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Water Productivity Evaluation of Drip and Furrow Irrigation System

(In the case of Hormat-Golina irrigation scheme)

A Thesis

In Hydraulic Engineering Stream

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DECLARATION

I declare that research work titled “Water productivity evaluation of drip and furrow irrigation system (In the case of Hormat-Golina irrigation scheme)” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged and referred.

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ABSTRACT

The development of irrigation scheme in Ethiopia contributes to the production of agricultural products which enhances food security & economic growth of the country. Hormat-Golina irrigation scheme plays a significant role in household income. Even though both drip and furrow irrigation systems are practicing, lack of information on balance applied irrigation water and crop water demand; and also there is no evaluation of water productivity of drip and furrow irrigation systems at the scheme. Thus the main objective of this study is to evaluate the water productivity of drip and furrow irrigation systems at the scheme. The model CROPWAT 8.0 was used to estimate crop water demand; although water productivity was evaluated as crop and economic terms for both irrigation systems with two irrigation seasons. At the season Dec, 2017 to May, 2018 the crop water productivity of drip was estimated as, 1.53, 1.02, 1.06 and 2.24 kg/m^3 for chickpea, garlic, onion, and watermelon respectively; and 0.52, 0.66 and 1.52 kg/m^3 for chickpea, onion, and watermelon respectively with furrow irrigation method. And also, at the season Dec, 2018 to May, 2019 the crop water productivity of drip irrigation system for the crops chickpea, garlic, and watermelon were determined as 1.18, 1.03 and 2.29 kg/m^3 respectively; and in the case of furrow irrigation system it was estimated as 0.47, 0.57, 0.64 and 1.43 kg/m^3 chickpea, garlic, onion, and watermelon respectively. In general, the estimated CWP of garlic and onion from the research was lower than previous studies. Similarly, in season Dec, 2017 to May, 2018 economic water productivity of drip irrigation system was estimated as 0.34, 1.29, 0.41 and 1.20 \$/m^3 for chickpea, garlic, onion, and watermelon respectively; and also 0.14, 0.25 and 0.85 \$/m^3 for chickpea, onion, and watermelon respectively from furrow irrigation system. In addition, at the season Dec, 2018 to May, 2019 economic water productivity were determined as 0.4, 1.41 and 1.74 \$/m^3 for chickpea, garlic, and watermelon respectively from drip irrigation method, and with furrow irrigation system were determined as 0.15, 0.77, 0.31 and 1.06 \$/m^3 for chickpea, garlic, onion, and watermelon respectively. The EWP of this research was similar with the previous researches. Based on thus results drip irrigation system is the advisable method for the scheme, and further studies require to improve water productivity.

Key words: Applied irrigation water, crop water demand, water productivity, Drip and Furrow irrigation systems.

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ABBREVIATIONS AND SYMBOLS

Symbol	Descripitions
CWR	Crop Water Requirement
CWP	Crop water productivity
DI-B	Drip irrigation blocks
E	Easting
ENMA	Ethiopian National Meteorology Agency
ETc	Crop evapotranspiration
ETo	Reference evapotranspiration
Es	Irrigation efficiency
EWP	Economic water productivity
FAO	Food and agriculture organization
FI-B	Furrow irrigation blocks
GVP	Gross value of product
HG	Hormat-Golina
ha	Hectare
hr	Hour
IAEA	International atomic energy agency
ICARDA	International center for agricultural research in dry area
IWR	Irrigation water requirement
Kc	Crop coefficients
KGVDP	Kobo Girana Valley Development Program
Km	Kilometer
Kw	Kilowatt
l/hr	Litter per hour
l/s	litter per second
l/s/ha	litter per second per hectare
LS	Lamb sum
LWDD	Land and Water Development of Division
Mm	Millimeter
MOA	Ministry of agriculture
N	Northing

P	Depletion levels
Peff	Effective precipitation
Qt	Quintal
SSI	Small scale irrigation
RH	Relative humidity
RWS	Relative water supply
USGS	United State Geological Survey
WLMD	Water and Land Management Department
WMO	World Meteorological Organization
WP	Water productivity
Wu	Water used
Zr	Rooting depth

CHAPTER 1 INTODUCTION

1.1 General background

In the design and planning of an irrigation system, investigation of water requirement is the basic need (Endalamaw, 2009). And also irrigation management plays an important role for effectively and efficiently using the available water sources to meet the possible variation of cropping pattern (Amare et al., 2016). The estimation of crop water demand is an essential component for managing water effectively in the irrigated command area (Naidu & Giridhar, 2016). However, the estimation of the water demand has proved to be much more difficult as it requires data on irrigated areas, types of crops, cropping calendars and specific crop water demands (Todorovic, 2017). Given these data, it becomes possible to calculate the total crop water requirement for each system and compare this with the total amount of water actually applied into the field. CROPWAT model is developed by FAO water and land management department (WLMD) for planning and management of irrigation as a practical tool to carry out standard calculations for reference evapotranspiration and irrigation water requirement (Allen et al., 1998).

The sharper increase in food demands as a result of population growth and frequent drought has revealed the importance of irrigation development in Ethiopia (Wondimkun & Tefera, 1995; Belay & Beyene, 2013; Dinka & Ndambuki, 2014). In Ethiopia, under the prevalent rain-fed agricultural production the progressive degradation of the natural resource base in highly vulnerable areas of the highlands coupled with climate variability have aggravated the incidence of poverty and food insecurity (Awulachew et al., 2007). Groundwater irrigation is being prioritized recently as the best alternatives for reliable and sustainable food security, income generation, livelihood improvement in the country (Awulachew et al., 2009). Since last two decades the government of Ethiopia has given great attention for the development of groundwater resources and it is a valuable resource in irrigation activity, agricultural food production and the development of nations and countries (Yazew et al., 2009; Tadesse et al., 2015).

Based on ADSWE, (2013) report, the Amhara region has abundant land and water resources which can be used for irrigation development, and also one of the major crop-growing regions in the country and contributes a lot for the domestic as well as foreign markets. The region is highly irrigation work on development or adaptation of modern irrigation infrastructure, especially in Kobo Girana Valley Development Program Office and the farmers permit to grow high value crops and that improve their diet (ADSWE, 2013). Kobo wereda is considered as one of the most important agricultural production areas in the region, and has special climate conditions allowing cereals, fruit and vegetable production in the dry season (ADSWE, 2013; Kidane, 2004). For suitable and sustainable irrigation system management, evaluation of water productivity is very essential in the field. Before the determination of water productivity, understand the concept of water productivity was needed (Ali & Talukder, 2008). According to Ali & Talukder, (2008), the term 'water productivity' has no unique definition and the value considered for the numerator might depend on the available data. Moreover, yihun (2015), the economic water productivity is defined as the net incomes value of the yield per cubic meter of water consumption, including 'green' water or effective rainfall for rain-fed areas and both 'green' water and 'blue' water or diverted water from water systems for irrigated areas; and crop water productivity also defined as the yield of the crops per cubic meter of water used for that purpose. Thus values were vary from region to region, basin to basin, scheme to scheme and from field to field (Yihun, 2015).

1.2 Statement of the problem

In Ethiopia drought is the main climatic related risk (Wondimkun & Tefera, 1995). Even in good years, Ethiopia cannot meet its large food deficit through rain fed agriculture production (Yihun, 2015). So, effective management of water under irrigated agriculture is crucial to ensure food security (Omotayo et al., 2015; Igbadun et al., 2018). Variable climate, absence of seasonal crop rotation, cropping pattern, poor irrigation water management, lack of skilled manpower, and awareness less of modern irrigation practice and irrigation technology are the causes for reduction of agricultural product in many irrigation schemes in Ethioipia (Yazew et al. 2009). Moreover, this research is to arise some existing problems in the Hormat-Golina irrigation scheme that are not solved yet. Even though both drip and furrow irrigation systems are practicing at the scheme, the problem under consideration is that the current cropping pattern is not economically efficient in the utilization of the available water resource and lack of information on the balance of crop water demand and field applied irrigation water, and also no water productivity evaluation of drip and furrow irrigation system at the scheme. So, this study is conducted for water productivity evaluation of drip and furrow irrigation system in the case of Hormat-Golina groundwater based irrigation scheme.

1.3 Research questions

This work attempts to address the following research questions:

- Does the amount of applied irrigation water balance with crop water demand in the Hormat-Golina irrigation scheme?
- What is the crop water productivity of drip and furrow irrigation systems at the scheme?
- What is the economic water productivity of drip and furrow irrigation systems at the scheme?

1.4 Objective of the study

1.4.1 Main objective

The main objective of this study is to evaluate water productivity of drip and furrow irrigation systems at Hormat-Golina irrigation scheme.

1.4.2 Specific objectives

The following points are the specific objectives of this study:

- To compute applied irrigation water and crop water demand in Hormat-Golina irrigation scheme.
- To evaluate crop water productivity of drip and furrow irrigation systems in the scheme.
- To evaluate economic water productivity of drip and furrow irrigation systems in the scheme.

1.5 Scope and limitations of the study

- The research was conducted on two consecutive irrigation seasons from December,20/2017 to end of May, 2018, and from mid of December, 2018 to May, 25/2019.

- Even though, there were different types of cultivated crops in the study area, this research was focused on only chickpea, garlic, onion and watermelon for computation of applied irrigation water and crop water demand and water productivity evaluation.

- Due the financial constraints it was not possible to collect the whole data of the irrigation schemes in Kobo-Girana groundwater based irrigation project. For this reason the study was limited on Hormat-Golina irrigation scheme.

- Despite there are many methods to evaluate water productivity of drip and furrow irrigation systems, for this study only yield estimation for crop water productivity and equation of gross value of crop product and determination of total crop production cost for economic water productivity was used.

1.6 Significance of the study

The central theme of this research was to provide a well-studied on water productivity evaluation of drip and furrow irrigation systems and their comparisons for dry season irrigation. Irrigation policy maker will benefit by using the result of this study as input and consequently, the population at large will benefit from the policy, which is the ultimate end. In addition, the paper can be used as an input for other researchers to look at the research gaps like the quality aspects. Despite its being a small scale study, more specifically, the finding of this study may helps:

- To provide information on the amount of applied irrigation water used and crop water demand, and thus, enabling the farmers to irrigate their crops as per the crop water requirement to reduce misuse of water at field.
- To assist in developing and managing sustainable water supply for the communities.
- To re-arrange the agricultural system practice and implement it by the farmers at the field.

CHAPTER 2 LITRATURE REVIEW

2.1. Basic concepts of water productivity

The basic concepts of water productivity is 'more crop per drop' or producing more food from the same water resources, or producing the same amount of food from less water resources (Simon, Francis, & Hugh, 2004). 'Water productivity' may carry different meanings to different people, and may differ between within groups of water users (Rodrigues et al., 2013; Singh, 2002; Kijne, Barker, & Molden, 2004). It can be defined with respect to different water using production sectors; such as crop production, fishery, domestic and industrial use. Based on Igbadun et al., (2006) and Namrata & Chandra, (2019) study, water productivity is the amount of output produced per unit of water involved in the production.

The definition of water Productivity is scale dependent (Snatosh, 2016; Kumar et al., 2003). To hydrologist, Water Productivity means the ratio of the volume of water used productively, i.e., transpired and in some cases also evaporated, from the area under study, to the volume of water potentially available for that purpose (Kumar et al., 2003). In fisheries, it might mean the ratio of fish produced to the volume of water used. To an economist, it might mean the monetary value of output divided by that of the necessary water input. To an irrigation engineer, it might mean the ratio of the amount or the value of crops produced in a farm or catchment to the supplied water. In agriculture, it is interested to produce more with less water because water is a limiting factor in many parts of the world.

Singh, (2002), in agricultural production systems profound water productivity analysis require quantification of different hydrological variables such as transpiration, evapotranspiration and percolation, and biophysical variables such as dry matter and grain (or seed) production in relation to different irrigation and agricultural management practices. In crop production system, water productivity (WP) is used to define the relationship between crop produced and the amount of water involved in crop production, expressed as crop production per unit volume of water used (Ali & Talukder, 2008). Crop production may be expressed in terms of total dry-matter yield or seed (or grain) yield (kg) or, when dealing with different crops, yield may be transformed into monetary units (i.e. US $) and more options are available to express water productivity resulted from different options (Ali & Talukder, 2008).

$$\mathrm{WP1} = \frac{\text{Grain or seed yield}}{\text{water applied to the field}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{option. 1.}$$

$$\mathrm{WP2} = \frac{\text{Total dry matter yield}}{\text{water applied to the field}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{option. 2.}$$

$$\mathrm{WP3} = \frac{\text{Total monetary value}}{\text{water applied to the field}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{option. 3.}$$

If the effectiveness of water use in a single crop is described, option.1 and option.2 are a good options. If regions are compared, or the effectiveness of water use in multiple cultures or under limiting water condition (without limiting land) option.3 is more appropriate.

2.1.1. Crop water productivity

Crop water productivity (CWP) denotes the amount or value of product (i.e., crop) over volume or value of water used (i.e., depleted or diverted) and it suggests that agricultural production can be maintained with 20–40% less water resources provided that new water management practices are adopted (Zwart & Bastiaanssen, 2004). Also it varies with location depending on the factors such as cropping pattern, crop genetic material, climatic conditions, irrigation technology, field water management, infrastructure and labor, fertilizer and machinery inputs as well as economic and policy incentives to produce (Zwart & Bastiaanssen, 2004).

In general crop water productivity is a function of water applied, which depends on space scale and generally increases from small plots to large domains at basin scale because applied water is recycled and reused (Molden et al., 2007).

2.1.2. Economic water productivity

Water productivity in economic term is the net income per amount of water used or $/m^3 (Kijne et al., 2004). Based on Yihun (2015) study, economic water productivity (EWP) relates the economic benefits obtained per unit of water used and also has been applied to relate water use in agriculture to nutrition, jobs, welfare and the environment. These economic values are useful to compare different crops, methods of irrigation and to evaluate the net benefits derived from a particular crop. The economic definition of water productivity also provides a better basis for policy makers to decide on agricultural and non-agricultural utilization of water such as for industries, bird habitats and tourism (Kijne et al., 2004).

According to (Kijne et al., 2004), the economic water productivity (EWP) of vegetables and crops cultivate with a methods of drip and furrow irrigation can be checked that which one is significant, and efficient water used, and it is obvious that by drip irrigation technique and frequently water can be applied, but the EWP value depends on crop or vegetable type and its market price of those crops. Water loss through runoff and evapotranspiration was much lower from soil surface under drip irrigation (Kijne et al (2004). It increases the water use efficiency as compared to surface irrigation (furrow). The possible expression of economic water productivity at different level as shown in the table below.

Table 2. 1 Expression of economic water productivity based Kijne et al (2004).

Scale	Economic water productivity expression
At field level	The ratio of gross value of product, or net value of product, or net benefit of irrigated production compared with rain fed production to water used.
At basin level	Any of the above valuations including those derived from raising livestock, fish or agro-forestry to water used.

In general, the values of economic water productivity specifically at the field or scheme scale is the monetary value of all direct and indirect economic benefits minus the associated costs, for all uses of water.

2.2. Indicators of water productivity

Water productivity is a robust measure that can be applied at different scales to suit the needs of different stakeholders and it is achieved by defining the inputs of water and outputs in units appropriate to the users' indicator needs (Prochnow et al., 2012; Simon et al., 2006).

The numerator (output derived from water use) can be defined in the following ways: the physical output, which can be total biomass or harvestable product; and the economic output (the cash value of output) either gross benefit or net benefit and the water input can be specified as volume (m^3) or as the value of water expressed as the highest opportunity cost in alternative uses of the water (Simon et al., 2006). As said by Peter & Geoff, (2001), the different indicators could be used to evaluate water productivity for a cropping system at different scales:

- **Crop scale**: it is interest to crop physiologists to assess how efficient a particular crop or cultivar of a crop is converting water into biomass. At this scale the output can be quantified either as total biomass or crop yield (harvestable produce). The water input that is relevant for this assessment is the water used in transpiration, which here we call process depleted water (Prochnow et al., 2012; Simon et al., 2006 and Peter & Geoff, 2001).
- **Field scale beneficial use**: it is interest to the farmer, agronomist and water specialist to assess how efficiently a particular cropping system converts water into beneficial output. At this scale the output can be quantified as total biomass or crop yield and the water inputs are the amount of water that was used in transpiration (Prochnow et al., 2012; Simon et al., 2006 and Peter & Geoff, 2001).
- **Field scale non-beneficial use**: it is interest to the farmer, agronomist and water specialist to assess the opportunities of saving water lost through non-beneficial use. At this scale the output can be quantified as total biomass, crop yield (kg), crop value ($) while the water input is the amount of water depleted from the system through, evaporation, flows to sinks that are not recoverable, pollution to levels that render it unfit for use and incorporation into the product (Prochnow et al., 2012; Simon et al., 2006 and Peter & Geoff, (2001).
- **Irrigation system scale**: it is interest to the irrigation system manager in assessing how productively the water available to the irrigation system is being used. At this scale the manager takes into consideration both the amount of water depleted and that which is recaptured for re-use downstream and the output can be quantified in physical and economic terms and the water can be accounted for in either volume or in value terms (Peter & Geoff, (2001); Prochnow et al., 2012 and Simon et al., 2006).
- **Sub-basin scale**: it is interest to planners and river-basin managers in assessing options for increasing water productivity at this scale. The output can be quantified as either biomass or harvestable produce in kg or their cash value in $. The water input becomes the net inflow, which is difficult to value in monetary terms and therefore generally assessed as volume (Peter & Geoff, 2001).
- **Basin scale**: it is interest to river-basin managers and planners in assessing the productivity of the renewable water that enters the basin, mainly as rainfall. The output includes all the

water benefits derived by water as it moves across the basin landscape (Peter & Geoff, 2001).

On the other hands, agricultural output also indicates establish relationship between agriculture outputs with unit irrigated land or unit irrigation water(Brown et al., 2013). Values of output per unit command area higher than output per unit irrigated area indicate that the irrigation intensity in the system is greater than one and lower value of output per unit irrigation supply if compared to the value of output per unit water consumed indicate that part of water applied to the field is not productive. The indicators are as per the equations below (Brown et al., 2013; Molden et al., 1998).

$$\text{Output per cropped Area } \left(\frac{\text{Birr}}{\text{ha}}\right) = \frac{\text{Production}}{\text{Irrigated cropped area}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots \text{eq. 2.1.}$$

$$\text{Output per unit command Area } \left(\frac{\text{Birr}}{\text{ha}}\right) = \frac{\text{Production}}{\text{Command area}} \ldots\ldots\ldots\ldots\ldots\ldots..\ldots.\ldots\ldots \text{eq. 2.2.}$$

$$\text{Output per unit irrigation supply } \left(\frac{\text{Birr}}{\text{m3}}\right) = \frac{\text{Production}}{\text{diverted irrig. supply}} \ldots\ldots\ldots\ldots..\ldots\ldots \text{eq. 2.3.}$$

$$\text{Output per unit water consumed } \left(\frac{\text{Birr}}{\text{m3}}\right) = \frac{\text{Production}}{\text{volume of water by ETc}} \ldots\ldots\ldots\ldots\ldots\ldots \text{eq. 2.4.}$$

Where: Production is the output of the area under irrigation in terms of gross or net value of production measured at local or world prices; Command area is the designed or nominal area to be irrigated; Diverted irrigation supply is the volume of water diverted to the command area; Volume of water consumed by ETc is the actual evapotranspiration of crops, and irrigated cropped area is the sum of the areas under crops during the period of analysis.

2.3. Major factors that affect water productivity

The major factors which affect or influence crop yield (numerator of the productivity equation), and water applied or need to be applied (denominator of the same equation), as a general influence on the value of water productivity (Ali & Talukder (2008). These factors are described below:

2.3.1. Crop cultivar type and grain filling

Based on the study of Ali & Talukder (2008), plants lose much quantity of water when they open their stomata for CO_2 uptake in an unsaturated air. Vapor diffuses out from the sub-stomata cavity into the air while CO_2 goes in the opposite way and mathematical modeling of these two opposing diffusion processes has shown that water productivity is largely a function of the CO_2 and vapor concentration gradients between the inside and outside of the leaf (Jones, 2004). Therefore, the crop type and stomata behavior will determine the water productivity of a particular species or cultivar (Ali & Talukder, 2008).

According to Jha & Naik, (2017), the grain filling is the final stage of growth in cereals where fertilized ovaries develop into caryopses. At this stage, about 40–50 % of total biomass is deposited into the grains and delayed whole plant senescence, leading to poorly filled grains and unused carbohydrate in straws, is a new problem increasingly recognized in crop production. So, slow grain filling may often be associated with delayed whole plant senescence.

Water deficit or drought stress during cereal grain development reduces the duration of grain filling, and If the rate of grain filling is not adjusted upward, final grain weight is reduced (Jha & Naik, 2017). Based on the readily utilization of grain filling and their availability may become a critical factor in sustaining grain filling and grain yield under drought stress.

2.3.2. Amount of applied irrigation water

In agriculture, many ways of conserving water have been investigated and techniques such as partial irrigation, deficit irrigation or drip irrigation have shown that water productivity can be enhanced (Ali & Talukder, 2008). When water supply is sufficient, excessive vegetative growth may lead to less root activity, unhealthy canopy structure and a lower harvest index or harvest ratio (ratio of seed yield to straw yield). That means high biomass production supported by high water supply will not lead to high water productivity (Ali & Talukder, 2008).

Crops will transpire water at the maximum rate when the soil water is adequate. Mateos et al., (1991) reported, that knowing seasonal crop water requirements is crucial for planning crop planting mixture especially during drought years. As said by Ali & Talukder, (2008), the growth and yield of any crop is related to the amount of water used and the variable amount of water contained in a soil and its energy state are important factors affecting growth of plants.

Generally, the determination of crop water requirements will be largely dependent on the type of the climatic data available and the accuracy of the method chosen to estimate the evapotranspiration. And also the improvement of water productivity of grain yield by limiting water supply to increase harvest index or harvest ratio. Recent research has shown that in some irrigated situations, grain yield can be improved while reducing the amount of water applied to the crop (Ali & Hassan, 2007). Mainly improved harvest index which has been shown as a key component to improve Water Productivity (Tagar, 2012).

2.3.3. Soil factor

Based on Tadesse & Belay, (2004), evaporative loss of water from the soil surface plays a significant role on plant growth during germination and seedling establishment, and also during other growth periods. Soil texture and organic matter content determine the water storage and release properties, and rapid drying of soil does not provide opportunity for osmotic regulation and adjustment, and thus affects yield and water productivity (Tadesse & Belay, 2004).

Within the concept of improved water productivity (WP), water transpired by crops should be increased relative to evaporation from the soil surface. Soil and stubble management may influence the water balance of the soil by affecting infiltration and water storage in the soil, and evaporation losses from the soil surface (Amare et al., 2016). These combined effects can also affect the amount of water available to a crop.

2.3.4. Agronomic and economic factor

A said by (Billib & Bardowicks, 2009), the agronomic factors which can affect water productivity (WP) are timeliness of sowing, evenness of establishment, use of herbicides, and the role of previous crop. Water productivity depends not only on how the crop is managed during its life, but also on how it is fitted into the management of a farm, both in space and time (Ali & Talukder, 2008). Irrigated agriculture notably increases crop productivity but may negatively impact river water quality because of the salt and agrochemical loadings in irrigation return flows (Billib & Bardowicks, 2009).

By better tuning both vegetative and floriferous development of a crop, optimal timing of harvest can be ensured; and thus, tactical advantage of variable weather can be taken by sowing the next crop at the right time, and facilitating good establishment (Srivastava, Panda, & Chakra borty, 2018). Any husbandry technique that facilitates rapid development and enables the crop to cover soil surface, shade out weeds, and reduce wind speed may, in most circumstances, increase crop competitiveness and water productivity (Srivastava, Panda, & Chakra borty, 2018). Practices that particularly contribute to these factors are early sowing, selection of varieties with early growth (under cool condition), adequate fertilization, and adequate plant population and close spacing (Srivastava et al., 2018).

The economic factors may influence the optimum level of water productivity (WP). Sometimes large additional costs are involved in increasing WP, for example, the investment in sprinkler, drip or hose pipe irrigation systems (Luhach et al., 2004). These systems include the fixed and operational costs of changing the irrigation system. The returns may include water saved plus the increased crop production (if any) and lining of irrigation channel also involves a considerable amount of fixed cost, which may not be bearable by the farmers, especially in third world countries (Luhach et al., 2004). In addition, adaptability of any cropping pattern depends on its profitability and the farmers respond to market rules searching for the highest return per unit of land or water, depending on the relative scarcity of both land and water resources.

2.4. Previous studies around the world

According to Sengupta (2017) and Chourasial (2016) in India, an experiment was conducted on evaluation of drip and furrow irrigation methods in participatory mode at the farmer’s field with an aim to develop understanding about potential benefits of drip irrigation system among the tribal farming community of the eastern plateau and hill region of India. This study revealed that, for the selected vegetables, adoption of drip irrigation improved the yields in the range of 38.2 to 65.8 % over furrow irrigation with highest yield increase in case of chickpea (65.8%) and tomato (58.7%). Based on Darouich, (2014), reported that yields about 20% higher with drip irrigation than for furrow as well as higher water productivity of chickpea was 3.87 and 1.87 kg/m^3 for drip and furrow, respectively.

As said by El-ganzori, (2012), in Egypt with water scarcity, the problem under consideration is that cropping pattern is not economically efficient in the utilization of the available water resource. The economic value of water depends on the user as well as on the use to which it is allocated and the value of water should reflect the economic, environmental, cultural and religious values of the society (El-ganzori, 2012). The crops like chickpea, garlic, onion and watermelon, reached the values generated from water use in the years 2008 and 2009 with values 0.05, 0.39, 0.23 and 0.20 $/m^3 respectively.

Based on Hailu, (2017) study, that conducted in Tunis, the average and marginal water productivity of two management practices (i.e. irrigation and mulching practice) for the crop of wheat resulted as 10.048 ton per unit hectare of land was needed 9513 m^3, 10355 m^3 , 10422 m^3 of water with drip, furrow and sprinkler respectively. When organic mulching was applied the values of water used was reduced to 9668 m^3, 9733 m^3 furrow and sprinkler respectively; but drip was not changed. Then crop water productivity was expressed as 1.056 kg/m^3, 0.970 kg/m^3, 0.964 kg/m^3 without mulching and 1.056 kg/m^3, 1.039 kg/m^3 and 1.032 kg/m^3 with organic mulching for drip, furrow and sprinkler respectively.

2.4.1. Previous studies in Ethiopia

According to Descheemaeker & Haileslassie, (2011), in Ethiopia irrigation is mainly implemented in small-scale irrigation schemes, which are often characterized by low water productivity and the study reported on the efficiency and productivity of a typical small-scale irrigation scheme in the highlands of the Blue Nile, Ethiopia. Based on (Descheemaeker & Haileslassie, 2011) water productivities of the cereal crops varied from 0.2 to 1.63 kg/m^3 and a significant volume of water was lost from small-scale irrigation systems mainly because farmers' water application did not match crop needs. Similarly, the study in north Gonder zone, Dembia district area by Yosef, 2016 the average crop water productivity of onion was 1.74 kg/m^3.

Gebru, Araya, & Habtu, (2018), in northern Ethiopia during the cropping season of 2014/2015 comparative study was undertaken between bar-shaped clay pot and furrow irrigation on tomato, pepper and Swiss chard crops. Results were compared on the basis of yield, water productivity and economic performance. The yields of Swiss chard, tomato and pepper were increased by up to 51, 32 and 30%, respectively, in bar-shaped clay pot irrigation system as compared to the control. Water saving was also considerably increased by 40.6, 41.2 and 41.7% for the respective crops as compared to the control. Similarly, the water productivities of Swiss chard, tomato and pepper were 10.9, 4.2, and 1.8 kg/m^3 respectively (Gebru et al., 2018).

CAHPTER 3 MATERIAL AND METHODOLOGY

3.1. Description of the Study Area

The Hormat-Golina irrigation scheme is one of the scheme in Kobo-Girana groundwater based irrigation project, that located between 11° 56' to 12° 08' N latitude and 39° 23' to 39° 47' E longitudes. Administratively, it is located in the northern Wollo Zone of the Amhara National Regional State, Kobo Wereda, at kebele 05. It lies near to the Dessie-Mekele main road between Woldiya and Alamata town around 565 km distance from north of Addis Ababa see figure (3.1).

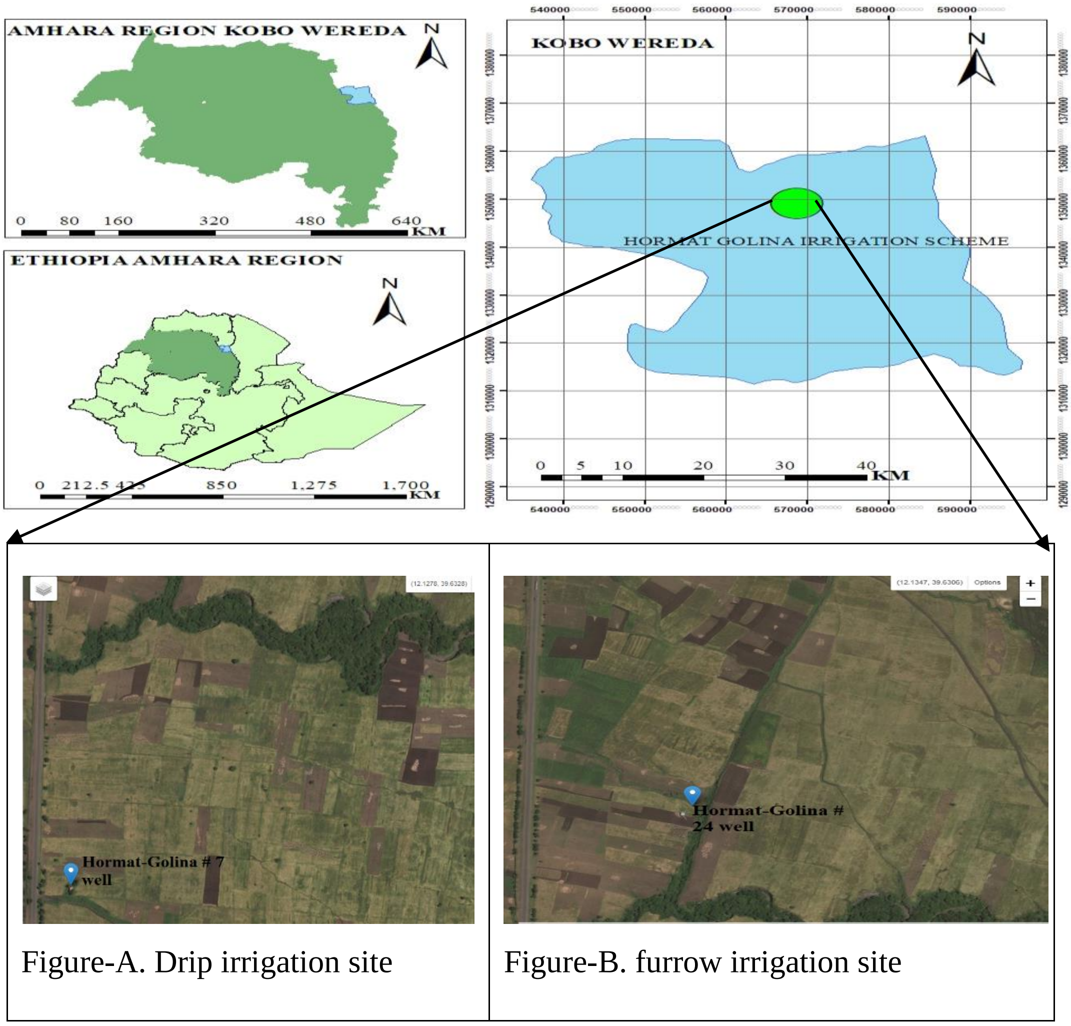

Figure-A. Drip irrigation site

Figure-B. furrow irrigation site

Figure 3. 1 Location of Hormat-Golina irrigation scheme.

It also located in one of the drought prone regions of the country (Natan et al., 2015). Based on ADSWE, (2013) report, the hydrogeology studies and aquifer tests was conducted on the project area, a safe yield for production wells existing in the project had been determined and the average safe yield of the wells ranges from 34 liter/second to 80liter/second. The topography of surrounding area of the site is valley and plain are comprised of several low lying depositional areas distributed in the middle of the area extended from north to south and the mountain rises from 1500m to more than 3000m and the plain is characterized by flat topography not greater than 1500m altitude (Natan et al., 2015).

3.1.1. Climate

The study area is one of the drought prone regions of the country. The summer is short and hot, lasting from June through September, with maximum air temperature ranging from 30.1°C to 35.5°C; winter lasts from December through February, with maximum air temperature ranging from 27.4°C to 28.9°C during the daytime. The principal feature of rainfall in the area is seasonal, poor spatial distribution and variability from year to year. Long-term average annual rainfall at the study area is about 792 and ranges between 338 - 1455 mm (see appendix-c). The higher rainfall amount occurs between July and August with peaks August (see figure 3.2).

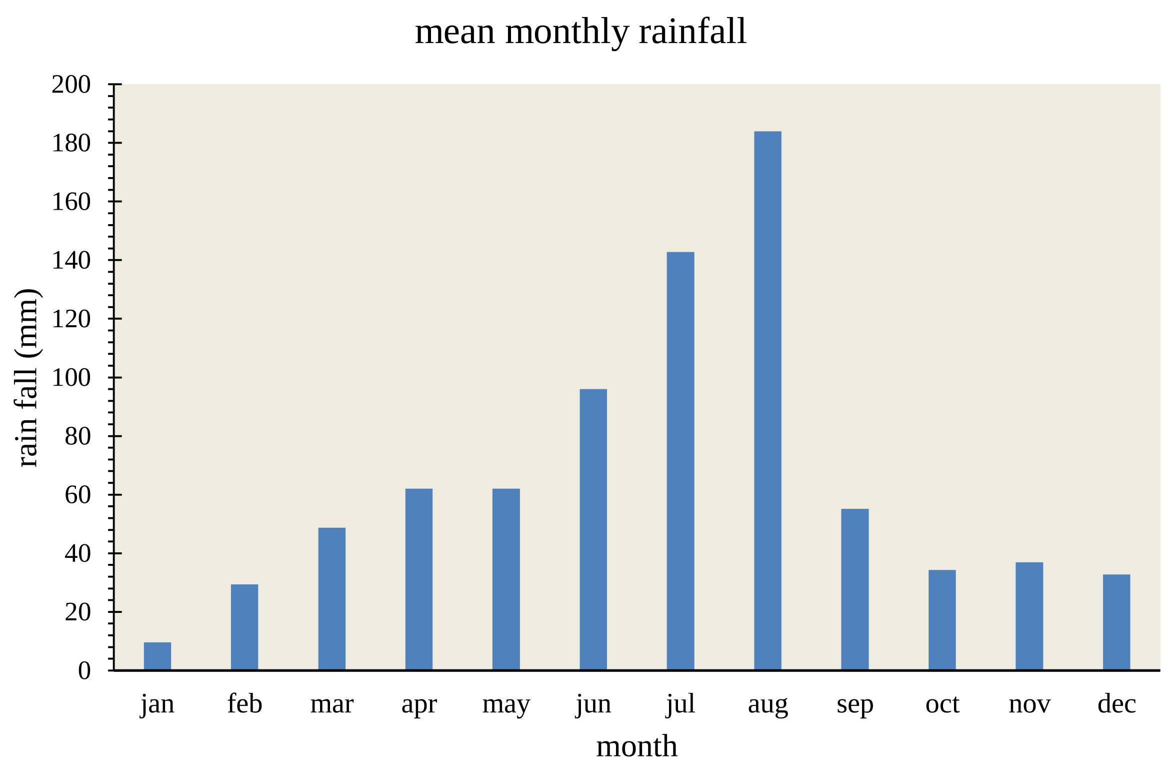

Figure 3. 2 Chart of monthly rain fall from year 2002-2017.

The daily sunshine hour in the study area ranges from 5.5 hr to 10.55 hr and the mean daily wind speed in the study area is ranges from the minimum value of 0.7 m/s to the maximum value of 2.1 m/s and which has mean monthly wind speed of 1.4 m/s. The minimum values recorded on December through January and the maximum value ranges from the month of May to the end of June. The daily relative humidity of this study area ranges from the minimum to the maximum value in percent is 10% and 85.8% respectively and the average value is 56.4% and this value is measured from the year 2002 to 2017.

3.1.2. Soil type

According to ADSWE, (2013) report, the soil of the study area is developed on recent alluvial-colluvium sediments derived from the adjacent mountain ranges provide the basic land resources for improvement of agricultural productivity. In general, two different major soil types have been identified: Vertisols (black heavy clay soils) and Fluvisols (medium textured soils with characteristic stratification). This soil also rich in organic and inorganic material for the production of crops. Specifically for Hormat-Golina irrigation scheme the soil type is black heavy clay soils (ADSWE, 2013).

3.1.3. Land use and vegetation covers

The main crops grown in the area before the Kobo-Girana valley development program were Teff, Sorghum, Maize, and other cereals from July through November (ADSWE, 2013). Due to the low rainfall amount and high rate of evaporation and transpiration during the Belg rainy, there was no crop grown during this period i.e. farmers were producing once a year. But now, with the use of ground water resource since 2007, farmers are producing twice a year (ADSWE, 2013). In addition to the above cereals, cultivation of the most commercial crops in the country such as tomato, onion, garlic, chickpea, watermelon, cabbage and pepper was possible during the dry season. For this research four commercial crops are selected, these are chickpea, garlic, onion and watermelon. The distribution system of irrigation water in the study area was through direct pumping of water from the wells. These wells have its own command area independently, that are 48 and50 hectare of land with the methods of drip and furrow irrigation respectively.

3.2. Methods data collection

3.2.1. Primary data collection

The observation of the study area was conduct from the date of October, 24/2018 to November 9/2018. The season was meher and harvesting time for some crops like; teff, maize, masho, and pepper. The period from December, 17/2018 to January, 07/2019 was the second field observation. Even though, the velocity-area method and depth of flow in the cross-section are used to measure the discharge rate of the available water resource (W.M.O, 1994). In order to measure the discharge rate, a deep water meter of appropriate capacity can be used (Kruseman, 2000; Stallman, 1976). But for this study the discharge was measured during wells pump recovery test; so, no need of any methods to measure it. In season of Dec, 2018 to May, 2019 the discharge capacity of the wells were measured as 42.47 l/sec or 152.89 m^3/hr and 44.25 l/sec or 158 m^3/hr for drip and furrow irrigation system respectively.

3.2.2. Secondary data collection

For determination of crop and economic water productivity of drip and furrow irrigation system and to estimate the crop water requirement in CROPWAT 8.0 various quantitative and qualitative data were collected from secondary data sources. Climatological data from 2002 to 2017 was collected from Ethiopian meteorological agency for kobo meteorological station. In addition, climatic data, discharge data were collected for the 2017-2018 to compute the amount of applied irrigation water. Using questionnaires the average crop per hectare of land and time of irrigation per unit hectare of irrigated land.

3.2.2.1. Climatological data

Precipitation

Before using the rainfall records of the station, it is necessary to check the data continuity. The continuity of the record may be broken with missing data due to absence of recorder, failure of the instrument and wind effect. Therefore, it is often necessary to estimate missing records by using the data of neighboring station (Chow, David R, & Mays, 1971; Helsel & Hirsch, 2002). The missing rainfall data were filled using the arithmetic mean method.

As it is depicted in the bar graph above, the average maximum rainfall was recorded in the month of August (184 mm) and the average minimum value obtained in the month of January

(9.64 mm). The majority of rainfall is concentrated during Ethiopian wet season (Kiremt). The climatic data from 2002-2017 is described in table below.

Table 3. 1 The long-term climate data of Kobo station.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmin (°c)	13.2	15.6	15.8	16.4	18.1	19.9	19.1	17.6	16.1	14.9	14.2	15.3
Tmax (°c)	28.6	29.8	30.2	30.5	33.7	35.5	32.7	31.1	30.1	30.4	29.0	27.4
RH (%)	53.8	39.8	48.3	67.4	71.8	69.8	68.5	66.0	71.8	47.0	73.7	57.9
Wind (m/s)	1.8	2.2	2.0	2.1	2.1	2.2	2.0	1.7	1.1	1.3	1.4	1.7
SSH (hr/day)	8.9	9.3	7.9	8.6	9.5	7.6	6.3	6.9	9.8	9.5	9.0	9.0
Rainfall (mm)	9.64	29.4	48.7	62.1	62	96.0	142.8	184	55.2	34.3	36.9	32.74

Temperature: Temperatures data in the study area were taken from Ethiopian meteorological agency for kobo station and analyzed in Microsoft Excel. The mean minimum monthly temperature was recorded in the month of January, which was 13.2 °c and the mean maximum temperature got in March that was 35.5°c (see table 3.1).

Relative humidity: Available data of relative humidity were taken from Ethiopian meteorological agency for kobo station and were analyzed. The mean monthly maximum and minimum values of relative humidity exist in September (73.7 %), and February (39.8 %) respectively and this is attributed to the rainy and dry season of Ethiopia respectively (see table 3.1).

Wind speed: the data of wind speed taken from Ethiopian meteorological agency for kobo station. Wind speed in the study area and the nearby station were measured at 2 m above the surface of the ground. The analysis indicated the minimum wind speed appeared in September 1.1 m/s and the maximum wind speed occurred in February and Jun 2.2 m/s as monthly basis (see table 3.1).

Sunshine hour: Sunshine hour plays a significant role in affecting evapotranspiration. Longer sunshine hour increases the evaporation rate and amount that in turn is depend on the intensity of solar radiation. The minimum hour for the sunshine was 6.5 hour per day that was recorded in July. In addition, the maximum sunshine hour was recorded in October and May 9.5 hours/ day (see table 3.1).

3.2.2.2. Soil, crop and water use data collected

Soil types, common crops that are grown in the area and infiltration capacity of the soil were used for the estimation of, ETC, crop water demand and were taken from KGVDP report. Major crop type, irrigation method, and, date of planting other additional data were gathered from the farmers using pretest-structured questioners. Forty-two farmers were used for questioners. Soil type and infiltration capacity were taken from KGVDP report.

Crop coefficient, initial soil moisture depletion, number of growing days and maximum root depth of chickpea, garlic, onion, and green watermelon were collected from FAO irrigation and drainage paper 56. Water use data for irrigation, were collected using water by questionnaires for 42 farmers. The data was collected from 2017 to 2019 covering two years period. The data includes the source of water for irrigation used, and crop type planted during dry season like chickpea, garlic, onion and watermelon. Same of the cultivated crops in the study area are shown in figure below.

Figure 3. 3 *Chickpea with drip irrigation system (photo, 25/01/2019).*

Figure 3. 4 *Onion with drip irrigation system (photo, 25/01/2019).*

3.3. Methods of the analysis

3.3.1. Computations of applied irrigation water and crop water demand at Hormat-Golina irrigation scheme

3.3.1.1. Determination of applied irrigation water in the scheme

According to Martin (2011), the irrigator's equation can be used to calculate the amount of applied irrigation water in (volume per hectare) or depth of water applied to the field. From the collected primary and secondary data the amount of applied irrigation water to the field of Hormat-Golina number-7 and Hormat-Golina number-24 groundwater based irrigation schemes were computed.

The amount of water used for the development of different crops on the schemes was various; Due to different crop characteristics, irrigation method, irrigation technology, management practice, and climatic condition. The applied irrigation water or irrigation water used to the field practice with drip and furrow irrigation methods is calculated by the following irrigator's equation below (Martin, 2011).

$$(Q * t) = (d * A) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ eq.\ 3.1.$$

Where: Q is the flow rate, (m^3/hr.); t is the set time or total time of irrigation (hr.); d is the depth of irrigation water per unit area (m^3/ha); and A is the area irrigated (ha). The calculation of volume of applied irrigation water was used to estimation crop water productivity and economic water productivity of drip and furrow irrigation system in the scheme.

3.3.1.2. Estimation of crop water demand using CROPWAT 8.0 model

Crop water requirement

Crop water requirement is defined as the depth of water needed to meet the water loss through evapo-transpiration (ETcrop) of a disease free crop growing in a large field under non-restricting soil conditions, including soil water and fertility, and achieving full production in a given growing environment (Endalamaw, 2009; Abebe, 2014; worku, 2013).

The irrigation water requirement includes additional loses due to application efficiency and non-uniformity of water application. The calculations of the crop water requirements (CWR), the crop coefficient approach is used (Allen et al.,, 1998).

It was assumed that for each month, if the total quantity of water available, given by the sum of monthly rainfall and water stored in the root zone was sufficient to satisfy the monthly crop water need, no irrigation is needed. Otherwise, if the rainfall is insufficient and soil water storage is depleted, the difference is the deficit that should be supplied by irrigation.

$$IWR = \sum_{i=1}^{n}(ET_o * K_c - P_{eff}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq. 3.2.$$

Where: IWR= irrigation water requirement (mm), ET_o= reference evapotranspiration (mm/day), K_c crop coefficient, P_{eff}= effective precipitation (mm).

To estimate the irrigation water requirement of major crops in the study area CROPWAT 8.0 was used. CROPWAT 8.0 is based on the versions CROPWAT 5.7 of 1992 and CROPWAT 7.0 of 1999. The model takes account the reference evapotranspiration using Penman-Monteith method and precipitation for calculation of irrigation water requirement (Allen et al., 1998). Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in no. 24 crop water requirements (Doorenbos et al., 1992), and FAO irrigation and drainage papers no. 56 crop evapotranspiration (Allen et al., 1998). The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily decade or monthly. Soil-water balance using various options for water supply and irrigation management conditions (Allen et al., 1998). For the estimation of crop water requirements (CWR), the climatological data as explained in the above section 3.2.2.1 covering

15 years (2002-2017) of monthly maximum and minimum temperature, relative humidity, sunshine hour, and wind speed data that was used. Crop water requirement and irrigation requirements were calculated for the main vegetables cultivated during the dry season in the study area. These were chickpea, garlic, onion, and watermelon.

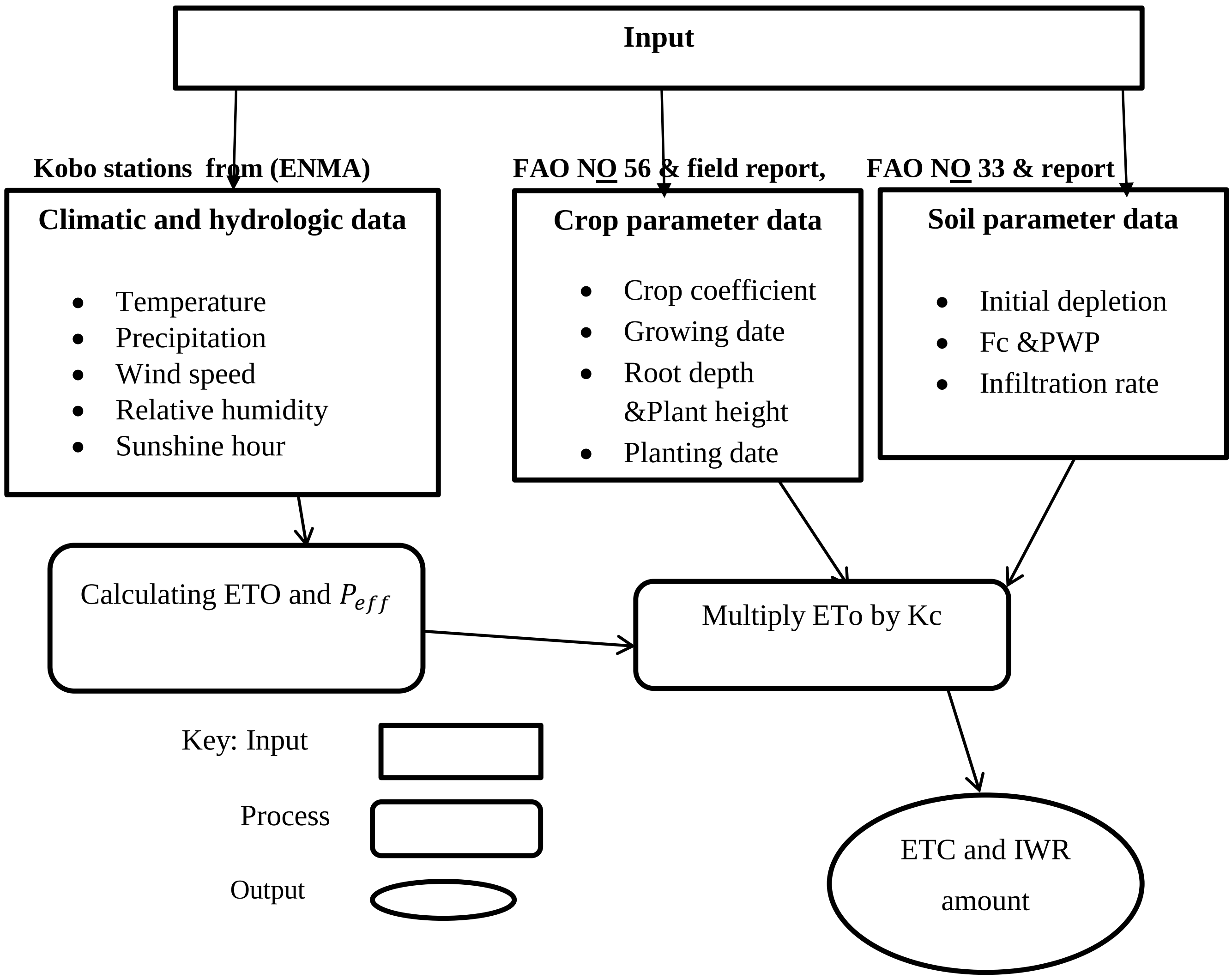

Figure 3. 5 Flow chart for ETC calculation using the CROPWAT model.

Effective precipitation

The effective rainfall (p_{eff}) for field crops is the portion of rainfall which is useful directly and/or indirectly for crop production at the site where it falls which depend on soil slope, soil texture and structure, plant cover or crop residue, storm intensity and duration, etc. Effective precipitation in this study was calculated according to the method of (USDA) United State department of agricultural soil conservation service. The reason to select this method is simple to use in monthly, decade or daily basis and world wide method.

$$\mathrm{P_{eff}} = \frac{\mathrm{P}*(125-0.2*3*\mathrm{P})}{125}, \text{if } \mathrm{P} \leq \frac{250}{3} \text{mm} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. \ldots \ldots \ldots \ldots \text{eq. } 3.3.\text{a}$$

$$\mathrm{P_{eff}} = \frac{125}{3} + 0.1 * \mathrm{P}, \text{if } \mathrm{P} > \frac{250}{3\text{mm}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \text{eq. } 3.3.\text{b}$$

Where, P_{eff} is the average monthly effective rain (mm); p monthly mean precipitation.

Calculating Reference Evapotranspiration (ET0*)*

Reference evapotranspiration is the evapotranspiration from a hypothetical reference crop with a height of 0.12 m, a surface resistance of 70 s/m and an albedo of 0.23, closely resembling an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water (Allen et al. 1998). The Penman-Monteith method is the most extensively used methodology for assessing ET from terrestrial surfaces and is preferred when the requisite data are available. FAO, in the 56th crop and irrigation paper, developed a modified form of this equation that can be modified for use with most vegetation (Allen et al., 1998). The FAO Penman-Monteith method to estimate ETo was derived.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.43U_2)} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . eq. 3.4.$$

Where: ETo: reference evapotranspiration [mm day-1], R_n: Net radiation at the crop surface [MJ m-2 day-1], G: soil heat flux density [MJ m-2 day-1], T: mean daily air temperature at 2 m height [°C],u_2: wind speed at 2 m height [m s-1], e_s: Saturation vapor pressure [kPa], ea: Actual vapor pressure [kPa], $e_s - e_a$: Saturation vapour pressure deficit [kPa], Δ: Slope vapor pressure curve [kPa °C-1] γ : psychrometric constant [kPa °C-1].

Cropping Pattern: A survey was carried out in the study area to assess the crops grown under irrigation. The present cropping pattern data was assessed through field observations, interviews with farmers.

***Soil type*:** total available soil moisture, maximum rooting depth, initial soil moisture depletion (%) of total available moisture); the above data of soil collected from the soil survey and FAO irrigation and drainage paper 33.

Table 3. 2 Crop calendar in the study area

Crops	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Winter Crop:												
Chickpea	→	→	→	→								
Garlic	→	→	→	→	→	→						
Onion	→	→	→	→	→	→						
Watermelon	→	→	→	→	→							
Summer Crop:												
Teff								→	→	→	→	→
Maize						→	→	→	→	→	→	
Sorghum						→	→	→	→	→	→	→

The root depth of each crop and crop variety, crop coefficient (Kc), field irrigation methods, allowable depletion levels, critical depletion fraction (p) and length of individuals crop growth stages cropping module requires crop data over the different development stages: initial, development, mid and late stages were taken from FAO irrigation and drainage paper 56 (Allen et al., 1998) and FAO irrigation and drainage paper 33.

Total available soil moisture, maximum rooting depth, initial soil moisture depletion (%) of total available moisture) were collected through soil survey. Table 3.4 shows the summary of the total growing period, initial soil moisture critical depletion level, Kc value, and root depth for major crops grown in the area.

Initial soil moisture deletion was calculating using FAO formula.

$$\mathrm{P} = \mathrm{P}_{\mathrm{table22}} + 0.04 * (5 - \mathrm{ETC}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq. 3.5.$$

Where $\mathrm{P}_{\mathrm{table22}}$ is the FAO paper 56 table that has a list of initial depletion value for crops that have evapotranspiration value of 5 mm/day.

Table 3. 3 Crop and soil parameters adapted from FAO irrigation and drainage paper No 56.

No	Crop type	Planting date	growing period	Kc and growth stage(day)				Soil water critical depletion p (%)	Range of maximum Root depth (m)
				Initi	Deve	Mid	Late		
1	chickpea	20/12		0.4		1	0.35	50	(0.6 – 1.0)
			100	25	30	30	15		
2	Garlic	20/12		0.7		1	0.7	30	(0.3 – 0.5)
			150	15	25	70	40		
3	Onion	20/12		0.7		1.05	0.75	30	(0.3 – 0.6)
			150	15	25	70	40		
4	watermelon	20/12		0.4		1	0.75	40	(0.8 – 1.5)
			120	25	35	40	20		

3.3.2. Crop water productivity evaluation of drip and furrow irrigation system in the scheme

3.3.2.1. Determination of crop yield at the scheme

According to Bennett & Harms (2013) and Karrou et al (2012), the yield of the crops in the study area was determine based on the collected primary and secondary data of the scheme. For this research the yield of each crops that cultivated on both drip and furrow irrigation methods with respect to two consecutive irrigation seasons was determined. The first irrigation season, from the third week of December, 20/2017 to the end of May, 25/2018 and the second irrigation season also from the second week of December, 15/2018 to May, 20/2019 was covered. The yield of each crops in the Hormat-Golina irrigation scheme, that practiced with both drip and furrow irrigation methods determined through the following simple equation (Osama, Elkholy, & Kansoh, 2017).

$$Yi = \boldsymbol{Yi}.ave * A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq. 3.6.$$

Where: Yi is the yield of crop i in (kg); $Yi._{ave}$ is the average product per unit hectare for crop i in (kg/ha); and A is the irrigated cropped area (ha).

The crop water productivity (CWP) of the scheme was determined as the amount or the yield of the crops over the volume applied irrigation water which was calculated in above section, and the following equation used, for the calculation (Molden et al., 2007; Igbadun et al., 2018; Hellegers, 2006).

$$CWPi = \frac{Yi}{WUi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq. 3.7.$$

Where: CWP i. is crop water productivity per cropping season (kg/m^3); Yi is the yield of crop i (kg) and WU i. is applied irrigation water used for the development of crop i (m^3).

3.3.3. Economic water productivity evaluation of drip and furrow irrigation system in the scheme

According to Mali & Sengupta (2017) and Hassen (2004), the economic water productivity (EWP) was positively related with water productivity. The economic water productivity (EWP) was calculated by multiplying beneficial biomass and the market price minus the total production costs divided by irrigation water used in the schemes (Abdul-Ganiyu et al., 2015; Hellegers et al., 2009).

$$EWP = \frac{[\ GVPi - CTi]}{wui} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq. 3.8.$$

Where: EWP is economic water productivity (\$/m^3); GVPi is the gross value from the yield of crop i (birr or dollar); CTi is the total production cost of crop i (\$) and WUi is irrigation water used for crop i (m^3). The determination of gross value of crop yield and the estimation of total cost requirement of crop production were necessary for the evaluation of economic water productivity in the scheme.

3.3.3.1. Determination of gross value of crop product in the scheme

The gross value of crop product in the study area of Hormat-Golina irrigation scheme were estimated based on the yield and seasonal local market price of each crops. The following equation was used to compute gross value of each crop on the schemes (Luhach et al., 2004).

$$GVPi = Yi * Pi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq. 3.9.$$

Where: GVPi is the gross value of crop product (\$); Yi is the yield of each crop on the scheme (kg) and Pi is the market price of each crop (birr/kg it changes to \$/kg).

3.3.3.2. Determination of total cost of crop production in the scheme

The calculation of the cost with each component of the irrigation system allows us to look at the total cost per hectare of irrigation (Hogan et al., 2011). The total cost is the sum of each individual cost of crop production and it was calculated through the following equation.

$$CTi = [Cs + Cf + Csp + Cl + Ct + Cp] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; eq. 3.10.$$

Where: CTi is the total cost of production for crop i (birr or dollar); Cs is cost of seed (birr or $), Cf is cost of fertilizer (birr or $), Csp is cost of spray (birr or $), Cl is cost of labor (birr or $), Ct is cost of transport (birr or $) and Cp is cost of pump (birr or $) for the production of crop i.

In order to estimate cost of pump, the calculation of gross power requirement of the pump in the schemes was necessary. A pump's energy requirement depends on the flow or pumping rate, the depth from which to pump or total head, pump and motor efficiency losses. The power required by a pump can be calculated by the following formula as (Robinson, 2002).

$$GPR = \frac{Q * HP}{[102 * Ep * dF]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; eq. 3.11.$$

Where: GPR is the gross power required (KW); Q is the flow rate of the wells (l/s); HP is the pumping head (m); Ep is pump efficiency (%) and dF is darting factors of the pump (%).

Total head needs to incorporate the level of sustainable drawdown and friction losses due to pumping(Robinson, 2002).

According to Robinson, (2002), Pump efficiency depends on pump design and will vary with pump speed, output pressure and flow rate. Most large pumps usually operate at efficiencies within the range 74 to 85%. The derating accounts for efficiency losses between the energy required at the pump shaft and the total energy required. Approximate derating factor for electric motors is 80% and for diesel motors is 75%.

CHAPTER 4 RESULT AND DISCUSSIONS

4.1. Computation of applied irrigation water and crop water demand in Hormat-Golina irrigation scheme

The calculation of applied irrigation water use for the scheme was necessary. Although, the crop water demand of the scheme was considered and it compared with the amount of applied irrigation water use, that was deliver to the field.

4.1.1. Determination of applied irrigation water in the scheme

Based on the collected primary and secondary data of this research, the amount of applied irrigation water or water delivered to the field of the scheme was determined with the help of the irrigator's equation (Martin, 2011). As said by wells operators, "the discharge capacity of wells are equally distributed for each blocks". These blocks has its own irrigated area. The following table shown as the wells discharge capacity and its distribution for drip and furrow irrigation methods at two consecutive irrigation seasons.

Table 4. 1 Wells discharge capacity per unit hectare of irrigable land.

Method	Drip irrigation			Furrow irrigation		
Irrigation season	Block Name	Well capacity (m^3/hr/ha)	Irrigated Area (ha)	Block Name	Well capacity (m^3/hr/ha)	Irrigated Area (ha)
Dec,2017 to May,2018	DI-B1	3.2625	12	FI-B1	3.2776	10
	DI-B2	3.2625	12	FI-B2	3.2776	10
	DI-B3	3.2625	12	FI-B3	3.2776	10
	DI-B4	3.2625	12	FI-B4	3.2776	10
				FI-B5	3.2776	10
Total	4		48	5		50
Dec,2018 to May,2019	DI-B1	3.1852	12	FI-B1	3.186	10
	DI-B2	3.1852	12	FI-B2	3.186	10
	DI-B3	3.1852	12	FI-B3	3.186	10
	DI-B4	3.1852	12	FI-B4	3.186	10
				FI-B5	3.186	10
Total	4		48	5		50

Based on methods of irrigation, soil type and crop characteristics the time requirement to irrigate the field was varied. The total irrigation time of the field was cover from sowing or initial stage of crop growth to maturity or late season of crop growth stage, that was collected by semi-structured questionnaires of Hormat-Golina irrigation scheme well operators and local farmers and it is shown as in Appendix-F.

The Hormat-Golina irrigation scheme was practiced with drip irrigation and furrow irrigation system and they called as Hormat-Golina number 7 and Hormat-Golina number 24 respectively. The total volume of applied irrigation water used in the field was calculated for both drip and furrow irrigation methods separately. The calculation was done based on irrigator's equation (3.1) and it calculated by volume as product of flow rate and total irrigation time for detail see appendix-A.

Table 4. 2 ***Volume of applied irrigation water for drip and furrow irrigation system in the scheme.***

Season	Dec, 2017- may, 2018		Dec, 2018- may, 2019	
Methods	Drip irrigation	Furrow irrigation	Drip irrigation	Furrow irrigation
Crops:	(m^3)	(m^3)	(m^3)	(m^3)
Chickpea	60134.4	106600.0	85318.2	97328.0
Garlic	14563.8	No cultivated	30274.2	25122.0
Onion	101476.8	167280.0	No cultivated	196236.0
Watermelon	17382.6	39360.0	33943.8	16748.0

The growth stages and irrigation time per unit hectare of land were needed for the calculation of applied irrigation water used in the field. These data were collected from FAO irrigation and drainage paper 56 and FAO irrigation and Drainage Paper No. 24 provides general lengths for the four distinct growth stages and the total growing period for various types of climates and locations (Allen et al., 1998; Doorenbos et al., 1977), shown in the appendix-B (Table-B-1). The required time to irrigate the unit hectare of land was collected from respondent. So, the total irrigation time was calculated by multiplying crop irrigated area with time to irrigate per unit hectare of land. Based on the calculated volume of irrigation water used by the farmer in the above table, and cultivated area proportion, the applied irrigation water depth can be estimated for the entire irrigation seasons (see table 4.3). The amount of applied water and irrigation depth was depends on irrigated area, time of irrigation, methods of irrigation and well discharge capacity at the scheme.

Table 4. 3 Estimated applied irrigation water depth for each cultivated crops in the scheme

Seasons	Crops:	Methods	Irrigated area ($x10^4$ m^2)	Volume of applied water (m^3)	Applied irrigation depth per season (mm/season)
Dec, 2017 to May,2018	Chickpea	drip	24	60134.4	250.6
		furrow	25	106600.0	426.4
	Garlic	drip	3	14563.8	485.5
		furrow	non	non	non
	Onion	drip	18	101476.8	563.8
		furrow	20	167280.0	836.4
	Watermelon	drip	3	17382.6	579.4
		furrow	5	39360.0	787.2
Dec, 2018 to May,2019	Chickpea	drip	36	85318.2	237.0
		furrow	22	97328.0	442.4
	Garlic	drip	6	30274.2	504.6
		furrow	3	25122.0	837.2
	Onion	drip	non	non	non
		furrow	23	196236.0	853.2
	Watermelon	drip	6	33943.8	565.7
		furrow	2	16748	837.4

4.1.2. Estimation of crop water demand using CROPWAT 8.0

In the study area cropping pattern of the past year was obtained from kobo wereda agricultural office, and local farmers, but the current year was observed from the field for the crops of chickpea, garlic, onion and watermelon. The crop water demand of the crops were calculated on Decades of month basis. Planting dates for these crops were chosen in such a way that the dates coincided with the local cropping calendar. Weather data like maximum and minimum temperature, relative humidity, wind speed and sunshine hours were obtained from Ethiopian national meteorological agency (ENMA) and the respective crop coefficients for chickpea, garlic, onion and watermelon, crops were selected based on FAO irrigation and drainage paper 56 (Allen et al., 1998). The determination of crop water demand was done with the software of CROPWAT 8.0 for window.

Reference evapotranspiration (ETo) calculation

The reference evapotranspiration (ET_o) of the area is computed by CROPWAT 8 window software, which uses the Penman-Monteith formula calculating ETo from temperature (minimum & maximum), wind speed at two meters above the surface, solar radiation and relative humidity data. Table 4.4 shows the calculated reference evapotranspiration in CROPWAT model. As can be seen from table 4.4, the lowest ETo was obtained in November and it was about 4.01 mm/day; while the highest ETo occurs during May and was about 5.5 mm/day. The annual average ETo was obtained as 4.88 mm/day.

Effective Rainfall: Rainfall data from 2002-2017 was taken to calculate effective rainfall. In this study USDA, soil conservation service approaches were used since it is a widely used method (Endalamaw, 2009). From the CROPWAT result, effective rainfall was obtained as 610.2 mm per annum out of the total average annual rainfall 729.9 mm, and the losses estimated as 17 percent of rainfalls in the study area. Table 4.4 shows that the maximum effective rainfall were occurred in August (129.9 mm) followed by July (110.2 mm), May (70.3 mm) and April (55.9 mm) months. The minimum amount of effective precipitation was found in January that is 9.5 mm. during the dry period effective rain fall was almost equal to the rain fall the water shed received due to the reason that the rain fall is too small and could not generate significant amount of loses. Comparison of the mean monthly rainfall and evapotranspiration indicates that, for the maximum crop production in the area during the dry season, irrigation is the most important choice.

Table 4. 4 ETO (Reference evapotranspiration), Rainfall and Effective rainfall of the study.

Month	ETo (mm/day)	Mean monthly Rain fall (mm)	Eff rain (mm)	Percentage effective rain fall (%)
January	4.37	9.6	9.5	99.0
February	5.48	29.4	28	95.2
March	5.29	48.7	44.9	92.2
April	5.13	62.1	55.9	90.0
May	5.5	80.7	70.3	87.1
June	5.39	13.5	13.2	97.8
July	4.83	142.8	110.2	77.2
August	4.77	184	129.8	70.5
September	4.88	55.2	50.3	91.1
October	4.86	34.3	32.4	94.5
November	4.01	36.9	34.7	94.0
December	4.1	32.7	31	94.8
Average	4.88	60.83	50.85	83.6

Crop evapotranspiration was calculated for chickpea, garlic, onion, and watermelon and summed up, to compare it with the monthly effective rainfall and the irrigation water requirement. When effective rainfall was insignificant, to meet crop water demand, irrigation was the only option. However, when the effective rainfall increase in much amount the irrigation water demand decrease and when it is greater than evapotranspiration no need of irrigation.

Crop water requirement and irrigation water requirement

Basically water requirement of the crops depends on the crop characteristics, length of growth stage of each crops, and method of irrigation (Tibebe, 2015). The estimated irrigation requirement for chickpea was 328.7 mm and 438.2 mm with drip and furrow methods respectively, for the entire growing season of Dec, 2017 to May, 2018 for detail information (see table 4.5). From the CROPWAT result, the irrigation water requirement of chickpea crop varies from 1.6 mm/Dec during December to 46.8 mm/Dec during February. Crop evapotranspiration varies from 1.6 mm/Dec to 56.7 mm/Dec during the whole stage of development.

Irrigation water requirement of garlic was estimated as 592.6 mm of water with drip irrigation system, for the entire growing season of Dec, 2017 to May, 2018. Irrigation water requirement of garlic crop varies from 2.9 mm/Dec during December to 46.9 mm/Dec during February, and its crop evapotranspiration varies from 2.9 mm/Dec at December to 58.0 mm/Dec during March. The variation is due to the stage and the presence of rainfall (see table 4.4).

The irrigation water requirement for onion was 635.9 mm with drip and 847.8 mm with furrow method for the entire growing season of Dec, 2017 to May, 2018. In addition, Irrigation water requirement of onion crop varies from 2.9 mm/Dec during December to 49.3 mm/Dec during January and crop evapotranspiration varies from 2.9 mm/Dec at December to 59.1 mm/Dec during February.

The irrigation water requirement for Watermelon was 417.8 mm and 557.1 mm with drip and furrow respectively for the entire growing season for detail (see table 4.5). And also the irrigation water requirement of watermelon crop varies from 1.6 mm/Dec during December to 44.8 mm/Dec during February and crop evapotranspiration varies from 1.6 mm/Dec at December to 57.8 mm/Dec during March. For more clarification see appendix- D. Since, all four crops their water requirement is minimal during the initial stage. However, it reaches a peak in development and flowering stage and then become minimum at the late season stage.

Table 4. 5 Crop water demand and irrigation water requirement from CROPWAT.

Seasons	Crops:	ETc (mm/season)	Gross Irrigation water requirement (mm/season)	
			Drip	Furrow
Dec, 2017 to May, 2018	Chickpea	364.7	328.7	438.2
	Garlic	691.5	592.6	-
	Onion	727.7	635.9	847.8
	Watermelon	474.9	417.8	557.1
Dec, 2018 to May, 2019	Chickpea	326.2	335.0	446.7
	Garlic	636.4	685.7	914.2
	Onion	669.7	-	967.4
	Watermelon	432.4	458.6	611.5

Generally, the above table shows us based on CROPWAT 8.0, the values of crop water demand was depends on the climatic data available and it varies from season to season, and the net irrigation requirement of each cultivated crop were estimated and it was also depends on methods of irrigation practice. Based on FAO guidelines or (Doorenbos et al., 1977) the indicative value of field application efficiencies of drip and furrow irrigation are 80 % and 40 % respectively were used in this research work.

From this research one of the finding out is to the balance of the irrigation water requirement and amount of applied irrigation water in the Hormat-Golina irrigation scheme. On the base of the calculated applied water and irrigation water requirement resulted from the CROPWAT 8.0 was shown in the table 4.6. As indicated in table 4.6, there was a scarce of water in the cultivated crops like, chickpea, garlic and onion in the scheme. Moreover, the crops irrigated with drip irrigation system has a minimum percentage of deficit relative to furrow irrigated crops in the field. However, in the case of watermelon there was excess water at both drip and furrow irrigation systems in the scheme. So, this research was addressed percent of exceeded and deficit irrigation in Hormat-Golina irrigation scheme, that will used to balance the demand and supply of irrigation water in the scheme.

Table 4. 6 Applied water used and irrigation water requirement from CROPWAT 8.0

Irrigation Seasons	Crops	Method	Applied irrigation (mm/season)	Gross irrigation requirement (mm/season)	water saved by drip (%)
Dec,2017 to May,2018	chickpea	Drip	250.6	328.7	41.2
		Furrow	426.4	438.2	
	garlic	Drip	485.5	592.6	
		Furrow	non	non	non
	onion	Drip	563.8	635.9	32.6
		Furrow	836.4	847.8	
	watermelon	Drip	579.4	417.8	26.4
		Furrow	787.2	557.1	
Dec,2018 to May,2019	chickpea	Drip	237.0	335.0	46.4
		Furrow	442.4	446.7	
	garlic	Drip	504.6	685.7	39.7
		Furrow	837.2	914.2	
	onion	Drip	non	non	non
		Furrow	853.2	967.4	
	watermelon	Drip	565.7	458.6	32.4
		Furrow	837.4	611.5	

4.2 Crop water productivity evaluation of drip and furrow irrigation system in the scheme

4.2.1. Determination of crop yield in the scheme

The yield of the crops in this study area was determine based on the collected primary and secondary data sources. The yield of each crops that practice with drip and furrow irrigation systems were calculated separately and the data included two consecutive irrigation seasons. The first irrigation season covered from December, 2017 to May, 2018 and the second irrigation season also from December, 2018 to May, 2019 was covered. Based on the information from Kobo Wereda agriculture office, and responded local farmers the average crop yield per unit hectare of irrigated land for the cultivated crops in the scheme was collected as secondary data. The reason that average yield under drip irrigation system is more than furrow irrigation system, because the soil water moisture is retained for long time due to driping rather than furrowing.

The yield of each crops in Hormat-Golina irrigation scheme for both drip and furrow irrigation methods were calculated with the help of the equation (3.6) and the results were shown in the following table.

Table 4. 7 The estimated crop yield of drip and furrow irrigation methods in the scheme

Methods		Drip irrigation			Furrow irrigation		
Irrigation season	Crop:	Yi.ave (qt/ha)	Area (ha)	Yield (kg)	Yi.ave (qt/ha)	Area (ha)	Yield (kg)
Dec,2017 to May,2018	chickpea	30	24	72000	22	25	55000
	Garlic	50	3	15000	-	-	-
	onion	60	18	108000	55	20	110000
	watermelon	130	3	39000	120	5	60000
	Total		48	234000		50	225000
Dec,2018 to May,2019	chickpea	28	36	100800	21	22	46200
	Garlic	52	6	31200	48	3	14400
	onion	-	-	-	55	23	126500
	watermelon	130	6	78000	120	2	24000
	Total		48	210000		50	211100

The total product of the crops in the season of December, 2017 to May, 2018 from drip irrigation method was determined as 2340 quintal or 234 ton over 48 hectare of irrigated land. In the same irrigation season, product of the crops from furrow irrigation method estimated as 2250 quintal or 225 ton over 50 hectare of irrigated land. Similarly, in the season of December, 2018 to May, 2019 the total yield of the crops from drip irrigation system was 2100 quintal or 210 ton over 48 hectare and from furrow irrigation method also determined as 2111 quintal or 211.1 ton over 50 hectare of irrigated land.The crop water productivity (CWP) of drip and furrow irrigation was estimated based on equation (3.7) see in the table 4.8 below.

Table 4. 8 The Calculated crop water productivity of both irrigation systems at the scheme.

Irrigation seasons		Dec, 2017 - May,2018		Dec,218 - May,2019	
Crops:	Method	CWP (kg/m^3)	CWP % by drip	CWP (kg/m^3)	CWP % by drip
Chickpea	Drip	1.53	66.01	1.18	39.83
	Furrow	0.52		0.47	
Garlic	Drip	1.02		1.03	55.34
	Furrow	Non		0.57	
Onion	Drip	1.06	37.74	Non	
	Furrow	0.66		0.64	
Watermelon	Drip	2.24	32.14	2.29	62.45
	Furrow	1.52		1.43	

The estimated crop water productivity (CWP) of drip and furrow irrigation systems in the Hormat-Golina irrigation scheme was vary with different irrigation seasons. In the season of December, 2017 to May, 2018, the crop water productivity of drip irrigation system for the crop of chickpea, garlic, onion, and watermelon was estimated as 1.53, 1.02, 1.06 and 2.24 kg/m^3 respectively, and also with the method of furrow irrigation the crop water productivity was resulted as 0.52, 0.66, and 1.52 kg/m^3 for chickpea, onion and watermelon respectively. These value indicates that the crop water productivity of drip irrigation system is more than furrow irrigation system with the percent of 66.01 %, 37.74 % and 32.14 % for cultivated crops of chickpea, onion and watermelon respectively.

For the season of December, 2018 to May, 2019, the crop water productivity of drip irrigation system was calculated as 1.18, 1.03, and 2.29 kg/m^3 for the crops chickpea, garlic, and watermelon respectively, in the same manner with the method of furrow irrigation system estimated as 0.47, 0.57, 0.64 and 1.43 kg/m^3 for chickpea, garlic, onion, and watermelon respectively. These value also indicates that drip irrigation system again beyond furrow irrigation system with a percent of productivity 39.83 %, 55.34 % and 62.45 % for the crops chickpea, garlic, and watermelon respectively in the scheme at that irrigation season. Generally, the estimated values of crop water productivity for drip and furrow irrigation system for puls crops within the ranges from 0.2 to 1.67 kg/m^3 reported by Descheemaeker & Hailesilassie, (2011). Particularly, the calculated crop water productivity of drip and furrow irrigation system for garlic and onion crops was lower than the previous studies 1.74 kg/m^3 by Yosef, (2016). This variations may due to the difference of period of the study, location of study area and methods of analysis.

4.3. Economic water productivity evaluation of drip and furrow irrigation system in the scheme

4.3.1. Determination of gross value of crop product in the scheme

The gross value of crop product depend on yield and seasonal local market price of the crop that grown on the scheme. The gross value of crop product was calculated by equation (3.10) and it includes both drip and furrow irrigation system at Hormat-Golina irrigation scheme. The gross value of crop product for chickpea, garlic, onion and watermelon was shown in table 4.9.

Table 4. 9 Gross value of crop product of drip and furrow irrigation system at the scheme.

Methods of irrigation			Drip		Furrow	
Irrigation seasons	Cultivated crops	Price (birr/kg)	Yield (kg)	GVP (birr)	Yield (kg)	GVP (birr)
Dec, 2017 to May,2018	Chickpea	8.5	72000	612000	55000	467500
	Garlic	35	15000	525000	Non	Non
	Onion	11	108000	1188000	110000	1210000
	Watermelon	15	39000	585000	60000	900000
Dec, 2018 to May,2019	Chickpea	10.5	100800	1058400	46200	485100
	Garlic	40	31200	1248000	14400	576000
	Onion	14.5	Non	Non	126500	1834250
	Watermelon	22	78000	1716000	24000	528000

4.3.2. Determination of total cost of crop production in the scheme

The total cost of crop production in the Hormat-Golina irrigation scheme were includes, cost of seed, cost of fertilizer, cost of spray, labor cost (land preparation, lateral layout, weeding removing and harvesting cost), cost of transport, and pumping cost but not includes installation cost. The components of irrigation system allows us to determine the total cost per unit hectare of irrigated land (Hogan et al., 2011). It calculated with help of equation (3.11). The total cost of chickpea, garlic, onion and watermelon with drip irrigation system was shown as in the table 4.10 and 4.11.

Table 4. 10 Determination of total cost for chickpea and garlic with drip irrigation system at the season Dec, 2017-may, 2018.

Crop types	Chickpea				Garlic			
Types of the cost	price per item	required items	Area (ha)	Cost (birr)	price per item	required items	Area (ha)	cost (birr)
Materials cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
Seeds	6.5	40	24	6240	11.5	50	3	1725
Fertilizer cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
DAP	12	50	24	14400	12	50	3	1800
URIEA	11.5	50	24	13800	11.5	50	3	1725
Sprays cost:	birr/lit	lit/ha	ha		birr/lit	lit/ha	ha	
Fungicides	80	1	24	1920	80	0.5	3	120
Insecticides	75	1	24	1800	75	0.5	3	112.5
Labor cost:	birr/hr	hr/ha		0	birr/hr	hr/ha	ha	
Land prepare	4	40	24	3840	4	32	3	384
Lateral layout	3	5	24	360	3	5	3	45
Weed removing	3.5	32	24	2688	3.5	32	3	336
Harvesting	5	48	24	5760	5	42	3	630
Transport cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
	0.02	750	24	360	0.02	500	3	30
Pumping cost:	Birr/kwh	Kwh	hr		Birr/kwh	kwh	hr	
	0.52	74.99	50	1949.7	0.52	74.99	65	2534.6
Total cost				53117.				9442.16

Table 4. 11 Determination of total cost for onion and watermelon with drip irrigation system in the season of Dec, 2017-may, 2018.

Crop types	Onion				Watermelon			
Types of the cost	price per item	required item per hectare	Area (ha)	Cost (birr)	price per item	required item per hectare	Area (ha)	cost (birr)
Materials cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
Seeds	8.5	75	18	11475	8.5	100	3	2550
Fertilizer cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
DAP	12	50	18	10800	12	25	3	900
URIEA	11.5	50	18	10350	11.5	25	3	862.5
Sprays cost:	birr/lit	lit/ha	ha		birr/lit	lit/ha	ha	
Fungicides	80	0.5	18	720	80	1	3	240
Insecticides	75	0.5	18	675	75	1	3	225
Labor cost:	birr/hr	hr/ha	ha		birr/hr	hr/ha	ha	
Land preparation	4	40	18	2880	4	40	3	480
Lateral layout	3	5	18	270	3	5	3	45
Weed removing	3.5	32	18	2016	3.5	32	3	336
Harvesting	5	60	18	5400	5	42	3	630
Transport cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
	0.02	1000	18	360	0.02	1800	3	108
Pumping cost:	Birr/kwh	Kwh	hr		Birr/kwh	kwh	hr	
	0.52	74.99	143	5576.27	0.52	74.99	102	3977.47
Total cost				50522.26				10354

Similarly, in the same irrigation season the cost of crop production with a method of furrow irrigation also determined for chickpea, onion and watermelon. The results were shown as in the next table 4.12 and 4.13.

Table 4. 12 Determination of total cost for chickpea and onion with furrow irrigation system in the season Dec, 2017-may, 2018.

Crop types	Chickpea				Onion			
Types of the cost	price per item	required item per hectare	Area (ha)	Cost (birr)	price per item	required item per hectare	Area (ha)	Cost (birr)
Materials cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
Seeds	7.5	40	25	7500	10.5	100	20	21000
Fertilizer cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
DAP	12	50	25	15000	12	50	20	12000
URIEA	11.5	50	25	14375	11.5	50	20	11500
Sprays cost:	birr/lit	lit/ha	ha		birr/lit	lit/ha	ha	
Fungicides	80	1	25	2000	80	1	20	1600
Insecticides	75	1	25	1875	75	1	20	1500
Labor cost:	birr/hr	hr/ha	ha		birr/hr	hr/ha	ha	
Land preparation	4	40	25	4000	4	40	20	3200
Lateral layout	3.5	32	25	2800	3.5	32	20	2240
Weed removing	5	48	25	6000	5	48	20	4800
harvesting	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
Transport cost:	0.02	550	25	275	0.02	900	20	360
	Birr/kwh	Kwh	hr		Birr/kwh	kwh	hr	
Pumping cost:	0.52	75.87	74	2919	0.52	75.87	150	5917.9
Total				56744				64118

Table 4. 13 Determination of total cost for watermelon with furrow irrigation system in the season Dec, 2017-may, 2018.

Crop type	Watermelon			
Types of cost	price per item	required item per hectare	Area (ha)	Cost (birr)
Materials cost:	birr/kg	kg/ha	ha	
Seeds	11.5	20	5	1150
Fertilizer cost:	birr/kg	kg/ha	ha	
DAP	12	25	5	1500
URIEA	11.5	25	5	1437.5
Sprays cost:	birr/lit	lit/ha	ha	
Fungicides	80	1	5	400
Insecticides	75	1	5	375
Labor cost:	birr/hr	hr/ha	ha	
Land preparation	4	40	5	800
Lateral layout	3.5	32	5	560
Weed removing	5	60	5	1500
Harvesting	birr/kg	kg/ha	ha	
Transport cost:	0.02	1600	5	160
	Birr/kwh	kwh	hr	
Pumping cost:	0.52	75.87	130	5128.812
Total				13011.31

In the season of December, 2018 to May, 2019 also the cost of the crop production of drip and furrow irrigation system were estimated with similar method in the above. The cost of production for the crop chickpea, garlic and watermelon with drip irrigation were determined as seen in the table 4.14 and 4.15

Table 4. 14 Determination of total cost for chickpea and garlic with drip irrigation system in the season Dec, 2018-may, 2019.

Crop type	Chickpea				Garlic			
Types of cost	price per item	required item per hectare	Area (ha)	cost (birr)	price per item	required item per hectare	Area (ha)	cost (birr)
Materials cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
Seeds	13.00	40	24	12480	16.50	50	3	2475
Fertilizer cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
DAP	13.25	50	24	15900	13.25	50	3	1987
URIEA	12.5	50	24	15000	12.5	50	3	1875
Sprays cost:	birr/lit	lit/ha	ha		birr/lit	lit/ha	ha	
Fungicides	160	1.25	24	4800	160	1	3	480
Insecticides	220	1.5	24	7920	220	1	3	660
Labor cost:	birr/hr	hr/ha		0	birr/hr	hr/ha	ha	
Land preparation	6	40	24	5760	6	32	3	576
Lateral layout	4.5	5	24	540	4.5	5	3	67.5
Weed removing	4.5	32	24	3456	4.5	32	3	432
Harvesting	8	48	24	9216	8	42	6	2016
Transport cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	ha	
	0.05	600	36	1080	0.05	500	6	150
Pumping cost:	Birr/kwh	Kwh	hr		Birr/kwh	kwh	hr	
	1.02	73.21	54	4032	1.02	73.21	68	5077
Total cost				80184.53				15797

Table 4. 15 Determination of total cost for watermelon with drip irrigation system in the season Dec, 2018-may, 2019.

Crop type	Watermelon			
Types of cost	price per item	required item per hectare	Area (ha)	cost (birr)
Materials cost:	birr/kg	kg/ha	ha	
Seeds	17.5	20	3	1050
Fertilizer cost:	birr/kg	kg/ha	ha	
DAP	13.25	25	3	993.75
URIEA	12.5	25	3	937.5
Sprays cost:	birr/lit	lit/ha	ha	
Fungicides	160	1.5	3	720
Insecticides	220	1.5	3	990
Labor cost:	birr/hr	hr/ha	ha	
Land preparation	6	40	3	720
Lateral layout	4.5	5	3	67.5
Weed removing	4.5	32	3	432
Harvesting	8	42	3	1008
Transport cost:	birr/kg	kg/ha	ha	
	0.05	1800	3	270
Pumping cost:	Birr/kwh	kwh	hr	
	1.02	73.21	102	7616.995
Total cost				14805.74

In addition, for the method of furrow irrigation, the cost of crop production of chickpea, garlic, onion, and watermelon were estimated (see table 4.16 and table 4.17).

Table 4. 16 Determination of total cost for chickpea and garlic with furrow irrigation system in the season Dec, 2018-may, 2019.

crop type	Chickpea				Garlic			
Types of cost	Price per item	Required item per hectare	Area (ha)	Cost (birr)	Price per item	Required item per hectare	Area (ha)	Cost (birr)
Materials cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	Ha	
Seeds	13	40	22	11440	16.5	50	3	2475
Fertilizer cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	Ha	
DAP	13.25	50	22	14575	13.25	50	3	1987.5
URIEA	12.5	50	22	13750	12.5	50	3	1875
Sprays cost:	birr/lit	lit/ha	ha		birr/lit	lit/ha	Ha	
Fungicides	85	1	22	1870	85	0.5	3	127.5
Insecticides	82	1	22	1804	82	0.5	3	123
Labor cost:	birr/hr	hr/ha		0	birr/hr	hr/ha	Ha	
Land preparation	6	40	22	5280	6	32	3	576
Lateral layout	4.5	5	22	495	4.5	5	3	67.5
Weed removing	4.5	32	22	3168	4.5	32	3	432
Harvesting	8	48	22	8448	8	42	3	1008
Transport cost:	birr/kg	kg/ha	ha		birr/kg	kg/ha	Ha	
	0.05	500	22	550	0.05	500	3	75
Pumping cost:	Birr/kwh	Kwh	hr		Birr/kwh	kwh	Hr	
	1.02	73.75	77	5792.325	1.02	73.75	78	5867.55
Total cost				67172.33				14614.05

Table 4. 17 Determination of total cost for onion and watermelon with furrow irrigation system in the season Dec, 2018-may, 2019.

crop type	Onion				Watermelon			
types of cost	price per item	required item per hectare	Area (ha)	Cost (birr)	price per item	required item per hectare	Area (ha)	cost (birr)
Materials cost:	birr/kg	kg/ha	Ha		birr/kg	kg/ha	ha	
Seeds	15.00	75	23	25875	17.5	100	2	3500
Fertilizer cost:	birr/kg	kg/ha	Ha		birr/kg	kg/ha	ha	
DAP	13.25	50	23	15237.5	13.25	25	2	662.5
URIEA	12.5	50	23	14375	12.5	25	2	625
Sprays cost:	birr/lit	lit/ha	Ha		birr/lit	lit/ha	ha	
Fungicides	80	0.5	23	920	80	1	2	160
Insecticides	75	0.5	23	862.5	75	1	2	150
Labor cost:	birr/hr	hr/ha	Ha		birr/hr	hr/ha	ha	
Land preparation	6	40	23	5520	6	40	2	480
Lateral layout	4.5	5	23	517.5	4.5	5	2	45
Weed removing	4.5	32	23	3312	4.5	32	2	288
Harvesting	8	60	23	11040	8	42	2	672
Transport cost:	birr/kg	kg/ha	Ha		birr/kg	kg/ha	ha	
	0.05	1000	18	900	0.05	1850	2	185
Pumping cost:	Birr/kwh	kwh	Hr		Birr/kwh	Kwh	hr	
	1.02	73.75	155	11659.88	1.02	73.75	132	9929.7
Total cost				90219.38				16697.2

According to the Ethiopian Electric Power Cooperation (EEPCO), the rate of payment for one-kilowatt hour power was 0.52 birr and 1.02 birr in the year 2017 and 2018 respectively. The pumps will work for about 16 to 18 hours in a day, 30 days in a month, and about 9 months in a year. Accordingly, the energy consumption for the pump was calculated on daily, monthly, and annual basis. Based on equation (3.9) the economic water productivity (EWP) was calculated by multiplying beneficial biomass and the market price minus the total production costs divided by irrigation water used in the schemes. All the results were shown in the table 4.18.

Table 4. 18 The estimated economic water productivity of drip and furrow irrigation system at the scheme.

Season	crops:	Method	water used (m3)	Income (Birr)	EWP (Birr/m3)	EWP ($/m3)	EWP by drip (%)
Dec, 2017 to May, 2018	chickpea	drip	60134.40	558882.26	9.29	0.34	58.54
		furrow	106600.00	410755.52	3.85	0.14	
	Garlic	drip	14563.80	515557.84	35.40	1.29	
		furrow	non	non	-	-	
	Onion	drip	101476.80	1137477.74	11.21	0.41	38.89
		furrow	167280.00	1145882.14	6.85	0.25	
	watermelon	drip	17382.60	574646.03	33.06	1.20	31.83
		furrow	39360.00	886988.69	22.54	0.82	
Dec, 2018 to May, 2019	chickpea	drip	85318.20	978215.47	11.47	0.40	62.55
		furrow	97328.00	417927.68	4.29	0.15	
	Garlic	drip	30274.20	1232203.00	40.70	1.41	45.10
		furrow	25122.00	561385.95	22.35	0.77	
	Onion	drip					
		furrow	196236.00	1744030.63	8.89	0.31	
	watermelon	drip	33943.80	1701194.26	50.12	1.74	39.09
		furrow	16748.00	511302.80	30.53	1.06	

The economic water productivity of drip irrigation system in the season Dec, 2017 to May, 2018 was estimated as 0.34, 1.29, 0.41 and 1.20 $/m3 for chickpea, garlic, onion, and watermelon respectively; and also in the season Dec, 2018 to May, 2019 it was calculated as 0.4, 1.41 and 1.74 $/m3 for chickpea, garlic, and watermelon respectively. In addition, the economic water productivity of furrow irrigation system in the season Dec, 2017 to May, 2018, was evaluated as 0.14, 0.25 and 0.85 $/m3 for chickpea, onion, and watermelon respectively; and also in the season Dec, 2018 to May, 2019 it was estimated as 0.15, 0.77, 0.31 and 1.06 $/m3 for chickpea, garlic, onion, and watermelon respectively. The EWP of this research was similar with the previous studies like, (El-ganzori, 2012) 0.05, 0.39, 0.23 and 0.20 $/m^3 for chickpea, garlic onion and watermelon respectively were cultivated at different states in Egypt.

Generally, the estimated economic water productivity in the study area drip irrigation system was more than the furrow one (see figure 4.1 and 4.2).

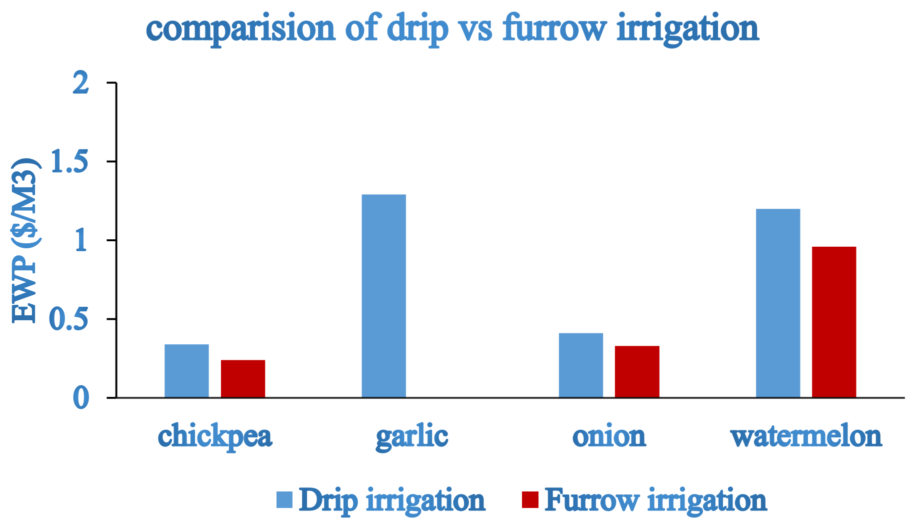

Figure 4. 1 Economic water productivity at Dec, 2017 to May, 2018

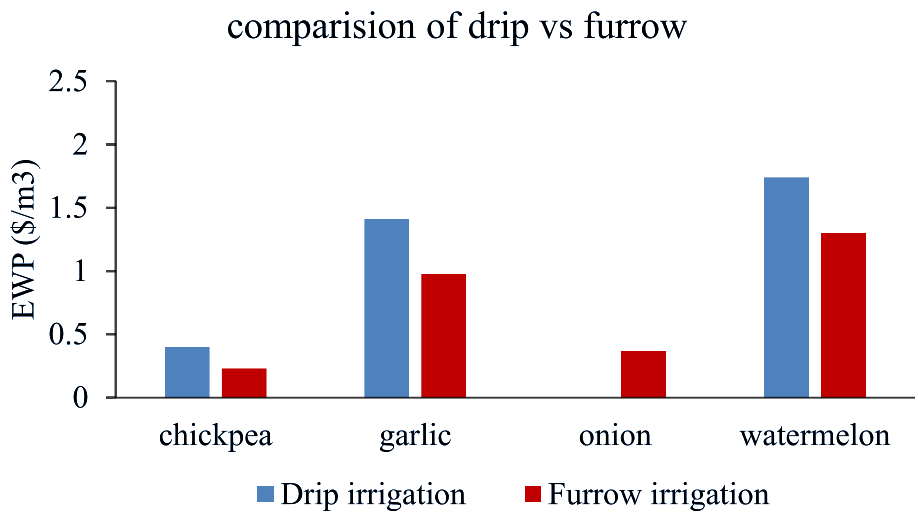

Figure 4. 2 Economic water productivity at season of Dec, 2018 to May, 2019.

Based on aforementioned reason in the previous section of this document and the limited water used and higher average crop yield under drip irrigation system the economic water productivity value is higher than furrow irrigation system. So this system is advisable rather than furrow irrigation methods at the scheme of the study area.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

By reducing the amount of water required for crop production, increasing crop water productivity is a key strategy for achieving food security and water sustainability in the scheme with growing demands. Based on the computed crop water demand and applied irrigation water use, there was imbalance between demand and supply in the Hormat-Golina irrigation scheme. The crop water demand of the scheme was greater than the amount of applied irrigation water use in the scheme, which shown as from CROPWAT 8.0 results in the appendices.

Water productivity evaluation of the scheme was shown as to give re-medial measures of the problems of the scheme. The crop water productivity and economic water productivity evaluation of drip and furrow irrigation system was essential in order to provide suitable irrigation practice and to implement the system at the scheme.

The estimated crop water productivity of drip irrigation system in the season of December, 2017 to May, 2018 was 1.53, 1.02, 1.06, 2.24 kg/m^3 for the crops chickpea, garlic, onion, and watermelon respectively; but, for the crops chickpea, onion, and watermelon were resulted as 0.86, 0.88 and 1.78 kg/m^3 respectively with furrow irrigation system. In the season of December, 2018 to May, 2019 also the crop water productivity (CWP) in the scheme were 1.18, 1.03 and 2.29 kg/m^3 chickpea, garlic, and watermelon respectively with method of drip irrigation; and 0.74, 0.72, 0.77 and 1.76 kg/m^3 chickpea, garlic, onion, and watermelon respectively with method of furrow irrigation. These value also indicates that drip irrigation system again beyond furrow irrigation system with a percent of productivity 37.29 %, 30.10 % and 23.14 % for the crops chickpea, garlic, and watermelon respectively in the scheme at that irrigation season. The estimated values of crop water productivity for drip and furrow irrigation system for cereal crops within the range from 0.2 to 1.67 kg/m^3 reported by Descheemaeker & Hailesilassie, 2011. The calculated crop water productivity of drip and furrow irrigation system for garlic and onion crops was lower than the previous studies 1.74 kg/m^3 by Yosef, (2016). This difference may due to time of study and location of study area.

The economic water productivity of drip irrigation system in the season Dec, 2017 to May, 2018 was estimated as 0.34, 1.29, 0.41 and 1.20 \$/m3 for chickpea, garlic, onion, and watermelon respectively; and also in the season Dec, 2018 to May, 2019 it was calculated as

0.4, 1.41 and 1.74 $/m3 for chickpea, garlic, and watermelon respectively. In addition, the economic water productivity of furrow irrigation system in the season Dec, 2017 to May, 2018, was evaluated as 0.24, 0.41 and 0.96 $/m3 for chickpea, onion, and watermelon respectively; and also in the season Dec, 2018 to May, 2019 it was estimated as 0.23, 0.98, 0.37 and 1.30 $/m3 for chickpea, garlic, onion, and watermelon respectively. The EWP of the research was more than the study by El-ganzori, (2012) for chickpea, garlic, onion and watermelon as 0.05, 0.39, 0.23 and 0.20 \$/m^3 respectively. For all cultivated crops in the study area economic water productivity of drip irrigation system was more than the furrow one and it must be adapot.

A range of CWP and EWP values for both irrigation methods, which may be caused by so many factors that influence soil–water–plant relationship, including time (growth stage at which stress was imposed), sequence of water stress. Considerable variations in CWP and EWP values are observed not only for different irrigation methods but also for the same irrigation system with different season.

5.2 Recommendations

The above findings indicated that Hormat-Golina irrigation scheme has potential for cereal and vegetable production. Therefore crops production in the study area should be increased and expanded to satisfy the wider regional market demand and to gain normal profit for all crop producers. However, garlic and onion producers in the study area lack to some extent skills and knowledge in proper agronomic and post-harvest handling practices necessary to obtain high onion yield and to reduce postharvest losses. Therefore, continuous training and extension services should be given by the respective stakeholders such as agricultural offices, universities and concerned non-governmental organizations.

The water productivity of drip and furrow irrigation system in case of Hormat-Golina irrigation scheme was depend on several factors. These factors have to be managed properly for increasing of water productivity, particularly for crop and economic water productivity in the scheme. But this research does not include such factors and for the future further studies are require for improvement of the water productivity. Moreover, from this study, the water productivity of drip irrigation was higher percentage than the surface (furrow irrigation). Therefore, for the schemes in kobo wereda and in general in Ethiopia the drip irrigation system is advisable in the future.

REFERENCES

Abdul-Ganiyu, S., Kyei-Baffour, N., Agyare, W. and, & Dogbe, W. (2015). An evaluation of economic water productivity and water balance of dry season irrigated rice under different irrigation regimes in northern Ghana., 1(1), 129–143.

Abebe, K. (2014). Surface runoff potential and irrigation suitability assessment of An-Lemo river watershed in Hadiya zone, SNNPRS.

ADSWE, A. D. & S. W. E. (2013). Feasibility Study and Detail Design Of Kobo, Alewuha, Chekorsa, Mehal-Amba And Tis-Abalima Groundwater Irrigation Project November, 2013.

Ali, M., & Hassan, A. (2007). Effects of deficit irrigation on yield , water productivity , and economic returns of wheat., 92, 151–161.

Ali, M., & Talukder, M. (2008). Increasing water productivity in crop production synthesis, 95, 1201–1213. https://doi.org/10.1016/j.agwat.2008.06.008

Allen, Pereira, L., Raes, D., Smith, M., & Abo, W. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56 By.

Allen, R., Richard, Pereria, K., Raes, M., Dirk, N., & Smith, M. (1998). FAO Irrigation and Drainage Paper Crop Evapotranspiration (guidelines for computing crop water requirements).

Amare, H., Fitsum, H., Zeleke, A., Ephrem, T., Dirk, H., & Simon, L. (2016). Institutions for irrigation water management in Ethiopia : Assessing diversity and service delivery.

Andualem, Y. (2018). Water Delivery Performance Evaluation of Koga Irrigation Scheme.

Avinash, S., Patwar, D., John, L., Niebe, K., Johns, M., & Eldon, L. (1990). Effective rainfall estimation And Numerous methods , empirical methods; and soil water balance methods, 116(2), 182–193.

Awulachew, S., Elizabeth, H., To Phuc, T., Helena, G., Ramadjita, T., & Joyce, B. (2007). Increasing the productivity and sustainability of rainfed cropping systems of poor, smallholder farmers: overview of recent findings from the Challenge Program on Water and Food.

Awulachew, S., Yilma, A., Loulseged, M., Loiskandl, W., Ayana, M., & Alamirew, T. (2009). water resources and irrigation development in Ethiopia.

Banavath, N., T, R., Latha, T, H., Babu, C., & Mahesh. (2015). Command area development by using FAO Cropwat 8 . 0 model and impact of climate change on crop water requirement-a case study on Araniar reservoir basin (Pichatur dam), 1(13), 142–155.

Belay, S., & Beyene, F. (2013). Small-scale irrigation and household income linkage : Evidence from Deder district , Ethiopia, 8(34), 4441–4451.

Bennett, D. R., & Harms, T. E. (2013). Crop Yield and Water Requirement Relationships for Major Irrigated Crops in Southern Alberta Crop Yield and Water Requirement Relationships for Major Irrigated Crops in Southern Alberta., 1784.

Billib, M., & Bardowicks, K. (2009). Integrated water resorces management for sustainable irrigation at the basin scale., 69(December), 69–80.

Brown, J., Schall, J., Morris, C., Doherty, S., Stein, J., & Warner, K. (2013). Urban Drainage Design Manual,Hydraulic Engineering Circular No. 22, Third Edition, 2009(22).

Chourasial, A. (2016). Maximising water productivity of wheat crop by adopting drip irrigation Maximising water productivity of wheat crop by adopting drip irrigation., (December).

Chow, V. Te, David R, M., & Mays, L. W. (1971). Applied hydrology,. McGRAW.HILL international editions Civil Engineering series.

Darouich, H. (2014). Drip versus furrow irrigation, A comparison focussing on water saving and economic returns using multicriteria analysis applied to cotton., 2. https://doi.org/10.1016/j.biosystemseng.2014.03.010

Descheemaeker, K., & Haileslassie, A. (2011). Irrigation water productivity as affected by water management in a small-scale irrigation scheme in the Blue Nile basin, Ethiopia, (January). https://doi.org/10.1017/S0014479710000839

Dinka, M. O., & Ndambuki, J. M. (2014). Identifying the potential causes of waterlogging in irrigated agriculture: the case of the Wonji-Shoa sugar cane plantation, (Ethiopia), 92(September 2013), 80–92.

Dong, Q. (2018). Study on the Crop Irrigation Water Requirement Based on Cropwat in Jinghuiqu Irrigation Area Study on the Crop Irrigation Water Requirement Based on Cropwat in Jinghuiqu Irrigation Area.

Doorenbos, J., Pruitt, W., Aboukhaled, A., Damagenez, J., Dastane, N., Vandenberg, C., … Frere, M. (1977). Food and Agricultural Organization of the united nations Rome, irrigation and drainage paper 24.

El-ganzori, I. E. A. (2012). Decision support system for economic value of irrigation water, 63–76. https://doi.org/10.1007/s13201-012-0029-2

Endalamaw, A. (2009). Optimum utilization of groundwater in nkobo valley, Easter Amhara region , Ethiopia. Shortage of precipitation in Kobo valley limits the production of vegetables during dry periods and the yield of cereals in the rainy periods.

Gebru, A. A., Araya, A., & Habtu;, S. (2018). Evaluating water productivity of tomato , pepper and Swiss chard under clay pot and furrow irrigation technologies in semi-arid areas of northern Ethiopia, 12(1), 54–65.

Hailu, F. S. (2017). Mariginal economic value of water in crop production. The effect of two types of management practices on the average and marginal water productivities.

Hassen, Y. (2004). Assessment of small scale irrigation using comparative performance indicators on two selected schemes in upper Awash River valley.

Hogan, R., Stiles, S., Tacker, K., Phil, J., Earl, L., Vories, M., Bryant, G. (2011). Estimating Irrigation Costs; Estimates of fixed costs are critical for investment analysis and operating cost estimates can assist in decisions regarding additional irrigations.

Igbadun, H., Mahoo, F., Tarimo, K., Andrew, K., Salim, B., & Baanda, A. (2006). Crop water productivity of an irrigated maize crop in Mkoji sub-catchment of the Great Ruaha River Basin , Tanzania, 85, 141–150. https://doi.org/10.1016/j.agwat.2006.04.003

Igbadun, H., Mudiare, O., Oyebode, M., & Oiganji, E. (2018). Water Productivity of a Maize crop under deficit irrigation scheduling using gravity Drip System.

Jha, B., & Naik, S. K. (2017). Yield , water productivity and economics of vegetable production under drip and furrow irrigation in Eastern Plateau and Hill Region of India, (April).

Jones, H. G. (2004). Combining thermal and visible imagery for estimating canopy temperature and identifying plant stress, 55(401), 1423–1431.

Karrou, M., Oweis, T., Abou, R., Enein, E., Sherif, M., & Mohammed, G. (2012). Yield and water productivity of maize and wheat under deficit and raised bed irrigation practices in Egypt., 7(11), 1755–1760.

Kemal, Y. O., Damot, G. A., & Zewudie, D. A. (2018). Effects of supplemental irrigation on yield and yield attributes of chickpea (Cicer arietinum L .) in Western Ethiopia, *11*(2), 97–112.

KGVDP. (2019). Amhara national regional state kobo girana valley development programme office report.

Kidane, G. (2004). Agricultural based Livelihood Systems in Drylands in the Context of Climate Change and inventory of Adaptation Practices and Technologies of Ethiopia.

Kijne, J., Barker, R., & Molden, D. (2004). Water Productivity in Agriculture : Limits and Opportunities for Improvement., (January), 7–9.

Kruseman, G. . (2000). Analysis and Evaluation of Pumping Test Data Second Edition (Completely Revised).

Kumar, O., Dinesh, M., Singh, P., Samad, M., Turral, H., & Purohit, C. (2003). water productivity of irrigated agricultural in india: potential areas for improvement., 121–140.

Luhach, M., Khatkar, R., Singh, V., Khatry, R., Kutakar, S., & Luche, K. (2004). Economic Analysis of Sprinkler and Drip Irrigation Technology in Haryana (Vol. 17, pp. 107–113).

Mali, N., & Sengupta, T. (2017). Yield , water productivity and economics of vegetable production under drip and furrow irrigation in Eastern Plateau and Hill Region of India., 7(April).

Martin, E. C. (2011). Determining the Amount of Irrigation Water Applied to a Field.

Mateos, L., National, S., Orgaz, F., National, S., & Fereres, E. (1991). A comparison between drip and furrow irrigation in cotton at two levels of water supply., 3774(June 2019). https://doi.org/10.1016/0378-3774(91)90024-D

Molden, D., Theib, Y. O., Pasquale, S., Jacob, W. K., Munir, A. H., & Prem, S. B. (2007). Water use and productivity in a river basin, Pathways for increasing agricultural water productivity Coordinating, 278–310.

Naidu, C. R., & Giridhar, M. V. S. S. (2016). UnSupervised Classification of Rice Crop using IRS LISS III Satellite Images for Wazirabad Command Area, 4(2), 2–5.

Namrata, K., & Chandra, R. (2019). Estimation of water productivity of different varieties of rice in Burhi Gandak basin of north Bihar Estimation of water productivity of different varieties of rice in Burhi Gandak basin of north Bihar, (February), 2–6.

Natan, T., Nedaw, D., Kifl, W., Tesfamicel, G., & Frankvan, S. (2015). Groundwater Management for Irrigation in the Raya and Kobo Valleys , Northern Ethiopia, p.p 36-46.

Omotayo, B., Adeboye, B., Schultz, K., O, A., Krishna, & Prasad. (2015). Crop water productivity and economic evaluation of drip ‑ irrigated soybeans (Glyxine. Agriculture & Food Security, 1–13.

Osama, S., Elkholy, M., & Kansoh, R. M. (2017). Optimization of the cropping pattern in Egypt. Alexandria Engineering Journal, 56(4), 557–566.

Peter, D., & Geoff, K. (2001). Estimating productivity of water at different spatial scales using simulation modeling.

Prochnow, A., Drastig, K., Klauss, H., & Berg, W. (2012). Water use indicators at farm scale : methodology and case study. https://doi.org/10.1002/fes3.6

Richard, H. (1998). Hydrlolgical analysis and design, (2nd ed.).

Robinson, D. W. (2002). Construction and Operating Costs of Groundwater Pumps for Irrigation in the Riverine Plain.

Rodrigues, C., Paredes, P., Goncalo, J., Alves, I., Pereira, K., & Luis, S. (2013). Comparing sprinkler and drip irrigation systems for full and deficit irrigated maize using multicriteria analysis and simulation modelling : Ranking for water saving vs farm economic returns, 126, pp,85-96.

Santosh Garg, K. (2005). Irriagtion Engineering and hydraulic Structures.

Sengupta, T. (2017). Yield , water productivity and economics of vegetable production under drip and furrow irrigation in Eastern Plateau and Hill Region of India., (April).

Simon, C., Francis, G., & Hugh, T. (2004). Agricultural water productivity : Estimation at Plot , Farm and Basin Scale.

Simon, C., Francis, G., & Turral, H. (2006). Agricultural water productivity: Issues , Concepts and Approaches Basin Focal Project Working Paper.

Singh, R. (2002a). Water productivity analysis from field to regional scale, Integration of crop and soil modelling, remote sensing and geographical information.

Singh, R. (2002b). Water productivity analysis from field to regional scale.

Snatosh, M. (2016). Basic Concepts of Water Productivity, (July).

Srivastava, R., Panda, R., & Chakraborty, A. (2018). Field Crops Research Enhancing grain yield , biomass and nitrogen use e ffi ciency of maize by varying sowing dates and nitrogen rate under rainfed and irrigated conditions: Field Crops Research, 221(June 2017), 339–349. https://doi.org/10.1016/j.fcr.2017.06.019

Stallman, W. (1976). Aquifer-test design, observation and data analysis. Techniques of Water Resources Investigations of the United States Geological Survey.

Tadesse, K., & Belay, K. (2004). Factors Influencing Adoption of Soil Conservation Measures in Ethiopia., 105(1), 49–62.

Tadesse, N., Dessie, N., Kifle, W., G/yohannes, T., & Steenbergen, F. (2015). Groundwater Management for Irrigation in the Raya and Kobo valleys, located in the northern parts of Ethiopia.

Tagar, A. (2012). Comparative Study of Drip and Furrow Irrigation Methods at Farmer ' s Field in Umarkot, 863–867.

Tibebe, M. (2015). Water Demand Analysis and Irrigation Requirement for Major Crops at Holetta Catchment , Awash Subbasin , Ethiopia., 5(15), 117–128.

Todorovic, M. (2017). Crop Water Requirements in agicultural area., (August), 6–9. https://doi.org/10.1002/047147844X.aw59

W.M.O. (1994). guide to hydrological practice for data acquision and processing, analysis, forcasting and other applications.

Wondimkun, Y., & Tefera, M. (1995). Household Water Harvesting and Small Scale Irrigation

Schemes in Amhara Region.

worku, negussie. (2013). Technical performance evaluation of Midhegdu Small scale irrigation scheme in west Hararge zone, oromiya region, Ethiopia.

Yazew, E., Gebru, T., G/ezigaber, T., Mezgebu, A., Habtu, S., Haile, A., Wester, F. (2009). Spate Irrigation Systems in Raya Valley (Ethiopia), 13.

Yihun, Y. M. (2015). Agricultural Water Productivity Optimization for Irrigated Teff (Eragrostic Tef) in Water Scarce Semi-Arid Region of Ethiopia.

Yosef, M. (2016). Assessment of onion production practices and effects of N::P2O5:S fertilizers rates on yield and yield component of onion (Allium cepa L) under irrigated farming system in Dembia dostrict, Amhara region, Ethiopia.

Zwart, S. J., & Bastiaanssen, W. G. M. (2004). Review of measured crop water productivity values for irrigated wheat , rice , cotton and maize., 69, 115–133.

APPENDICES

Appendix – A: Applied irrigation water use with drip and furrow irrigation system in the scheme.

Table-A. 1 Applied irrigation water use with drip irrigation system 2017/18.

Drip irrigation Method in the season of dec,2017 to May,2018							
Crop	Growth stage	Days of growth (day)	area (ha)	time/ha	total time (hr)	well Discharge (m3/hr)	Volume of water (m^3)
Chickpea	initial	25	24	6	144	156.6	22550.4
	development	30	24	7	168	156.6	26308.8
	Mid-season	30	24	3	72	156.6	11275.2
	late season	15	24	0	0		0
	Total	100			384		**60134.4**
garlic	initial	15	3	6	18	156.6	2818.8
	development	25	3	7	21	156.6	3288.6
	mid season	70	3	12	36	156.6	5637.6
	late season	40	3	6	18	156.6	2818.8
	total	150					**14563.8**
onion	initial	15	18	6	108	156.6	16912.8
	development	25	18	8	144	156.6	22550.4
	mid season	70	18	16	288	156.6	45100.8
	late season	40	18	6	108	156.6	16912.8
	total	150					**101476.8**
Water-melon	initial	25	3	8	24	156.6	3758.4
	development	30	3	10	30	156.6	4698
	mid season	35	3	16	48	156.6	7516.8
	late season	30	3	3	9	156.6	1409.4
	total	120					**17382.6**

Table-A. 2. Applied irrigation water use with drip irrigation for December, 20/2018 to May, 24/2019.

Drip irrigation Method in the season of dec,2018 to May,2019							
Crop	Growth stage	Days of growth	area (ha)	time/ha	total time (hr)	well Discharge (M3/hr)	Volume of water (m^3)
Chickpea	initial	25	36	7	252	152.9	38530.8
	development	30	36	5.5	198	152.9	30274.2
	Mid-season	30	36	3	108	152.9	16513.2
	late season	15	36		0	152.9	0
	total	100					**85318.2**
garlic	initial	15	6	6	36	152.9	5504.4
	development	25	6	9	54	152.9	8256.6

	mid season	70	6	12	72	152.9	11008.8
	late season	40	6	6	36	152.9	5504.4
	total	150					**30274.2**
Water-melon	initial	**25**	6	6	36	152.9	5504.4
	development	**30**	6	12	72	152.9	11008.8
	mid season	**35**	6	16	96	152.9	14678.4
	late season	**30**	6	3	18	152.9	2752.2
	total	**120**					**33943.8**

Table-A. 3 Applied irrigation water use with furrow irrigation for December, 20/2017 to May, 25/2018.

Furrow irrigation Method in the season of dec,2017 to may,2018							
Crop	Growth stage	Days of growth	area (ha)	irrigation time per hectare (hr/ha)a	total time (hr)	well Discharge (m3/hr)	Volume of water used in (m^**3)**
Chickpea	initial	25	25	10	250	164	41000
	developmen t	30	25	11	275	164	45100
	Mid-season	30	25	5	125	164	20500
	late season	15	25	0	0	0	0
	Total	100			650	164	**106600**
onion	initial	15	20	12	240	164	39360
	developmen t	25	20	13	260	164	42640
	mid season	70	20	18	360	164	59040
	late season	40	20	8	160	164	26240
	total	150			1020	164	**167280**
Water-melon	initial	25	5	11	55	164	9020
	developmen t	30	5	15	75	164	12300
	mid season	35	5	17	85	164	13940
	late season	30	5	5	25	164	4100
	total	120			240		**39360**

Table-A. 4 Applied irrigation water use with furrow irrigation for December, 20/2018 to May, 28/2019.

Furrow irrigation Method in the season of dec,2018to may,2019							
Crop	Growth stage	Days of growth	area (ha)	irrigation time per hectare (hr/ha)	total time (hr)	well Discharge (m^3/hr)	Volume of water used in (m^3)
Chickpea	initial	25	22	11	242	158	38236
	development	30	22	12	264	158	41712
	Mid-season	30	22	5	110	158	17380
	late season	15	22		0	158	0
	Total	100			616	158	**97328**
garlic	initial	15	3	15	45	158	7110
	development	25	3	13	39	158	6162
	mid season	70	3	17	51	158	8058
	late season	40	3	8	24	158	3792
	total	150			159	158	**25122**
onion	initial	15	23	13	299	158	47242
	development	25	23	14	322	158	50876
	mid season	70	23	20	460	158	72680
	late season	40	23	7	161	158	25438
	total	150			1242	158	**196236**
Water-melon	initial	25	2	13	26	158	4108
	development	30	2	16	32	158	5056
	mid season	35	2	17	34	158	5372
	late season	30	2	7	14	158	2212
	total	120			106		**16748**

Appendix- B: Growth stages of crops

Table-B. 1 Growth stages of cultivated crops in the scheme

Crops	Initial	Development	Mid-stage	Late-season	Total
Chickpea	25	30	30	15	100
Garlic	15	30	65	40	150
Onion	15	25	70	40	150
Watermelon	25	35	40	20	120

Appendix C. Yearly rain fall from 2002 – 2017

Table-C. 1 Yearly rainfall in mm from 2002-2017

Year	2002	2003	2004	2005	2006	2007	2008	2009
Month								
Jan	22.3	32.7	29.9	8.3	0.0	17.8	13.7	9.6
Feb	2.5	32.7	0.0	0.0	10.8	11.8	44.0	76.2
Mar	0.0	34.8	28.1	34.0	46.7	36.9	59.3	81.6
Apr	31.3	66.3	88.1	158.2	56.6	46.6	37.7	28.7
May	47.0	32.8	3.0	125.6	16.2	7.7	18.8	30.0
Jun	67.0	11.0	25.9	2.8	3.0	29.0	15.2	1.4
Jul	99.7	138.0	116.2	125.2	81.2	220.7	183.3	145.9
Aug	116.6	247.5	162.4	190.9	222.9	220.7	164.0	126.3
Sep	16.0	41.8	9.2	23.2	75.4	16.3	139.4	10.8
Oct	0.0	0.0	74.2	8.7	12.5	0.0	6.3	52.2
Nov	66.6	0.0	35.5	64.8	0.0	0.0	31.9	21.1
Dec	66.6	42.8	10.2	0.0	16.6	0.0	0.0	51.7
total	**536**	**680**	**583**	**742**	**542**	**608**	**714**	**635**

Conti……

Year	2010	2011	2012	2013	2014	2015	2016	2017
Month								
Jan	0.0	0.0	0.0	18.8	0.0	1.2	0.0	0.0
Feb	11.4	8.7	6.0	18.8	7.7	52.7	97.7	90.0
Mar	4.3	28.8	53.4	0.0	58.6	87.9	166.2	58.6
Apr	63.8	30.2	35.8	7.3	57.5	86.3	141.4	57.5
May	64.3	79.5	14.8	57.5	158.1	237.2	240.8	158.1
Jun	1.8	0.0	43.5	4.9	4.5	3.0	1.4	1.4
Jul	239.4	109.0	148.9	138.7	154.2	131.0	107.8	145.9
Aug	316.6	177.5	233.3	61.6	255.8	192.6	129.3	126.3
Sep	33.9	10.8	38.0	30.4	189.7	142.3	94.9	10.8
Oct	14.7	13.4	19.0	0.0	189.7	98.4	7.1	52.2
Nov	0.0	62.8	0.0	0.0	189.7	105.4	12.0	0.0
Dec	0.5	0.0	4.0	0.0	189.7	120.7	21.0	0.0
total	**751**	**521**	**597**	**338**	**1455**	**1259**	**1020**	**701**

Appendix- D: CROPWAT 8.0 window program outputs

Crop water requirement report # 1

-ETo station: Kobo crop: **Chickpea**

-Rain station: Kobo planting date: December, 20

- Calculation time step =10 Day(s)

- Irrigation Efficiency =80%

- Printing Time 15/09/19 6:24:26 PM

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	2	initial	0.4	1.64	1.6	1.1	1.6
Dec	3	initial	0.4	1.68	18.4	8.5	10.0
Jan	1	initial	0.4	1.71	17.1	4.3	12.8
Jan	2	deve	0.46	1.99	19.9	1.3	18.6

Jan	3	deve	0.66	3.15	34.6	4.0	30.6
Feb	1	deve	0.88	4.54	45.4	7.3	38.1
Feb	2	mid	1.01	5.62	56.2	9.4	46.8
Feb	3	mid	1.01	5.53	44.2	11.2	33.0
Mar	1	mid	1.01	5.40	54.0	13.3	40.7
Mar	2	late	0.92	4.84	48.4	15.2	33.2
Mar	3	late	0.53	2.75	24.8	13.4	8.4

Crop water requirement report # 2

- ETo station: Kobo crop: **Garlic**
- Rain station: Kobo planting date: December, 20
- Calculation time step =10 Day(s)
- Irrigation Efficiency =80%
- Printing Time 15/09/19 7:07:17 PM

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req mm/dec
Dec	2	initial	0.7	2.87	2.9	1.1	2.9
Dec	3	initial	0.7	2.93	32.3	8.5	23.8
Jan	1	deve	0.73	3.12	31.2	4.3	26.9
Jan	2	deve	0.83	3.62	36.2	1.3	34.9
Jan	3	deve	0.94	4.43	48.8	4.0	44.8
Feb	1	mid	1.01	5.21	51.1	7.3	44.8
Feb	2	mid	1.01	5.62	56.2	9.4	46.9
Feb	3	mid	1.01	5.52	44.2	11.2	32.9

Mar	1	mid	1.01	5.39	53.9	13.3	40.7
Mar	2	mid	1.01	5.33	53.3	15.2	38.0
Mar	3	mid	1.01	5.27	58.0	16.4	41.7
Apr	1	late	1.01	5.21	52.1	17.4	34.8
Apr	2	late	0.95	4.88	48.8	18.5	30.3
Apr	3	late	0.88	4.61	46.1	20.2	25.9
May	1	late	0.80	4.32	43.2	24.1	19.1
May	2	late	0.74	4.05	32.4	21.4	5.6

Crop water requirement report # 3

-ETo station: Kobo crop: **Onion**

-Rain station: Kobo planting date: December, 20

- Calculation time step =10 Day(s)

- Irrigation Efficiency =80%

- Printing Time 15/09/19 7:58:08 PM

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	2	initial	0.7	2.87	2.9	1.1	2.9
Dec	3	initial	0.7	2.93	32.3	8.5	23.8
Jan	1	deve	0.74	3.17	31.7	4.3	27.4
Jan	2	deve	0.88	3.84	38.4	1.3	31.1
Jan	3	mid	1.02	4.84	53.3	4.0	49.3
Feb	1	mid	1.06	5.48	54.8	7.3	47.5
Feb	2	mid	1.06	5.91	59.1	9.4	49.7

Feb	3	mid	1.06	5.80	46.4	11.2	35.2
Mar	1	mid	1.06	5.66	56.6	13.3	43.4
Mar	2	mid	1.06	5.59	55.9	15.2	40.7
Mar	3	mid	1.06	5.54	60.9	16.4	44.6
Apr	1	late	1.06	5.47	54.7	17.4	37.4
Apr	2	late	1.0	5.14	51.4	18.5	32.9
Apr	3	late	0.93	4.88	48.8	20.2	28.6
May	1	late	0.85	4.59	45.9	24.1	21.8
May	2	late	0.79	4.33	34.6	21.4	7.8

<u>Crop water requirement report # 4</u>

-ETo station: Kobo crop: **<u>Watermelon</u>**

-Rain station: Kobo planting date: December, 20

- Calculation time step =10 Day(s)
- Irrigation Efficiency =80%
- Printing Time 15/09/19 7:59:27 PM

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req mm/dec
Dec	2	initial	0.4	1.64	1.6	1.1	1.6
Dec	3	initial	0.4	1.68	18.4	8.5	10.0
Jan	1	initial	0.4	1.71	17.1	4.3	12.8
Jan	2	deve	0.45	1.96	19.6	1.3	18.3
Jan	3	deve	0.63	2.96	32.6	4.0	28.6

Feb	1	deve	0.81	4.18	41.8	7.3	34.5
Feb	2	mid	0.97	5.42	54.2	9.4	44.8
Feb	3	mid	1.01	5.53	44.2	11.2	33.0
Mar	1	mid	1.01	5.89	53.9	13.3	40.9
Mar	2	mid	1.01	5.33	53.3	15.2	38.1
Mar	3	late	1.00	5.26	57.8	16.4	41.5
Apr	1	late	0.91	4.74	47.4	17.4	30.0
Apr	2	late	0.80	4.11	32.9	14.8	14.3

Appendix-E: Crop evapotranspiration and irrigation requirements of the crop are shows below

Chart- A,

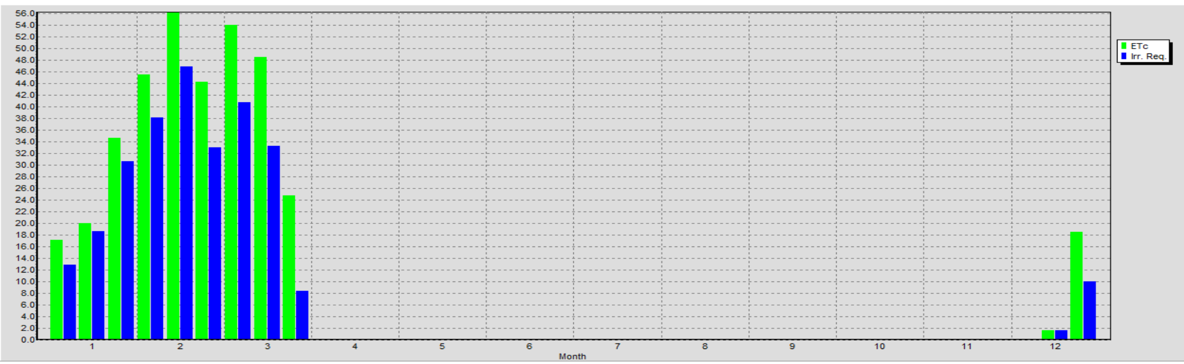

Figure- A. 1 Chart of evapotranspiration and irrigation requirement for chickpea.

Chart- B,

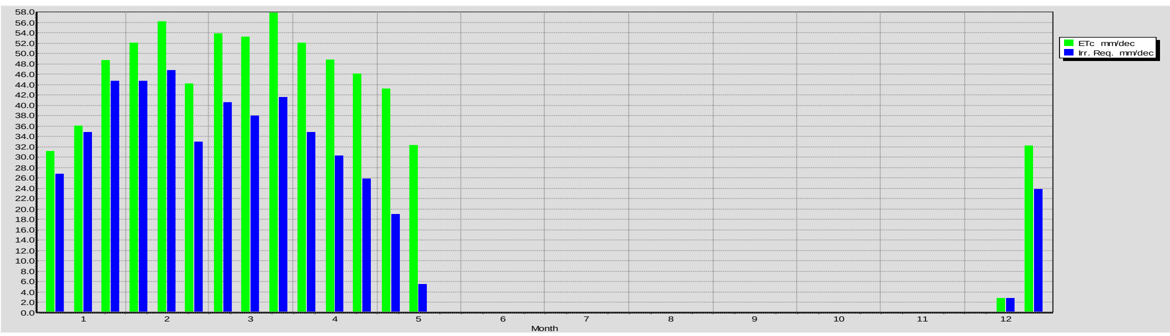

Figure- A. 2 Chart of evapotranspiration and irrigation requirement for Garlic.

Chart- C,

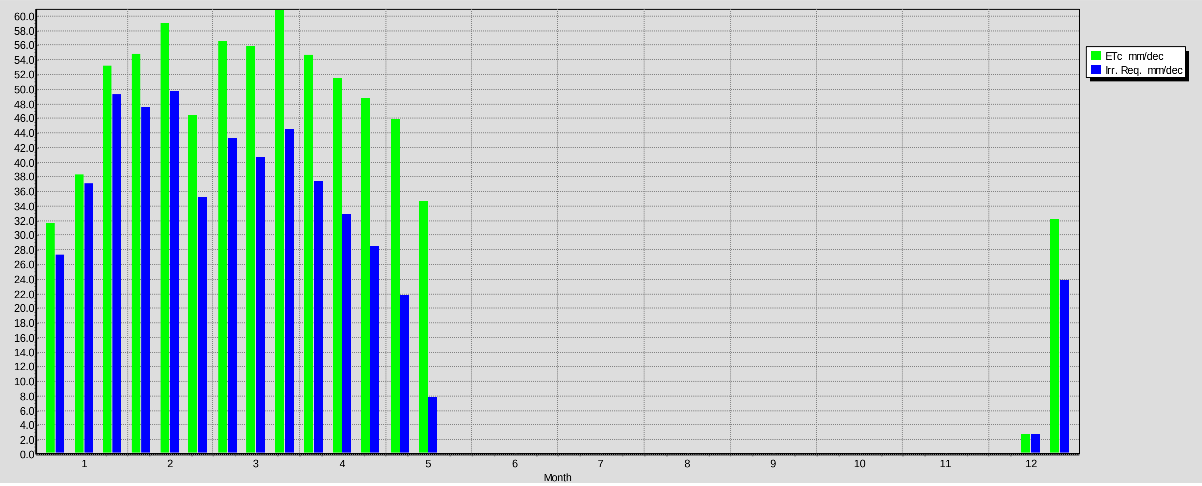

Figure- A. 3 Chart of evapotranspiration and irrigation requirement for Onion.

Chart- D,

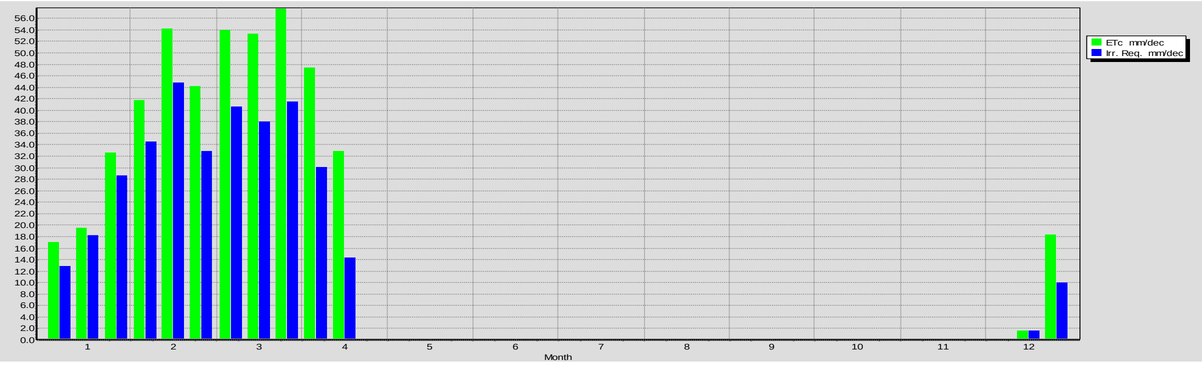

Figure- A. 4 Chart of Evapotranspiration and irrigation requirement of Watermelon.

Appendix- F: Irrigation time requirement from the questionnaires and interview

Irrigation methods			Drip irrigation		Furrow irrigation	
Irrigation season			20/12/17-25/05/18	18/12/18-19/05/19	15/12/17-20/05/18	20/12/18-28/05/19
Cultivated crop	Growth stage	Days of growth (day)	Time to irrigate per hectare (hr/ha.)	Time to irrigate per hectare (hr/ha.)	Time to irrigate per hectare (hr/ha.)	Time to irrigate per hectare (hr/ha.)
Chickpea	Initial	25	6	7	10	11
	Development	30	7	5.5	11	12
	Mid-season	30	3	3	5	5
	Late-season	15	0	0	0	0
	Total	100				
Garlic	Initial	15	6	6		15
	Development	25	7	9		13
	Mid-season	70	12	12		17
	Late-season	40	6	6		8
	Total	150			0	
onion	Initial	15	6		12	13
	Development	25	8		13	14
	Mid-season	70	16		18	20
	Late-season	40	6		8	7
	Total	150				
Water-melon	Initial	25	8	6	11	13
	Development	35	10	12	15	16
	Mid-season	40	16	16	17	17
	Late-season	20	3	3	5	7

Appendix-G: Hormat-Golina irrigation scheme water use Questionnaires

Questionnaires were developed to gather data from individual water users in the agricultural and non-agricultural sectors. Each questionnaire included a section on contact information, amount of water use in the field, and amount information, planting date, crop type, harvesting date, fertilizer amount and well information.

Questions were structured to collect information that was immediately available or easily obtained by the well owner/operator. Information on water use patterns was collected to allow for a calculation or estimate of water use when records and user estimates were unavailable.

A: contact Information and location

Respondent

Name ________________________________

Do you agree to answer this question? A) Yes B) no if you say yes, go next step

Sex ________________________________

Village _____________________________

Phone number________________________

B: Amount of water used

1. How much hectare of land do you have (ha)?

____

2. Out of how much area is only irrigated in dry season (ha)?

____

3. What is your main water source for irrigation?

   A) Well, B) Bore hole, C) other

4. Do you use well water? A) No B) yes,
5. How deep is your farm well? (m) or don't know
6. What is your methods of irrigation?

   A) Drip B) Furrow C) Sprinkler D) other

7. How much hectare of land is only irrigated by well (ha)?

   ____

8. Which crops do you irrigate?

A=Teff, B=Onion, C=cabbage, D=masho, E=Garlic, F=Chickpea, G=Watermelon, H=others

9. Please fill detail of irrigated crops;

Area: Crop area (indicate square meter or hectares) use the maximum area irrigated Amount: Amount of water for one application during a dry season (indicate mm or litters)

Duration: Length of time for one irrigation application per unit hectare (indicate hours, days, or weeks)

Season: Length of irrigation season (indicate weeks or months)

Chickpea area ____________amount _____________ duration _________ season ____

Garlic area ____________ amount ______________ duration _________season____

Onion area ____________amount ______________ duration ________season ____

Watermelon area ____________ amount ______________ duration ________season ____

10. What is the amount of fertilizer applied to irrigated crops?

Chickpea quintal/ha ________________

Garlic quintal/ha ________________

Onion quintal/ha ________________

Watermelon quintal/ha ________________

11. What is the average yield of crops from irrigated land in the season 2017/18 and 2018/19?

Chickpea quintal/ha _________ and ____________

Garlic quintal/ha _________and ___________

Onion quintal/ha ________and ____________

Watermelon quintal/ha _______and ___________