Performance Evaluation of Ameleke and Halo-Gelana Small Scale Irrigation Schemes located in Gedeb and Wonago Woredas Gedeo Zone Southern Nations, Nationalities and people Region, Ethiopia

MSC thesis

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Performance Evaluation of Ameleke and Halo-Gelana Small Scale irrigation Schemes located in Gedeb and Wonago Woredas Gedeo Zone Southern Nations, Nationalities and people Region, Ethiopia

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As members of the Examining Board of the Final MSc Open Defense, we certify that we have read and evaluated the thesis prepared by **Natnael Zewdu** entitled **Performance Evaluation of Ameleke and Halo-Gelana Small Scale Irrigation Schemes located in Gedeb and Wonago Woredas Gedeo Zone Southern Nations, Nationalities and people Region, Ethiopia** and recommend that it be accepted as fulfilling the thesis requirement for the degree of **Master of Science in Water Resource Engineering and Management**

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DEDICATION

I dedicate this thesis manuscript to my father Zewdu Debela, my mother s/r Senait Mekuria and my wife s/r Banchiamlak Tadesse for supporting me with affection and love and for their dedicated partnership in the success of my life.

STATEMENT OF THE AUTHOR

I declare that this thesis is my bonafied work and all sources of materials used for this thesis have been duly acknowledged. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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LIST OF ABBREVIATIONS AND ACRONYMS

AR	Advance Ratio
ADLI	Agricultural Development Led Industrialization
Bd	Bulk Density
CWR	Crop Water Requirement
CROPWAT 8	Crop Water Requirement Estimation Model Window 8
DPR	Deep Percolation Ratio
DAs	Developmental Agents
Ea	Application Efficiency
Ec	Conveyance Efficiency
ETc	Crop Evapotranspiration
ET	Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization of United Nation
GDP	Gross Domestic Product
IWMI	International Water Management Institute
Kc	Crop Coefficient
MoAFS	Ministry of Agriculture and Food Security
MoWR	Ministry of Water Resource
NGOs	Non-Governmental Organizations
OESPO	Oromia Economic Study Project Office
SSI	Small Scale Irrigation
UK	United Kingdom

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ABSTRACT

This study was conducted to evaluate the performance of Ameleke and Halo Gelana small scale irrigation schemes at Gedeo Zone, southern Ethiopia with command area of 42 ha and 75ha respectively. To achieve the objective primary and secondary data were collected. Ameleke and Halo Gelana irrigation schemes were compared using internal and external performance indicators. In order to evaluate the irrigation water use efficiency of farmers at field level, nine farmer fields were selected from each irrigation schemes in relation to their location (from the head, middle and tail end water users). The internal process indicators which include conveyance, application, storage, deep percolation ratio and overall irrigation efficiency were used to check the internal performance of the two irrigation schemes. From the analyses of the internal performance indicators, the mean conveyance efficiencies per 100m length at main canal were found to be 93.3 and 78% and application efficiencies were found to be 72.13 and 67.55% for Ameleke and Halo Gelana, respectively. The runoff ratio for both schemes was nil as the furrows are closed end type. Deep percolation ratios in the same order of the schemes were found to 28.20 and 32.45% for Ameleke and Halo Gelana. Storage efficiencies of 77.35 and 80.7% were also found for Ameleke and Halo Gelana irrigation schemes, respectively. From the analysis of external indicators, the outputs per cropped area were found as 2,852.77 and 2,179.41 US$ ha^{-1} for Ameleke and Halo Gelana irrigation schemes respectively, but the value of the outputs per command area of schemes were 2,852.77 and 1,278.59 US$ ha^{-1} for Ameleke and Halo Gelana irrigation schemes respectively. The output per unit irrigation supply of Ameleke is 0.17 and that of Halo Gelana is 0.13 US$ m^{-3}. Output per water consumed was 0.18 and 0.14 US$ m^{-3} for Ameleke and Halo Gelana irrigation schemes respectively. The water use performance of the two schemes were compared, relative water supply and relative irrigation supply were found as 1.06 and 1.07 Ameleke and Halo Gelana respectively. The irrigation ratio of Ameleke was found to be 1.00 which means 100% of command area was under irrigation and that of halo Gelana was 0.59 which means about 41% of command area is not under irrigation during study period. In general, based on the assessment carried out, Ameleke irrigation scheme performed better than Halo Gelana scheme. But there is still a room for improvement of the performance of both schemes specially on improving water delivery system, introducing high value crops and agricultural intensification.

Keywords: *Performance; Evaluation; Comparative indicators*

1 INTRODUCTION

1.1 Background

Ethiopia is one of few African countries endowed with abundant water resources, of which agriculture is the main water user. Predominantly no reliable data on the area of small-scale irrigation are available and most irrigation infrastructures are not effectively used. Because, the performance of many irrigation systems is significantly under their potential due to a number of shortcomings, such as poor design and construction, operation and maintenance (sedimentation impacts and small holders' limited skills in operation and maintenance), sustainability of irrigation area, water delivery performance and watershed managements (Awulachew et al., 2010b). However sustainable production increase can be achieved by two ways in irrigated agriculture; either new irrigation projects can be developed or existing schemes can be evaluated and their performance can be improved. In Ethiopia water resources are huge and untapped but low economy of the country not much attractive to develop new irrigation schemes. Therefore improving the existing irrigation schemes followed by constructing additional new irrigation schemes is more preferable for sustainable development of the country. 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).

In recent years improving irrigation systems performance is more preferable than developing new irrigation schemes due to investment in irrigation has failed to produce the expected result in many countries. According to Luis, 1999 field evaluation play a fundamental role in improving irrigation systems. Awulachew et al. 2010a reported that improving low-performing schemes specifically small scale irrigation schemes requires incorporating applied research on irrigated agriculture. Performance evaluation result provides the information required for design, model validation, and mainly for advising irrigators on how to improve their systems and management practices. Irrigated agriculture is a complex that is influenced by weather, labor, irrigation scheduling, on-farm water managements, farming practices / agronomic, crop selection, cropping pattern, soil fertility/, the availability and management of inputs (fertilizers, chemicals) equity, cost recovery, marketing and organizational aspects. Crop production can also be increased through close linking of both inputs of water and nutrients; plant nutrients and water are complementary inputs. Where current crop yields are far below their potential, improvements in soil and nutrient management can generate major gains in water use efficiency (Molden, 2007). Moreover sustainability is not just the problem of technology and natural resources alone; it is also human, social (institutional and organizational) problem. Adequate institutionalization and organizational development is crucial to enhance management and sustainability of the irrigation systems.

Generally there are two types of performance indicators to evaluate irrigation systems: internal and external indicators. The aim of applying external indicators is to evaluate outputs and impacts of irrigation management practices, interventions across different systems and system levels, as well as to compare various irrigation seasons and technologies with one another while internal indicators are used to assess actual irrigation performance relative to system specific management goals and operational target (Kloezen et al., 1998). Evaluating and improving the performance of the existing schemes is an attractive way for sustainable development and used as a bench mark or point of entry for further irrigation development.

1.2. Statement of the Problem

In Ethiopia, scheme performance is estimates on average 36% below design capacity, implying a loss of significant amount of irrigated land. Small scale irrigation schemes account for 90% of this irrigation performance gap (Awulachew et al., 2010a, b).The interventions so far made in SNNPR region focuses on the development of new irrigation schemes and upgrading the physical infrastructures of existing traditional irrigation schemes. The performance of many irrigation schemes in SNNPR region is far below their potential mainly due to inefficient irrigation water management, poor maintenance and problems associated to input supply and marketing. Poor management of available water for irrigation, both at system and farm level has led to a range of problems and further aggravated water availability and has reduced the benefits of irrigation investments (FAO, 1996). Additionally poor soil fertility limits the ability of plants to efficiently use water (Bossio et al., 2008). Particularly in Gedeo zone little or no attention is given to the monitoring and evaluation of the performance of already established irrigation schemes. Wonago and Gedeb Districts are of the areas in Gedeo Zone, where population density is very high and shortage of farm land problems are frequently observed and also the community in the above two districts rely on rain fed coffee plantation and agriculture which let them to harvest once per year and be in a seviour poverty. As a coping mechanism for the problems around 4 small scale irrigation schemes were constructed in different years. From those, Ameleke and Halogelana small scale irrigation schemes cover an area of 42 and 75ha respectively.

Ameleke and Halogelana SSI schemes have been giving service for 6 and 3 years respectively. However the schemes have not been fully functional as expected and their performances are lower and the structures are under failure. More generally there are many factors accountable for the poor performance of irrigation schemes at the existing conditions. Despite the poor performance of the irrigation schemes, evaluation of small scale irrigation schemes and benchmarking of the results is not common; this is particularly true in using the comparative performance indicators. This study aimed to undertake a comparative performance evaluation of Ameleke and Halo Gelana SSI schemes.

1.3 Objectives

1.3.1 Major objective

The major objective of the study was to undertake performance evaluation on Ameleke and Halo Gelana small scale irrigation schemes located in SNNPR Gedeo zone Wonago and

Gedeb Districts and contribute to the improvement of irrigation efficiency and crop productivity of the schemes

1.3.2 Specific objectives

The specific objectives of the study were:

- To evaluate and compare the performance of Ameleke and Halo Gelana small scale irrigation schemes using internal and external performance indicators;
- To generate baseline information for further performance improvements.

1.4. Research Questions

1. How is the status of Ameleke and Halo Gelana small scale irrigation schemes in view of internal and external performance indicators?

2. What were the main constraint problems that affect land and water productivity and how is the level of land and water productivity at both irrigation schemes?

3. What were the main out puts and impacts existed due to the intervention of irrigation schemes at scheme and across system levels?

1.5. Significance of the Study

This study provided information regarding internal and external performance of the two selected irrigation schemes. The study had significant contribution to understand the draw backs and best achievements within and across system levels. And also gave insights on the impacts of intervention and directions for policy makers, it also used as a benchmark and entry point for development works and future studies.

1.6. Scope of the Study

The study was conducted on Ameleke and Halo Gelana small scale irrigation schemes located in SNNPR Gedeo zone Wonago and Gedeb Districts. The out puts of this research are:

- Document the performance of two irrigation schemes in terms of internal and external indicators.
- Recommendations to improve the performance of irrigation schemes and list of best experiences from each scheme for scale up.

2 LITERATURE REVIEW

2.1 Irrigation

Irrigation is the supply of water to agricultural crops by artificial means, designed to permit farming in arid regions and to offset the effect of drought in semi-arid regions. Even in areas where total seasonal rainfall is adequate on average, it may be poorly distributed during the year and variable from year to year. Where traditional rain-fed farming is a high-risk enterprise, irrigation can help to ensure stable agricultural production (FAO, 1997).

2.1.1 Perspectives and objectives of irrigation

A reliable and suitable irrigation water supply can result in vast improvements in agricultural production and assure the economic vitality of the region. Many civilizations have been dependent on irrigated agriculture to provide the basis of their society and enhance the security of their people. Some have estimated that as little as 15-20 percent of the worldwide total cultivated area is irrigated. Judging from irrigated and non-irrigated yields in some areas, this relatively small fraction of agriculture may be contributing as much as 30-40 % of gross agricultural output (FAO, 1989).

Many countries depend on surface irrigation to grow crops for food and fiber. Without surface irrigation their agricultural production would be drastically lower and problems of unreliable food supply, insufficient rural income and unemployment would be widespread. Although precise data are lacking, estimation of surface irrigation accounts for some 80 to 90 percent of the total 260 million hectares of irrigated land worldwide, mainly in developing countries in the tropics and sub-tropics, where hundreds of millions of farmers depend on surface irrigation to grow their crops (Jurriens *et al.,* 2001).

The method, frequency and duration of irrigations have significant effects on crop yield and farm productivity. For instance, annual crops may not germinate when the surface is inundated causing a crust over the seedbed (FAO, 1989). .

After emergence, inadequate soil moisture can often reduce yields, particularly if the stress occurs during critical periods. Even though the most important objective of irrigation is to maintain the soil moisture reservoir, how this is accomplished is an important consideration. The technology of irrigation is more complex than many appreciate. It is important that the scope of irrigation science is not limited to diversion and conveyance systems, or solely to the irrigated field, or only to the drainage pathways.

Irrigation is a system extending across many technical and non-technical disciplines. It only works efficiently and continually when all the components are integrated smoothly (FAO, 1989).

FAO, 1989 outlined the problems irrigated agriculture may face in the future, one of the major concerns is the generally poor efficiency with which water resources have been used for irrigation. A relatively safe estimate is that 40 percent or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface runoff (FAO, 1989). .

Irrigation in arid areas of the world provides two essential agricultural requirements: (1) a moisture supply for plant growth which also transports essential nutrients; and (2) a flow of water to leach or dilute salts in the soil. Irrigation also benefits croplands through cooling the soil and the atmosphere to create a more favorable environment for plant growth (FAO, 1989).

2.1.2 Definition of small scale and large scale irrigation

The first question in any discussion of irrigation, as stated by Turner, 1994 is the definition. Certainly the application of water to plants is irrigation. There could be great differences between countries and agencies over what is meant by "small". In fact, small according to the Indian definition is regarded as large in Africa. Turner, 1994 points out those irrigation systems can be classified according to size, source of water, management style, degree of water control, source of innovation and landscape niche or type of technology.

Most authors, however, agree that concepts of local management and simple technology should be combined with size, and the best working definition seems to be that used by the UK Working group on Small Scale Irrigation (SSI): small scale irrigation is 'Irrigation, usually on small plots, in which farmers have the major controlling influence and using a level of technology which the farmers can effectively operate and maintain'.

According to Jorge, 1993 irrigation system fall in two broad categories: those in which the principal management responsibility is exercised by government agencies with the farmers playing a subsidiary role, and those in which most management activities are carried out and decision made by the farmers themselves with the government providing periodic technical or logistical support.

The latter category in which farmers assume the dominant role is referred to as Farmer-Managed Irrigation Systems (FMIS). In general, an important characteristic of FMIS is that the farmers also control and manage the water abstraction from its source.

Governments often classify these systems as "small-scale irrigation system" or "minor irrigation systems," although examples of FMIS may be found with command areas of hectares. FMIS are also known as traditional, indigenous, communal or people's systems. The precise set of activities and functions that the farmers and their organizations perform varies from country to country and from system to system.

2.1.3 Farmer Managed Irrigation System (FMIS) changing trends

Irrigation has been practiced for at least 5000 years in Egypt and China, 4000 years in India and the Tigris-Euphrates basin and 2,500 years in the central Andes. Large-scale systems were developed under state or royal patronage where there were well-organized social systems and long-term stability prevailed. But small-scale irrigation must be even older. In more recent times, major schemes were developed in India in the late 19th century, followed by other parts of Asia, Egypt and Sudan. These schemes were often seen as an ideal way to increase food production and reduce dependence on the variability of rainfall. They were also prestige developments, and later similar schemes appealed particularly to newly independent countries and attracted large amounts of foreign aid, especially in the 1960s and 1970s (Jorma, 1999). Turner, 1994 also described other reasons for the appeal of such schemes to governments and to donors. However, many problems became apparent when these large- scale schemes failed to live up to the expectations, costing far more and producing much lower crop yields than estimated and introducing many new problems while alienating the majority of farmers.

In recent years, there has been an emphasis on the concept of sustainable development, which is often incompatible with increasing river regulation. There is also now a tendency to decentralize management and encourage FMIS by rehabilitating old schemes and handing over control to the farmers involved (Jorma, 1999).

2.1.4 Importance of Farmers' Managed Irrigation System

Despite the lack of available statistic, there is no doubt about the importance of small-scale irrigation (SSI) in many developing countries.

For many farmers, irrigation is only part of their livelihood but often a very important part. Irrigated fields are usually valued very highly. Turner, 1994 gave the following reasons for the importance of such FMIS: it can be used to extend the length of the growing season; and as a form of insurance so that when rains start late and upland crops are at risk, crops planted in the valley bottoms or those which receive supplementary irrigation are often the only ones to reach maturity.

Farmers are empowered since they are able to apply water when and where they need it. Capital costs are lower and local labor and skills are employed. In many cases, smallholders can be more productive with their yields and more efficient in water use than larger irrigation schemes (Jorma, 1999).

Irrigation is thus a valuable insurance. Several crops, such as tomatoes and leafy vegetable, grow far better in the dry season when they do not suffer attacks of mildew or pests prevalent in the wet season, and other crops require the lower temperatures of the dry season. There is also a major advantage in combining dry season and wet season cultivation. The latter is used for the staple crops but the area a family can cultivate is often limited by the labour required during operations like weeding. Dry season cultivation makes deficient use of labour at a less busy time of year. Much FMIS is for subsistence cultivation and improves the diet by providing a supply of fresh vegetable throughout the year, but it is also important as a source of high value crops, providing income when access to roads and markets is possible (Turner, 1994).

There is much evidence that farmer-controlled small-scale irrigation has better performance than government-controlled small-scale systems. The substantial farmer-controlled small-scale irrigation sector that exists in many countries in Africa, often without government support, indicates that these systems are economically viable. Areas under farmer-controlled small-scale irrigation systems have grown rapidly over the past decades, and account for large and growing share of irrigated area in Sub Saharan Africa (McCornick *et al.*, 2003).

For the most part bypassed by the green revolution and other successful innovations in agriculture production, smallholders live at or below the poverty level and are highly averse to risk; their very livelihoods are focused on keeping the margin for error as small as possible. At the same time, smallholders are capable of managing irrigation systems efficiently provided they have access to affordable technologies that are easy to operate, maintain and repair. Small-scale systems and technologies are attractive since they put the operation, maintenance and management of systems directly in the hands of the individual farmers, thus eliminating any need for centralized control or management (Jorma, 1999).

In general, according to McCornick *et al.*, 2003 all small-scale systems may have advantages over large-scale systems. These advantages include that small-scale technology can be based on farmers existing knowledge; local technical, managerial and entrepreneurial skills can be used; migration or resettlement of labour is not usually required; planning can be more flexible; social infrastructure requirements are reduced; and external input requirements are lower.

2.1.5 Purposes and need for small-scale irrigation in Ethiopia

Faced with a poverty driven depleted resource base, the risk averting strategy that has been followed by the rural community is increasing unsustainable pressure on natural resources leading to land and water depletion and degradation and/or ‘forced’ migrations to urban areas. In addition, the absence of off-farm income in rural areas has also contributed to the high population pressure on arable land, which leads to fast deterioration of natural resources.

This situation will remain a challenge until a high rate of agricultural transformation coupled with maximum and sustainable agricultural productivity (per unit area of land-intensification) takes off from the present crisis. Realizing the present socio-economic situations, it is evident that Ethiopia cannot meet its food security and food self-sufficiency objectives using the prevailing land and water use systems (McCornick *et al.*, 2003).

Small-scale irrigation has been chosen by the majority of the cooperating sponsors as a strategic intervention to address food security in Ethiopia, According to Tom *et al.*, 1999, a number of factors led to this choice. The most obvious of which is that irrigation increases the potential for producing more food more consistently in the drought-prone food-insecure areas. This remains the central theme for these activities and investments.

Another factor favoring the adoption of irrigation was that irrigation was seen as a “window of opportunity” to avert the food shortage during the mid-1980s, despite decades of traditional efforts at promoting SSI.

Getting good statistics on small-scale irrigation, which also includes traditional schemes, is understandably difficult. At present, the figures most frequently cited estimate a total of approximately 65,000 hectares in Ethiopia. These same documents, however, raise the issue of the need for rehabilitation and upgrading many of these schemes. These figures are in sharp contrast to the widely cited overall potential for irrigation throughout the country, including small, medium and large-scale irrigation, which is thought to be possible in the ranges of 1.8 to 3.4 million hectares, of which anywhere from 180,000 to 400,000 hectares are considered potentially developable as small-scale themes (Tom *et al.,* 1999).

Furthermore, there is a need to know the area of the food insecure regions in the country; what percentage of the existing SSI is within these areas; and what percentage of the projected potential area for small-scale irrigation is within these foods insecure woredas. A similar analysis could be carried out on the basis of population and small-scale irrigation users.

2.1.6 Traditional small-scale irrigation innovations

In Ethiopia, irrigation schemes are classified into small, medium and large scale. Small-scale schemes are those covering an irrigated area of less than 200 hectares and growing primarily subsistence crops. Small irrigation schemes serve mainly to supplement rainfall and provide a greater degree of security to peasant farmers (McCornick *et al.*, 2003). Because of increasing trend of population growth in the last seven decades, (from 17 million in 1940 to 100 million in 2010) and increased exploitation of land resources, the balance of water resources has also been negatively affected. Although traditional small scale irrigation practices existed in a few places, scaling-up activities must have started since the 1960s. The traditional irrigation practices by the farmers have some setbacks like:

- High labor requirement to build canals,

- Loss of productive land due to soil and stone ridging as well as tree cutting for construction purposes,

- Gully formation as a result of deep canals,

- Lack of water control to each canal resulting in poor water distribution to the stakeholders, and Because of the lack of extension advice on water management, the impact from such practices has been small and should be improved through improvement of the technologies.

However, farmers growing some high value cash crops and living near market centers use small pumps and generators to raise water to higher points for gravity application. Out of necessity, farmers adopt the principle of irrigation from their relatives and neighbors. Some farmers have adopted irrigation practice provided water is available.

Jorma, 1999 discussed further on the problems faced by the SSI in Ethiopia and lists some of them as follows:

- In a number of instances, SSI development was almost exclusively focused on the operations associated with constructing the head works and primary canal.

- Schemes are not designed with feasible command areas that justify the capital costs of the major head works and primary canal.

- Almost everywhere, SSI activity designers and planners are faced with a lack of good data on the hydrology of the stream/river system that will be their water source and on the local weather and climate conditions.

- In remote rural areas of Ethiopia, Meteorological stations are almost non-existent.

- SSI schemes operating on the basis of uncertain data regarding water supply will be more severely affected by any losses to net water availabilities, including leakage within the system, evaporation from surface waters (of particular concern with reservoirs) and a poor grasp of proper irrigation water management by the Development Agents (DA) and the farmers.

2.2 Irrigation Scheme Performance Assessment

2.2.1 Importance of performance assessment

The evaluation of surface irrigation at field level is an important aspect of both management and design of the system. Field measurements are necessary to characterize the irrigation system in terms of its most important parameters, to identify problems in its function, and to develop alternative means for improving the system (FAO, 1989).

Hence, reliable measures of system performance are extremely important for improving irrigation policy making and management decisions. However, experience has shown that there are still considerable constraints and setbacks that hinder the introduction of smallscale irrigation.

According to Molden et al., (1989) 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 performance of any irrigation system is the degree to which it achieves desired objectives. As many SSIS do not perform as well as they should, there is a need to identify the areas in which they fall short of their potential. It is therefore important to measure and evaluate their success or failure objectively and identifies specific areas in need of improvement (Jorge, 1993).

Public agencies in many developing countries want to assist farmer-managed irrigation systems improve their performance through better management. And, better management is dependent upon appropriate methods and measures by which system performance can be evaluated relative to the management objectives (Oad & Sampath, 1995). Hence, reliable measures of system performance are extremely important for improving irrigation policy making and management decisions.

The development potential for small-scale irrigation seems attractive in view of cost effectiveness, well-focused target group and its sustainability through empowerment of the beneficiaries. However, experience has shown that there are still considerable constraints and setbacks that hinder the introduction of small-scale irrigation

2.2.2. Factors affecting the performance of irrigation schemes

According to Odi (1995), the factors that account for under performance of irrigation schemes include, among others:

- Poor system management and service provision,
- Poor understanding of farmer priorities and inadequate markets for produce,
- Lack of clear and sustainable water rights accorded to users, at on individual or group level,
- Lack of clear and recognized responsibilities and authority vested in the managing organizations,
- Lack of transparent accountability; and supporting incentives for the managing entities.

2.2.3. Performance assessment methods

The type of performance measures chosen depends on the purpose of the performance assessment activity (Molden *et al*., 1998). There are four potential kinds of performance gaps that can occur with irrigation systems (Douglas and Juan, 1999).

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 normal solution to technology performance gaps is to change the type, design or condition of physical infrastructure.

The second arises due to management gaps: arises between how management procedures are supposed to be implemented and how they are actually implemented. This includes such problems as how people adjust gates, maintain canals and report information. This can be called a gap in implementation performance. A problem of this kind generally requires changes in procedures, supervision or training.

The third kind of performance gap is a difference between management targets and actual achievements. This can be called a gap in achievement. Such problems are generally addressed either by changing the objective or increasing the capacity of management to achieve them (increasing the resource available or reforming organizations).

The fourth one is impacts of management, the 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 more a problem of policy than management.

Most authors propose to use different indicators and different methodologies or tools to measure the same indicators (Bos et al., 1994). But this causes much confusion in evaluation. To avoid this, IWMI developed two types of indicators to evaluate irrigation systems: internal performance and external performance indicators.

2.2.3.1. Internal performance Indicator

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

Common indicators defined under internal performance indicator include:

- Conveyance efficiency
- Application efficiency
- Deep percolation ratio
- Storage efficiency
- Overall scheme efficiency

2.2.3.2. External performance Indicator

The aim of applying external indicators is to evaluate outputs and impacts of irrigation management practices, interventions across different systems and system levels, as well as to compare various irrigation seasons and technologies with one another. These indicators are small, not data intensive and are cost-effective (Molden et al., 1998)

International Water Management Institute (IWMI) has proposed a minimum set of indicators for external performance studies in irrigation systems. It is mainly focused on water, land and crop production in different systems. Such evaluation using external indicators can give the response to which irrigation system utilizes limited water and land resources optimally (Molden et al., 1998)

As standardized by IWMI External performance indicators are normally classified into four groups, namely

- Agricultural performance indicators
- Water use performance indicators
- Physical indicators
- Economic performance indicators

2.2.4. Performance indicators

Indicators are used to measure performance. An indicator describes the level of actual achievements in respect of objectives of irrigation. It is useful to consider an irrigation system in the context of nested systems to describe different types and uses of performance indicators (Small and Svendsen, 1992). An irrigation system is nested within an irrigated agricultural system, which in turn can be considered part of an agricultural economic system. For each of the systems, process, output, and impact measures can be considered. Process measures refer to the processes internal to the system that lead to the ultimate output, whereas output measures describe the quality and quantity of the outputs where they become available to the next higher system (Molden *et al.*, 1998).

An irrigation system, consisting of a water delivery and a water use sub systems, can be conceptualized to have two sets of objectives. One set relates to the outputs from its irrigated area, and the second set relates to the performance characteristics of its water delivery system (Oad and Sampath, 1995).

Bos, (1997) summarizes the performance indicators currently used in the Research Program on Irrigation Performance (RPIP). Within this program field data are measured and collected to quantify and test about 40 multidisciplinary performance indicators. These indicators cover water delivery, water use efficiency, maintenance and sustainability of irrigation, environmental aspects, socio-economics and management. He also noted that it is not recommended to use all described indicators under all circumstances.

The number of indicators you should use depends on the level of detail with which one needs to quantify (e.g., research, management, information to the public) performance and on the number of disciplines with which one needs to look at irrigation and drainage (water balance, economics, environment, management).

A true performance indicator includes both an actual value and an intended value that enables the assessment of the amount of deviation. It further should contain information that allows the manager to determine if the deviation is acceptable. Some of the desirable attributes of performance indicators suggested by Bos, (1997) are:

Scientific basis: the indicator should be based on an empirically quantified, statistically tested causal model of that part of the irrigation process it describes.

The indicators must be quantifiable: the data needed to quantify the indicator must be available or obtainable (measurable) with available technology. The measurement must be reproducible.

Reference to a target value: this is, of course, obvious from the definition of a performance indicator. It implies that relevance and appropriateness of the target values and tolerances can be established for the indicator.

These target values and their margin of deviation should be related to the level of technology and management (Bos *et al.*, 1991).

Provide information without bias: ideally, performance indicators should not be formulated from a narrow ethical perspective. This is, in reality, extremely difficult as even technical measures contain value judgments.

Ease of use and cost effectiveness: particularly for routine management, performance indicators should be technically feasible, and easily used by agency staff given their level of skill and motivation. Further, the cost of using indicators in terms of finances, equipment, and commitment of human resources, should be well within the agency’s resources.

2.2.5. Features of External performance indicators

With the many variables that influence performance of irrigated agriculture, including infrastructure design, management, climatic conditions, price and availability of inputs, and socioeconomic settings, the task of comparing performance across systems is formidable. However, if we focus on commonalties of irrigated agriculture water, land, finances, and crop production it should be possible to see, in a gross sense, how irrigated agriculture is performing within various settings (Molden *et al.*, 1998).

An approach to cross-system comparison is to compare outputs and impacts of irrigated agriculture. “External” indicators are used to relate outputs from a system derived from the inputs into that system. They provide little or no detail on internal processes that lead to the output. For example, the critical output of an irrigation system is the supply of water to crops. This output in turn is an input to a broader irrigated agricultural system where water combined with other inputs, leads to agricultural production. As irrigated agriculture always deals with water and agricultural production it should be possible to develop a set of external indicators for cross-system comparison.

The indicators reveal general notions about the relative health of the irrigation system, yet they are not too data-intensive to discourage widespread and regular application. Such a set of indicators potentially has several purposes.

The indicators will allow for comparison between countries and regions, between different infrastructure and management types, and between different environments, and for assessment over time of the trend in performance of a specific project. They will allow an initial screening of systems that perform well in different environments, and those that do not. They will allow for both assessing impact of interventions and managers to assess performance against strategic, long-term objectives.

IWMI's minimum set of external indicators was originally presented by Perry, (1996). The indicators have been widely field-tested and slightly amended. The intent of presenting this set of indicators is to allow for cross-system performance.

Some of the features of the indicators are the following (Molden *et al*., 1998)

The indicators are based on a relative comparison of absolute values, rather than being referenced to standards or targets.

The indicators relate to phenomena that are common to irrigation and irrigated agricultural systems. The set of indicators was small, yet reveals sufficient information about the output of the system. Data collection procedures are not too complicated or expensive. The indicators relate to outputs and are bulk measures of irrigation and irrigated agricultural systems, and thus provide limited information about internal processes (Molden et al., 1998).

This set of indicators is designed to show gross relationships and trends and should be useful in indicating where more detailed study should take place.

For instance, where a project has done extremely well, or where dramatic changes have taken place. This approach differs from that of using ratios of actual to target in that the interpretation of these ratios relative to performance is not always clear.

A relative comparison of values at least allows us to examine how well one system is performing in relation to others. And, if we have enough samples, this approach may ultimately allow us to develop standards and targets.

The main audience for these external indicators comprises policy makers and managers making long-term and strategic decisions, and researchers who are searching for relative differences between irrigation systems while the main audience for internal indicators comprises irrigation system managers interested in day-to day operations where ratios of actual to target values may be quite meaningful

2.3 Soil water availability

Soil water availability refers to the capacity of a soil to retain water available to plants. After heavy rainfall or irrigation, the soil will drain until field capacity is reached. Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased. 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).

Total available soil water

Soil water content at field capacity (FC) and permanent wilting point (PWP) is important for irrigation scheduling; assessing plant water requirement and soil suitability for different land uses (Burt and Styles, 1999).

Readily available water

It is the portion of the total available water (FC-PWP) which is most easily extracted by the plant roots without creating stress. The term Maximum or Management Allowable Deficiency, (MAD) can be used to compute the amount of water that can be used without adversely affecting the plants (ICE, 1983).

2.4 C**rop water and irrigation water requirement**

The amount of water required to compensate the evapo-transpiration loss from the cropped field is defined as crop water requirement. Although the values for Crop evapotranspiration under standard conditions (ETc) and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapo-transpiration refers to the amount of water that is lost through evapotranspiration.

Irrigation is required when rainfall is insufficient to compensate for the water lost by evapo-transpiration. The primary objective of irrigation is to apply water at the right period and in the right amount. By calculating the soil water balance/budget of the root zone on a daily basis, the timing and the depth of future irrigations can be planned. In order to compute the irrigation water requirement, CROPWAT 8.0 computes a daily water balance of the root zone.

CROPWAT 8.0 computer program was used to estimate the total water requirements of major grown crops in the irrigation schemes. FAO (1992) Penman-Monteith method was selected to calculate the reference crop evaporation (ETo).The model needs climatic, crop and soil data for the determination of crop water and irrigation requirements. To determine ETo values the model requires climatic data; mean monthly minimum and maximum temperature (0C), relative humidity (%), wind speed (km/day) and sunshine hours (hr).

2.5 Irrigation scheduling

The purpose of irrigation scheduling is to determine the exact amount of water to apply to the field and the exact timing for application. The amount of water applied is determined by using a criterion to determine irrigation need and a strategy to prescribe how much water to apply in any situation. Hence the importance of irrigation scheduling is that it enables the irrigator to apply the exact amount of water to achieve the goal. This increases irrigation efficiency.

Irrigation scheduling is the process of determining when to irrigate and how much water to apply per irrigation. Proper scheduling is essential for the efficient use of water, energy and other production inputs, such as fertilizer. It allows irrigations to be coordinated with other farming activities including cultivation and chemical applications. Among the benefits of proper irrigation scheduling are: improved crop yield and/or quality, water and energy conservation, and lower production costs (James, 1988).

Time of irrigation

Soil based irrigation scheduling involves determining the current water contents of the soil, comparing it to a predetermined minimum water content and irrigation to maintain soil water contents above the minimum level. Soil indicators of when to irrigate also provide data for estimating the amount of water to apply per irrigation. According to Mishra and Ahmed, (1990) irrigation time (interval) is calculated by the formula:

$$\text{Irrigation interval(days)} = \frac{\text{RAW}}{\text{CWR}} \ldots\ldots\ldots\ldots\ldots\ldots. [2.1]$$

Where: RAW = readily available water

CWR = crop water requirement

Depth of irrigation application

It is the depth of water that can be stored within the root zone between field capacity and the allowable level the soil water can be depleted for a given crop, soil and climate. It is equal to the readily available soil water over the root zone (James, 1988).

How much water to apply is depending on the irrigator's strategy. A critical element is accurate measurement of the volume of water applied or the depth of application. A farmer cannot manage water to maximum efficiency without knowing how much water applied. Also, uniform water distribution across the field is important to derive the maximum benefits from irrigation scheduling and management. Accurate water application prevents over-or under irrigation.

According to FAO, (1989) the total available water (TAW), for plant use in the root zone is commonly defined as the range of soil moisture held at a negative apparent pressure of 0.1 to 0.33 bar (a soil moisture level called 'field capacity') and 15 bars (called the 'permanent wilting point'). The TAW will vary from 25 cm/m for silty loams to as low as 6 cm/m for sandy soils.

The net quantity of water to be applied depends on magnitude of moisture deficit in the soil, leaching requirement and expectancy of rainfall. When no rainfall is likely to be received and soil is not saline, net quantity of water to be applied is equal to the moisture deficit in the soil, i.e. the quantity required to fill the root zone to field capacity.

The moisture deficit (d) in the effective root zone is found out by determining the field capacity moisture contents and bulk densities of each layers of the soil (Mishra and Ahmed, 1990).

$$d = \sum_{i=1}^{n} \left(\frac{FC_i - PW_i}{100}\right) * AS_i * D_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [2.2]$$

Where: FCi = field capacity of the ith layer on oven dry weight basis

PWi = actual moisture contents of the ith layer on oven dry weight basis

Asi= apparent specific gravity of the ith layer

Di = depth of ith layer and,

n=number of layers in the root zone

According to Jurriens et al., (2001) the required depth (d) is not usually the same as the applied depth (Da), which is equal to the applied volume divided by the area. If the applied depth infiltrates the field area entirely, the applied depth equals the average infiltrated depth (Dave). Jurriens et al., 2001 further discussed on that, the average depth of water that is actually stored in the target root zone Dreq is the storage depth (Ds). When the target zone is entirely filled, Ds will equal Dreq. If Ds < Dreq, then there is under-irrigation and if Ds > Dreq, then there is deep-percolation.

3 MATERIALS AND METHODS

3.1 General Descriptions of the Study Area

The study areas Wonago and Gedeb woredas found in Gedeo zone SNNPR in the southwest of Ethiopia, Wonago and Gedeb woredas are the homeland of the Gedeo people. Lying about 385 and 410 kilometers from Addis Ababa on main asphalt road respectively, Gedeo zone occupies a narrow strip of the Ethiopian highlands on the Eastern Escarpment. Gedeo is bordered by Sidama zone on the north, and encircled on the other three sides by the Oromia region, according to 2007 Census conducted by the Central Statistical Agency of Ethiopia reports this Zone has a total population of 847,434, of whom 424,742 are men and 422,692 women; with an area of 1,210.89 square kilometers, Gedeo zone has a population density of 699.84person/ square kilometers

3.1.1 Halo-Gelana small scale Irrigation Project

Establishment: Prior to the development of the Halo gelana small scale Irrigation Project, the life of the farmers in the vicinity were relied on the production of rain fed crops, coffee and livestock. The agricultural production was not satisfactory due to the fact that population density and farm production gain are not proportional. The farmers were forced to move and work in the neighboring coffee processing sites as daily laborers and the government and some NGO's, for their survival, had to feed some of the farmers. Considering the seriousness of the problem and to eradicate it from the area, Halo Gelana irrigation project was funded by IFAD and constructed by SNNPR government irrigation schemes administration agency in 2008EC. Initially the scheme was designed to cover a total irrigable land of 75ha but recently only 44ha is under irrigation.

Location and topography: Halo Gelana Irrigation Project is located in The Rift Valley basin in SNNPR Gedeo Zone Gedeb woreda just 16 km from Gedeb town. The scheme is bounded by the Gelana River in the south and extensive rain fed agricultural land in the north, east and west. The elevation of the project area is from 1650 to 1900 meters above sea level.

The land of irrigation project is characterized by plain land of very gentle slope, which is suitable for surface irrigation. The total designed irrigable area of the project is 75 ha but only 44 ha is under cultivation and 165 house hold farmers are beneficiaries.

Climate: based on the climatological data of Dilla Metrology Center, the nearest weather station, The area has sub-humid tropical climate receives mean annual rainfall 1500mm with range of 1200mm and 1800 mm. The rainfall pattern is bimodal, with short rain season between March and May accounting for 30% of total rain fall and long rain season between July and October accounting for more than 60 % of total rainfall. The mean monthly temperature is 21.5 ^{o}C with mean monthly maximum and minimum temperature of 25^{o}C and 18^{o}C, respectively. The area experiences agro ecologic Zone Namely 'Dega'

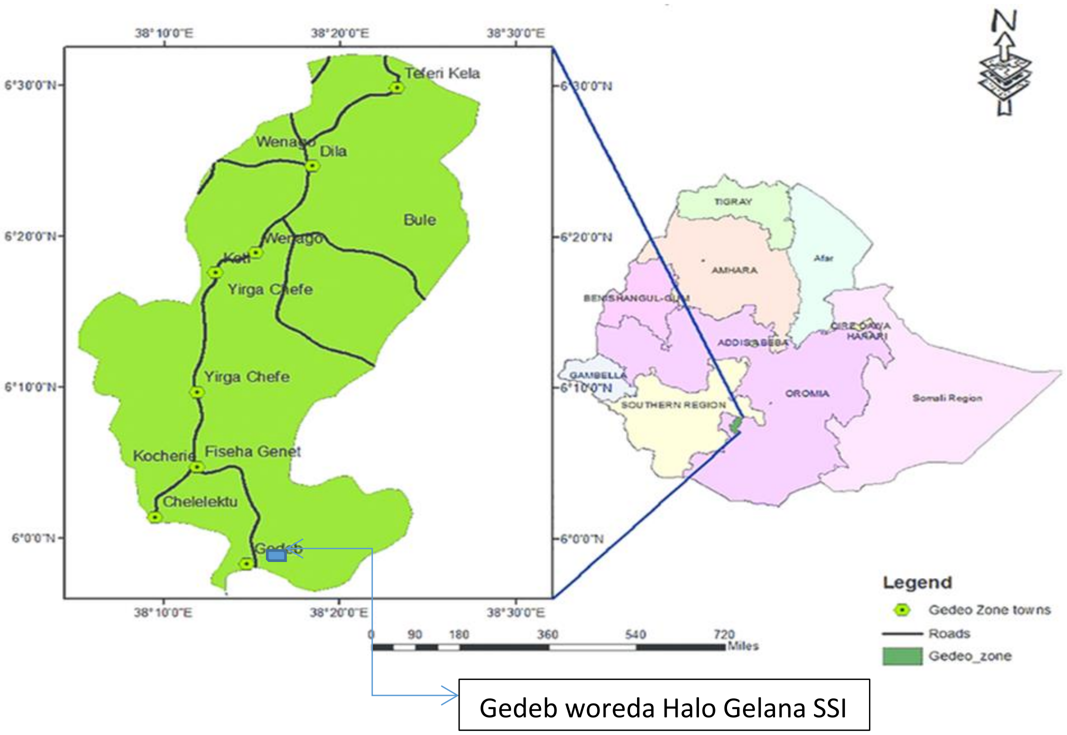


Figure 3.1 location maps of Gedeb woreda and Halo Gelana irrigation scheme

Water sources and abstraction: The irrigation project draws water from Halo-Gelana River that has continuous discharge throughout the year.

Since river is located at lower elevation than the command area to abstract irrigation water from the river, the project has 2 surface diesel pumps, which are pumping water to storage reservoir, operating rotationally throughout the irrigation season. Pumping system comprises pump house, surface pump and main supply pipeline.

Water distribution system: the irrigation water pumped from the river is discharged to a small storage reservoir that is used to dissipate the energy. Then 500 meter length masonry made lined primary canal carries the water to secondary canals. The secondary canals having a total length of 2100 meters runs longitudinally and with the help of several turnouts along the canal distributes the water to tertiary canals laterally.

3.1.2 Ameleke small scale Irrigation Project

Establishment: Prior to the development of the Ameleke small scale Irrigation Project, the life of the farmers in the vicinity were relied on the production of rain fed crops, coffee and livestock. The agricultural production was not satisfactory due to the fact that population density and farm production gain are not proportional. The farmers were forced to move and work in the neighboring coffee processing sites as daily laborers and the government and some NGO’s, for their survival, had to feed some of the farmers. Considering the seriousness of the problem and to eradicate it from the area, Ameleke irrigation project was funded by IFAD and constructed by SNNPR government irrigation schemes administration agency in 2005EC. Initially the scheme was designed to cover a total irrigable land of 42 ha and all command area is under irrigation.

Location: Ameleke irrigation project is located in The Rift Valley basin SNNPR Gedeo Zone wonago woreda Kara soditi kebele just 17km south of wonago town. The scheme is bounded by the Ameleke River in the north and extensive rain fed agricultural land in the south, east and west. The elevation of the project area is around 1850 meters above sea level

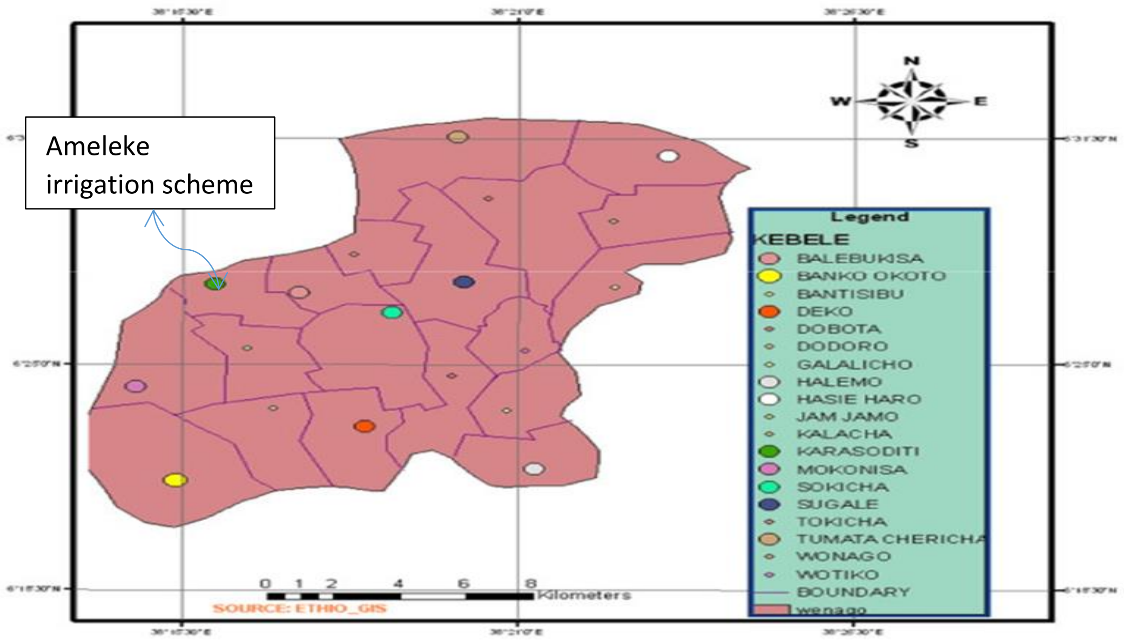


Figure 3.2 Location maps of Ameleke irrigation scheme

Climate: based on the climatological data of Dilla metrological station, The area has sub-humid tropical climate receives mean annual rainfall 1500mm with range of 1200mm and 1800 mm. The rainfall pattern is bimodal, with short rain season between March and May accounting for 30% of total rain fall and long rain season between July and October accounting for more than 60 % of total rainfall. The mean monthly temperature is 21.5 ^{o}C with mean monthly maximum and minimum temperature of 25^{o}C and 18^{o}C, respectively. The area experiences agro ecologic Zone Namely ‘Dega’.

Water sources and abstraction: The source of water for the irrigation project is the Ameleke River. The Ameleke River is diverted to the main canal by constructing a diversion weir with a control gate at a location where there is small natural protruding land in the river.

3.2. Data Collection and Analysis

3.2.1. Data collection methods

This research was carried out starting from November 2018 to April 2019 of the irrigation season. In this study quantitative and qualitative research approach; primary and secondary data have been gathered and engaged for the study purpose. For field data collection and measurement purposes; Current Meter, Double ring Infiltro-Meter, Auger, Tape Meter, 3” parshall Flumes, Garmin GPS and Sensitive Balance were used during the study period.

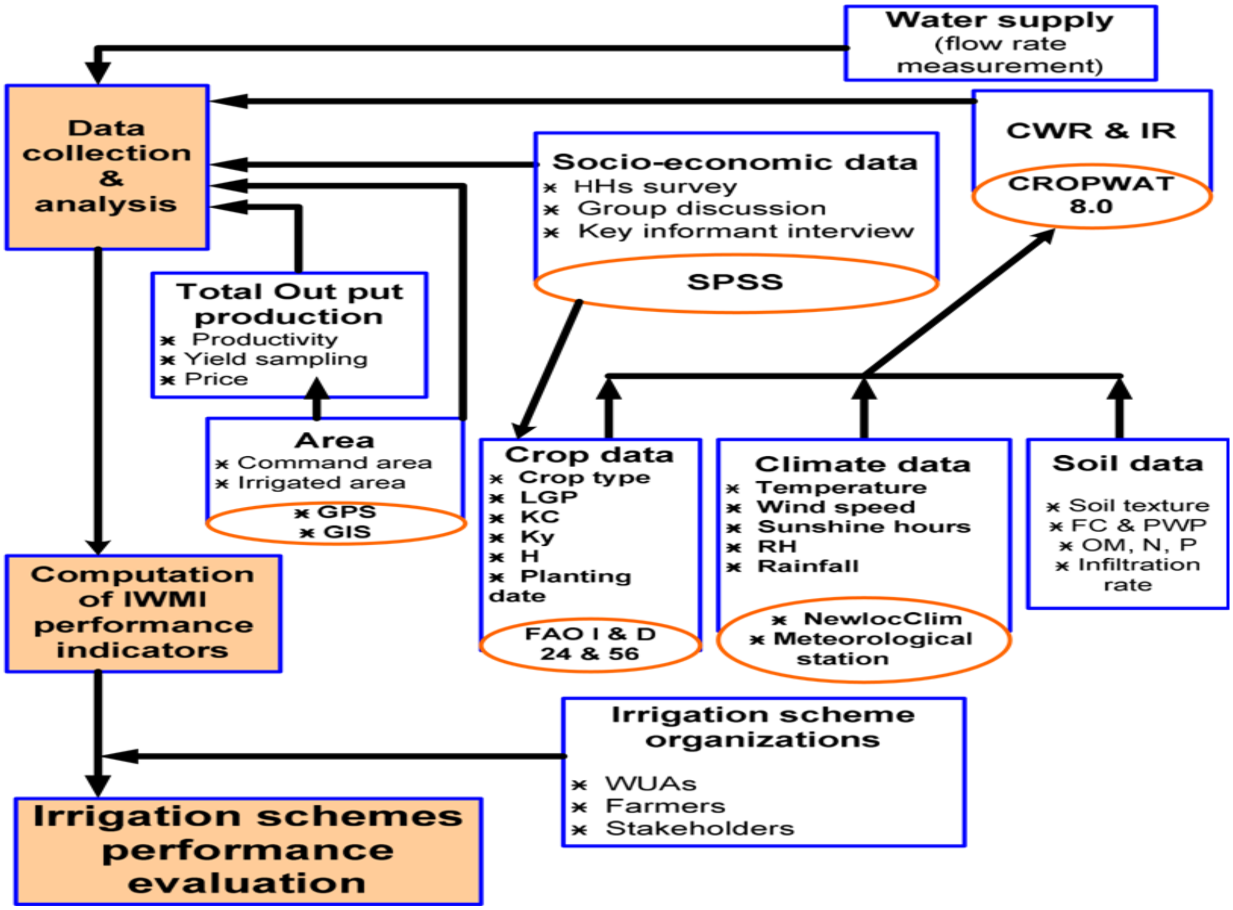


Figure 3.3: Flow chart of methodology adopted in the present study

3.2.1.1. Primary data collection

Various types of primary data have been collected through formal and informal survey approaches. Field surveys, house hold surveys, key informant interviews with respective stakeholders and group discussions have been deeply practiced for cross comparison and wellbeing of information gathering and analysis. A comprehensive field survey has been carried out starting from November 2018 to April 2019.

Soil samples were collected for the determination different soil parameters and soil infiltration rate test was taken for both sites. Additionally GPS data were also recorded.

1. Soil Sampling and Infiltration rate

Composite soil samples at 20cm, 40cm and 60cm depths have been collected at each stratum for the determination of soil physical properties; soil texture, Field capacity (FC) and Permanent Wilting Point (PWP), the values have been computed through laboratory working procedures.

For the determination of soil textural class three composite soil samples at the specified depths were taken at each stratum (head, middle and tail). Soil particle size composition of each particle was calculated in laboratory. Based on the percentage of composition, the soil textural class was determined by USDA soil textural triangle method (Bouyoucos, 1951).

For the determination of total available water (TAW) amount in the soil; field capacity (FC) and Permanent wilting point (PWP) of the soil was determined by taking two composite soil samples from each stratum. The analysis was carried out through pressure plate apparatus in the laboratory.

The total available soil moisture for the plant is between FC and PWP. The magnitude of the total available moisture is a function of soil texture and structure and indicates the capacity of the soil to have water extracted by the plant. TAW is the total amount of water a crop can extract from its root zone. Before a wilting point reached a plant is already suffering from water stress. Readily available water (RAW) uses the fraction (P) of the total saturation that can be safely removed before stress occurs. Based on soil parameters of textural class, FC, PWP could specify the value of depletion fraction (P) from FAO Irrigation & Drainage paper 24 and 56 recommendations.

The soil infiltration rates of the two schemes were characterized by using double ring infiltrometer apparatus. Infiltration is the process of entry of water downwards from the air medium to soil, or from soil surface into the soil medium. This phenomenon has a greater practical importance in irrigation and rain-fed farming systems. Infiltration characteristic of the soil is one of the dominant variables influencing irrigation application. When sufficient water is applied and maintained at atmospheric pressure, the flux (i.e. the volume of water passing through a unit cross sectional area per unit time) flowing into the soil profile is termed as infiltration rate. Infiltration rate is very rapid at the start of water application, but it decreases rapidly with the advance of time and eventually approaches to constant value. The nearly constant infiltration rate that reaches after some lapsed time from start of irrigation is termed as the basic infiltration rate (Appendix figure 3 & 4).This value, basic infiltration rate, was used as an input data for CROPWAT 8.0 model, for the computation of crop water and irrigation requirements.

2. Water flow rate measurement

Water flow rate measurement is a relevant data for irrigation scheme performance evaluation activities, computation of conveyance efficiency and losses. There are different methods to measure the flow of water in the rivers/canals. For this study Current Meter and 3” parshall Flume water flow rate measurement equipment were used.

A total of ninty flow measurements have been taken starting from intake to referenced point of main and secondary canals; through using Current Meter for both schemes

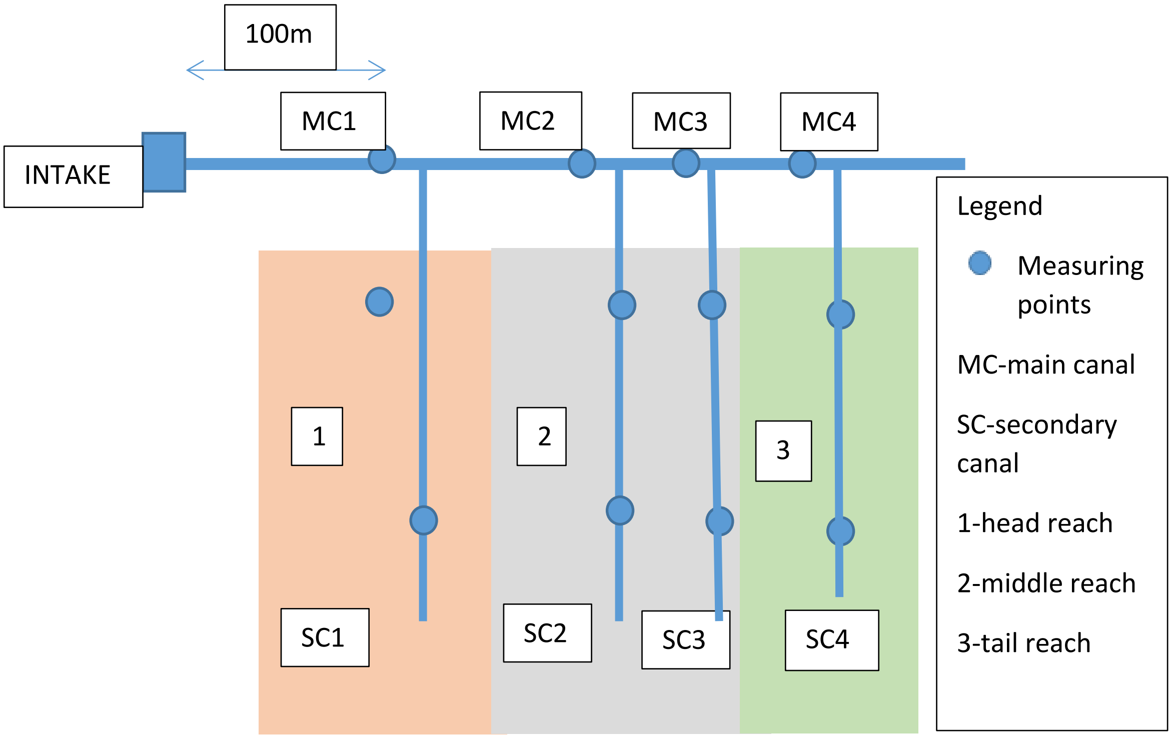


Figure3.4. Layout for water flow measurement at Ameleke small scale irrigation scheme (not scaled)

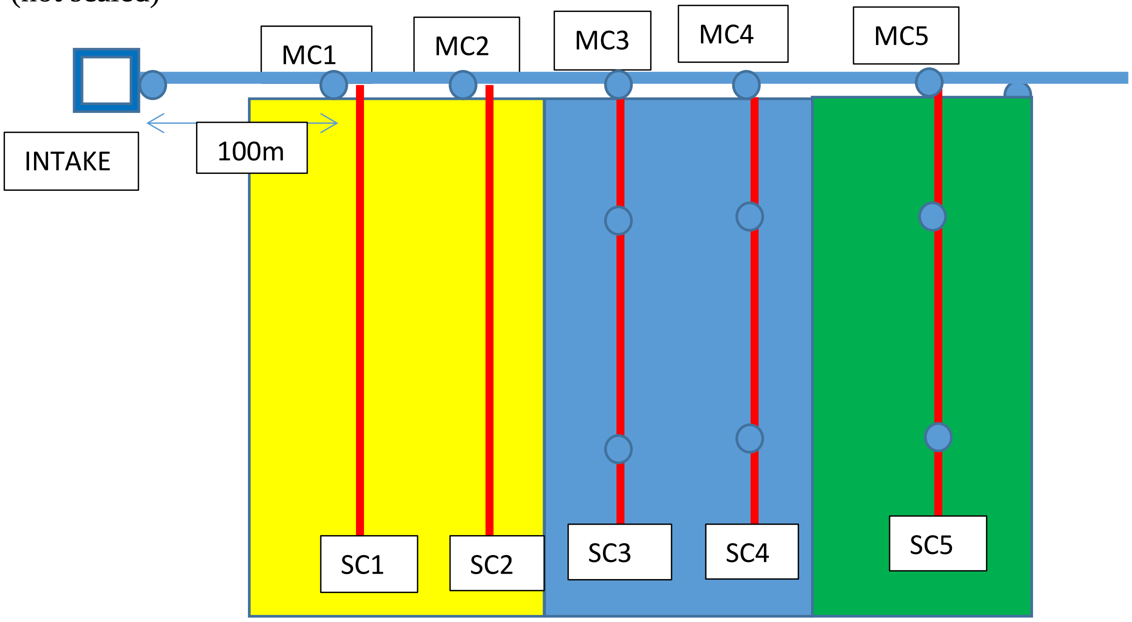


Figure3.5. Layout for water flow measurement at Halo Gelana small scale irrigation scheme (not scaled)

Through Current Meter; at straight and regular reach of intake, main canals and secondary canals; flow rate measurements were taken in weekly bases to capture temporal and spatial fluctuates of irrigation water flows along the scheme.

From the main canal (head of major secondary canals) 4 for Ameleke and 5 for Halo Gelana measuring points, were bench marked to capture the amount of inflow before entering to the secondary canals and out flow; used to compute lost amounts relative to the diverted amounts

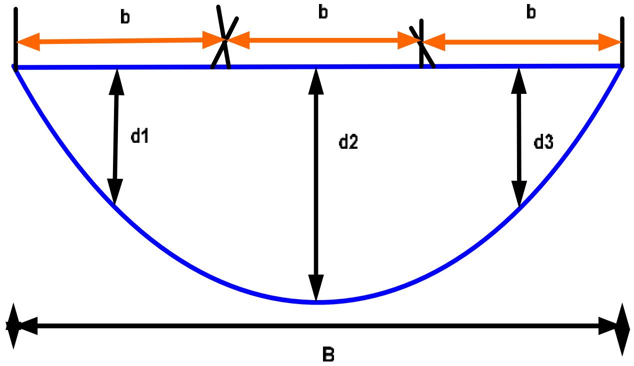


Figure3.6 water flow profile in irrigation canal

Halo Gelana irrigation scheme’s main canal is constructed in lined masonry; whereas the secondary canal is also lined but it is cracked and fractured, and it has been out of function.

The cross sectional structure of Ameleke and Halo Gelana SSI schemes is rectangular. The discharge amount would be equal to the product of the average velocity (Va) and the area of the cross-section (A). The wetted width of the canal was divided into three equal cross sections (at left edge, center and right edge) and the flow depth was measured at each division. The average flow velocity was measured at a depth of (0.6*d) from the water surfaces at each vertical; where‘d’ is the respective depths of each division (James, 1988).

The discharge (q), in each sub section of the canal could be determined by applying the area of the sub section by the average flow velocity in that section. The total discharge would be the summation of individual discharges in the specified cross section**.**

$$q = b * \left(\frac{d1+d2}{2}\right) * \left(\frac{v1+v2}{2}\right) \text{------------------------} [3.1]$$

$$Q = \sum_{n=1}^{n} q \text{--} [3.2]$$

Where;

d1, d2, d3= flow depth at each cross section (m)

B= bottom width (m)

b= wetted width of the cross section (m)

q= individual flow rate at each cross section (m3/s)

V= velocity (m/s)

Q=total discharge

Two measuring points have been fixed in 100m length at main canals, to capture the amount of losses and to compute the conveyance efficiencies.. For the case of Ameleke SSI scheme flow rate was measured at Secondary canals of (1, 2, 3 and 4) at two locations at each canal. While in Halo Gelana SSI scheme flow rates were measured at two secondary canals of 4 and 5 in 100m length. Unlike, Ameleke SSI scheme, Halo Gelana SSI scheme's main canal inflow is divided into two secondary canals; due to small cross section and maintenance problems.

To determine the flow rate at farm inlets measurements were taken by 3" parshall Flumes from sampled farmers. Totally nine farmer plots were selected purposively at each canal reaches (head, middle and tail) at both schemes. The 3" parshall Flumes from the graduated wall can read depth of flow in (m) and discharge rate in (m^3/s)

To determine the amount of water applied by the farmers to their fields, 3" parshall Flumes was installed at the entrance of each field and frequent readings were taken. During the determination of the amount of water applied to the field, the average water depth of irrigation water passing through the flume to the field and respective time intervals was recorded with the sizes of the fields to be irrigated.

The free flow equation for Parshall flume flow rate is

$$Q_{free} = CH^n \quad \text{.............................} \text{ .[3.3]}$$

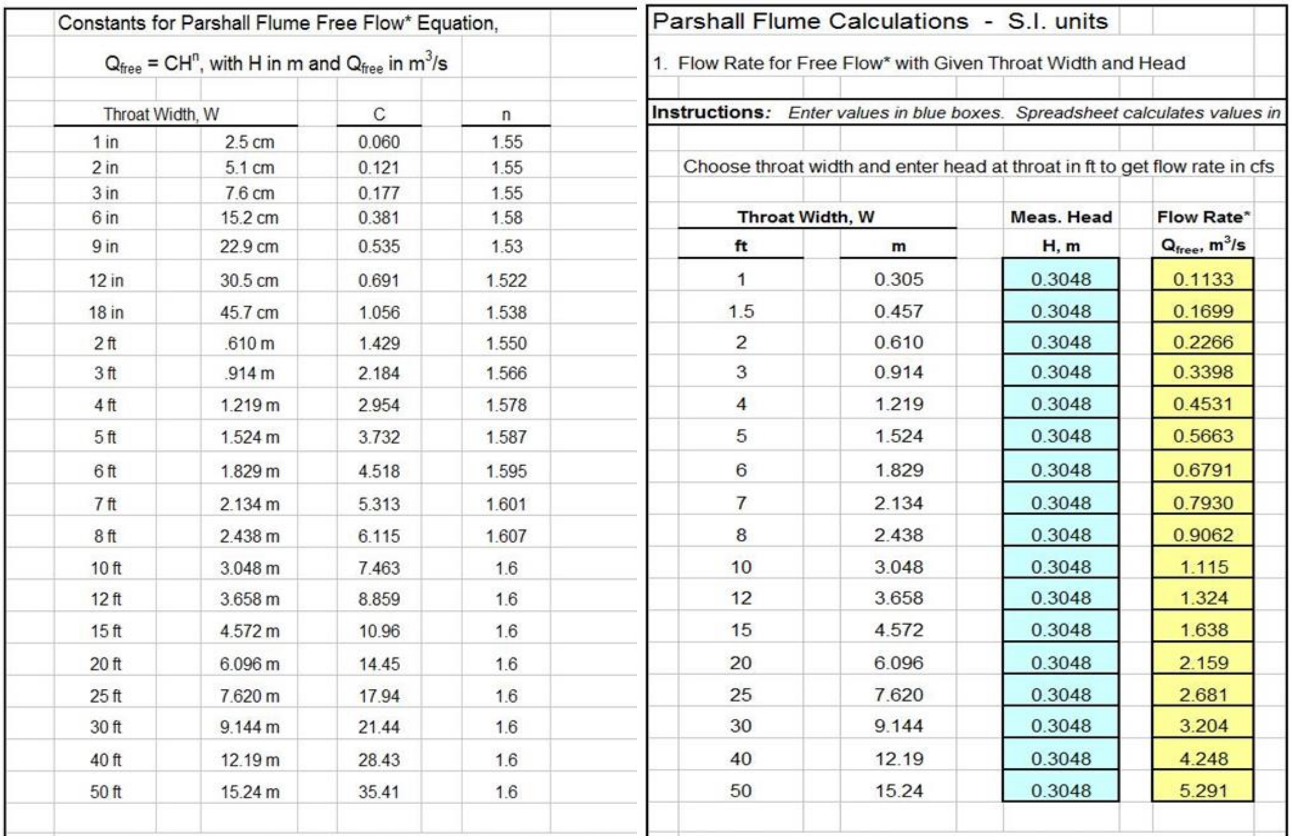
Where,

Q_{free} =open channel flow rate through the Parshall flume under free flow conditions in m^3/s.

H = head measured at the correct point in the converging section of the Parshall flume in m

C and n are constants for a given Parshall flume throat width, W.

The tables below give the constants C and n in the equations for a free flow Parshall flume flow rate calculator for S.I. units (U.S EPA, 1984).



Constants for Parshall Flume Free Flow* Equation,

$Q_{free} = CH^n$, with H in m and Q_{free} in m^3/s

Throat Width, W		C	n
1 in	2.5 cm	0.060	1.55
2 in	5.1 cm	0.121	1.55
3 in	7.6 cm	0.177	1.55
6 in	15.2 cm	0.381	1.58
9 in	22.9 cm	0.535	1.53
12 in	30.5 cm	0.691	1.522
18 in	45.7 cm	1.056	1.538
2 ft	.610 m	1.429	1.550
3 ft	.914 m	2.184	1.566
4 ft	1.219 m	2.954	1.578
5 ft	1.524 m	3.732	1.587
6 ft	1.829 m	4.518	1.595
7 ft	2.134 m	5.313	1.601
8 ft	2.438 m	6.115	1.607
10 ft	3.048 m	7.463	1.6
12 ft	3.658 m	8.859	1.6
15 ft	4.572 m	10.96	1.6
20 ft	6.096 m	14.45	1.6
25 ft	7.620 m	17.94	1.6
30 ft	9.144 m	21.44	1.6
40 ft	12.19 m	28.43	1.6
50 ft	15.24 m	35.41	1.6

Parshall Flume Calculations - S.I. units

1. Flow Rate for Free Flow* with Given Throat Width and Head

Instructions: *Enter values in blue boxes. Spreadsheet calculates values in*

Choose throat width and enter head at throat in ft to get flow rate in cfs

Throat Width, W		Meas. Head	Flow Rate*
ft	m	H, m	Q_{free}, m^3/s
1	0.305	0.3048	0.1133
1.5	0.457	0.3048	0.1699
2	0.610	0.3048	0.2266
3	0.914	0.3048	0.3398
4	1.219	0.3048	0.4531
5	1.524	0.3048	0.5663
6	1.829	0.3048	0.6791
7	2.134	0.3048	0.7930
8	2.438	0.3048	0.9062
10	3.048	0.3048	1.115
12	3.658	0.3048	1.324
15	4.572	0.3048	1.638
20	6.096	0.3048	2.159
25	7.620	0.3048	2.681
30	9.144	0.3048	3.204
40	12.19	0.3048	4.248
50	15.24	0.3048	5.291

Figure 3.7 flow measurement by parshall flume

Determination of the amount of water applied to the fields

The discharges of irrigation water diverted from Ameleke and Halo-Gelana Rivers at the irrigation projects was determined by similar methods .the discharge of the main canal at Ameleke diversion weir and Halo Gelana reservoir was measured by using current meter (James, 1988).

To calculate the total amount of water diverted to the total irrigated areas within a season, the total flow time of irrigation water in the main canal was recorded and multiplied by the respective discharges.

3.2.1.2 Secondary data collection

Secondary sources kept by the responsible bodies or officials at each irrigation project, Woreda Agricultural Offices, Irrigation Offices at Regional, Zonal, and Central levels collected as much as possible. Furthermore, Research Centers and NGOs of the agricultural sectors visited periodically to gather further information. The Secondary data included total yields, farm gate prices of irrigated crops, area irrigated per crop per season or per year, crop types, production cost per season or per year, incomes generated by the irrigation associations and cropping pattern. Continuous data triangulation was made to get the perception of the farmers about the water distribution with in the project. Much effort was spent through survey and observations of different documents at different places to check the reliability and consistency of these data.

Climatic data (rainfall, temperature, wind speed, humidity, sunshine hour) of each irrigation projects was collected from the nearby weather stations. Dilla town metrological station was the sources of the climatic data for Halo Gelana and Ameleke irrigation projects, respectively. The design documents of the irrigation projects was collected from the respective sponsor organizations and used as a source of information on the investment costs of the irrigation projects. The financial data used to calculate some of the parameters in this study was copied from the documents that have been audited and checked by the responsible government offices.

3.2.2 Data analysis techniques

3.2.2.1 Laboratory analyses

Bulk density of the soil

Bulk density refers to compactness of a soil and should be distinguished from the soil density of the solid soil constituents, usually called the particle density. The bulk density is also the ratio of oven dried mass of a soil to its volume for undisturbed soil condition and is expressed on dry weight basis of the soil as (Blake, 1965)**.**

$$\mathrm{B_d} = \frac{\mathrm{M_d}}{\mathrm{V_c}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.4]$$

Where: B_d is the soil bulk-density (gm cm-3), M_d is the weight of oven-dried soil (gm) and V_c is the volume of core (cm 3)

Moisture content of soil

The moisture content of soil samples were determined using gravimetric method. Soil samples were taken with soil auger and weighed and dried in an oven at 105^{o}C for about 24 hours, until all the moisture is driven off. The difference in weight is the amount of moisture in the soil (Luis, 1999).

$$W_\theta = \left(\frac{W_w - W_d}{W_d}\right) * B_d * 100 \ldots\ldots\ldots\ldots\ldots . [3.5]$$

Where: W_θ is volumetric soil moisture content (% volume bases), W_w is wet weight of the soil (g), W_d is dry weight of the soil (g) and B_d is bulk density of soil (g cm-3).

Total available soil water

Soil water content at field capacity (FC) and permanent wilting point (PWP) is important for irrigation scheduling; assessing plant water requirement and soil suitability for different land uses. The total Available Soil Water (TAW) was computed from the soil moisture content at Field Capacity (FC) and Permanent Wilting Point (PWP) using expression (Burt and Styles, 1999).

$$TAW = 1000(FC - PWP) * R_z \ldots\ldots [3.6]$$

Where: TAW is total available water (mm), FC and PWP in (m^3 / m^3), and R_z is the maximum effective root zone depth (m).

Readily available water

It is the portion of the total available water (FC-PWP) which is most easily extracted by the plant roots without creating stress. The term Maximum or Management Allowable Deficiency, (MAD) can be used to compute the amount of water that can be used without adversely affecting the plants.

$$RAW = (TAW*P) \ldots\ldots\ldots\ldots\ldots\ldots [3.7]$$

Where: RAW is readily available water and P is in fraction for allowable soil moisture depletion for no stress, for this case 0.45 is taken as value of p.

3.2.2.2 Determination of crop water and irrigation water requirement

CROPWAT 8.0 computer program was used to estimate the total water requirements of major grown crops in the irrigation schemes. FAO (1992) Penman-Monteith method was selected to calculate the reference crop evaporation (ETo).The model needs climatic, crop and soil data for the determination of crop water and irrigation requirements. To determine ETo values the model requires climatic data; mean monthly minimum and maximum temperature (^{0}C), relative humidity (%), wind speed (km/day) and sunshine hours (hr).

The amount of water required to compensate the evapo-transpiration loss from the cropped field is defined as crop water requirement. Although the values for Crop evapotranspiration under standard conditions (ETc) and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapo-transpiration refers to the amount of water that is lost through evapotranspiration.

The program estimates (ETc) based on equation.

$$ET_c = ET_o * K_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.8]$$

Where: ETc is actual evapo-transpiration of crops (mm), ETo is reference evapo-transpiration (mm) and Kc is the crop coefficient varies with a crop growing stages.

The value of Kc of each major crops were taken from FAO Irrigation and drainage papers 24 (1984) and 56 (1998). The determination of irrigation requirement (IR) was made after estimation of effective rainfall (RFeff) by USDA Soil Conservation Service Method (Clarke et al., 1998).

Irrigation is required when rainfall is insufficient to compensate for the water lost by evapo-transpiration. The primary objective of irrigation is to apply water at the right period and in the right amount. By calculating the soil water balance/budget of the root zone on a daily basis, the timing and the depth of future irrigations can be planned. In order to compute the irrigation water requirement, CROPWAT 8.0 computes a daily water balance of the root zone (FAO Irrigation and drainage paper 45, 1992) computed as;

$$IR = ET_c - RF_{eff} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots [3.9]$$

And to estimate the total crop water requirement at scheme level input data of actual irrigated area by crop type was included. The crop requirement was calculated for each month using the following equation (FAO Irrigation and drainage paper 45, 1992).

$$CWR_{december} = CWR_{onion} * \left(\frac{area_{onion}}{area_{total}}\right) + CWR_{tomato} * \left(\frac{area_{tomato}}{area_{total}}\right) + CWR_{snap\ bean} * \left(\frac{area_{snap\ bean}}{area_{total}}\right) \dots [3.10]$$

3.2.2.3. Irrigation scheduling

For determination of irrigation schedule of the irrigation schemes and to make comparison with the current irrigation practices; moisture content, field capacity, permanent wilting point, depletion fraction at each growing stage data were collected, additionally farmer's irrigation practices were determined; such as irrigation methods, irrigation frequency and interval of irrigation, and application depths.

During the determination of the amount of water applied to the field, the average water flow rate to the farm inlet and respective time were recorded with the size of the fields being irrigated. The total volume of water applied to the field was obtained by multiplying the discharge rate with the inflow time. The depth of water applied to the field was obtained by dividing the total volume of water applied to the area irrigated.

The irrigation intervals at each growth stages of the main grown crops were determined procedurally through equations [2.1] and [2.2]. Furthermore, through the determined irrigation intervals; the required depth of applications at each growth stages was determined by CROPWAT 8.0. Finally the irrigation schedules of main crops at both irrigation schemes were determined.

3.3 Performance evaluation methods

Performances of the two irrigation schemes were evaluated using both internal and external performance indicators. A total of nine locations per each scheme were selected based on distance apart from the irrigation scheme, i.e. three from the head (H1, H2, and H3); three from the middle (M1, M2, and M3) and three from the tail (T1, T2 and T3) end water users of irrigation scheme which represented appropriate sampling of study (Bos M et al., 1993).

3.3.1 Internal performance indicators

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

3.3.1.1 Conveyance efficiency

It is the ratio of water delivered in to the field from outlet point of the canal (Q_o) to water entering in to the canal at it staring point (Q_i). The measurements were taken throughout study period at two benchmarked initial and final points of main canal which are 100m apart (Ramulu S, 1998)

$$EC = \frac{Q_o}{Q_i} * 100 \quad \ldots\ldots [3.11]$$

Where: Ec is conveyance efficiency (%),

Q_i is depth of water diverted from the source (m3)

Q_o is depth of water applied to the field (m3).

3.3.1.2 Application efficiency

The application efficiency was computed as the ratio of quantity of water stored in to the root zone of crops (NIR) to the quantity of water actually delivered in to the field (GIR) (Ramulu S, 1998).

Application efficiency was computed as follows

$$E_a = \frac{NIR}{GIR} * 100 \ldots\ldots\ldots\ldots [3.12]$$

Where: E_a is application efficiency (%),

NIR is average depth of water stored to the root zone (mm)

GIR is average depth of water applied to the field (mm)

3.3.1.3 Deep percolation ratio

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

$$DPR = (100 - Ea - RR) \ldots\ldots\ldots [3.13]$$

3.3.1.4 Storage efficiency

The storage efficiency is the ratio of the quantity of water stored in the root zone to that intended to be stored in the root zone. After determining the storage and the required depths, the storage efficiency was calculated using the following formula(Ramulu S, 1998).

$$E_s = \frac{NIR}{W_n} * 100 \ldots\ldots\ldots [3.14]$$

Where: E_s is storage efficiency (%),

NIR is water stored in the root zone (mm)

W_n is water desired to be stored in the root zone (mm).

3.3.1.5 Overall scheme efficiency

Overall scheme efficiency was calculated as the product of conveyance and application efficiency (Ramulu S, 1998). It was computed using following formula

$$Ep=Ec*Ea \text{ ……………………} [3.15]$$

Where: Ep is overall scheme efficiency (%),

Ec is conveyance efficiency (%)

Ea is application efficiency (%).

3.3.2 External performance indicators

External performance indicators are normally classified into four groups, namely agricultural, water use, physical and economical performances' as standardized by IWMI and all four external indicators are utilized under this study

3.3.2.1 Agricultural performance indicators

The selected indicators of agriculture performance were output per cropped area (Birr ha^{-1}), output per command area (Birr ha^{-1}), output per irrigation supply (Birr m^{-3}), Output per water consumed (Birr m^{-3}) as the ratio of production per volume of water consumed (Birr/m^{3}) (Ministry of Agriculture and Food Security, Irrigation Section, 2002).

Output per unit irrigated area (Birr/ha): It was computed as the total value of production per harvested area in the irrigation season. The harvested area includes the areas that were irrigated in the irrigation season (Ministry of Agriculture and Food Security, Irrigation Section, 2002).

$$OPUIA = \frac{seasonal\ value\ of\ production}{irrigated\ harvested\ area} \text{ ………………} [3.16]$$

Where: OPUIA is output per unit irrigated cropped area,

Seasonal production is the output of the irrigated area in terms of gross or net value of production measured at local price and Irrigated harvested area is the areas under crops

Output per unit command area (Birr/ha): This indicator quantifies the value of production that obtained per unit command irrigable area. High value result shows good intensive irrigation while small values are not pertinent from land productivity point of view(Ministry of Agriculture and Food Security, Irrigation Section, 2002). Command area is the nominal or design area to be irrigated.

$$OPUCA = \frac{seasonal\ value\ of\ production}{command\ area(nominal)} \text{………………} [3.17]$$

Where: OPUCA is output per unit command area, Seasonal production is the output of the irrigated area in terms of gross value of production measured at local price and Command area is the nominal or design area to be irrigated.

Output per unit irrigation water supply (Birr/m3): Water productivity indicators were calculated as the total value of production per unit water diverted. Supplied irrigation water is the volume of surface irrigation water diverted to the command area can estimated by equation below (Molden D et al., 1998).

$$OPUIS = \frac{\text{seasonal value of production}}{\text{total diverted irrigation water}} \ldots\ldots\ldots\ldots [3.18]$$

Where: OPUIS is output per unit irrigation water, Seasonal production is the output of the irrigated area and total diverted irrigation supply is the volume of surface irrigation water diverted to the command area, plus net removals from groundwater

Output per unit water consumed (Birr/m3): Consumed water is the actual evapo-transpiration or process consumption from only irrigated crops (ET); it excludes other losses and water depletion from the hydrological cycle. It has a contribution for irrigation management aspects; to take measurements those minimize evapo-transpiration losses (Molden D et al., 1998).

$$OPUWS = \frac{\text{seasonal value of production}}{\text{total water consumped by the crop}} \ldots\ldots\ldots [3.19]$$

Where: OPUWS is output per unit water consumed, Seasonal production is the output of the irrigated area in terms of gross or net value of production measured at local price and Total volume of water consumed by ET is the actual evapotranspiration of crops.

3.3.2.2 Water use performance indicators:

These indicators depict the state of water availability or shortage and how tightly supply and demand are related.

Relative irrigation supply (RIS): This is the ratio of annual irrigation supply (which excludes rainfall) to annual irrigation demand. Values of Relative Irrigation Supply (RIS) higher than one indicate that excess irrigation water is being supplied (Molden D et al., 1998). The indicators are estimated as per the equations below

$$Relative\ irrigation\ supply(RIS) = \frac{\text{Irrigation supply}}{\text{Irrigation demand}} \ldots\ldots\ldots [3.20]$$

Relative water supply (RWS): This is the ratio of total annual water supplied (irrigation plus rainfall) to the annual crop water demand which was estimated by equation below (Bos G, 1997)

$$Relative\ water\ suppy(RWS) = \frac{\text{Total water supply}}{\text{crop demand}} \ldots\ldots \quad [3.21]$$

3.3.2.3 Physical indicators

Two physical performance indicators were used for the evaluation of irrigation schemes those are irrigation ratio and Sustainability of irrigated area.

Irrigation ratio (IR): being an indicator used to evaluate the degree of utilization, which the land available for irrigation is also a useful indicator of whether there are factors contributing for under irrigation of the command area (Molden D et al., 1998).

$$IR = \frac{\text{Irrigated cropped area}}{\text{Command area}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [3.22]$$

Where, Irrigated crop area (ha) is the portion of the actual irrigated land in any given irrigation season

Command area (ha) is the potential scheme command area

Sustainability of irrigated area (SIA): tells us the command area under irrigation is contracting or expanding as compared to the area irrigated initially (Molden D et al., 1998). Those are expressed as follows

$$SIA = \frac{\text{Currently irrigable area}}{\text{Initially irrigated area}} \ldots\ldots\ldots\ldots\ldots\ldots \quad [3.23]$$

Where, Current irrigable area is the area currently can be irrigated (ha)

Initially irrigated area is the designed/nominal/irrigable area (ha).

3.3.2.4 Economic performance indicators

The economic performance indicators for this particular study were gross returns on investment and financial self-sufficiency.

Gross return on investment: it was calculated as the ratio of production to the cost of infrastructure at the irrigation scheme (Vermillion D, 2000)

$$Gross\ return\ on\ investment = \frac{\text{Production}}{\text{cost of irrigation structure}} \ldots\ldots\ldots \quad [3.24]$$

Financial self-sufficiency (FSS): it was calculated as the ratio of revenue from irrigation to the total operational and maintenance expenditure (Vermillion D, 2000)

$$FSS = \frac{\text{Revenue from irrigation charges}}{\text{Total operation and maintenance expenditure}} \ldots\ldots\ldots \quad [3.25]$$

4. RESULTS AND DISCUSSION

4.1. Soil Data Analysis Results

Soil samples were taken at depth of (0-20, 20-40 and 40-60cm) to investigate the soil physical properties of the irrigation schemes. From the sampled soil texture field capacity (FC) and permanent wilting points (PWP) were analyzed.

4.1.1. Soil textural class

The soil textural class of both irrigation schemes was determined based on the particle size distribution through using USDA SCS Soil Textural Triangle method (figure 3.5). As indicated in table 4.1 and figure 4.1, the soil textural class in the project area is loam for the selected farms at both irrigation schemes(Appendix table 25), indicating that soils of both schemes are more or less similar in texture(.

The bulk density values ranged from 0.95 to 1.08 g/cm^3 at Ameleke and 1.05 to 1.21 g/cm^3 at Halo Gelana scheme. The bulk density values of the soils at both irrigation schemes were low as per the bulk density rating of Jones et al., 2003 indicating that there was no compaction that could limit infiltration of water into and through the soil and root penetration.

Table 4.1: Average Soil textural classes of Ameleke and Halo Gelana irrigation schemes

Irrigation scheme	Particle size distribution (%)			Textural class	Bulk density (g/cm3)
	sand	silt	clay		
Ameleke SSI	37	43.78	19.22	Loam	1.03
Halo Gelana SSI	34.33	44.45	19.22	Loam	1.13

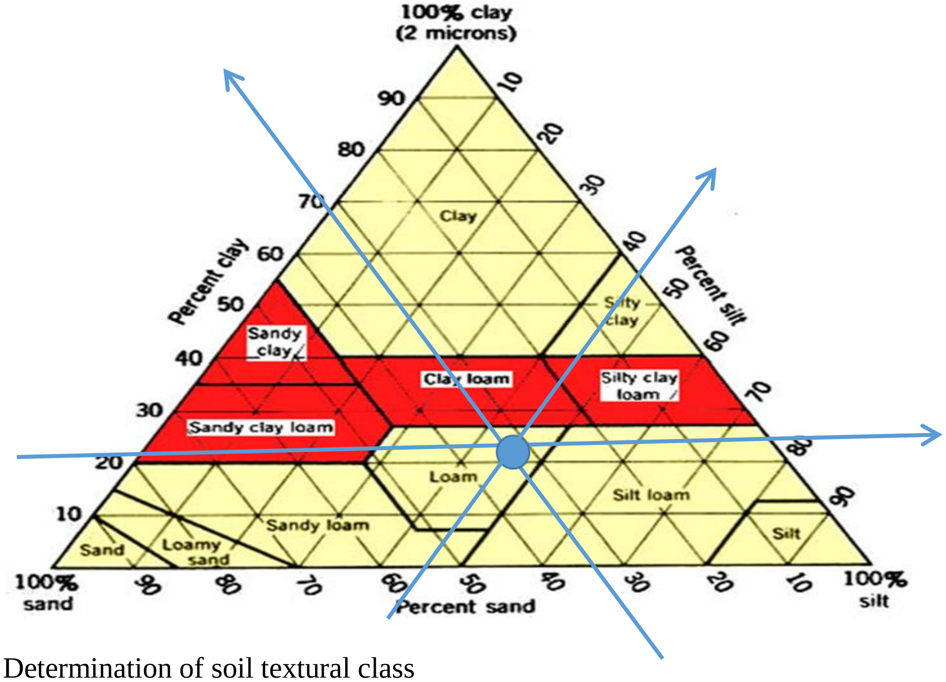


Figure 4.1 Determination of soil textural class

4.1.2. Soil field capacity and permanent wilting point

Computed soil moisture characteristics values of field capacity (FC), permanent wilting point (PWP) and total available water content (TAW) are indicated in table 4.2. Volumetric moisture content retained at field capacity varied from 26-31 and 27-31% at Ameleke and Halo Gelana irrigation schemes, respectively, whilst the volumetric moisture content at permanent wilting point varied from 11-15% for soils of both schemes. Furthermore, the total available water holding capacity of soils selected fields from both schemes ranged from 12 to 19%.In general soil of both schemes are medium as per available water holding rating of McIntyre, (1974). The result depict that the relevant soil physical properties measured are not different to a great deal from each other with depth and across the different sampling points which indicate that the soils of the study area is homogeneous.

Table 4.2: Soil FC, PWP and TAW of the irrigation schemes

Irrigation schemes	Canal reaches	Soil depth (cm)	FC (%)	PWP (%)	TAW (%)
Ameleke SSI	Head	0-20	30	11	19
		20-40	28	13	15
		40-60	31	14	17
	Middle	0-20	26	11	15
		20-40	27	13	14
		40-60	29	15	14
	Tail	0-20	30	12	18
		20-40	29	14	15
		40-60	31	15	16
Halo Gelana SSI .	Head	0-20	30	11	19
		20-40	27	13	14
		40-60	28	14	14
	Middle	0-20	29	11	18
		20-40	28	13	15
		40-60	27	15	12
	Tail	0-20	30	11	19
		20-40	29	12	17
		40-60	31	15	16

Where; FC= field capacity, PWP= permanent wilting point, TAW= total available water,

4.1.3. Soil infiltration rate

The basic infiltration rates of 25.5mm/hr and 22.5mm/hr ; after 4 hrs test at field conditions; were computed in Ameleke and Halo Gelana SSI schemes respectively. The infiltration rate of both scheme was between the range recommended for loam soil (20 -30 mm hr-1) (Savva and Frenken, 2002). The detail of observed infiltration test values are indicated in appendix table 1 and 2.

4.2. Determination of Crop Water Requirements and Irrigation Requirements

CROPWAT 8.0 model computed the crop water requirements based on equation [3.8] and it needs climatic data for ETo computation, crop characteristics data and soil description for the determination of crop water requirements and irrigation water requirements. Crop water requirements are defined as the depth of water needed to meet the water loss through evapotranspiration. It was determined for the main crops grown in both irrigation schemes based on equation [3.8]. The main crops grown in the irrigation seasons were onion, tomato and snap bean

Description of crop characteristics; i.e., planting date and length of growing period (LGP) were collected from secondary data source. Main crop's lengths of growing periods were fixed for the computation of water demands in the irrigation seasons. Crop coefficient (Kc), maximum root depth (m), crop height, yield reduction factor (Ky) values were adopted from FAO Irrigation & Drainage paper 24 and 56, the detailed values in growth stage based are described in (Appendix table 4,5 and 6).The values of Kc in the growing period are represented by crop coefficient curve, the values varies in the growing period. The CROPWAT model required the three Kc coefficients (KC of initial, development and late stages).

Furthermore, the allowable soil moisture depletion fraction for each crops at each growing stage were adopted from FAO Irrigation & Drainage paper 24 and 56, and research documents. Allowable moisture depletion fraction is a critical soil moisture level where the first drought stress occur affecting evapotranspiration and crop production. The fraction normally varies from 0.2-0.6 with the lower value being for sensitive crops with limited rooting systems, for this study 0.45 is taken as allowable moisture depletion fraction. Through the above input data the total crop water and irrigation water requirements were computed. The net irrigation requirement (NIR) in the growing season, in monthly bases was also determined for a given cropping pattern of the irrigation schemes. NIR showed the total monthly irrigation demand of the crops under irrigation.

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

The seasonal crop and irrigation water requirements of the major crops (onion, tomato and snap beans) grown in the study area during the study period as estimated by the CROPWAT 8 model, are indicated in Appendix Tables 4, 5 and 6. The results indicated that for each of the three crops, the seasonal crop and irrigation water requirements were equal since there was no rainfall during the study period. Accordingly, the seasonal crop and irrigation water requirement of onion, which was planted at the beginning of November and harvested during the first decade of April was estimated as 589.4 mm

(Appendix Table 4). Similarly, the water requirement of tomato, planted at the beginning of November and harvested during the first decade of April was estimated to be 620 mm (Appendix Table 5). Additionally, the water requirement of snap beans, planted at the beginning of November and harvested during second decade of February, was found to be 366.2 mm (Appendix Table 6). The estimated crop and irrigation water requirements indicated that tomato crop, which has about equal length of crop cycle with onion, had relatively higher crop and irrigation water requirement compared to onion whereas snap bean had much lower water requirement than both onion and tomato crops presumably owing to its short crop cycle.

Furthermore, most of the crops had the highest crop and irrigation water requirement during their mid-season stage, followed by the late season stage. This being so, the water requirement of onion during the initial, developmental, mid-season and late-season stages accounted for 8.6, 17.2, 38.6, and 35.6% , respectively, of the seasonal water requirement of the crop. Similarly, the figures for the same growth stages of tomato were 11.1, 22.7, 33, and 33.2%, respectively, of the seasonal water requirement. For snap bean, the initial, development, mid-season and late-season stages‟ water requirements accounted for 8.7, 22.6, 36.9, and 31.8% of the seasonal water requirement of the crop. These figures indicate that crops harvested for their fresh products require high amount of water even during their late-season stage.

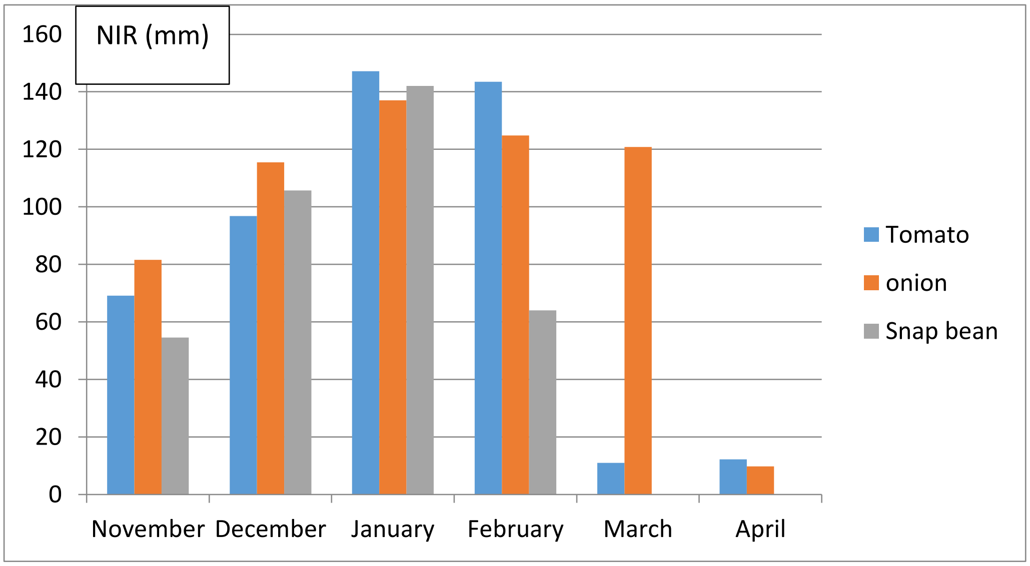


Figure 4.2: monthly Net irrigation requirement of crops at both schemes

4.3. Water Flow Rate Measurement

It was quite difficult to measure water flow rates continuously from intake to farm inlets; because there was flow fluctuations, the farmer uses rotational scheduling systems, and sometimes there were water abstractions in the upstream/illegal water users/, and absence of reliable and functional flow control systems at each division boxes.

4.3.1. Flow rate measurement at Ameleke SSI Scheme

Flow rate at Intake

As indicated in figure 4.3 and 4.4 below; there were weekly and monthly flow variations at the intake across the irrigation season. The flow fluctuation was high in the case of weekly records. The possible reasons were; the variation might be existed from the way of farmer's diversion at the head and also diversion intake has not been gated; instead it was fenced with mesh metal bars to protect derbies; it has side effect for full flow of water to the system. It collects derbies, sands and river boulders and it clogs intake.

Table 4.3: Mean flow rate at the intake site of Ameleke irrigation scheme

	Weekly	**Monthly**
Number of observation	10	6
Mean flow	100l/s	99.98l/s

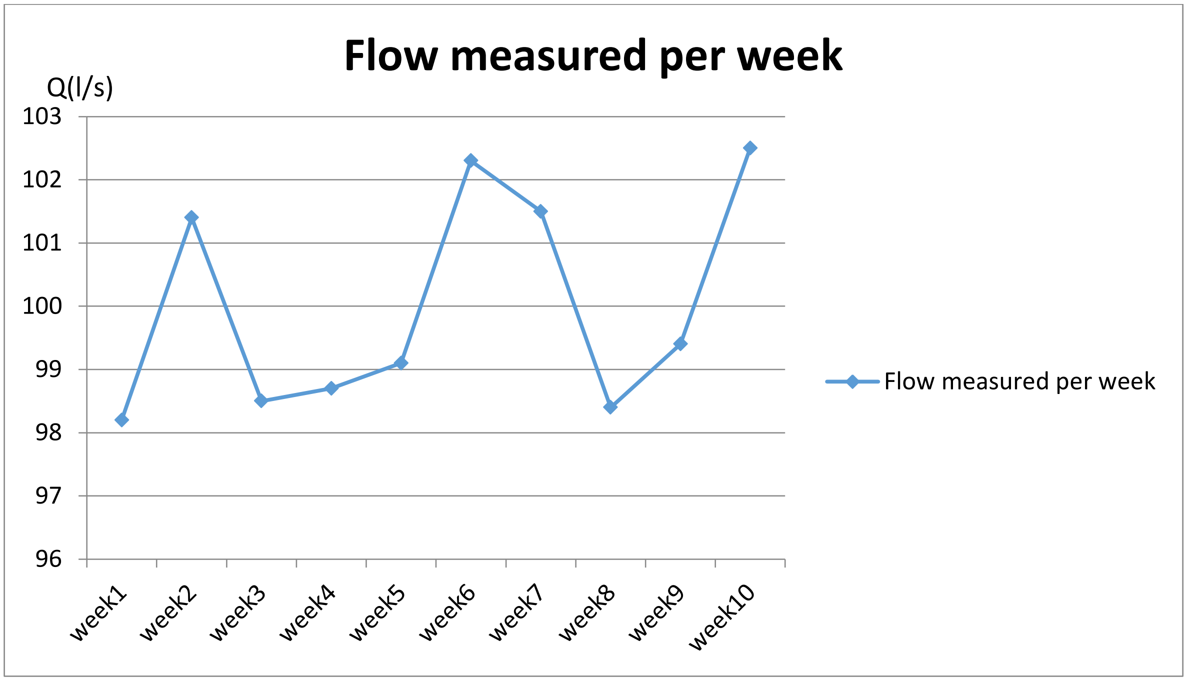


Figure 4.3: Weekly flow rate variations at Ameleke SSI intake

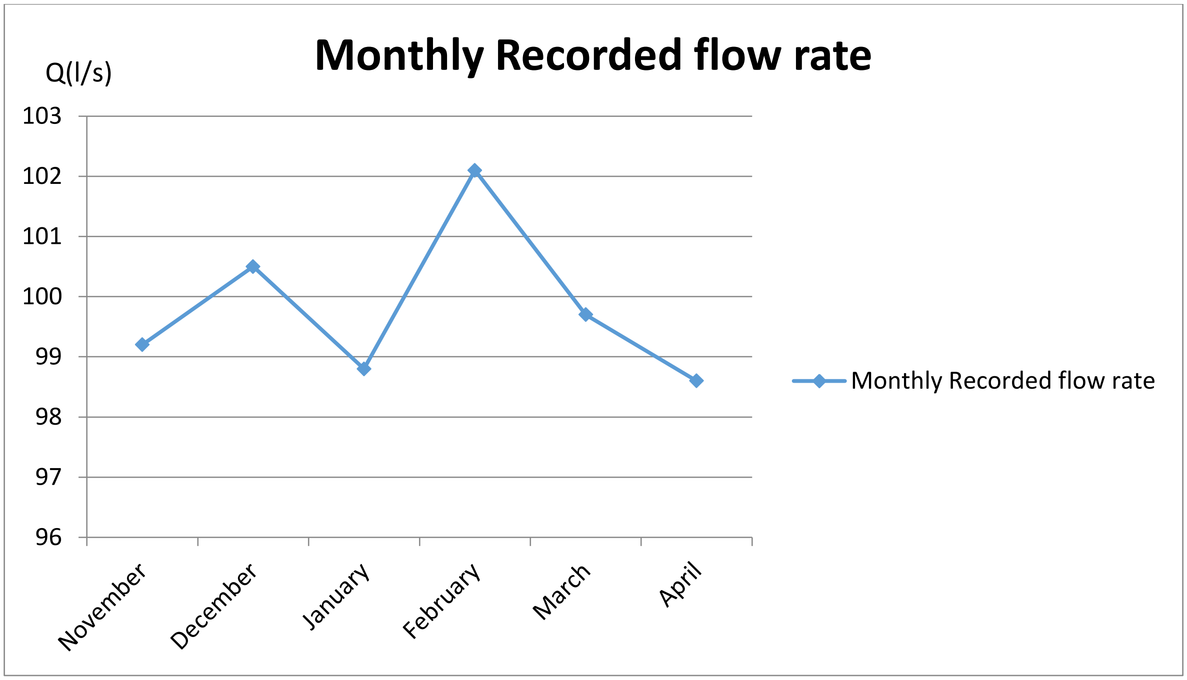


Figure 4.4: Monthly flow rate variations at Ameleke SSI intake

Flow rates at main canal

As indicated in table 4.4 below; 10 different measurements were done from two locations which are 100m apart in the main canal and the result revealed that there was 93.26 l/s mean out-flow rates from main canal, for detail refer Appendix table 7

Table 4.4: Mean flow rate and CE at the main canal of Ameleke SSI

	Main canal		
	Q_I (l/s)	Q_0 (l/s)	CE
N	10	10	10
Mean	100	93.26	0.933

Where; N-Number of observations, CE- conveyance efficiency/100m length, Qi –inflow, Qo-outflow

4.3.2. Flow rate measurement at Halo Gelana SSI Scheme

Flow Rate at Intake

As indicated in figure 4.4 and 4.5 below; there were slight weekly and monthly flow variations at the intake across the irrigation season.

Table 4.5: Mean flow rate at the intake site of Halo Gelana irrigation scheme

	Weekly	**Monthly**
Number of observation	10	6
Mean flow	98.33	96.93

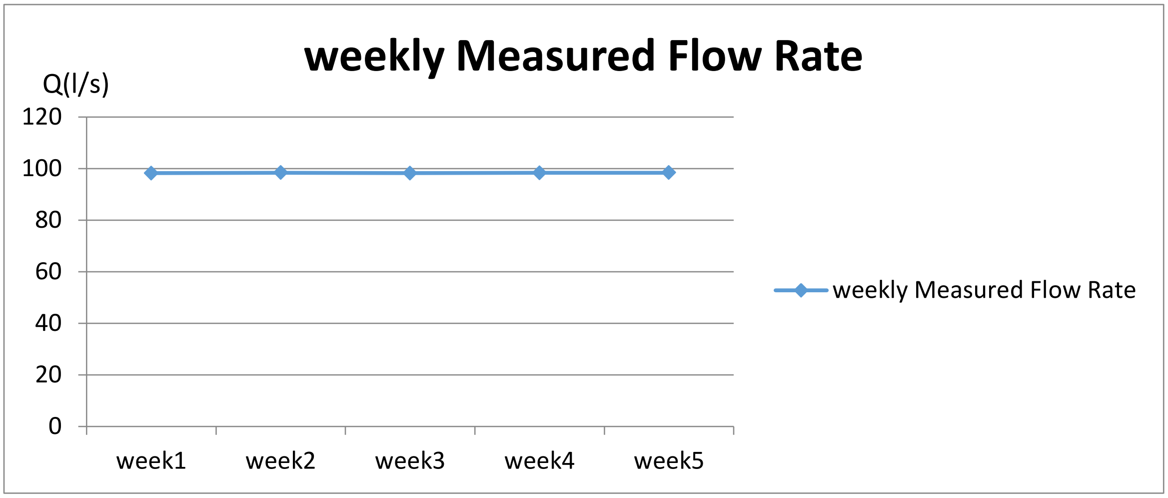


Figure 4.4: Weekly flow rate variations at Halo Gelana SSI intake

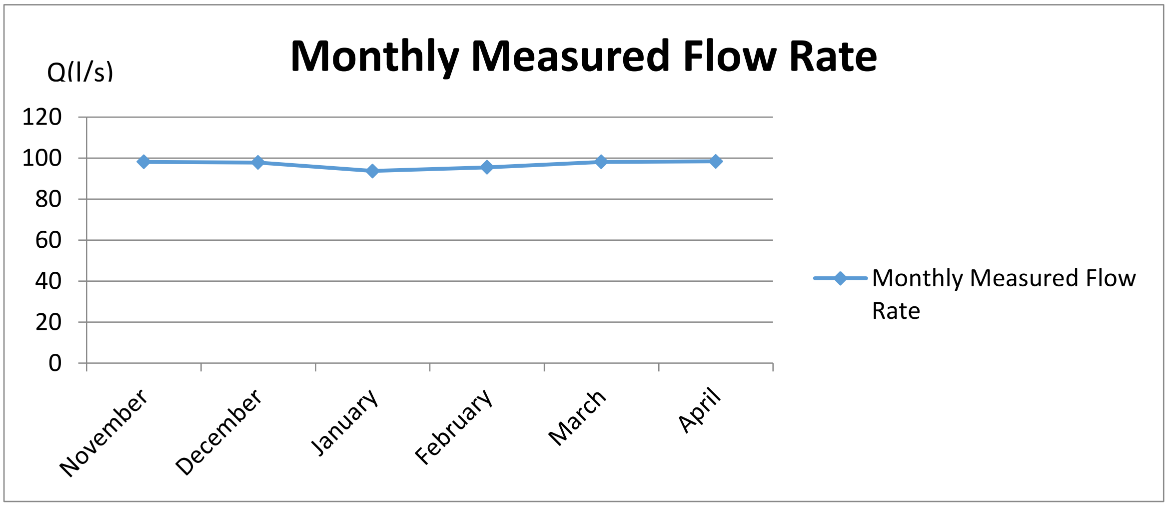


Figure 4.5: Monthly Flow rate variations at Halo Gelana SSI intake

Flow Rates at Main canal

As indicated in table 4.6 below; 10 different measurements were done from two locations which are 100m apart in the main canal and the result revealed that there was 76.68 l/s mean out-flow rates from main canal at Halo Gelana irrigation scheme, for detail refer Appendix table 8 .

Table 4.6: Mean flow rate and CE per 100m length at the main canal of Halo Gelana SSI

Main canal Halo Gelana SSI			
	Q_I (l/s)	Q_0 (l/s)	CE
N	10	10	10
Mean	98.33	76.68	0.78

Where; N-Number of measurements, QI=inflow, Q0= outflow, CE=conveyance efficiency

4.4 Irrigation Scheduling

Existing irrigation schedule at Ameleke small scale irrigation scheme

In Ameleke irrigation scheme, water user association was grouped in to six groups each group contains 10 households. Irrigation management was carried out in rotation among the six groups in which the farmers are free to irrigate till they have received enough water. There was irregular irrigation interval in the scheme with average of 12 days depending on their rounds. Regarding scheduling, all the six groups get water turn by turn and the method of water distribution was a rotational type.

The farmers are organized in to six different teams in the scheme so the next irrigation turn will be repeated after all the six teams have fully irrigated their farms. The availability of water for upstream and downstream farmers is the same i.e. there is ample water in the scheme.

Water application depth and interval in days are the important elements in irrigation scheduling. However, there was a problem in irrigation schemes in applying the required depth of water at the proper time to optimize crop yield. The irrigation interval in Ameleke SSI scheme is rigid rotational schedule, the average cycle length is 12 days. The irrigation interval was similar for different crops.Table 4.7 below showed the irrigation intervals practiced by farmers. Volume of water applied during irrigation events was determined through multiplying the average flow rate by duration of flow in that particular event. Average depth of water entered into the farmers' field during irrigation events were determined by dividing volume of water applied by their respective area. (Appendix table 9)

Based on field measurements, mean irrigation water applied to the crop fields' per irrigation were

- 48.86 mm for onion
- 45.17 mm for tomato
- 44.9 mm for snap bean

Table 4.7 Irrigation interval practiced by farmers in Ameleke irrigation schemes

Ameleke Irrigation scheme		
Crop types	Irrigation interval (days)	Irrigation frequency(number of irrigation per crop growth period)
Onion	12	12
Tomato	12	12
Snap bean	12	8

Required irrigation interval and depth

Irrigation schedule is very important to achieve the maximum crop yield and water productivity. As a result, it needs to fix the most suitable and practicable interval which is constant at each growth stages. Scheduling at farmers' fields should consider fixed interval and fixed water depth application techniques at the different growing stages, because farmers are not in a position to measure and monitor the moisture contents of the soil prior to irrigation event Additionally, plant water requirement is highly dependent and varies on the growing stages, i.e. plant water demand at initial stage is not equal to the plant water demand at development stage. As a result it is better grouped the depth and interval based on growing stages. Furthermore, it helps to minimize the confusion gaps of farmers on irrigation scheduling.

The total available water (TAW), the difference between field capacity and wilting point of the soil in the root zone, was computed using Eq. [3.6]. To avoid crop water stress, irrigation should be applied before or at the moment when the readily available soil water is depleted. To avoid deep percolation losses that may leach nutrients out of the root zone, the net irrigation depth should be smaller than or equal to the root zone depletion (Allen *et al*., 1998).

By using Equations [2.1] and [2.2] accordingly irrigation intervals of the main crops were determined (Table 4.8). Thus, in this study the depth of irrigation water (D) and schedules were computed through CROPWAT 8.0 for three major crops (onion, tomato and snap bean) of the scheme The detailed irrigation schedules of onion, tomato and snap bean in Ameleke irrigation scheme were indicated in appendix table 19,20 and 21.

Ameleke SSI scheme

Table 4.8 Computed irrigation intervals at each growth stage and irrigation frequencies

Crops	Irrigation interval in days				
	initial	Development	Mid-season	Late-season	Frequency
Onion	24	22	17	17	8
Tomato	23	22	16	14	10
Snap bean	31	21	17	15	5

The existed irrigation intervals were far different from the required irrigation interval at Ameleke SSI scheme. All major crops required long irrigation interval with relatively large application depth but the existed practice was frequent irrigation with large application depth.

As number of irrigation frequencies required or calculated was by far smaller than farmers existing irrigation frequencies, it is better to scheduling growing crops with pre-determined cropping arrangements; to achieve better irrigation water management and crop production

Existing irrigation schedule at Halo Gelana small scale irrigation scheme

In Halo Gelana irrigation scheme, water user association was grouped in to ten groups each group contains average of 17 households. Irrigation management was carried out in rotation among the ten groups in which the farmers are free to irrigate till they have received enough water. There was irregular irrigation interval in the scheme with average of 14 days depending on their rounds. Regarding scheduling, all the ten groups get water turn by turn and the method of water distribution was a rotational type. .

Water application depth and interval in days are the important elements in irrigation scheduling. However, there was a problem in irrigation schemes in applying the required depth of water at the proper time to optimize crop yield. The irrigation interval in Halo Gelana SSI scheme is rotational schedule, the average cycle length is 14 days. The irrigation interval was similar for different crops.

Table 4.9 below showed the irrigation intervals practiced by farmers. Volume of water applied during irrigation events was determined through multiplying the average flow rate by duration of flow in that particular event. Average depth of water entered into the farmers' field during irrigation events were determined by dividing volume of water applied by their respective area. (Appendix table 9).Based on field measurements, mean irrigation water applied to the crop fields' per irrigation were

- 52.08mm for onion
- 51.8mm for tomato
- 50.96mm for snap bean

Table 4.9 Irrigation interval practiced by farmers in Halo Gelana irrigation schemes

Halo Gelana Irrigation scheme		
Crop types	Irrigation interval (days)	Irrigation frequency(number of irrigation per crop growth period)
Onion	14	11
Tomato	14	11
Snap bean	14	7

Required irrigation interval and depth

Irrigation schedule is very important to achieve the maximum crop yield and water productivity. As a result, it needs to fix the most suitable and practicable interval which is constant at each growth stages. Scheduling at farmers' fields should consider fixed interval and fixed water depth application techniques at the different growing stages, because farmers are not in a position to measure and monitor the moisture contents of the soil prior to irrigation event Additionally, plant water requirement is highly dependent and varies on the growing stages, i.e. plant water demand at initial stage is not equal to the plant water demand at development stage. As a result it is better to group the depth and interval based on growing stages. Furthermore, it helps to minimize the confusion of farmers on irrigation scheduling.

The total available water (TAW), the difference between field capacity and wilting point of the soil in the root zone, was computed using Eq. [3.6]. To avoid crop water stress, irrigation should be applied before or at the moment when the readily available soil water is depleted. To avoid deep percolation losses that may leach nutrients out of the root zone, the net irrigation depth should be smaller than or equal to the root zone depletion (Allen *et al*., 1998).

By using Equations [2.1] and [2.2] accordingly irrigation intervals of the main crops were determined (Table 4.10). Thus, in this study the depth of irrigation water (D) and schedules were computed through CROPWAT 8.0 for three major crops (onion, tomato and snap bean) of the scheme. The detailed irrigation schedules of onion, tomato and snap bean in Ameleke irrigation scheme were indicated in appendix table 22, 23 and 24.

Halo Gelana SSI scheme

Table 4.10 Computed irrigation intervals at each growth stage and irrigation frequencies

Crops	Growth stages(Irrigation interval) in days				
	Initial	Development	Mid-season	Late-season	Frequency
Onion	22	17	16	16	9
Tomato	25	24	16	14	10
Snap bean	33	21	18	16	5

The existed irrigation intervals were different from the required irrigation interval at Halo Gelana SSI scheme especially at initial and development stages of the crops. All major crops required long irrigation interval with relatively large application depth but the existed practice was frequent irrigation with large application depth.

As per the scientific calculation, the number of irrigation frequencies required was smaller than the number of farmers existing irrigation frequencies. As a result, it is better to irrigate growing crops with pre-determined schedule of irrigation; to achieve better irrigation water management and crop production

4.5 Performance assessment of irrigation schemes

4.5.1 Internal performance indicators

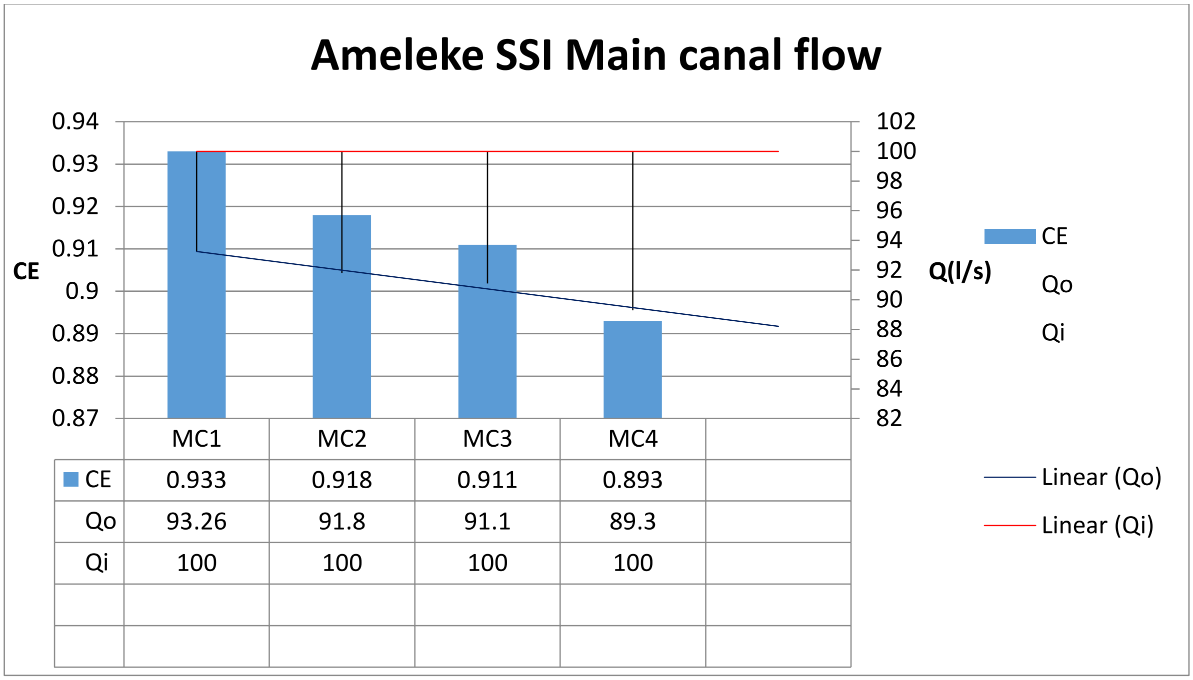
4.5.1.1 Conveyance efficiency

In the main canal

In Ameleke SSI scheme the conveyance efficiency of the main canal was decreasing as far from the water source; from head to tail of the scheme. The mean observed conveyance efficiency ranges from 59-96%, the minimum one occurred at the tail / before branched to secondary canal four. The conveyance efficiency of the main canal measured at two points which are 100m apart was 93.3% for Ameleke SSI. The conveyance efficiency of Halo Gelana scheme also ranges from 69-96%, the minimum one occurred at the tail, the conveyance efficiency of the main canal measured at two points which are 100m apart was 78% for Halo Gelana SSI

As indicated in figure 4.6 and 4.7 below; the lost amounts showed an increasing trend, with spatial variations in both schemes, from head to tail of the scheme.

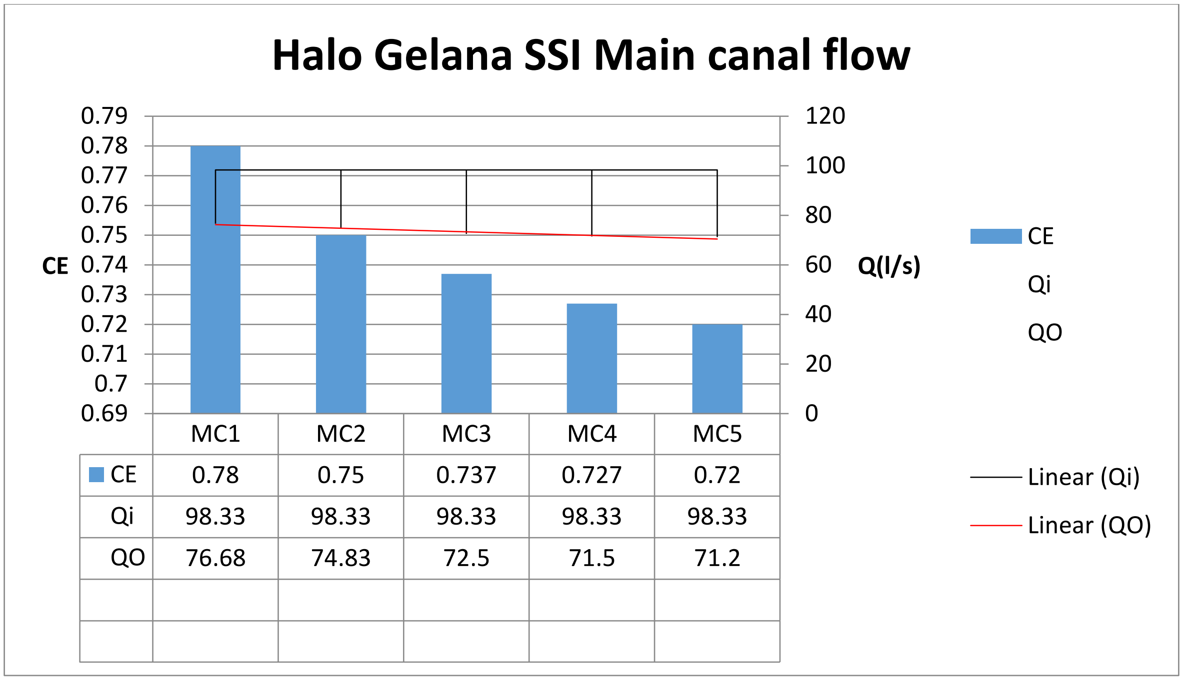
In addition to common losses(seepage and evaporation); none functional flow control gates, unauthorized water turnouts (breaching of main canals that leads leakage) and illegal water abstractions contributed for high water losses or low conveyance efficiencies at both irrigation schemes



	MC1	MC2	MC3	MC4	
CE	0.933	0.918	0.911	0.893	
Qo	93.26	91.8	91.1	89.3	
Qi	100	100	100	100	

Where; Q_I inflow, Q_0 outflow, CE conveyance efficiency

Figure 4.6: Mean inflow, outflow and CE at the main canal in Ameleke SSI



	MC1	MC2	MC3	MC4	MC5
▆ CE	0.78	0.75	0.737	0.727	0.72
Qi	98.33	98.33	98.33	98.33	98.33
QO	76.68	74.83	72.5	71.5	71.2

Where; Q_I inflow, Q_0 outflow, CE conveyance efficiency

Figure 4.7: Mean inflow, outflow and CE at the main canal in Halo Gelana SSI

The following points were factors which contributed for low CE or higher conveyance losses at Halo Gelana SSI scheme

- Canals have been silted with weeds and soils,
- Most length of the Canals were cracked and broken,
- The canals had small cross sectional area that leads to over flow,
- Sides and beds have been greatly damaged by scouring water due to steep bed slope and drop structures.
- It has no any flow controlling structures.

4.5.1.2 Application efficiency

Ameleke SSI

As indicated in table 4.11 below, the application efficiency of selected fields at Ameleke irrigation scheme were at head (68.09%), middle (73.05%) and tail (75.24%) with an average application efficiency of 72.13%

Table 4.11:Average field application efficiency of Ameleke small-scale irrigation scheme

Field code	Moisture before irrigation (%)	Moisture after irrigation (%)	Moisture stored(mm)	Water depth applied(mm)	Application efficiency(E_a)%	Average Ea(%)
H1	81.2	97.8	33.45	45.41	73.66	68.09
H2	80.48	97.13	33.45	49.92	67	
H3	80.49	96.66	32.6	51.26	63.6	
M1	75.79	93.26	36.26	50.16	72.29	73.05
M2	78.68	95.29	34.22	39.74	86.11	
M3	80.24	93.93	27.7	45.6	60.75	
T1	79.92	96.75	34.49	38.66	89.21	75.24
T2	80.92	95.3	29.47	50.54	58.31	
T3	81.97	98.9	35.58	45.5	78.2	
Average application efficiency of the system						72.13

Halo Gelana SSI

As indicated in table 4.12 below, the application efficiency of selected fields at Halo Gelana irrigation scheme were at head (67.1%), middle (71.47%) and tail (64.08%) with an average application efficiency of 67.55%

The finding indicates that the application efficiency of Ameleke irrigation scheme was slightly better than Halo Gelana irrigation scheme. This may be associated with the institutional set up of Ameleke irrigation scheme which is stronger than that of Halo Gelana. Generally the application efficiency of both schemes are typical results for furrow irrigation (Savva and Frenken, 2002), which is recommended as 50-70% for properly designed furrow irrigation

Table4.12:Average field application efficiency of Halo Gelana irrigation scheme

Field code	Moisture before irrigation (%)	Moisture after irrigation (%)	Moisture stored(mm)	Water depth applied(mm)	Application efficiency(E_a)%	Average Ea(%)
H1	81.2	97.8	34.6	49.71	69.6	67.10
H2	80.48	97.13	36.7	52.17	70.35	
H3	80.49	96.66	33.37	54.38	61.36	
M1	75.79	93.26	34.14	54.33	62.84	71.47
M2	78.68	95.29	36.33	51.46	70.60	
M3	80.24	93.93	40.16	49.59	80.98	
T1	79.92	96.75	33.75	51.57	65.45	64.08
T2	80.92	95.3	28.42	56.97	49.89	
T3	81.97	98.9	34.1	44.34	76.91	
Average application efficiency of the system						67.55

4.5.1.3. Deep percolation Ratio (DPR)

Deep percolation ratio indicates the irrigation applied to a field percolates into the soil below the root zone. Higher deep percolation ratio values are indications of over irrigation. As depicted in Table 4.13 below average deep percolation ratio at Ameleke irrigation scheme was found to be 28.20% and that of Halo Gelana irrigation scheme was 32.45%. In both schemes, there is high deep percolation ratio which indicates over irrigation.

Table 4.13: Deep percolation ratio of Ameleke and Halo Gelana irrigation schemes

Name of irrigation scheme	Application efficiency	DPR=(100-Ea-RR)	Remark
Ameleke	71.8	28.2	RR=0,no run-off
Halo Gelana	67.55	32.45	

4.5.1.4 Storage efficiency

Storage efficiency of selected fields from Ameleke irrigation scheme was at head (72.26%), middle (84.57%) and tail (75.24%) with an average storage efficiency of 77.35% and also Storage efficiency of selected fields from Halo Gelana irrigation scheme was at head (82.48%), middle (91.05%) and tail (68.57%) with an average storage efficiency of 80.70% The details of storage efficiency for selected fields and the average storage efficiency in both schemes are shown in Appendix Tables 9 and 10 and the details of all samples collected from each farm at different depth was presented in Appendix Tables 11 and 12.from the results the storage efficiency at Halo Gelana irrigation scheme was slightly greater than Ameleke, but in general the storage efficiency of both schemes were very good as compared to 63% storage efficiency usually found in typical furrow irrigation systems (Raghuwanshi and Wallender, 1998).

4.5.1.5. Overall scheme efficiency

The overall efficiency of the scheme is the ratio of water made available to the crop to the amount released at the headwork. In other words, it is the product of conveyance efficiency and application efficiency. In the present study the overall efficiencies of the irrigation schemes at Ameleke and Halo Gelana were found to be 67.29 and 52.69%, respectively. The details of overall scheme efficiency of both schemes were derived from the data shown in Appendix Tables 7, 8, 9 and 10 while the average overall irrigation scheme efficiencies of both schemes are shown in Table 4.14 below.

The result indicated that, the overall efficiency of Ameleke and Halo Gelana irrigation schemes were above the range of values (40-50%) commonly observed in other similar African irrigation schemes (Savva and Frenken, 2002).

Table4.14. Over all irrigation efficiencies at Ameleke and Halo Gelana irrigation schemes

Internal indicators	**Name of irrigation scheme**	
	Ameleke	**Halo-Gelana**
Conveyance Efficiency (main canal) (%)per 100m	93.3	78
Application Efficiency (%)	72.13	67.55
Deep percolation Ratio (%)	28.2	32.45
Storage Efficiency (%)	77.35	80.70
Overall Scheme Efficiency (%)	67.29	52.69

4.5.2. External Performance Indicators

4.5.2.1. Agricultural performance indicators

Under this comparison land and water productivity levels and major constraints were analyzed. As indicated in table 4.20 and table 4.21 the output production values were estimated from the irrigation seasons of 2010/11EC production year. The output per irrigated area shows the response of each cropped area on generating gross return within the available water; the capacity of land productivity. While the output per unit water consumed describes the outcome gained through using a meter cube (1m3) of applied water; the capacity of water productivity.

Through using equations [3.16], [3.17], [3.18] and [3.19]; the agricultural output indicators of Output per Unit Irrigated Area (OPUIA), Output per Unit Command Area (OPUCA), Output per Unit Irrigation Water Diverted (OPUIS), Output per Unit Irrigation Water delivered (OPUID) and Output per Unit Water Consumed (OPUWC) were computed, respectively. The basic parameters for the computation of these indicators have been listed in table 4.15 below

Table 4.15: Parameters for agricultural performance indicators

Scheme	Command irrigable area (ha)	Area harvested (ha)	Production value ($)	Irrigation water diverted (m^3)	Crop water consumed (m^3)
Ameleke	42	42	119,816.5	702,000	661,752
Halo Gelana	75	44	95,894.12	742,392	693,264

Output per unit irrigated area (OPUIA)

The output per unit irrigated area shows the response of each irrigated area on generating gross return. This parameter gives a clue about the management practice in every scheme. According to the data collected from each irrigation schemes the outputs per unit irrigated area were 2,852.77 and 2,179.41 US$ ha-1 for Ameleke and Halo Gelana irrigation schemes, respectively. Nearly similar study reported by Degirmenci H,(2003) who found the output per irrigated area was varied between 308 and 5771 US$/ha for the 12 irrigation schemes found in the Southeastern Anatolia Project. The details of outputs per unit cropped area for both schemes are shown in Appendix Tables 15 and 16 and the average output per unit cropped area was presented in Table 4.17.

Based on OPUIA result calculated, the response or income per cropped area at Ameleke was better than at the Halo Gelana irrigation scheme. This was mainly due to the improved irrigation management in Ameleke scheme. This can be associated with the input use and strong institutional set up at the Ameleke irrigation scheme.

Output per unit of command area (OPUCA)

This indicator expresses the average return per design command area. It is an indication of whether all the command areas are generating returns or not. The outputs per unit command area of Ameleke and Halo Gelana irrigation scheme were 2,852.77 and 1,278.59 US$ ha-1, respectively. Similar result found in Southeastern Anatolia Project, which was the output per unit-cropped area varies between 1223 and 9436 US$/ha for the period 1997-2001 overtime for the 12 irrigation schemes as reported by Degirmenci H,(2003).

The details of outputs per unit command area in both the irrigation schemes are shown in Appendix Table 15 and 16 and the average output per unit command area was presented in Table 4.17.

Output per unit irrigation supply (OPUIS)

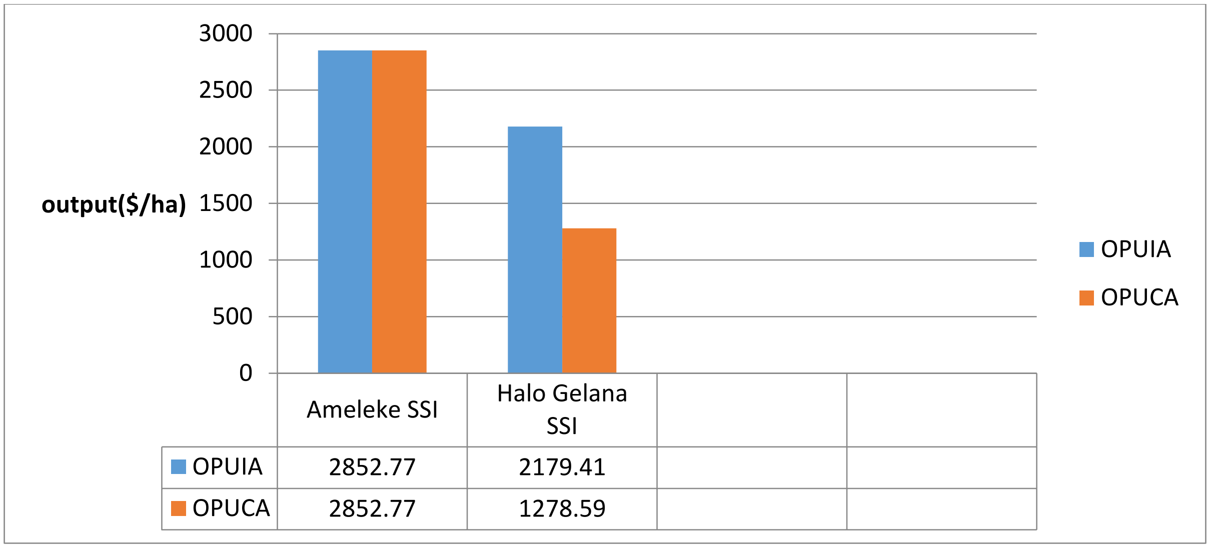
The outputs per unit irrigation supply show the revenue from agricultural output for each meter cube of irrigation water supplied. The total amount of water pumped by Halo Gelana irrigation scheme during the crop growth period was estimated based on the output per second of the pump, the number of pumps used, duration of operating hours each day, and total days taken by crops to mature. Ameleke irrigation project has diversion weir with control gate to divert water to the main canal. Therefore, it diverts 0.1m^3/s for 13 hours per day for 150days which means total amount of water diverted was 702,000 m3 during 150 days growth period of onion. Similarly, the total amount of water pumped during the growth period of onion in Halo Gelana calculated from the two pumps of capacity 0.0982 m3 per second each, and operating for 7 hours(3.5hour per pump per day) per day was about 742,392 m3. Thus, the output per m3 of water supply for Ameleke was found to be 0.17 US$ m-3 and that of Halo Gelana was 0.13US$ m-3. According to Cakmak B, (2003) output per unit irrigation delivered of both schemes was lies on range from 0.03 $/m3 to 2.21 $/m3 where the study conducted in sixty irrigation schemes found in Kızılırmak Basin, Turkey.

The result for output per m3 of water supply indicated that at the Ameleke irrigation scheme, the response of crops per m3 of water is better as compared to at the Halo Gelana irrigation scheme. This might be due to the excess supply of water beyond crop requirement to fields in Halo Gelana irrigation scheme than Ameleke. Moreover use of inputs also affects the returns from the irrigation schemes.

Output per unit water consumed (OPUWC)

The output per unit water consumed is used to describe the return on water actually consumed by the crop. This indicator gives due attention to the water consumed by each scheme and tells us how water is efficiently utilized by the scheme from economic point of view. The outputs per water consumed for Ameleke irrigation scheme was 0.18US$ m-3 and that of Halo Gelana irrigation scheme was about 0.14 US$ m-3 of water (Table 4.17). Both schemes of output per unit water consumed were in the range of 0.15-1.55 US$ m3 as reported by Çakmak B, (2003) where the study conducted in the Kızılırmak Basin irrigation schemes.

This result shows that the water use efficiency is better at Ameleke than at the Halo Gelana irrigation scheme. The reason for this may be institutional set up of Ameleke which is stronger than at the Halo Gelana irrigation scheme.



	Ameleke SSI	Halo Gelana SSI		
🟦 OPUIA	2852.77	2179.41		
🟧 OPUCA	2852.77	1278.59		

Figure 4.10: OPUIA and OPUCA ($/ha) values at both irrigation schemes

4.5.2.2 Water use performance indicators

Relative water supply (RWS)

The relative water supply depicts whether there is enough irrigation water supplied or not. Both the relative water supply and relative irrigation supply relate supply to demand, and give some indication as the condition of water abundance or scarcity, and how tightly supply and demand is matched. The relative water supply value below one normally indicates that the water applied is less than the crop demands and values above one indicate extra water is added to the root zone beyond plant demands. The relative water supply of Ameleke irrigation scheme was found to be 1.06 and that of the Halo Gelana scheme was 1.07.

Relative irrigation supply (RIS)

The relative irrigation supply shows whether the irrigation demand is satisfied or not. Since there was no rainfall in the area during study period the value of relative irrigation supply and relative water supply is the same which means 1.06 for the Ameleke irrigation scheme and 1.07 for the Halo Gelana irrigation scheme (Table 4.17).

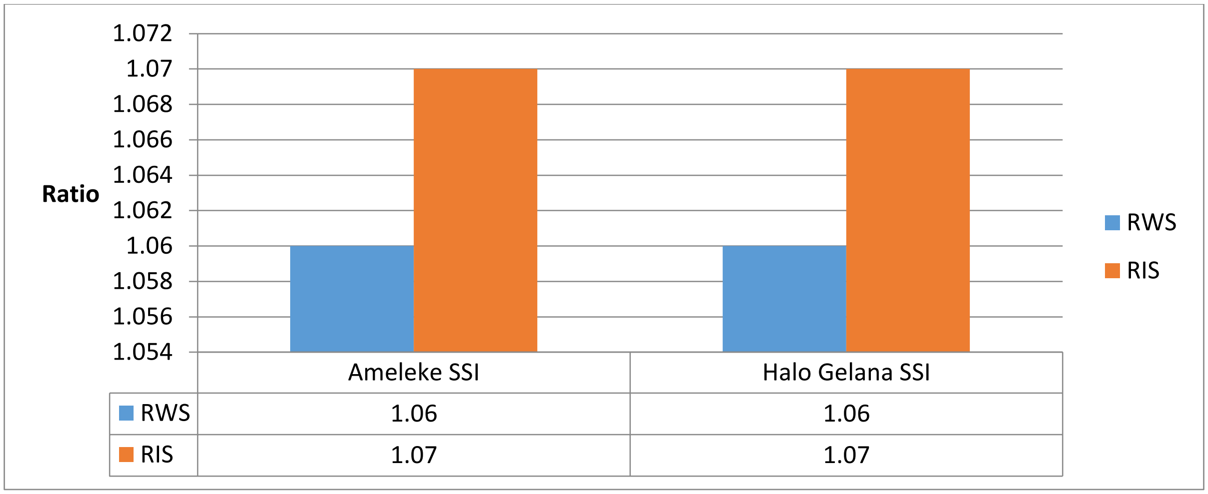


Figure 4.11: RWS and RIS indicators

4.5.2.3 Physical performance indicators

Two basic physical indicators of irrigation ratio (IR) and sustainability of irrigated areas (SIA) were selected and computed, based on equations [2.10] and [2.11], to evaluate the status of both irrigation schemes. The result is depicted in table 4.16.

Irrigation ratio

Irrigation ratio for the Ameleke irrigation scheme was 1.00, which means that total command area of the scheme was under irrigation during the study period, but the irrigation ratio of Halo Gelana irrigation scheme was 0.58 which means about 41% of command area of the scheme was not under irrigation during the study period. The main reasons for this were farmers‟ capacity to afford inputs and fuel costs to pump water from the river, and weak institutional set up of water use association at the scheme. The details of cropped land area during the study period of both schemes are shown in Appendix Tables 15, and 16 and the irrigation ratio of both schemes are presented in Table 4.16.

Sustainability of irrigated area (SIA)

Sustainability of irrigated area for the Ameleke irrigation scheme was 1.00, which means that total command area of the scheme was under irrigation with no attempt either to expand or decline the size of irrigated area, but the Sustainability of irrigated area of Halo Gelana irrigation scheme was 0.8 the computed values of sustainability of irrigated area at Halo Gelana scheme was below one, which indicates the current irrigable area is below the irrigable area proposed during the construction period of the irrigation scheme. The main reasons farmers raised were water shortage; i.e. the design command area is at higher elevation than the water source so that the farmers were using two diesel surface pumps to pump water to their farms which exposed farmers to spend huge amount of money to buy fuel, those farmers with scarce resource to buy fuel prefer to cease irrigation which directly contributed to decreasing trend of irrigated area.

Table 4.16: Basic parameters and computed values of IR and SIA

Scheme	Command Area(ha)	Initial irrigated area (ha)	Currently irrigable area (ha)	IR	SIA
Ameleke	42	42	42	1	1
Halo Gelana	75	55	44	0.58	0.8

Where IR- irrigation ratio, SIA-sustainability of irrigable area

4.5.2.4 Economic performance Indicators

Gross Return on investment

This indicator considers the production and the total cost of infrastructure for each scheme. Table 4.17 shows that the gross return on investment of Ameleke is better than Halo Gelana irrigation scheme. i.e. 1.49 and 0.311 for Ameleke and Halo Gelana irrigation schemes, respectively. The details of the gross return on investment for both schemes are shown in Appendix Tables 17 and 18.

This is mainly associated with the lower infrastructure cost incurred at the Ameleke than Halo Gelana which were 70178.57 and 241,326.00US$, respectively for command areas of 42 and 75 ha. However, the area irrigated during the study period (2018/2019) was 100 and 59% of their design potential for Ameleke and Halo Gelana schemes, respectively. The costs of the infrastructure considered here were the total expenditure for constructing all infrastructures found in the schemes and the purchasing cost of water pumps.

Financial self-sufficiency

Financial self-sufficiency indicates the ratio of revenue from the irrigation to the expenditure for operation and maintenance. It shows the compensation ratio of management and maintenance costs for irrigation system based on the income obtained from the irrigation. This in other words implies the sustainability of the schemes, and perception of the farmers towards the irrigation scheme. The financial self-sufficiency of this particular research indicates 5.29 for Halo Gelana scheme and 27.77 for Ameleke scheme. The details of the financial self-sufficiency data for both schemes are shown in Appendix Tables 17 and 18.

Table4.17. Different values of external performance indicators at Ameleke and Halo Gelana irrigation Schemes

External indicators	Ameleke	Halo Gelana
Agricultural performance		
Output per unit cropped area (US$ ha-1)	2852.77	2179.41
Output per unit command area (US$ ha-1	2852.77	1278.59
Output per irrigation supply (US$ m-3)	0.17	0.13
Output per unit water consumed (US$ m-3)	0.18	0.14
Water use performance		
Relative water supply (ratio)	1.06	1.06
Relative irrigation supply (ratio)	1.07	1.07
Physical performance		
Irrigation ratio	1	0.59
Sustainability of irrigated area	1	0.8
Economic performance		
Gross return on investment(ratio)	1.49	0.311
Financial self-sufficiency (ratio)	27.77	5.29

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In this study, an attempt was made to evaluate the performance of two small scale irrigation schemes at Gedeb and wonago woredas of Gedeo Zone SNNPR, using internal and external performance indicators. The internal performance indicators computed were conveyance efficiency, application efficiency, storage efficiency, deep percolation ratio and overall efficiency. The standardized performance indicators established by IWMI were taken as external indicators. The external indicators included in this study were agriculture, water use, physical and economic performance.

The assessment of the irrigation efficiencies in both irrigation schemes (Ameleke and Halo gelana) indicated that the availability of irrigation water is not a constraint and high amounts of water was diverted to the farmer's field. During the study period there was enough water in both Ameleke and halo Gelana Rivers even during the dry time and pumped with a high capacity as compared to the area irrigated. Especially in Ameleke irrigation scheme where farmers use river diversion weir with intake gate to convey water, no cost of fuel gives farmers the opportunity to apply more water than the crops requirement.

The conveyance efficiency of Ameleke scheme at all hydraulic levels showed some good values but it showed low value for Halo Gelana scheme even in the lined part of the main canal due to lack of regular maintenance. But there is a room for improvement if the scheme gets regular maintenance. The application efficiency of both schemes has, however, showed good when we compare with application efficiency of 50-70% for furrow irrigation observed in other African countries.

The relative water and irrigation supply for both schemes shows that there is little high ratio, which implies the amount of water applied during irrigation events was somehow higher than what was required by crops. This type of irrigation affects the farmers by extra expenses they pay for water pumping specially those using diesel fuel due to high cost of fuel price and also causes water wastage that can cultivate extra fields.

The output per cropped area at Halo Gelana was low as compared to Ameleke, implying that the irrigation practice in Halo Gelana was relatively poor. The output per unit command area was observed relatively low in Halo Gelana. This implies that large amount of command area was not under irrigation during the study season in Halo Gelana due to farmers economical capacity to afford high inputs (Fertilizers, crop protection chemicals and improved seeds) required for cash crop production and high fuel price to pump water. The return from one meter cube of irrigation water was high in Ameleke than Halo Gelana scheme. This implies that water utilization in Ameleke was better than Halo Gelana scheme. The gross return on investment of halo gelana was relatively low. This variation was due to high infrastructure cost of Halo gelana irrigation project.

In general, based on the assessment carried out, it can be concluded that the Ameleke irrigation scheme performed better than the Halo Gelana scheme but it cannot be said the

Ameleke scheme does not need improvement so measures should be taken to improve the performance of both schemes. As there is no shortage of water, the schemes have room to expand and to provide irrigation opportunities to the surrounding community relying on rain fed agriculture.

The comparison of the performance of irrigation systems will help to know the present status of these systems. Therefore for the improvement of the irrigation system management and the irrigation practice frequent performance evaluation is very important. According to the results obtained, water management practice of Halo Gelana scheme was generally poor. This however can be improved by sharing experience from Ameleke and other well performing schemes. Therefore, farmers, development agents (DAs) and concerned bodies of these systems better arrange visits to the sites for sharing their strong points one another. Further, it is required from the government side to give on-farm training on water management and performance evaluation techniques for farmers and development agents associated with the schemes.

The financial self-sufficiency of Halo Gelana scheme was observed relatively low but it is at good status at present with regard to its sustainability. Therefore, in order to improve its revenue from scheme, the productivity shall be improved by using appropriate agricultural inputs, and/ or minimization of the costs for production. The diesel pump of Halo Gelana irrigation scheme should be changed into electric pump as the electric line passes over the scheme in order to decrease cost of production incurred for fuel purchase. Furthermore, hydraulic flow metering structures should be constructed at different locations of the canals. This will assist to monitor the activities in relation to water utilization and irrigation efficiencies as well.

Especially Farmers at Halo Gelana irrigation scheme are paying for water pumping service /diesel based on the area they irrigate so the construction of hydraulic flow meter structures, used for the equitable payments for water they use, rather than payment based on the area they irrigate.

5.2 RECOMMENDATIONS

- Farmers must be advised to appropriate irrigation water management to get much return from the production. Assigning DAs and office assistants for improvement of irrigation scheme and used as mechanism to develop healthy perception of farmers about irrigation water.
- Earlier to developing an irrigation scheme for farmers, the capability of farmers whether they manage it or not must considered. Moreover, close monitoring practiced than completely left the operation and maintenance for farmers.
- Water delivery efficiencies at both scheme is very low. Therefore, the conveyance systems should be improved through regular canal cleaning and maintenance of broken irrigation infrastructures
- Introducing high value crops, agricultural intensification, increasing land and water productivity through integrated management and increasing irrigation intensities are very relevant to increase the output value of production per unit irrigated area and command area
- To avoid over irrigation at both irrigation schemes water allocation shall be carried out based on predetermined and designed cropping pattern with irrigation scheduling and also the farmers should be get awareness about how to use, when to use and how much to be used on their fields.
- Putting formal way of fee collection mechanisms and preparing of legal receipts, and finally utilize the collected money for maintenance works are relevant to create transparency and to increase farmer's participation.
- In Halo Gelana irrigation scheme priority should be given to change the existing diesel operated surface pump by hydroelectric power source(as the electric line is passing near to the scheme) with this the uncultivated command areas can be fully cultivated and agricultural productivity increases

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7. Appendixes

7.1. Appendix tables

Appendix table 1. Soil infiltration rate in Ameleke irrigation scheme by double ring infiltrometer

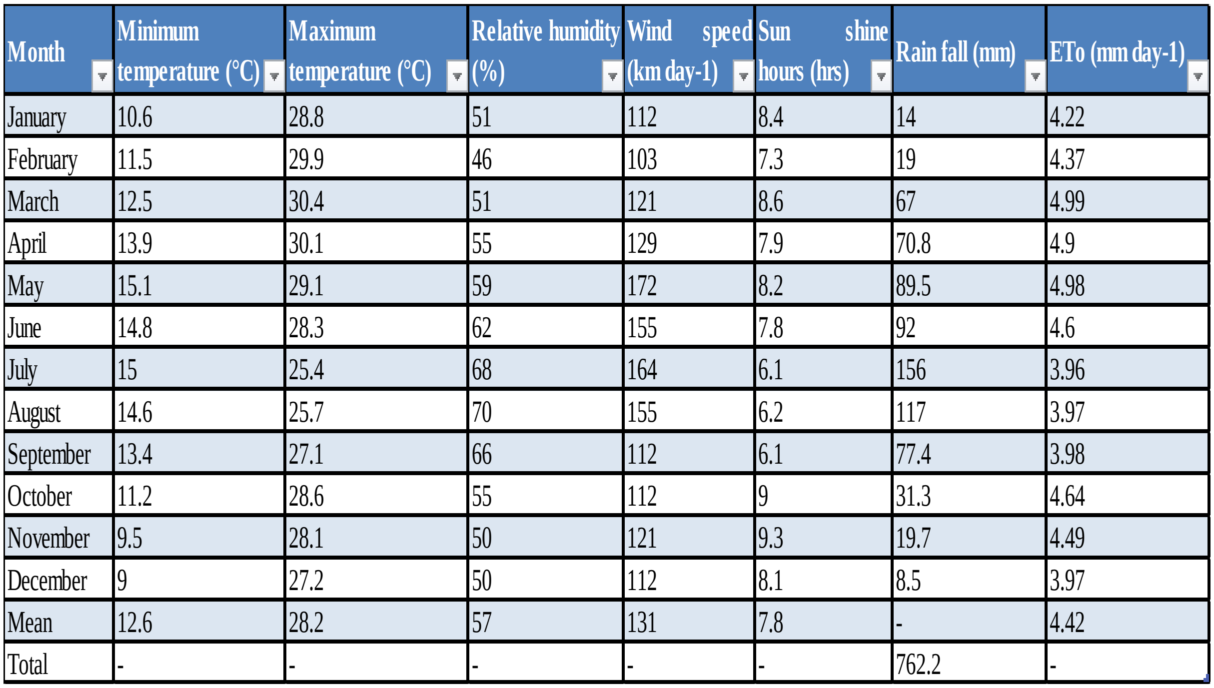
Cumulative time (minute)	Elapsed time (minute)	Reading (cm)	Reading difference (cm)	Cumulative intake(cm)
0.00	0.00	31.00		
0.25	0.25	30.6	0.4	0.4
0.5	0.25	30.3	0.3	0.7
1	0.5	30	0.3	1
2	1	29.7	0.3	1.3
5	3	29.3	0.4	1.7
10	5	29.2	0.1	1.8
20	10	28.8	0.4	2.2
30	10	27.7	1.1	3.3
45	15	26.9	0.8	4.1
60	15	26.0	0.9	5.0
90	30	24.2	1.8	6.8
120	30	22.4	1.8	8.7
160	40	20.7	1.7	10.4
200	40	19.0	1.7	12.1
240	40	17.3	1.7	13.8

Appendix table 2. Soil infiltration rate in Halo Gelana irrigation scheme by double ring infiltrometer

Cumulative time (minute)	Elapsed time (minute)	Reading (cm)	Reading difference (cm)	Cumulative intake(cm)
0.00	0.00	29.50		
0.25	0.25	29.2	0.3	0.3
0.5	0.25	29.1	0.1	0.4
1	0.5	28.7	0.4	0.8
2	1	28.5	0.2	1.0
5	3	28.2	0.3	1.3
10	5	28.0	0.2	1.5
20	10	27.7	0.3	1.8
30	10	26.8	0.9	2.7
45	15	25.8	1.0	3.7
60	15	25.0	0.8	4.5
90	30	23.4	1.6	6.1
120	30	21.9	1.5	7.6
160	40	20.4	1.5	9.1
200	40	18.9	1.5	10.6
240	40	17.4	1.5	12.1

Appendix table 3.

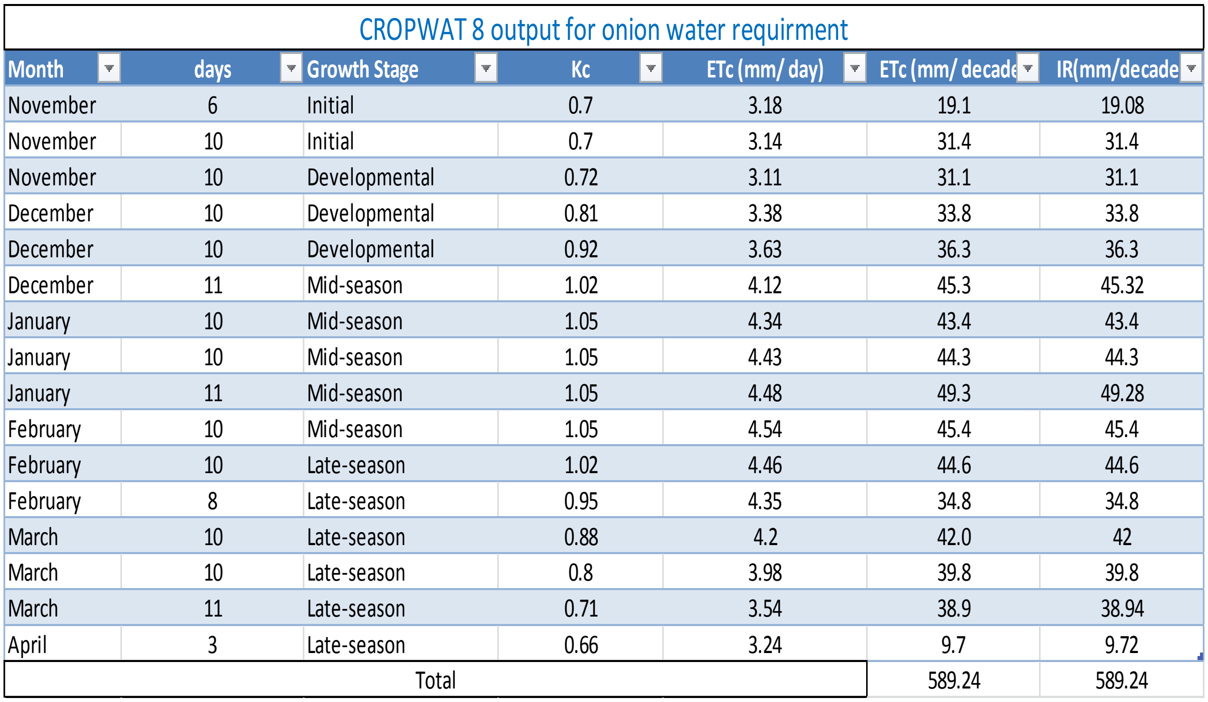
Average 20 years (1991-2010 EC) climatic data at Dilla metrological station and ETo CROPWAT 8 output



Month	Minimum temperature (°C)	Maximum temperature (°C)	Relative humidity (%)	Wind speed (km day-1)	Sun shine hours (hrs)	Rain fall (mm)	ETo (mm day-1)
January	10.6	28.8	51	112	8.4	14	4.22
February	11.5	29.9	46	103	7.3	19	4.37
March	12.5	30.4	51	121	8.6	67	4.99
April	13.9	30.1	55	129	7.9	70.8	4.9
May	15.1	29.1	59	172	8.2	89.5	4.98
June	14.8	28.3	62	155	7.8	92	4.6
July	15	25.4	68	164	6.1	156	3.96
August	14.6	25.7	70	155	6.2	117	3.97
September	13.4	27.1	66	112	6.1	77.4	3.98
October	11.2	28.6	55	112	9	31.3	4.64
November	9.5	28.1	50	121	9.3	19.7	4.49
December	9	27.2	50	112	8.1	8.5	3.97
Mean	12.6	28.2	57	131	7.8	-	4.42
Total	-	-	-	-	-	762.2	-

ETo is reference evapotranspiration

Appendix table 4. CROPWAT 8 output for onion water requirement

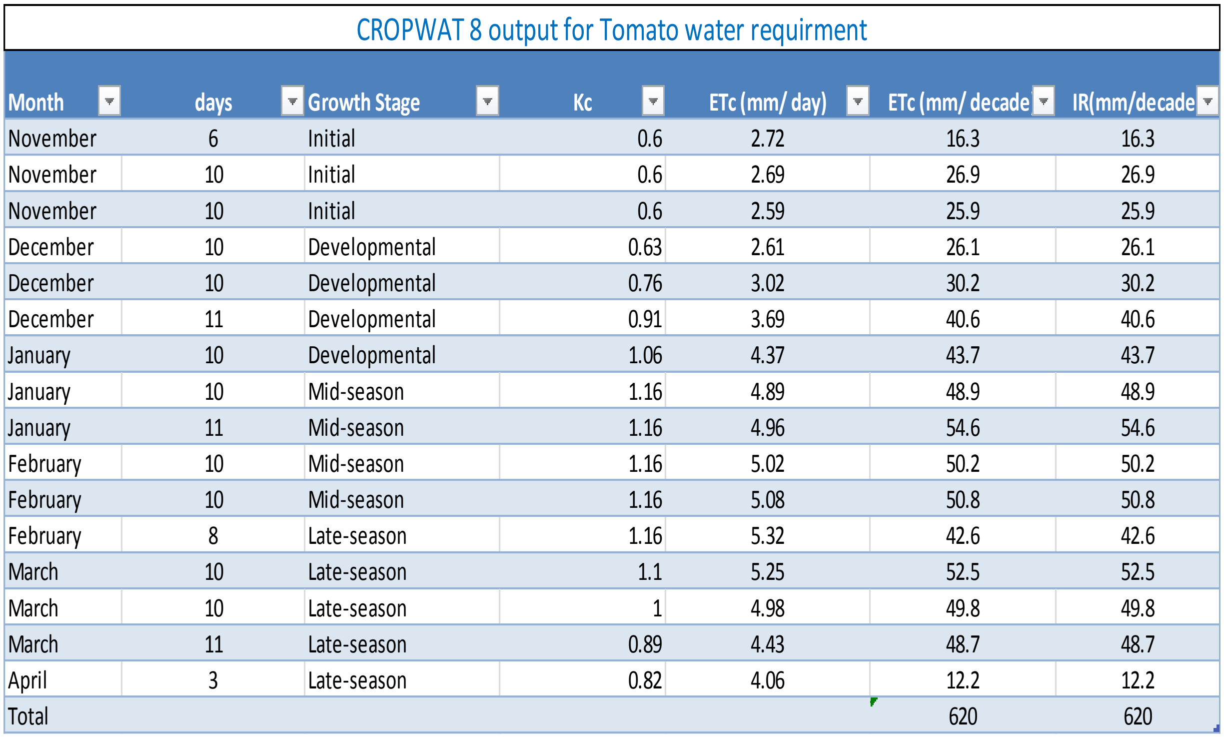


CROPWAT 8 output for onion water requirment

Month	days	Growth Stage	Kc	ETc (mm/ day)	ETc (mm/ decade	IR(mm/decade
November	6	Initial	0.7	3.18	19.1	19.08
November	10	Initial	0.7	3.14	31.4	31.4
November	10	Developmental	0.72	3.11	31.1	31.1
December	10	Developmental	0.81	3.38	33.8	33.8
December	10	Developmental	0.92	3.63	36.3	36.3
December	11	Mid-season	1.02	4.12	45.3	45.32
January	10	Mid-season	1.05	4.34	43.4	43.4
January	10	Mid-season	1.05	4.43	44.3	44.3
January	11	Mid-season	1.05	4.48	49.3	49.28
February	10	Mid-season	1.05	4.54	45.4	45.4
February	10	Late-season	1.02	4.46	44.6	44.6
February	8	Late-season	0.95	4.35	34.8	34.8
March	10	Late-season	0.88	4.2	42.0	42
March	10	Late-season	0.8	3.98	39.8	39.8
March	11	Late-season	0.71	3.54	38.9	38.94
April	3	Late-season	0.66	3.24	9.7	9.72
Total					589.24	589.24

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

Appendix table 5. CROPWAT 8 output for tomato water requirement

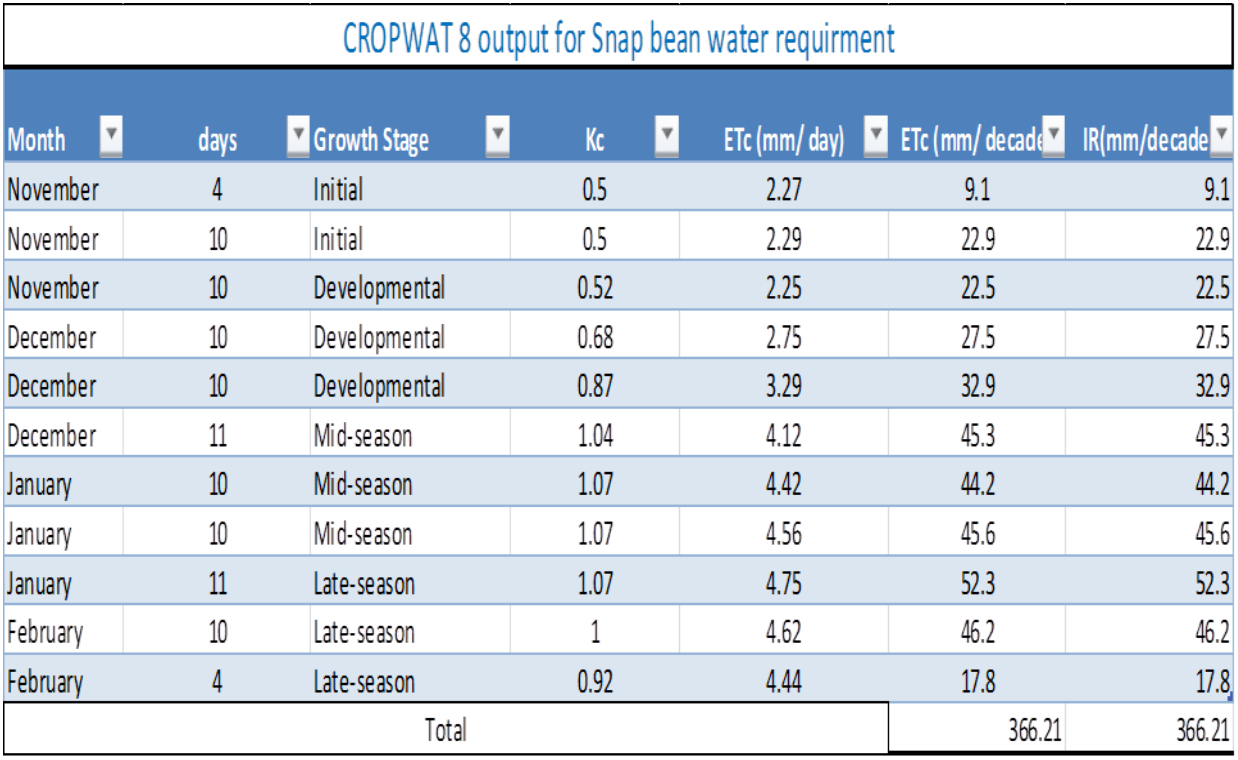


CROPWAT 8 output for Tomato water requirment

Month	days	Growth Stage	Kc	ETc (mm/ day)	ETc (mm/ decade	IR(mm/decade
November	6	Initial	0.6	2.72	16.3	16.3
November	10	Initial	0.6	2.69	26.9	26.9
November	10	Initial	0.6	2.59	25.9	25.9
December	10	Developmental	0.63	2.61	26.1	26.1
December	10	Developmental	0.76	3.02	30.2	30.2
December	11	Developmental	0.91	3.69	40.6	40.6
January	10	Developmental	1.06	4.37	43.7	43.7
January	10	Mid-season	1.16	4.89	48.9	48.9
January	11	Mid-season	1.16	4.96	54.6	54.6
February	10	Mid-season	1.16	5.02	50.2	50.2
February	10	Mid-season	1.16	5.08	50.8	50.8
February	8	Late-season	1.16	5.32	42.6	42.6
March	10	Late-season	1.1	5.25	52.5	52.5
March	10	Late-season	1	4.98	49.8	49.8
March	11	Late-season	0.89	4.43	48.7	48.7
April	3	Late-season	0.82	4.06	12.2	12.2
Total					620	620

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

Appendix table 6. CROPWAT 8 output for snap beans water requirement



CROPWAT 8 output for Snap bean water requirment

Month	days	Growth Stage	Kc	ETc (mm/ day)	ETc (mm/ decade	IR(mm/decade
November	4	Initial	0.5	2.27	9.1	9.1
November	10	Initial	0.5	2.29	22.9	22.9
November	10	Developmental	0.52	2.25	22.5	22.5
December	10	Developmental	0.68	2.75	27.5	27.5
December	10	Developmental	0.87	3.29	32.9	32.9
December	11	Mid-season	1.04	4.12	45.3	45.3
January	10	Mid-season	1.07	4.42	44.2	44.2
January	10	Mid-season	1.07	4.56	45.6	45.6
January	11	Late-season	1.07	4.75	52.3	52.3
February	10	Late-season	1	4.62	46.2	46.2
February	4	Late-season	0.92	4.44	17.8	17.8
Total					366.21	366.21

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

Appendix table 7. Main canal flow at four canal Reaches in Ameleke SSI

canal reach	observatio	Qi(l/s)	Qo(l/s)
MC1	1	98.2	91.2
	2	101.4	93.5
	3	98.5	92.4
	4	98.7	92.8
	5	99.1	93.6
	6	102.3	94.5
	7	101.5	93.7
	8	98.4	92.3
	9	99.4	94
	10	102.5	94.6
Average		100	93.26
MC2	1	98.2	90.8
	2	101.4	92.5
	3	98.5	91
	4	98.7	91.2
	5	99.1	91.6
	6	102.3	93
	7	101.5	92.4
	8	98.4	90.4
	9	99.4	91.9
	10	102.5	93.2
	Average	100	91.8
MC3	1	98.2	90.3
	2	101.4	92.1
	3	98.5	90.5
	4	98.7	90.7
	5	99.1	90.8
	6	102.3	92.4
	7	101.5	91.9
	8	98.4	89.5
	9	99.4	90.5
	10	102.5	92.4
	Average	100	91.1
MC4	1	98.2	88.5
	2	101.4	89.9
	3	98.5	88.8
	4	98.7	88.9
	5	99.1	89.3
	6	102.3	89.8
	7	101.5	90
	8	98.4	88.9
	9	99.4	89.1
	10	102.5	89.9
	Average	100	89.3

Appendix table 8. Main canal flow at five canal Reaches in Halo Gelana SSI

canal reach	observation	Qi(l/s)	Qo(l/s)
MC1	1	98.2	77
	2	98.4	75.5
	3	98.2	72.5
	4	98.3	79
	5	98.2	86.5
	6	98.4	74
	7	98.7	75.5
	8	98.6	77
	9	98.2	72.5
	10	98.1	77.25
	Average	98.33	76.68
MC2	1	98.2	75.2
	2	98.4	74.8
	3	98.2	73.2
	4	98.3	74.2
	5	98.2	76.5
	6	98.4	74
	7	98.7	75.47
	8	98.6	75.22
	9	98.2	72.5
	10	98.1	77.25
	Average	98.33	74.83
MC3	1	98.2	73.2
	2	98.4	74.8
	3	98.2	73.2
	4	98.3	74.2
	5	98.2	71.7
	6	98.4	70.8
	7	98.7	72.3
	8	98.6	70.8
	9	98.2	72.5
	10	98.1	71.5
	Average	98.33	72.5
MC4	1	98.2	71.6
	2	98.4	73.6
	3	98.2	71.2
	4	98.3	72.2
	5	98.2	70.7
	6	98.4	70.5
	7	98.7	71.6
	8	98.6	70.5
	9	98.2	71.8
	10	98.1	71.3
	Average	98.33	71.5
MC5	1	98.2	71.4
	2	98.4	73.3
	3	98.2	71
	4	98.3	71.9
	5	98.2	70.5
	6	98.4	70.4
	7	98.7	71.5
	8	98.6	70.3
	9	98.2	70.5
	10	98.1	71.2
	Average	98.33	71.2

Appendix table 9. Measured water depths applied to field, field application efficiency and storage efficiency of Ameleke irrigation scheme

Field code	Water head (cm)	Canal width (cm)	Velocity(m/ s)	Q(m3/s)	Elapsed time (minute)	Area(m2)	Total volume (m3)	Depth applied (mm)	Water stored at Zr(mm)	Wn(mm)	Ea(%)	Er(%)
H1	13	10	0.85	0.011	172	2500	113.52	45.41	33.45	45.9	73.66	72.876
H2	10	10	1.3	0.013	160	2500	124.8	49.92	33.45	45.9	67.01	72.876
H3	11	10	1.09	0.012	178	2500	128.16	51.26	32.6	45.9	63.60	71.024
M1	6	10	1.83	0.011	95	1250	62.7	50.16	36.26	38.7	72.29	93.695
M2	12	10	0.75	0.009	92	1250	49.68	39.74	34.22	38.7	86.11	88.424
M3	6	10	1.67	0.01	95	1250	57	45.6	27.7	38.7	60.75	71.576
T1	12	10	0.75	0.009	179	2500	96.66	38.66	34.49	44.1	89.21	78.209
T2	12	10	1.08	0.013	162	2500	126.36	50.54	29.47	44.1	58.31	66.825
T3	13	10	0.92	0.012	158	2500	113.76	45.5	35.58	44.1	78.20	80.680
										Mean	72.13	77.35

H 1, H2 and H3 are code of fields selected from head water users, M1, M2 and M3 are code of fields selected from middle scheme water users, and T1, T2 and T3 are code of fields selected from tail end water users, Wn is water desired in root zone for onion at 45% depletion fraction, Ea is application efficiency, Er is storage efficiency.

Appendix table 10. Measured water depths applied to field, field application efficiency and storage efficiency of Halo Gelana irrigation scheme

Field code	Water head (cm)	Canal width (cm)	Velocity(m/ s)	Q(m3/s)	Elapsed time (minute)	Area(m2)	Total volume (m3)	Depth applied (mm)	Water stored at Zr(mm)	Wn(mm)	Ea(%)	Er(%)
H1	21	10	0.662	0.0139	149	2500	124.27	49.71	34.6	42.3	69.60	81.80
H2	22	10	0.691	0.0152	143	2500	130.42	52.17	36.7	42.3	70.35	86.76
H3	24	10	0.679	0.0163	139	2500	135.94	54.38	33.37	42.3	61.36	78.89
M1	24	10	0.642	0.0154	147	2500	135.83	54.33	34.14	40.5	62.84	84.30
M2	22	10	0.609	0.0134	160	2500	128.64	51.46	36.33	40.5	70.60	89.70
M3	20	10	0.63	0.0126	164	2500	123.98	49.59	40.16	40.5	80.98	99.16
T1	22	10	0.618	0.0136	158	1250	128.93	51.57	33.75	46.8	65.45	72.12
T2	21	10	0.681	0.0143	83	1250	71.21	56.97	28.42	46.8	49.89	60.73
T3	24	10	0.621	0.0149	77	1250	68.84	44.34	34.1	46.8	76.91	72.86
										Mean	67.55	80.70

H1, H2 and H3 are code of fields selected from head water users, M1, M2 and M3 are code of fields selected from middle scheme water users, and T1, T2 and T3 are code of fields selected from tail end water users, Wn is water desired in root zone for onion at 45% depletion fraction, Ea is application efficiency, Er is storage efficiency.

Appendix table 11. Soil moisture contents one day before and after irrigation of Ameleke irrigation scheme

Field code	Soil depth (cm)	Bulk density (g/cm3)	Moisture before irrigation (%)	Moisture after irrigation (%)	Moisture stored (%)	Moisture stored (mm)
H1	0-20	1.03	23.48	33.97	10.49	21.61
	20-40	0.95	28.37	32.51	4.14	7.87
	40-60	1.01	29.35	31.32	1.97	3.98
H2	0-20	1.03	25.32	35.04	9.72	20.02
	20-40	0.95	27.13	31.86	4.73	8.99
	40-60	1.01	28.03	30.23	2.2	4.44
H3	0-20	1.03	24.96	34.56	9.6	19.78
	20-40	0.95	27.41	31.17	3.76	7.14
	40-60	1.01	28.12	30.93	2.81	5.68
M1	0-20	1.08	24.53	32.08	7.55	16.31
	20-40	1.01	25.6	31.3	5.7	11.51
	40-60	1	25.66	29.88	4.22	8.44
M2	0-20	1.01	24.35	34.83	10.48	21.17
	20-40	1.08	26.61	31.37	4.76	10.28
	40-60	1.01	27.72	29.09	1.37	2.77
M3	0-20	1	24.78	32.73	7.95	15.90
	20-40	1.01	26.93	31.18	4.25	8.59
	40-60	1.08	28.53	30.02	1.49	3.22
T1	0-20	1.04	23.47	33.85	10.38	21.59
	20-40	0.98	26.63	31.37	4.74	9.29
	40-60	1.03	29.78	31.53	1.75	3.61
T2	0-20	1.04	24.78	33.28	8.5	17.68
	20-40	0.98	27.81	31.04	3.23	6.33
	40-60	1.03	28.33	30.98	2.65	5.46
T3	0-20	1.04	25.51	35.52	10.01	20.82
	20-40	0.98	27.43	32.41	4.98	9.76
	40-60	1.03	29.03	30.97	1.94	4.00

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

Appendix table 12. Soil moisture contents one day before and after irrigation of Halo Gelana irrigation scheme

Field code	Soil depth (cm)	Bulk density (g/cm3)	Moisture before irrigation (%)	Moisture after irrigation (%)	Moisture stored (%)	Moisture stored (mm)
H1	0-20	1.13	23.81	32.29	8.48	19.16
	20-40	1.05	26.62	30.42	3.8	7.98
	40-60	1.12	27.54	30.87	3.33	7.46
H2	0-20	1.13	24.02	33.14	9.12	20.61
	20-40	1.05	26.09	30.82	4.73	9.93
	40-60	1.12	27.68	30.43	2.75	6.16
H3	0-20	1.13	24.46	34.96	10.5	23.73
	20-40	1.05	28.41	31.07	2.66	5.59
	40-60	1.12	29.12	30.93	1.81	4.05
M1	0-20	1.2	25.45	33.46	8.01	19.22
	20-40	1.15	26.73	31.72	4.99	11.48
	40-60	1.13	28.52	30.04	1.52	3.44
M2	0-20	1.2	24.15	33.83	9.68	23.23
	20-40	1.15	27.92	32.27	4.35	10.01
	40-60	1.13	28.72	30.09	1.37	3.10
M3	0-20	1.2	24.18	33.91	9.73	23.35
	20-40	1.15	27.91	32.28	4.37	10.05
	40-60	1.13	28.13	31.12	2.99	6.76
T1	0-20	1.21	23.37	32.29	8.92	21.59
	20-40	1.08	26.52	30.2	3.68	7.95
	40-60	1.14	27.83	29.68	1.85	4.22
T2	0-20	1.21	24.98	32.36	7.38	17.86
	20-40	1.08	27.63	30.47	2.84	6.13
	40-60	1.14	28.24	30.18	1.94	4.42
T3	0-20	1.21	24.06	33.42	9.36	22.65
	20-40	1.08	27.98	30.98	3	6.48
	40-60	1.14	27.53	29.71	2.18	4.97

H1, H2 andH3 are code of fields selected from head water users, M1, M2 and M3 are code of fields selected from middle water users, and T1, T2 and T3 are code of fields selected from tail end water users

Appendix table 13. Ameleke small scale irrigation scheme, determination of CU and DU values from selected 9 farm plots/Grids

	Depth of irrigation stored in the root zone(mm)			DU (%)	CU (%)
Field code	1	2	3	90.916	93.94
H	33.45	33.45	32.6		
M	36.26	34.22	27.7		
T	34.49	29.47	34.58		

H1, H2 andH3 are code of fields selected from head water users, M1, M2 and M3 are code of fields selected from middle water users, and T1, T2 and T3 are code of fields selected from tail end water users, DU is distribution uniformity and CU is Christianson uniformity

Appendix table 14. Halo Gelana small scale irrigation scheme, determination of CU and DU values from selected 9 farm plots/Grids

	Depth of irrigation stored in the root zone(mm)			DU (%)	CU (%)
Field code	1	2	3	91.99	94.02
H	34.6	36.7	33.37		
M	34.14	36.33	40.16		
T	33.75	28.42	34.1		

H1, H2 andH3 are code of fields selected from head water users, M1, M2 and M3 are code of fields selected from middle water users, and T1, T2 and T3 are code of fields selected from tail end water users, DU is distribution uniformity and CU is Christianson uniformity

Appendix table 15. Crop production, productivity, production costs and prices of crop at Ameleke irrigation scheme (2010 EC production season)

Crop Type	Total area (ha)	Productivity (Quintals ha^{-1})	Total products (Quintals)	SGVP (US$)	Production costs (US$)	Revenue (US$)	Price kg^{-1} (US$)
Snap beans	16.00	64.00	1024.00	22287.06	3952.94	18334.12	0.22
Tomato	1.00	220.00	220.00	3882.35	607.06	3275.29	0.18
Cabbages	1.00	32000 heads	32000 heads	4705.88	477.65	4228.24	0.15
Onion	24.00	180.00	4320.00	88941.18	10051.76	78889.41	0.21
Total	42.00	-	-	119,816.50	15,089.41	104,727.06	–

SGVP, is Sum of Gross Value Product in US$

Appendix table 16. Crop production, productivity, production costs and prices of crop at Halo Gelana irrigation scheme (2010EC production season)

Crop Type	Total area (ha)	Productivity (Quintals ha^{-1})	Total products (Quintals)	SGVP (US$)	Production costs (US$)	Revenue (US$)	Price kg^{-1} (US$)
Snap beans	22.00	50.00	1100.00	23941.18	7661.18	16280.00	0.22
Tomato	8.00	148.00	1184.00	20894.12	4894.12	16000.00	0.18
Cabbage	5.00	32000 heads	160000 heads	23529.41	2647.06	20882.35	0.15
Onion	8.00	160.00	1280.00	26352.94	5176.47	21176.47	0.21
Garlic	1.00	20.00	20.00	1176.471	470.59	705.88	0.59
Total	44.00			95894.12	20849.41	75044.71	

SGVP, is Sum of Gross Value Product in US$

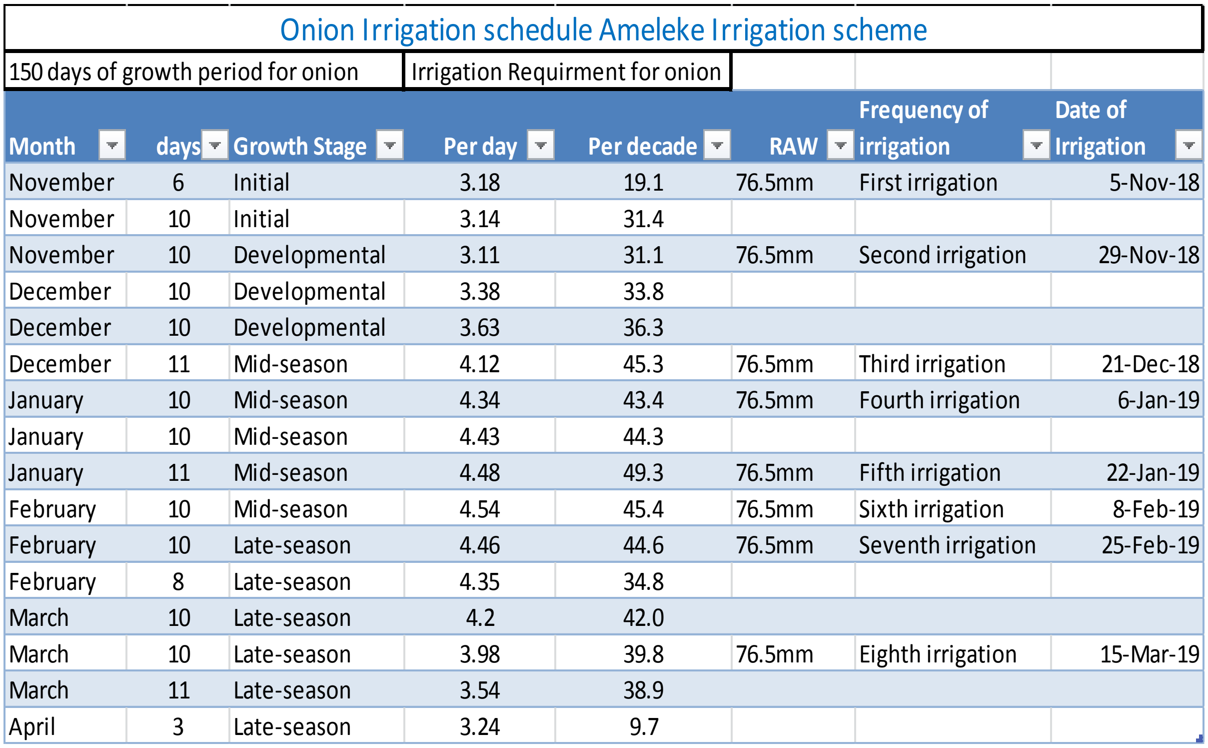
Appendix table 17. Investment, operation and maintenance costs of Ameleke irrigation project

Type of costs	Amount of money (US$)
Initial investment cost	70,178.57
Operation & maintenance cost in 2010/2011 EC	3,771.23
Total	73,949.8

Appendix table 18. Investment, operation and maintenance costs of Halo Gelana irrigation project

Type of costs	Amount of money (US$)
Initial investment cost	241,326.00
Operation & maintenance cost in 2010/2011 EC	14,188.24
Total	255,514.24

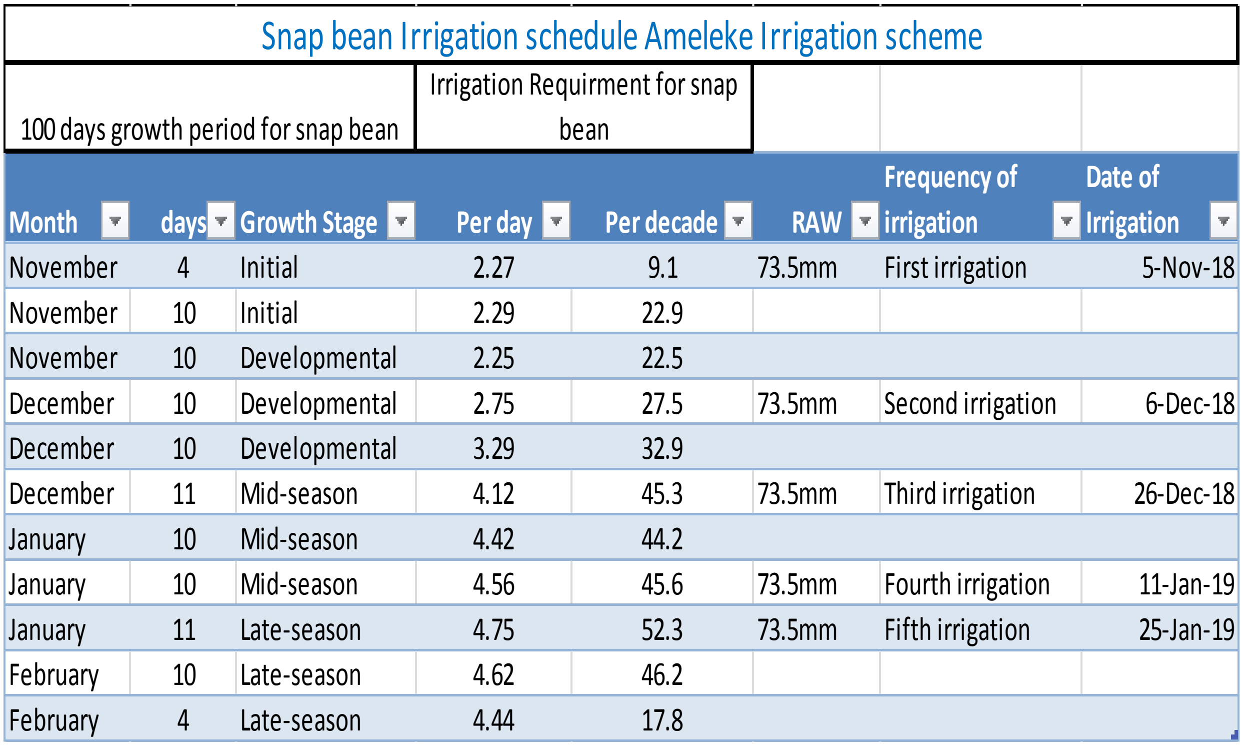
Appendix table 19 Onion irrigation schedule at Ameleke irrigation scheme



Onion Irrigation schedule Ameleke Irrigation scheme

150 days of growth period for onion			Irrigation Requirment for onion				
Month	days	Growth Stage	Per day	Per decade	RAW	Frequency of irrigation	Date of Irrigation
November	6	Initial	3.18	19.1	76.5mm	First irrigation	5-Nov-18
November	10	Initial	3.14	31.4			
November	10	Developmental	3.11	31.1	76.5mm	Second irrigation	29-Nov-18
December	10	Developmental	3.38	33.8			
December	10	Developmental	3.63	36.3			
December	11	Mid-season	4.12	45.3	76.5mm	Third irrigation	21-Dec-18
January	10	Mid-season	4.34	43.4	76.5mm	Fourth irrigation	6-Jan-19
January	10	Mid-season	4.43	44.3			
January	11	Mid-season	4.48	49.3	76.5mm	Fifth irrigation	22-Jan-19
February	10	Mid-season	4.54	45.4	76.5mm	Sixth irrigation	8-Feb-19
February	10	Late-season	4.46	44.6	76.5mm	Seventh irrigation	25-Feb-19
February	8	Late-season	4.35	34.8			
March	10	Late-season	4.2	42.0			
March	10	Late-season	3.98	39.8	76.5mm	Eighth irrigation	15-Mar-19
March	11	Late-season	3.54	38.9			
April	3	Late-season	3.24	9.7			

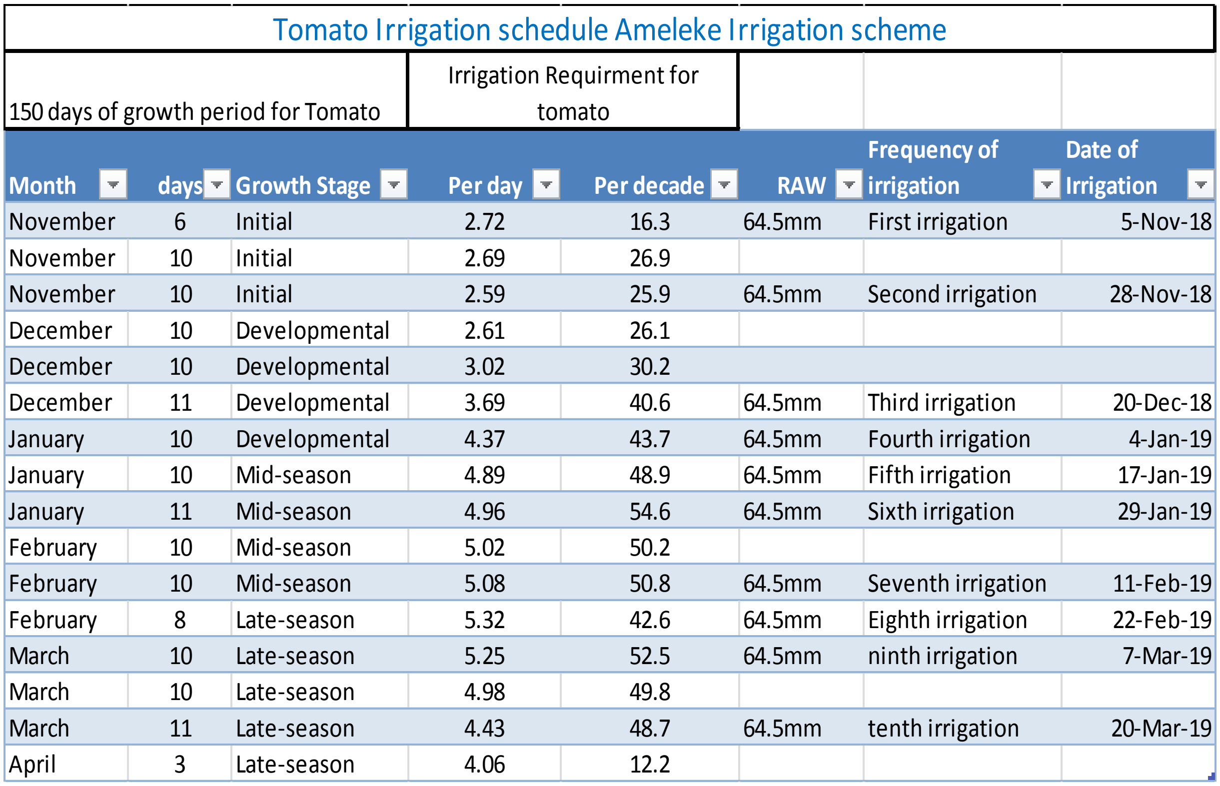
Appendix table 20: Snap bean irrigation schedule at Ameleke irrigation scheme



Snap bean Irrigation schedule Ameleke Irrigation scheme

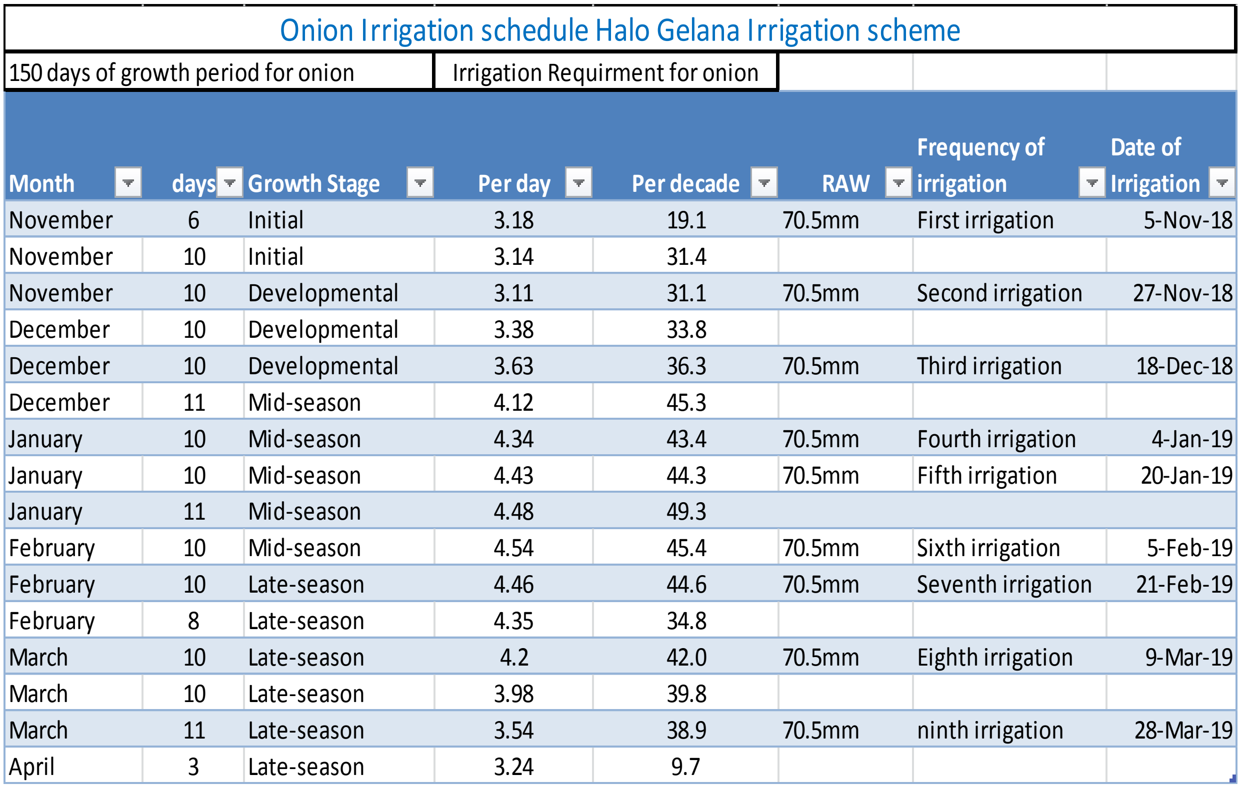
100 days growth period for snap bean			Irrigation Requirment for snap bean				
Month	days	Growth Stage	Per day	Per decade	RAW	Frequency of irrigation	Date of Irrigation
November	4	Initial	2.27	9.1	73.5mm	First irrigation	5-Nov-18
November	10	Initial	2.29	22.9			
November	10	Developmental	2.25	22.5			
December	10	Developmental	2.75	27.5	73.5mm	Second irrigation	6-Dec-18
December	10	Developmental	3.29	32.9			
December	11	Mid-season	4.12	45.3	73.5mm	Third irrigation	26-Dec-18
January	10	Mid-season	4.42	44.2			
January	10	Mid-season	4.56	45.6	73.5mm	Fourth irrigation	11-Jan-19
January	11	Late-season	4.75	52.3	73.5mm	Fifth irrigation	25-Jan-19
February	10	Late-season	4.62	46.2			
February	4	Late-season	4.44	17.8			

Appendix table 21: Tomato irrigation schedule at Ameleke irrigation scheme



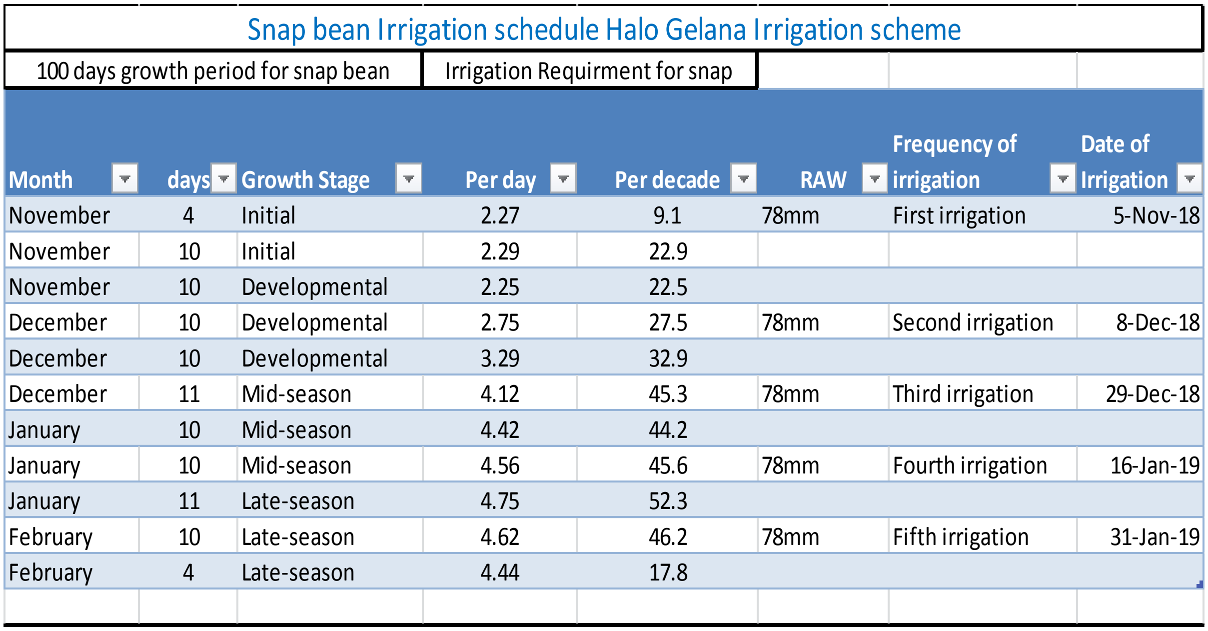
Tomato Irrigation schedule Ameleke Irrigation scheme							
150 days of growth period for Tomato			Irrigation Requirment for tomato				
Month	days	Growth Stage	Per day	Per decade	RAW	Frequency of irrigation	Date of Irrigation
November	6	Initial	2.72	16.3	64.5mm	First irrigation	5-Nov-18
November	10	Initial	2.69	26.9			
November	10	Initial	2.59	25.9	64.5mm	Second irrigation	28-Nov-18
December	10	Developmental	2.61	26.1			
December	10	Developmental	3.02	30.2			
December	11	Developmental	3.69	40.6	64.5mm	Third irrigation	20-Dec-18
January	10	Developmental	4.37	43.7	64.5mm	Fourth irrigation	4-Jan-19
January	10	Mid-season	4.89	48.9	64.5mm	Fifth irrigation	17-Jan-19
January	11	Mid-season	4.96	54.6	64.5mm	Sixth irrigation	29-Jan-19
February	10	Mid-season	5.02	50.2			
February	10	Mid-season	5.08	50.8	64.5mm	Seventh irrigation	11-Feb-19
February	8	Late-season	5.32	42.6	64.5mm	Eighth irrigation	22-Feb-19
March	10	Late-season	5.25	52.5	64.5mm	ninth irrigation	7-Mar-19
March	10	Late-season	4.98	49.8			
March	11	Late-season	4.43	48.7	64.5mm	tenth irrigation	20-Mar-19
April	3	Late-season	4.06	12.2			

Appendix table 22: Onion irrigation schedule at Halo Gelana irrigation scheme



Onion Irrigation schedule Halo Gelana Irrigation scheme							
150 days of growth period for onion			Irrigation Requirment for onion				
Month	days	Growth Stage	Per day	Per decade	RAW	Frequency of irrigation	Date of Irrigation
November	6	Initial	3.18	19.1	70.5mm	First irrigation	5-Nov-18
November	10	Initial	3.14	31.4			
November	10	Developmental	3.11	31.1	70.5mm	Second irrigation	27-Nov-18
December	10	Developmental	3.38	33.8			
December	10	Developmental	3.63	36.3	70.5mm	Third irrigation	18-Dec-18
December	11	Mid-season	4.12	45.3			
January	10	Mid-season	4.34	43.4	70.5mm	Fourth irrigation	4-Jan-19
January	10	Mid-season	4.43	44.3	70.5mm	Fifth irrigation	20-Jan-19
January	11	Mid-season	4.48	49.3			
February	10	Mid-season	4.54	45.4	70.5mm	Sixth irrigation	5-Feb-19
February	10	Late-season	4.46	44.6	70.5mm	Seventh irrigation	21-Feb-19
February	8	Late-season	4.35	34.8			
March	10	Late-season	4.2	42.0	70.5mm	Eighth irrigation	9-Mar-19
March	10	Late-season	3.98	39.8			
March	11	Late-season	3.54	38.9	70.5mm	ninth irrigation	28-Mar-19
April	3	Late-season	3.24	9.7			

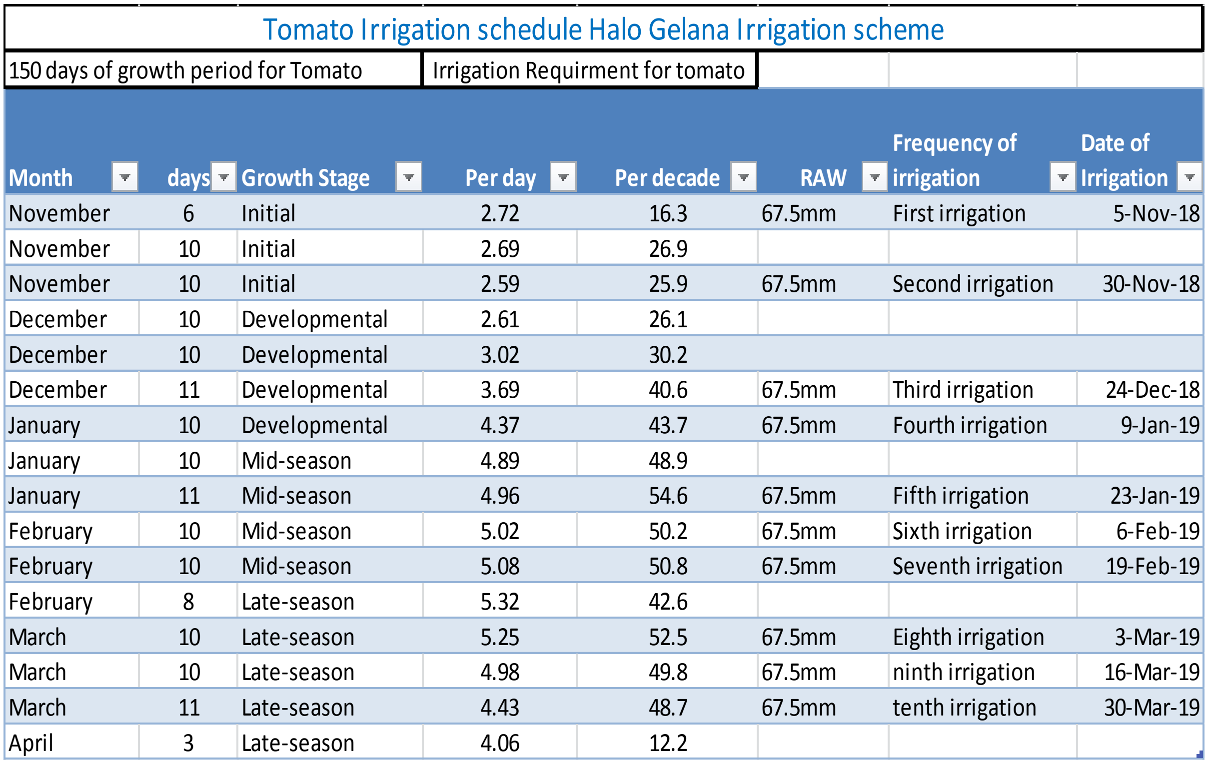
Appendix table 23: Snap bean irrigation schedule at Halo Gelana irrigation scheme



Snap bean Irrigation schedule Halo Gelana Irrigation scheme

100 days growth period for snap bean			Irrigation Requirment for snap				
Month	days	Growth Stage	Per day	Per decade	RAW	Frequency of irrigation	Date of Irrigation
November	4	Initial	2.27	9.1	78mm	First irrigation	5-Nov-18
November	10	Initial	2.29	22.9			
November	10	Developmental	2.25	22.5			
December	10	Developmental	2.75	27.5	78mm	Second irrigation	8-Dec-18
December	10	Developmental	3.29	32.9			
December	11	Mid-season	4.12	45.3	78mm	Third irrigation	29-Dec-18
January	10	Mid-season	4.42	44.2			
January	10	Mid-season	4.56	45.6	78mm	Fourth irrigation	16-Jan-19
January	11	Late-season	4.75	52.3			
February	10	Late-season	4.62	46.2	78mm	Fifth irrigation	31-Jan-19
February	4	Late-season	4.44	17.8			

Appendix table 24: Tomato irrigation schedule at Halo Gelana irrigation scheme



Tomato Irrigation schedule Halo Gelana Irrigation scheme

150 days of growth period for Tomato			Irrigation Requirment for tomato				
Month	days	Growth Stage	Per day	Per decade	RAW	Frequency of irrigation	Date of Irrigation
November	6	Initial	2.72	16.3	67.5mm	First irrigation	5-Nov-18
November	10	Initial	2.69	26.9			
November	10	Initial	2.59	25.9	67.5mm	Second irrigation	30-Nov-18
December	10	Developmental	2.61	26.1			
December	10	Developmental	3.02	30.2			
December	11	Developmental	3.69	40.6	67.5mm	Third irrigation	24-Dec-18
January	10	Developmental	4.37	43.7	67.5mm	Fourth irrigation	9-Jan-19
January	10	Mid-season	4.89	48.9			
January	11	Mid-season	4.96	54.6	67.5mm	Fifth irrigation	23-Jan-19
February	10	Mid-season	5.02	50.2	67.5mm	Sixth irrigation	6-Feb-19
February	10	Mid-season	5.08	50.8	67.5mm	Seventh irrigation	19-Feb-19
February	8	Late-season	5.32	42.6			
March	10	Late-season	5.25	52.5	67.5mm	Eighth irrigation	3-Mar-19
March	10	Late-season	4.98	49.8	67.5mm	ninth irrigation	16-Mar-19
March	11	Late-season	4.43	48.7	67.5mm	tenth irrigation	30-Mar-19
April	3	Late-season	4.06	12.2			

Appendix table 25: Soil textural classes of Ameleke and Halo Gelana irrigation schemes

Irrigation scheme	Canal reaches	Soil depth (cm)	Particle size distribution (%)			Textural class	Bulk density (g/cm3)
			sand	silt	clay		
Ameleke SSI	Head	0-20	39	44	17	Loam	1.03
		20-40	34	47	19	Loam	0.95
		40-60	37	43	20	Loam	1.01
	Middle	0-20	40	41	19	Loam	1.08
		20-40	38	41	21	Loam	1.01
		40-60	37	45	18	Loam	1.00
	Tail	0-20	39	42	19	Loam	1.04
		20-40	35	43	22	Loam	0.98
		40-60	34	48	18	Loam	1.03
Halo Gelana SSI	Head	0-20	33	46	21	Loam	1.13
		20-40	31	49	20	Loam	1.05
		40-60	40	42	18	Loam	1.12
	Middle	0-20	33	47	20	Loam	1.20
		20-40	34	49	17	Loam	1.15
		40-60	36	45	19	Loam	1.13
	Tail	0-20	33	46	21	Loam	1.21
		20-40	33	49	18	Loam	1.08
		40-60	36	45	19	Loam	1.14

7.2 .Appendix Figures

(a) (b)

Appendix Figure1.Measuring water flow on main canal (a) and lined part of Ameleke main canal (b)

(a) (b)

Appendix Figure 2. Functional division box of Ameleke (a) and non-functional division box of Halo Gelana (b) irrigation schemes

(a) (b)

Appendix Figure 3. Onion fields (a) and measuring water flow at field (b)

(a) (b)

Appendix Figure 4. Soil sampling (a) at Ameleke and applied irrigation water flow measurement (using 3”parshal flume) (b) Halo Gelana