes were redesigned (Appendix Table 8 and 9) and (Appendix figure 5). i.e. MC and SC-1 & MC/d/s, MC & SC-2 & MC/d/s, MC & SC-3 & MC/d/s and MC & SC-4 & MC/d/s. All the hydraulic parameters computed using excels spreed sheet with the type of canals. Sites for division boxes were identified (Appendix Figure 4).

4.4.5.2. Drop structures

There were only one drop structure constructed as per the design project (Appendix figure 3. b). Even if the existing drop structure was constructed as per the design project, due to the reason that the design discharge was unmeasured value, all the hydraulic design parameters such as basin length (L), critical flow- width of nocth (bc), critical depth(dc), lip height (a) and others were over designed (Appendix Table 12). Due to this reason the hydraulic parameters of seven drop structures was redesigned using the measured design discharge 99.36 lit/sec (Appenedix Table 11).

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary

Many researchers state that SSI has a significant role to play in agricultural and economic development of rural societies to increase their income and food security. Governments are also paying attention in promoting the development of small holder irrigation schemes.

Evaluating the performance of irrigation systems plays a fundamental role to improve system operations, to diagnosis constraints and to assess the general health of the system. This study was initiated with the purpose of assessing the performance of *Guder* SSI scheme by using internal and external performance indicators, under taking social and inistitutional factor analysis through interview and questionnaires administered to beneficiary farmers

Overall activities in primary data collection included: field measurements, field observation and interviewing beneficiary farmers. Primary and secondary data were collected from the secondary sources including supporting documents and useful literatures in line with the proposed study.

CropWat 8 computer program was used to estimate the crop water requirement, irrigation scheduling and irrigation requirement of crops at field levels and the irrigation project as a whole. Socio-institutional and management status of users was analized descriptively.

Conveyance loss in the main canals was significant. This was due to spillage and seepage loss. Conveyance efficiency was as low as 79% for the unlined canal. The maximum value of conveyance efficiency was 99% for the main canal section delivering irrigation water from head to middle. Application efficiency obtained from three irrigation events has mean value of 49.74%. farmers located at head fields are more efficient in applying water.

The distribution uniformity obtained from investigation is found to be 84.7%, 82.2% and 80% in the head, middle and tail end of fields, respectively. The system has 90.2% mean Christianson's uniformity coefficient.

Storage efficiency, *Es* of the scheme varies between 74% and 63% with mean value of 70%. The highest value was obtained from head users while middle and tail positions indicate that there is significant water loss and the irrigation system was inadequate in fulfilling the soil moisture required.

Institutional support service in the form of irrigation extension and technical expertise was non existence at the time of the study. Support services in terms of supplying selected improved seeds, fertilizer and other inputs, was found unsatisfactory.

There were structural problems found on the irrigation systems and has implementation problem and improper water management. The *Guder* River base flow was 99.36 lit/sec measured on 29 Nov. 2016. The over all irrigation efficiency of the scheme was 36%.

5.2. Conclusion

The conclusions drawn from the findings of this research are:

There is a substantial room to improve the technical performance of the scheme. Large amount of water is lost from the system before reaching the target fields due to seepage in the unlined portion of the main canal. The lined main canal could be considered as good while the unlined main and secondary canal were low. Moreover, this lose might be attributed to seepage and spillage loss which could potentially irrigate 11.54 ha of land.

The overall scheme users have low irrigation water management skill and there is a substantial room to improve their skill.

Flatness of irrigation farm plots and short furrow length could have better distribution uniformity and christianson’s uniformity coefficient. Frequencies of water application to the irrigation fields could have significancies on adequacy of soil moisture storage.

Beneficiaries have low awareness on modern water management and implementation. Sedimentation or siltation from various sources can also potentially possess adverse impact on the schemes’ efficiency. Absence of WUAs and weak linkage of community representatives “*Yewuha abat’’* causes weak perception on scheme operation and maintenance. Conflicts could reduced through training and awereness cration on modern irrigation water management.

Unmeasured base flow leads to over design or under designed. Guder irrigation scheme was over designed. Due to this the diversion weir, main canal, drop structure aand division boxs were redesigned.

5.3. Recommendation

About 90.15% of the canal portion which was planned to be lined is unlined and some part of it was not maintained for four years, so that the water loss at the canal portion was somehow high (20.78 lit/sec). To minimize this water loss, it may be better to make the unlined canal to line by redesigned project and maintain the existing portion of lined canal. Drop structures and division boxes should be constructed using redesigned hydraulic parameters. The Woreda Agricultural Office or Regional Bureau of Agriculture should support the necessary budget and contiguous action should be taken to complete the water canals and control structures. And also it is recommend that frequent reservoir and canal cleaning is necessary to minimize the accumulation of silt and sediments that minimizes the volume of water through the canal.

To increase the agricultural output from irrigation farms crop-pattern should include different varieties of vegetables and crop intensity should be increased. Training and awareness creation to farmers should be done to improve their operation and management skills.

Water users associations (WUA) should be organized and empowered with its legally registered bylaw and fortifying the existing social structure in order to improve the performance of SSI schemes and minimize conflicts. Assigning irrigation agronomist and technician to the scheme and conducting on-job training to them may have an overriding contribution to the improvement of the scheme technical performance.

Institutional support services such as credit supply, inputs supply and market networking should be improved and continuous monitoring, evaluation and maintenance of the scheme should be done.

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7. APPENDICES

7.1. Appendix Table

Appendix Table 1. Monthly Eto(mm/day and mm) and effective rain fall (mm)

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	**Ave/total**
Eff. rain(mm)	9.5	8.6	38.7	64.6	167.7	152.2	172.4	178.7	166.9	105	38.4	14	**1116.70**
ETo(mm/day)	2.91	3.12	3.66	3.95	3.95	3.42	3.09	3.94	3.35	2.85	2.88	2.75	**3.16**
ETo (mm)	90.18	87.36	113.54	118.54	122.32	102.55	95.9	91.06	100.58	88.32	86.46	85.43	**1182.24**

Appendix Table 2. Mean monthly weather data at *Dangila* meteorological station from 2000 to 2015

Month	Min.Temp °C	Max. Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	7	22.2	45	11	9.2	20.5	2.91
February	6.5	23.9	28	14	9.2	21.9	3.12
March	11.2	28.7	39	15	8.2	21.7	3.66
April	13	28.9	36	16	8.3	22.3	3.95
May	15.3	26.5	51	15	8	21.5	3.95
June	15.3	24.2	62	20	5.8	17.9	3.42
July	15.3	22.7	66	19	4.4	15.9	3.09
August	12.3	22.6	67	8	4.2	15.8	2.94
September	12	23.5	64	7	6.3	18.8	3.35
October	10.9	20.5	43	7	6	17.5	2.85
November	8.4	20.9	53	10	8	19	2.88
December	5.8	21.4	47	11	9	19.6	2.75
Average	11.1	23.8	50	13	7.2	19.4	3.24

Appendix Table 3. Field capacity, permanent wilting point, bulk density and total available moisture

Sample location	Soil depth (cm)	Bulk density (gm/cm3)	FC (%)		WP (%)		TAW (mm/m)	TAW (mm)
			w/w	v/v	w/w	v/v		
Head	0 - 20	1.28	31.41	40.21	18.27	23.39	168.19	33.64
	20 - 40	1.22	32.66	39.84	25.75	31.41	84.30	16.86
	40 - 60	1.22	42.03	51.28	33.22	40.53	107.48	21.50
Middle	0 - 20	1.24	21.48	26.63	11.62	14.40	122.26	24.45
	20 - 40	1.26	27.37	34.48	19.05	24.00	104.83	20.97
	40 - 60	1.33	30.25	40.23	20.61	27.41	128.21	25.64
Tail	0 - 20	1.22	35.26	43.02	26.43	32.25	107.73	21.55
	20 - 40	1.22	46.18	56.34	38.38	46.82	95.16	19.03
	40 - 60	1.24	44.89	55.66	36.40	45.13	105.28	21.06

Appendix Table 4. Crop water requirement (CWR), effective rainfall (Pe), irrigation requirement and percent of CWR to be met by effective rainfall (Pe).

Crop	Planting date	Cropped area (ha)	Total rain fall (mm)	Eff.rain (mm)	CWR (mm)	Irr.requier ment (mm)	Pe (%CWR)
Potato	Jan 01	24.84	106.3	77.0	338.8	261.8	22.72
Barley	Oct 10	14.26	199.0	166.3	278.8	177.1	59.65
Maize	Jan 01	3.68	418.5	216.3	413.1	196.8	52.36
Cabbage	Oct 15	2.30	108.1	76.0	239.5	163.5	31.73
Wheat	Nov 05	0.92	79.2	61.2	304.6	243.4	20.09
Total		46	911.1	596.8	1574.8	1042.6	37.89

Appendix Table 5. Total depth of moisture stored within the root zone

Farm	AMC after irrigation (mm)	AMC before irrigation (mm)	Total depth of moisture stored (mm)
Head	66.75	43.46	140.00
Middle	56.00	33.47	135.00
Tail	70.83	51.48	116.00

Appendix Table 6. Applied water measured using three inch parshall flume

Field location	Time (sec)	Flume height (cm)	Respective discharge (l/sec)	Area (m^2)	Total Volume (liter)	Applied depth (mm)
Head	18122.50	7.20	3.00	205	54367.50	265.00
Middle	22107.00	6.40	2.50	205	55267.50	270.00
Tail	25643.25	5.60	2.00	205	51286.50	250.00
Average						**262.00**

Appendix Table 7. Computed irrigation interval in the scheme

Crop	TAW (mm)	Zeff (m)	Ptab (fraction)	Padj (fraction)	RAW (mm)	ETo (mm/day)	Kc (fraction)	ETc (mm/day)	Dn (days)
Potato	45.6	0.4	0.35	0.44	20.06	3.95	0.80	3.16	7.00
Barley	57.0	0.5	0.60	0.71	40.47	3.95	0.56	2.21	18.00
Maize	68.4	0.6	0.55	0.64	43.78	3.95	0.70	2.76	16.00
Cabbag	45.6	0.4	0.35	0.45	20.52	3.95	0.90	3.56	7.00
Wheat	57.0	0.5	0.50	0.61	34.77	3.95	0.60	2.37	15.00

Appendix Table 8. Redesign Hydraulic parameters of division box

Dividing canal Name	Chain age	Q0 (lit/sec)	Q1 (lit/sec)	Q2 (lit/sec)	B0 (m)	D0 (m)	H0 (m)	D (D0+FB) (m)	B (m)	L0 (m)	L1 (m)	L2 (m)
MC	0	0.0994				0.400	0.400	0.600				
MC and SC-1	0+200	0.0994	0.089	0.011	0.400	0.400	0.400	0.600	1.200	0.231	0.300	0.200
MC and SC-2	0+346	0.0886	0.045	0.043	0.400	0.400	0.400	0.600	1.200	0.206	0.300	0.300
MC and SC-3	0+400	0.4536	0.040	0.005	0.400	0.400	0.400	0.600	1.200	1.055	0.300	0.200
MC and SC-4	0+852	0.04	0.000	0.040	0.400	0.400	0.400	0.600	1.200	0.093	0.300	0.300

Appendix Table 9. Thickness of Division box wall and supports

Thickness of Protection	t_p	m	0.3
Thickness of Wall	t_w	m	0.3
Thickness of support	t_f	m	0.3
Depth of Support	d_s	m	0.4

Appendix Table 10. Designed Division box profile

Parent Canal Type	Number	Branching	Q1 M^3/sec	Q2 M^3/sec	Q3 M^3/sec	B1	B2	B3	H	Lo	ts	tp	tw
MC	4	FC	0.14	0.14	0.02	0.5	0.5	0.3	0.6	0.5	0.3	0.5	0.3

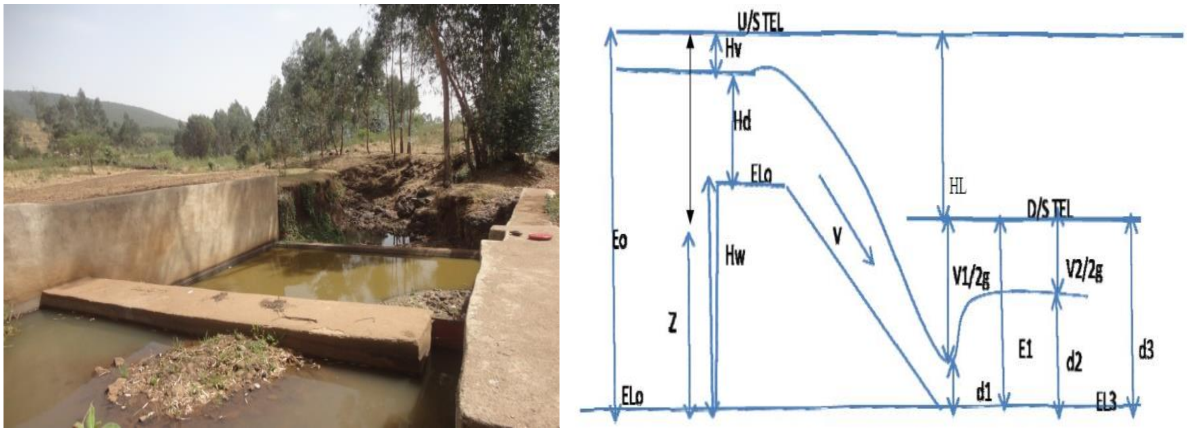
Appendix Table 11. Redesign hydraulic parameters of drop structres

Parameters	Drop on		Main canal						
	Chain age		0+061	0+274	0+300	0+320	0+371	0+883	0+902
	Symbols	Units	Values						
Design discharge	Q	(m^3/s)	0.099	0.099	0.099	0.099	0.099	0.099	0.099
Velocity	V	(m/s)	0.537	0.537	0.537	0.537	0.537	0.537	0.537
Bed width	b	(m)	0.400	0.400	0.400	0.400	0.400	0.400	0.400
Head water depth	H	(m)	0.415	0.415	0.415	0.415	0.415	0.415	0.415
Incoming canal depth	d	(m)	0.400	0.400	0.400	0.400	0.400	0.400	0.400
Drop height, for < 2 m^3/s	h	(m)	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Top width of drop wall	b1	(m)	0.400	0.400	0.400	0.400	0.400	0.400	0.400
Unit discharge	q	(m^3/s/m)	0.331	0.331	0.331	0.331	0.331	0.331	0.331
Critical depth	dc	(m)	0.224	0.224	0.224	0.224	0.224	0.224	0.224
Basin length	L	(m)	1.302	1.302	1.302	1.302	1.302	1.302	1.302
Basin width, must be > bc	B	(m)	0.581	0.581	0.581	0.581	0.581	0.581	0.581
Thickness of the stilling basin = 0.4m	t	(m)	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Lip height, must be > 0.15 m	a	(m)	0.328	0.328	0.328	0.328	0.328	0.328	0.328
Critical flow - width of notch > = 0.3m	bc	(m)	0.300	0.300	0.300	0.300	0.300	0.300	0.300
U/S protection	L1	(m)	1.673	1.673	1.673	1.673	1.673	1.673	1.673
D/S protection	L2	(m)	1.673	1.673	1.673	1.673	1.673	1.673	1.673

Appendix Table 12. Design hydraulic parameters of dop structures

Drop on	Chain age	Q (m3/s)	V (m/s)	b (m)	H(e) (m)	d (m)	h (m)	b_1 (m)	q (m^3/s/m)	d_c (m)	L (m)	B (m)	t (m)	a (m)	b_c (m)	L1 (m)	L2 (m)
MC	61	0.14	0.95	0.5	0.45	0.4	1	0.5	0.41	0.26	1.41	0.69	0.3	0.35	0.35	1.76	1.76
	274	0.14	0.95	0.5	0.45	0.4	1	0.5	0.41	0.26	1.41	0.69	0.3	0.35	0.35	1.76	1.76
	300	0.14	0.95	0.5	0.45	0.4	1	0.5	0.41	0.26	1.41	0.69	0.3	0.35	0.35	1.76	1.76
	320	0.14	0.95	0.5	0.45	0.4	1.5	0.5	0.41	0.26	1.67	0.69	0.3	0.43	0.35	1.76	1.76
	371	0.14	0.95	0.5	0.45	0.4	1.2	0.5	0.41	0.26	1.52	0.69	0.3	0.38	0.35	1.76	1.76
	883	0.14	0.95	0.5	0.45	0.4	1	0.5	0.41	0.26	1.41	0.69	0.3	0.35	0.35	1.76	1.76
	902	0.14	0.95	0.5	0.45	0.4	1	0.5	0.41	0.26	1.41	0.69	0.3	0.35	0.35	1.76	1.76
	1035	0.14	0.95	0.5	0.45	0.4	1	0.5	0.41	0.26	1.41	0.69	0.3	0.35	0.35	1.76	1.76
	1104	0.14	0.95	0.5	0.45	0.4	1	0.5	0.41	0.26	1.41	0.69	0.3	0.35	0.35	1.76	1.76
	1328	0.14	0.95	0.5	0.45	0.4	1	0.5	0.41	0.26	1.41	0.69	0.3	0.35	0.35	1.76	1.76
	1393	0.14	0.95	0.5	0.45	0.4	1	0.5	0.41	0.26	1.41	0.69	0.3	0.35	0.35	1.76	1.76
	1445	0.14	0.95	0.5	0.45	0.4	1.5	0.5	0.41	0.26	1.67	0.69	0.3	0.43	0.35	1.76	1.76

7.2. Appendix Figure



Appendix Figure 1. U/S and D/S siltation and seepage which needs high maintenance

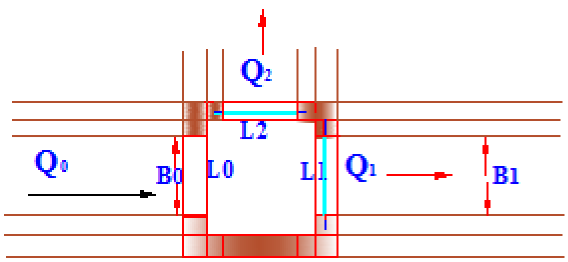
a) b)

Appendix Figure 2. a) Lined main canal cros section and b),Unlined main canal seepage that contributes for significant amount of conveyance losses

a) b)

Appendix figure 3. a), Sites selected for drop structures in the scheme and b) constructed drop

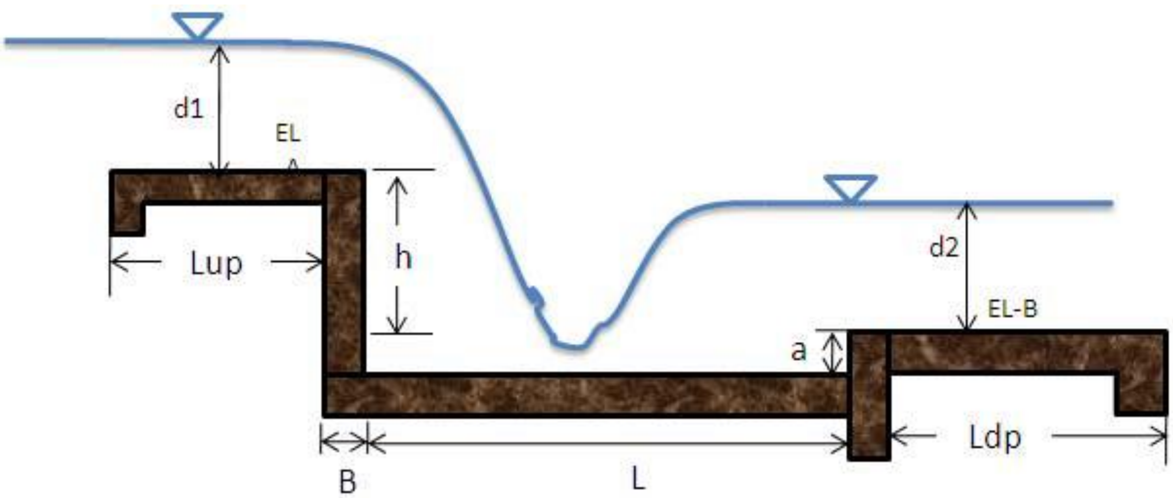
Appendix figure 4. Sites identified for division box structures



Appendix figure 5. sextion view of redesigned division box

Appendix figure 6. Farmers irrigation practice and irrigation plots

Appendix figure 7. Discussion with farmers



Appendix figure 8. Section view of drop structure design

7.3. Annexes

Annex I. Questionnaires for evaluation of Guder small scale irrigation Scheme.

Zone …………………………. Woreda …………… Region ………………

Project Name......................................

Farmer Name...

Enumerator Name...

A) Socio-economic characteristics of the farmer

1. Household head ……………Male…………………..Female
2. Educational level………...
3. Do you think the scheme is important in your area? Yes………………No…………..
4. If yes, has the use of irrigation increased your annual income? Yes…………No………….
5. If yes, what is the estimated proportion of increment in the amount of income from crops compared to before the scheme time? ……………. %
6. Is it possible to increase the economic benefit of the irrigation scheme more than its current level? Yes……………. No……………..
7. If yes, what should be done to achieve it?...
8. Is there any change on the work load of women due to irrigation project? Yes……No……
9. Who manages and control the irrigation water?
   a. The community as a whole   b. Representatives of the community
   c. Kebele or PA administrators   d. Others (Specify): ______________
10. Is there any conflict on the irrigation water source? Yes…………… No …………..
11. If yes, what do you think is/are the common source(s) of conflicts?
    a. Water shortage   b. Land shortage
    c. Water theft   d. Water management (unfair distribution)
    e. Others (specify):
12. Is water equally available to all users in the scheme? Yes…………. No……….
13. Is the water distribution is adequate? Yes…………… No ……………..
14. Is there problem of water theft or unauthorized canal breaching? Yes……. No………..
15. Do you foresee any conflict on the water use in the future? Yes………….. No………..

16. If yes, what will be the causes? ....

17. What should be done to avoid the conflict? ....

B) Project Evaluation

I. Planning

1. Who initiate the idea of constructing the structures?

    a. Local people b. DA

    c. Project staff d. Others...

2. If it is not the local people, have you agreed about the construction of the structures?

    Yes…………………. No…………………….

    Why? ....

3. Have you been consulted for the construction? Yes……………No …………………

4. How was the planning process?

    a. Group discussion b. Simple information by DAs

    c. Simple information by PA leader d. Simple information by project personnel

5. Have you participate in planning of any project? Yes………………….. No ………

II. Design/ layout

1. Who design or put the layout of the structure?

    a. DA b. Project staff

    c. Woreda expert

2. Were you agreed on the project/dam site? Yes …………….. No………………………

3.What is your opinion about the site of the scheme? …………………………………….

4. Did you face any problem because of the site selection? Yes……………No…………..

    If yes, what was the problem? ....

5. Do you think any additional works on the scheme? Yes …………….. No ……………..

6. if yes, which part of the scheme?

    a. Head work b. Main canal

    c. Secondary canal d. Tertiary canal

    e. other specify …………………………………………………………

III. Implementation

1. Do you participate in the construction of the diversion structure and irrigation canals?

Yes…………..... No ……………….

If yes, in what way you participate?

a. Voluntarily without payment

b. By rule without payment (mass mobilization)

c. Through payment in the form of money

d. Through payment in the form of food aid (EGS)

e. Both with and without payment

2. Do you use the irrigation project by now? Yes……………….. No………………….

If No, why? ....

3. Do you know the cause of any failure? Yes……………...……..No……………………….

If yes, what are they?

a. Seepage from the head work and/or the canals and its structure

b. Structural failure

c. Design problem

4. Do you expect these failures? Yes …………………… No……………………………….

If Yes, why? ....

5. Do you see any structural failure? Yes…………………… No……………………………

If yes, which structures?

a. The head work b. The canals

c. The spillway d. The canal structures

e. All f. Other structures (indicate)...........

6. Do you see any seepage on the headwork, canals and canal structures? Yes…….. No……

C) Institutional supports

1. Access to improved technology for agricultural production

1.1 Do you have access to different input supply for irrigation? Yes……….No…………….

1.2 Did you use improved seed, fertilizer, chemicals and hand tools? Yes……… No……..…

1.3 If yes, explain improved technology use in the year 2007 E.c ……………………………

1.4 Do you use agricultural inputs as per the recommended rate? Yes………..No…………..

1.5 Do you have responsible institution that supply input for irrigation farming as per the schedule of your irrigation practice? Yes ………………….… No………….……………

D) Organizations

1. Is there water users association in your locality? Yes…………… No……………………...

1.1. If yes, are you a member of water users association? Yes……………… No……………

1.2. If yes, how was the association formed? ....

1.3. If you are the member of WUAs, what benefits do you get from being a member?

a. Irrigation water on program basis b. Economic water use

c. Adapt social accountability and responsibility d. All

1.4. As a member of WUA what is your contribution for the sustenance of the scheme?

a. Cost sharing b. Labour contribution

c. Others

1.5. Generally, how do you perceive the overall contribution of WUA to the scheme functioning and sustenance?

a. It has positive contribution b. No contribution at all

c. Not known

1.6. Do you think your WUAs strong? Yes…………………….………No……………………..

E) Water management

1. What criteria should you used to decide when to irrigated crops?

a. Wait until see signs of wilting on the leaves b. check the soil near the roots

c. When it is dry, I irrigate d. irrigate every day

2. Do you think your yield is reduced because of you cannot apply enough water to your crop?

Yes…………………………………… No………………………………………………

3. Who makes decisions on the sequence of using irrigation water? ....

4. What is the system of water allocation?

a. Proportional to the amount of land you have under irrigation.

b. Equal division among members of the association

c. Specify if any other system..

5. Does the community have a system of rule for controlling water distribution default?

Yes……………………….....................No………………………………………………

6. Are there special considerations for crop-type and stage of growth during water allocation?

Yes……………………………………...No……………………………………………

F) Sustainability of the scheme

1. Do you feel that the irrigation scheme belongs to you? Yes……………..No……………..
2. If No, whom do you think it belongs to?

   a. to the community b. to the government

   c. to the NGOs d. any combination of the above
3. Have you ever participated in maintenance of the irrigation scheme? Yes……..No……….
4. If you do not make the maintenance, what is the reason?

   a. It is not my responsibility b. I do not know how to do it

   c. Others (specify)

Annex II. Informal Survey Checklist

1. Small- scale irrigation site identification and characteristics
   a) Site/Project: ....
   b) Location: ....
   c) Approximate Altitude of scheme: ……………………..….......................................
   d) Agro-ecological zone: ....
   e) Brief project history (proposed by, how identified, by whom): ....
   f) Water User Association WUA Established: ....
   g) Number of Beneficiary Participants in WUA: ……………………..........................
   h) Area to be irrigated: .... (ha)...
   i) Average size of Household irrigated plot: ……………(ha)……………......................
   j) Previous use of irrigated area: ……………………...
   k) Proposed crops: …………………………………...
2. Analyzing the basic parameters such as:
   a) Water resources availability…………………………………………………………
   b) Catchments status and others……………………………………………………...