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ASRIC Journal on Water, Energy and Environment 1 (2020) 34-60

Performance Evaluation of Small Scale Irrigation Schemes By Using Process and Comparative Indicators: Case Study on Golina and Kokono Small Scale Irrigation Schemes, North Wollo Zone, Amhara Region, Ethiopia

Ketema Feye Ayane [a,1]

[a] *Debre Tabor University, Hydraulic and Water Resources Engineering Department, Debre Tabor, Ethiopia*

Received 11 November 2019; revised 20 July 2020; accepted 3 December 2020

Abstract

The study was conducted to evaluate the performance of two small scale irrigation schemes at north Wollo zone, Amhara regional state using process and comparative performance indicators. The irrigation schemes were Golina and Kokono with command area of 400ha and 80ha respectively. Primary data collection includes measuring discharge at diversion weir, soil moisture before and after irrigation and depth of water applied. The secondary data collection includes determination of crop types, total yields, farm gate prices of irrigated crops, area irrigated per crop per season, and cost of production. The two schemes were compared using minimum sets of comparative performance indicators which include agricultural, water use and physical performance indicators. The process indicators (conveyance, application and storage) were used to check the performance of the two schemes. From the analyses of the internal performance indicators, the conveyance, application, storage and overall efficiencies were found to be 76.58%, 52.51%, 48.38% and 40.21% for Golina scheme and 38.02%, 65.93%, 44.89% and 25.07% for Kokono scheme respectively. From the analysis of comparative indicators, the outputs per cropped area were found as 1111.67 and 753.38 us$ ha^{-1}, the value of the outputs per command area of schemes were 2166.37 and 768.44 us$ ha^{-1}, the output per unit irrigation supply of 0.11 and 0.1us$$m^{-3}$, output per water consumed was 0.2 and 0.18 us$ m^{-3} for Golina and Kokono respectively. The water use performances of the two schemes were compared, RWS found to be 1 at both schemes and RIS was found as 4 and 1.7 at Golina and Kokono. The irrigation ratio of Golina was found to be 0.974 and that of Kokono was 0.51. In general, based on the assessment carried out, Golina scheme performed better than Kokono scheme.

Keywords: Golina; Kokono; Irrigation; Performance; Indicators; Scheme

1. Introduction

Agriculture is regarded as the backbone of Ethiopian economy and a key driver of its long term growth and food security. It directly supports 85 percent of the population constitutes 45 percent of gross-

[1] Corresponding author. *Email addresses*: (K.F. Ayane)

domestic product (GDP), and 85 percent of export value (Tilahun *et al*., 2011). The majority of population of Ethiopia is dependent on rain-fed agricultural production for its livelihood. However, estimated crop production is not close to fulfill the food requirements of the country. One of the best alternatives to consider for reliable and sustainable food security development is expanding irrigation development on various scales (whether small, medium or large) and options (diversion, storage, gravity, pumped, etc.) (Lambisso, 2008).

Irrigation development has been identified as an important tool to stimulate economic growth and rural development, and is considered as a cornerstone of food security and poverty reduction in Ethiopia. Increased availability of irrigation and less dependency on rain-fed agriculture is taken as a means to increase food production and self-sufficiency of the rapidly increasing population of the country (Awulachew *et al*., 2010c).

The irrigation development is increased when the construction and the function of irrigation scheme increased. However, despite water resources and irrigation potential in Ethiopia best owed, the area developed under irrigation is less than its potential. Even those developed irrigation schemes do not perform well as planned and expected because of several inter related factors. One of the factors of the irrigation potential is the performance of conveyance structure is not well functional. Therefore, improving the performance of the irrigation scheme is one of the issues of development of irrigation in developing countries and also crucial due to relatively low performances (Awulachew and Ayana, 2011).

Improving the water utilization of the scheme, which requires improving the management skills of the users, is one challenge to be tackled to ensure the sustainability of the schemes. In the country, water development for agriculture is a priority, but poorly designed and planned irrigation undermines efforts to improve livelihoods and exposes people and environment to risks. Recent estimates indicate that the total irrigated area in Ethiopia is 640,000 ha around 4 to 5 % of the existing cultivated area and 12% of its irrigation potential (Awulachew *et al.*, 2010c).

Poor management of irrigation water is one of the principal reasons for the low water use efficiency in irrigation. As available water resources become scarce, more emphasis is given to efficient use of irrigation water for maximum economic return and water resources sustainability. This requires measuring how efficiently water is extracted from a water source and used to produce crop yield. The inadequate and often unreliable water deliveries in the main system cause farmers to face regular shortages in the water supply, resulting in reduced yields and incomes as well as in much smaller areas being irrigated than originally planned. At field level, inappropriate field layout and mismanagement also lead to further water losses and reduced yields. There is a need for research and capacity building to understand the complex issues of water use and water management, so as to enhance national and local capacity to deal with water and land management issues to enhance food security, reduce poverty and speed up national economic development.

2. Materials and Methods

2.1. Description of Study Area

Golina irrigation scheme: Golina Irrigation Scheme is found in Eastern Amhara Regional state under North Wollo administrative zone, Kobo district. It is located 10 km far from Kobo town in the south direction and 38 km from Woldiya town in the Northern direction. Geographically, the scheme lies at $12^{\circ}04'00''$ N to $12^{\circ}05'30''$ N latitude and $39^{\circ}37'00''$ E to $39^{\circ}39'30''$E longitude. The scheme was implemented to irrigate 400 ha of land.

The diversion weir of this irrigation scheme was constructed on Golina River by Commission for Sustainable Agriculture and Environmental Rehabilitation in Amhara Region (Co- SAERAR) in 1991 E.C and gave a service for 19 years operational period. The silt excluder, settling basin, and spillways of the scheme are working properly. Golina irrigation scheme was classified into 5 blocks for operation and management purpose and there are 5 water user groups.

The length of main canal of this scheme is 2.66 km (the lined main canal is about 1.4 km long while the unlined main canal is about 1.26 km long). There are 5 earthen secondary canals, 5 division boxes and

15 drop structures constructed on the main canal. In the irrigation scheme, flow control gates (metal sheets) were installed in the whole irrigation system at division boxes or turnouts, but half of them became un-functional.

Kokono Irrigation Scheme: Like Golina irrigation scheme, Kokono small scale Irrigation Scheme is found in Eastern Amhara Regional state under North Wollo administrative zone, Habru district, 033 and 034 kebeles. It is located 5 km far from district town and 30 km from zone town. Geographically, the scheme lies at $\mathbf{11^{\circ}39'40''}$ N to $\mathbf{11^{\circ}40'40''}$ N latitude and $\mathbf{39^{\circ}39'40''}$ E to $\mathbf{39^{\circ}40'50''}$ E longitude and it covers the area of 80 ha.

The diversion weir were constructed on Kokono River in 1991 E.C by Commission for Sustainable Agriculture and Environmental Rehabilitation in Amhara Region (Co- SAERAR) having a design area of 80 ha. According to the report of Habru District, the Kokono weir was damaged and re-constructed by Amhara water works construction enterprise (AWWCE) in 2005 E.C.

The main canal of Kokono small scale irrigation scheme is unlined and has a total length of 1.14 km; sediment and seepage are the big problem of this scheme. For operation and management purpose the command area was classified in to 3 water user groups.

2.2. Data Collection Methods

This research was carried out starting from November 2017 to June, 2018 of the two irrigation seasons. Primary and secondary data have been gathered and engaged for the study purpose. For field data collection and measurement purposes, Current Meter, Double ring Infiltrometer, Auger, measuring Tape, Parshall Flume, GPS and Sensitive Balance were used during the study period.

2.2.1. Primary data collection

The primary data were collected through field observations, measurements and laboratory analyses. Field topography and configurations, water applications and practices related to water management techniques made by the farmers, measurements of discharge at diversion (intake) points of each irrigation scheme and also at the initial and final points of main, secondary, tertiary and field canals, soil samples (for the determination of different soil parameters) and soil infiltration rate test were recorded for both irrigation schemes.

Additionally GPS data were also recorded to locate the boundary of the command area, actual canals network and location of canal structures. This was done by walking around the boundary of the command area and along canals and taking point data. These point data were transferred to map source then downloaded to GIS software, and then digitized to locate the command area with irrigation canal network and layout within the boundary on ArcGIS.

2.2.2. Secondary data collection

For each of the selected irrigation schemes, secondary data were collected from Agricultural and Rural Development Office, Water Resource Offices and irrigation offices at regional, zonal, district levels. The secondary data included total yields, farm gate prices of irrigated crops, area irrigated per crop per season, production cost per season, incomes generated by the irrigation associations and cropping pattern. Climatic data of the irrigation schemes were collected from the nearby meteorological station. For Golina small scale irrigation scheme, total command area, irrigable area, irrigated area, crop yield and price, were collected from Kobo district and Weldiya Zone agricultural experts, DA's reports of Aradom kebele 08 while for Kokono small scale irrigation scheme, Habru district and DA's reports of kebele 033 and 034. Key informant interviews with respective stakeholders and group discussions were carried out for verification of information gathered. A comprehensive field survey has been carried out starting from November 2017.

2.3. Methods used to measure performance indicators

There are large numbers of indicators proposed by different researchers to evaluate the performance of irrigation systems (Bos *et al*., 2005). All performance indicators can however be broadly classified into internal or process indicators and external or comparative indicators (Renault *et al*., 2007). The purpose of comparative indicators is to evaluate outputs and impacts of activities related to irrigation management and interventions across different systems or within the same system over time, while process indicators are used to assess the actual irrigation performance in relation to system-specific management goals.

2.2.3. Internal performance indicators

These indicators examine the technical or field performance of a project by measuring how close an irrigation event is to an ideal one. An ideal or reference irrigation is one that can apply the right amount of water over the entire region of interest (i.e. depth of root zone) uniformly and without losses. Analysis of the field data allows quantitative definition of the irrigation system performance. The performance of irrigation practice is determined by the efficiency with which the water is conveyed through the canal, how irrigation is applied to the field, how adequate the amount is and how the application is uniformly applied to the field (Feyen and Zerihun, 1999).

a. Conveyance efficiency

Significant volume of water is lost by the networks of the conveyance canals due to seepage and evaporation depending on the nature of the soil and agro-climatic zone in which the canals are located. Conveyance efficiency is defined as the ratio of the amount of water that reaches the field to the total amount of water diverted into the irrigation system and can be expressed as:

$$\mathrm{E_c} = 100\left(\frac{\mathrm{Q_{out}}}{\mathrm{Q_{in}}}\right)\% \tag{1}$$

Where: Ec is conveyance efficiency (%), Q_{in} and Q_{out} are the inflow and outflow discharge in specified canal reach.

The concept can also be viewed as the evaluation of the water balance of the main, secondary and tertiary canals and related structures of the irrigation system (Murray-Rust, 1993). It is one of the several closely related and commonly used output measures of performance that focus on the physical efficiency of water conveyance by the irrigation system (Bos, 1997). Losses of irrigation water in the conveyance system can be a major component of the overall water losses particularly for farms located at significant distances from water sources where the main canals are long and unlined. The amount lost depends on quality of operation, maintenance and the nature of the soil that affects the seepage rate.

b. Application efficiency

Depending on the type of the source, water is diverted, or pumped to a canal or pipe for conveyance to the farm for distribution and finally for application to the crops in the field. When water is diverted into any water application system such as furrows, part of the water infiltrates into the soil for consumptive use by the crop, while the rest is lost as deep percolation and as runoff. The efficiency terms determine these components and compare them with the volume of water actually applied to the field is regarded as application efficiency. The term is an indication of the effectiveness of the system in reducing losses during an irrigation event.

The Application Efficiency is a term initially formulated by Israelson (1950) and measures the ratio between the volumes (depth) of water stored in the root zone for use by the plant to the volume (depth) of water applied to the field. The term has been expressed in different ways over the years to include different parameters by different authorities. Field irrigation efficiencies are influenced by factors such as soil type, field application methods, depth of application and climate. Very high values are achieved in arid climates and where water shortages prevail. However, in the area where the water applied exceeds water required, indicating an over irrigation, emphases should be given to reduce the amount of irrigation water (Hailu and Shiberu, 2011). The water application efficiency is defined as:

$$E_a = 100\left(\frac{w_c}{w_f}\right) \qquad (2)$$

Where: w_f the water delivered to the field and w_c is water available for use by the crop.

c. Storage efficiency

The water storage efficiency refers how completely the water needed prior to irrigation has been stored in the root zone during irrigation. It is the ratio of the quantity of water stored in the root zone during irrigation event to that intended to be stored in the root zone. The value is important either when the irrigations tend to leave major portions of the field under-irrigated or where under-irrigation is purposely practiced to use precipitation as it occurs. This parameter is most directly related to the crop yield since it will reflect the degree of soil moisture stress. Usually, under-irrigation in high probability rainfall areas is a good practice to conserve water but the degree of under-irrigation is a difficult question to answer at the farm level (Hailu and Shiberu, 2011). The total available water in the root zone is the difference between the water content at field capacity and wilting point (Allen *et al.*, 1998).

$$\mathrm{TAW} = 1000(\mathrm{FC} - \mathrm{PWP})\mathrm{Z_r} \qquad (3)$$

Where: TAW the total available soil water in the root zone [mm], FC the water content at field capacity [m^3 m^{-3}], PWP the water content at permanent wilting point [m^3 m^{-3}], Z_r is the rooting depth [m]. TAW is the amount of water that a crop can extract from its root zone, and its magnitude depends on the type of soil and the rooting depth. The fraction of TAW that a crop can extract from the root zone without suffering water stress is the readily available soil water.

$$\mathrm{RAW} = \mathrm{pTAW} \qquad (4)$$

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

If there are plants growing on the soil, the moisture level continues to drop until it reaches the "permanent wilting point" (PWP). Soil moisture content near the wilting point is not readily available to the plant. Hence the term "readily available moisture" has been used to refer to that portion of the available moisture that is most easily extracted by the plants, approximately 75% of the available moisture. After that, the plants cannot absorb water from the soil quickly enough to replace water lost by transpiration (Yusuf, 2004). Therefore, readily available moisture is:

$$\mathrm{W_n} = 75\%\mathrm{TAW} \qquad (5)$$

Then the storage efficiency is calculated as:

$$\mathrm{E_s} = \frac{\mathrm{W_d}}{\mathrm{W_n}} \qquad (6)$$

Where $\mathrm{W_d}$ water stored in the root zone during irrigation event (mm) and $\mathrm{W_n}$ is water desired to be stored in the root zone (mm).

d. Overall scheme efficiency

Irrigation efficiencies are evaluated at scheme or farm level for the purpose of identifying the losses that occur in the irrigation system starting at the water abstraction point, through the conveyance system down to water application in the field to determine the overall irrigation efficiency. In addition to design and other technical factors, the farm efficiency is much regulated by the operation of the main supply system to meet the actual field supply requirements and the skill of the system operators (FAO, 1977). Burman *et al.* (1983), defined the overall irrigation efficiency (or farm irrigation efficiency) as the product of the component terms (E_c, E_a), expressed as ratios.

$$\mathbf{E_o = E_c * E_a} \quad (7)$$

2.2.4. External performance indicators

External performance indicators evaluate irrigation systems based on a relative comparison of absolute values rather than being referenced to standards or target. Many indicators used for external performance evaluation can be calculated from secondary data rather than primary data. These set of indicators are designed to show gross relationship and trends and are useful in indicating where more detailed study should take place, where a project has done extremely well, or where dramatic changes take place. According to Bos *et al.* (1994), external performance indicators are grouped as:

a. Agriculture performance indicators

A number of indicators were developed with regard to irrigated agricultural systems. They are used for the evaluation of the project performance in terms of the production it results in. It expresses the output of irrigated area in terms of the gross or net value of production measured at local or world prices. This addresses the direct impact of operational inputs in terms of such aspects as area actually irrigated and crop production, over which an irrigation manager may have some but not full responsibility. Four indicators related to the output of different units were used for the evaluation of agricultural performance. These indicators were calculated as follows (Malano *et al.*, 2004 and Molden *et al.*, 1998)

$$\text{Output per cropped area} = \frac{\text{Value of production(\$)}}{\text{Irrigated Cropped area(ha)}} \quad (8)$$

$$\text{Output per unit Command} = \frac{\text{Value of production(\$)}}{\text{command area(ha)}} \quad (9)$$

$$\text{Output per unit irrigated supply} = \frac{\text{Value of production(\$)}}{\text{Diverted Irrigation supply } (\text{m}^3)} \quad (10)$$

$$\text{Output per unit water consumed} = \frac{\text{Value of production(\$)}}{\text{volume of water consumed by ET } (\text{m}^3)} \quad (11)$$

Value of production: is the output of the irrigated area (US$) in terms of the gross or net value of production measured at local or world prices. Irrigated cropped area (ha) is the sum of areas under crops during the time period of analysis. Command area (ha) is the nominal or design area to be irrigated. Diverted irrigation supply (m^3) is the volume of surface irrigation water diverted to the command area. In this study production from irrigated agriculture is the principal issue to compare systems. However there are difficulties when comparing different crops across a system, say onion and tomato, as 1kg of onion is not readily comparable with 1kg of tomato. When only one irrigation system is considered, or irrigation systems in a region where prices are similar, production can be measured as the net value of production and gross value of production using local values. As a result, agricultural output production values were determined through local price and finally, they were converted to US$; to standardize and to compare the results relative to other research findings in the world.

b. Water supply indicators

Molden *et al.* (1998), states that the water supply indicators (relative water supply and relative irrigation supply) are better suited to place the irrigation system in its physical and management context.

Higher values of these indicators indicate a more generous supply of water. In this case, productivity to land may be more important. Where the water supply indicators show a lower value it indicates a situation of a more constrained water supply and values of productivity per unit of water are more important.

According to Bos *et al.* (1994), these indicators deal with the primary task of irrigation managers in the capture, allocation, and conveyance of water from a source to field by management of irrigation facilities. Indicators address several aspects of this task: efficiency of conveying water from one location to another, the extent to which agencies maintain irrigation infrastructure to keep the system running efficiently, and the service aspects of water delivery which include such concepts as predictability and equity.

i. Relative water supply (RWS)

According to Levine (1982), Relative water supply indicates the adequacy of water applied to the amount of water demanded by the crop. It is the ratio of total water supplied by irrigation plus rainfall to total water demanded by crop i.e. actual crop evapotranspiration (*ETc*).

$$\text{Relative water supply} = \frac{\text{Total water supply}}{\text{Cropped water demand}} \qquad (12)$$

Where, Total water supply = diverted water for irrigation plus rainfall (m^3), Crop water demand = potential crop evapotranspiration, or the real evapotranspiration (ETc) when full crop water requirement is satisfied (m^3).

ii. Relative irrigation supply (RIS)

This is the second water supply indicator and described as the ratio of irrigation supply to irrigation demand. Irrigation water is a scarce resource in many irrigation schemes and it is a major constraint for production. This indicator is useful to assess the degree of irrigation water stress/abundance/ in relation to irrigation demand (Molden et al., 1998 and Perry, 1996).

$$\text{Relative irrigation supply} = \frac{\text{irrigation supply}}{\text{irrigation demand}} \qquad (13)$$

Irrigation supply = only the surface diversion for irrigation (m^3), Irrigation demand = the crop ET minus effective rainfall (m^3).

RIS relates irrigation supply to irrigation demand of the irrigation schemes in the production season. The computed value shows some indication as to the condition of water abundance or scarcity, and how tightly supply and demand are matched. If the value greater than 1, it indicates irrigation supply was beyond the irrigation demand; if it is less than 1, the irrigation supply was below the irrigation demand. While if it is equal to 1, the supplied amount of irrigation was sufficient to demand, i.e. neither surplus nor deficit. Most of the time it is better to have a RIS near 1 than a higher value.

However, the indicator did not show the monthly relation between irrigation supply and irrigation demand. Additionally, care must be taken in the interpretation of results; the value 0.8 may not represent a problem; rather it may provide an indication that farmers are practicing deficit irrigation with a short water supply to maximize returns on water.

c. Physical performance indicators

Physical indicators are related to changing or losing irrigated land in the command area due to different reasons. Water scarcity and input availability are the main reasons why lands in command area are not fully under irrigation in a particular season. From physical performance, two important indicators were selected to measure the sustainability and irrigation intensities of the system.

i. Irrigation Ratio

Sener *et al.* (2007), developed a relation between currently irrigated areas to the command (nominal) area to be irrigated to quantify the level of utilization of the potential irrigable area for irrigated agriculture for a particular production time period. Lower utilization of the given irrigable area may be due to different constraints; i.e. lack of irrigation infrastructure, shortage of irrigation water, lack of interest on irrigation due to less return and market problems, and reduced productivity due to (soil nutrient depletion, lack of improved technologies, lack of inputs and waterlogging) etc.

To compute the indicator information of irrigated areas in the irrigation season and designed irrigable areas of both schemes were collected from Agricultural and Rural development Offices. Irrigation ratio is determined as follows (Molden et al., 1998).

$$\text{Irrigation ratio} = \frac{\text{Irrigated area}}{\text{command (nominal) irrigable area}} \qquad (14)$$

Where, Irrigated area = irrigated area in the irrigation season (ha), Command area = the design (nominal) irrigable area (ha).

3. Results and Discussion

3.1. Soil Physical Properties

To investigate some of the physical properties of soil in the study area (moisture content at field capacity (FC) and permanent wilting point (PWP), moisture content before and after irrigation, texture and bulk density), for the purpose of understanding the general feature of the irrigated soil type, different field samples were taken and analyzed.

3.1.1. Particle size distribution (texture)

Based on the laboratory analysis of particle size distribution, the textural class of Golina Small scale irrigation scheme was found to be clay loam at upper and lower and clay at the middle while the particle size distribution of Kokono Small scale irrigation scheme was clay loam at upper and middle and clay at lower.

3.1.2. Bulk density, field capacity, PWP and total available water

Bulk density

The bulk densities of the soil of the two small scale irrigation schemes varied between 0.95 and 1.37 gcm^{-3} at Golina and 1.13 to 1.34 gcm^{-3} at Kokono scheme. The average bulk density of the soil in the study area was found to be 1.18 gcm^{-3} and 1.25 gcm^{-3} at Golina and Kokono small scale irrigation schemes respectively. Edelson *et al.* (1995), recommended the soil bulk density below 1.4 gcm^{-3} for clays and 1.6 gcm^{-3} for sands in order to get better plant growth. The bulk density values of the soils at both irrigation schemes were low as per the bulk density rating of Van den Akker *et al.* (2003) indicating that there was no compaction that could limit infiltration of water into and through the soil and root penetration.

Field capacity, permanent wilting point, and total available water

Volumetric moisture content retained at field capacity varied from 19-40% and 17-40% at Golina and Kokono irrigation schemes respectively while the volumetric moisture content at permanent wilting point varied from 7-20% for soils of both irrigation schemes. Furthermore, the total available water holding capacity of soils selected fields from Golina scheme ranged from 120-250 mm m^{-1} and 100-240 mm m^{-1} at Kokono. In general soil of both schemes are medium as per available water holding rating (McIntyre, 1974 and ICE, 1983). The results depict that the relevant soil physical properties measured are not different from a great deal from each other with depth and that the soils of the study area are homogeneous.

3.1.3. Soil Infiltration Rate

The infiltration rate was measured at the head, middle and tail end of three test plots to determine the infiltration characteristics of the soil using double ring infiltrometer. Infiltration rate is very rapid at the start of water application, but it decreases rapidly with the advance of time and eventually approaches a constant value. The nearly constant infiltration rate that reaches after some elapsed time from the start of irrigation is termed as the basic infiltration rate.

From the result obtained the average basic infiltration rates of Golina and Kokono Small scale irrigation schemes were measured as 6 mm/h and 5.4 mm/h respectively. The infiltration rates of both schemes were between the ranges recommended by FAO. According to Kay (1986), the basic infiltration rate of soil in the range of 1-10 mm/hr, is classified as soil with low infiltration rate which is the typical characteristics of clay textured soil. The textural class and average infiltration rate are agreed on the textural class of the schemes.

3.2. Determination of Reference Evapotranspiration (ET_o)

Based on the procedure described in the methodology part, ET_o values of the two schemes were computed. The minimum and maximum daily ET_o values of Golina irrigation scheme were 4.13 mm/day in December and 6.12 mm/day in June. In Kokono the maximum ET_o was estimated to be 4.88 mm/day in the month of May and the minimum was 2.73 mm/day in October. The estimated average daily ET_o values of Golina and Kokono SSI were 5.11 and 4 mm/day, respectively.

3.3. Water Flow Rate Measurement

It was quite difficult to measure water flow rates continuously from intake to farm inlets because there was a flow fluctuation; the farmer uses rotational scheduling systems. Sometimes, there were water abstractions in the upstream/illegal water users/ and the absence of reliable and functional flow control systems at each division boxes. The flow rate at intake, main canals, secondary canals and flow applied to the field was recorded five times for the purpose of determining conveyance efficiency, application efficiency and total water demand for irrigation. According to the primary field survey, the average discharge at the inlet of the intake gate was 394.334 l/s for Golina and 34.325 l/s for Kokono.

3.4.1. Water flow rate measurement at farm inlets

In Golina irrigation scheme the total inflow that came through the main canal got divided into five secondary canals and then it divided into twenty-seven tertiary canals. The measured observations indicated that a mean in-flow rate of 9.47 l/s reached the farm inlets. In the case of Kokono SSI scheme the total inflow that came through the main canal divided into 5 field canals. Measurements in farm inlets showed that a mean of 4.75 l/s inflow rate reached them.

The above two mean inflow rates were used for the determination of total water delivered to farm fields at both irrigation schemes. In both SSI scheme farmers have been practicing two irrigation seasons; the amount of diverted and delivered water in those schemes was the total sum of the two irrigation seasons for the year 2017/18.

3.4. Crop Water Requirements and Irrigation Requirements

CROPWAT 8.0 model computed the crop water requirements and it needs climatic data for ET_o computation, crop characteristics data and soil description for the determination of crop water requirements and irrigation water requirements. Crop water requirements are defined as the depth of water needed to meet the water loss through evapotranspiration. It was determined for the major crops grown in both irrigation schemes. The major crops grown during the study period have been identified for both schemes.

Crop coefficient (K_c), maximum root depth (m), crop height, yield reduction factor (K_y) values were adopted from FAO Irrigation & Drainage paper 24 and 56, the detailed values in growth stage based. The values of K_c in the growing period are represented by the crop coefficient curve, the values vary in the growing period. The CROPWAT 8.0 model required the three K_c coefficients (K_c of initial, development and late stages).

Furthermore, the allowable soil moisture depletion fraction for each crop at each growing stage was adopted from FAO I & D paper 24 and 56, and research documents. Allowable moisture depletion fraction is a critical soil moisture level where the first drought stress occurs affecting evapotranspiration and crop production. According to Wondatir (2016), the fraction normally varies from 0.2-0.6 with the lower value being for sensitive crops with limited rooting systems. To estimate yield reductions associated with drought stress, yield response factor (K_y) was given as an input variable in the crop data option.

Through the above input data, the total crop water and irrigation water requirements were computed for the estimation of total water demands at the irrigation schemes in the growing seasons. The total crop water requirement/demand/, irrigation requirements for the season I and II in both SSI schemes were presented in Table 1. To change the depth to the volume of CWR, total irrigation requirement was multiplied with the total irrigated area.

Table 1 CWR and IR per season for Golina and Kokono SSI schemes

Scheme	Season	CWR		IR		Eff. Rainfall	
		mm/season	m^3	mm/season	m^3/season	mm/season	m^3/season
Golina	I	602.2	2306879	115.4	442226.8	485.7	1860710
	II	544.7	1994703.4	154.5	565636.1	388.2	1421514.4
Kokono	I	381.2	150204.7	209.8	82680.5	178.6	70370.2
	II	465.7	194178.9	305.7	127465.8	191.4	79805.9

Where; CWR- crop water requirement, IR- irrigation requirement

3.5. Comparison of the Two Small Scale Irrigation Schemes

3.5.1. Internal Performance Indicators

Transporting the diverted water to the location of use, i.e. to the cropped field, is the main purpose of water delivery systems. In the course of this transport, there are different losses that reduce the amount of water reaching the farm.

a. Conveyance efficiency

i. In the main canal

In Golina SSI scheme the mean conveyance efficiency of the lined main canal was 96.54% with the mean conveyance loss of 0.077 (l/s/m). According to FAO (1989), the recommended value of conveyance efficiency for the lined canal is 95% and the recommended value for conveyance loss of lined main canal is $\leq 0.00031(l/s/m)$ (Akkuzu *et al.*, 2007).

The result obtained in conveyance efficiency (96.54%) is in the recommended value while the loss in the canal is higher than the recommended value. The mean conveyance efficiency in the unlined main canal was 97.20% and 38.02% with the mean conveyance loss of 0.003 (l/s/m) and 0.027 (l/s/m) for Golina and Kokono small scale irrigation schemes respectively. FAO (1989) recommended the value of conveyance efficiency for the unlined canal as 80% and the recommended value of conveyance loss in the earthen canal was from 0.0017 to 0.005 (l/s/m) for clay loam soil (Wachyan and Rushton, 1987). The conveyance loss of Golina was within the recommended value and that of Kokono scheme was higher. This shows that more water was lost at the unlined main canal of Kokono than Golina.

The mean conveyance loss, at the unlined main canal in Kokono 0.027 (l/s/m) was higher than, in Golina 0.003 (l/s/m). Despite the computed values, as observed during field assessment the situation seems the reverse; because the main canal structure of Golina SSI scheme was relatively good than

Kokono's. Moreover, in Kokono seepage and logging on an earthen canal, leakage and underflow losses contributed to the high losses.

Generally, canal conveyance efficiency is affected by different canal attributes, which are canal types and flow rate amounts. These results were much higher than similar research findings in Ethiopia. Derib *et al.* (2011) reported about 0.0258 l/s/m water losses from lined main canal of average 43.21 l/s flow rate capacity in the Blue Nile and Wondatir (2016) reported about 0.016 and 0.011 l/s/m for average flow rate of 35.62 l/s and 58.16 l/s respectively.

In spite of common losses, seepage and evaporation, no functioning flow- control gates, unauthorized water turnouts (breaching of main canals that leads to leakage) and illegal water diverted contributed for high water losses or low conveyance efficiencies at both irrigation schemes.

The major causes of low efficiencies in Kokono relative to Golina were water seepage, sediment problem at the head and non-functionality of water flow control gates as shown in Figures 1 and 2. This inefficient conveyance affected the equity of water distribution throughout the systems; particularly the tail users did not get their equitable share within the required time.

Figure 1 water losses at Kokono irrigation scheme

Figure 2 Sediment problem of Kokono SSIS

ii. In the secondary canal

In Kokono small scale irrigation scheme, the farmers divert the water directly from the main canal to their fields and there is no secondary canal in the scheme. Therefore, conveyance efficiency in the secondary canal was only determined for Golina scheme. The minimum and maximum conveyance efficiencies of 50% and 98.18% were calculated in secondary canals of Golina irrigation scheme and the overall mean conveyance efficiency was 79.32% for the average inlet flow rate of 74.94 l/s. From this an average loss of 3.312 l/s/100m of the average flow rate in the secondary canal was lost per 100m length of secondary canals; which account 4.42% loss per 100m from the average flow rate in the secondary canal. The obtained amount of water loss was very high because the secondary canals of Golina schemes are unlined; the water was lost by overtopping, seepage, at the entrance of tertiary canals and canal widening as indicated in Figure 3.

Generally, the computed amount of loss was none comparable, which were higher than the research findings reported in other parts of the world. Bakry and Awad (1997), reported 0.17 to 0.70% per 100 m canal losses in Egypt for canal capacity of 2000 to 12100 l/s. But the value was smaller than reported research finding in South Wollo by Wondatir (2016) as 5.87% loss per 100m from the average flow rate of 40.98 l/s in the secondary canals. The overall conveyance efficiency of Golina was determined by multiplying conveyance efficiency of the main canal by the secondary canal and the result obtained was 76.58% while that othe f Kokono was 38.02% obtained only from main canal.

Figure 3 Water loss at Golina irrigation scheme

b. Application efficiency

Water application efficiency provides a general indication of how well an irrigation system performs its primary task of delivering water from the conveyance system to the crop. It tells us whether the irrigation water is stored in the intended soil profile or lost as surface runoff or/and deep percolation. The average application efficiency of selected fields at the Golina irrigation scheme were found to 49.26%, 51.91% and 56.35% for upper users, middle users and lower users respectively with a mean of 52.51% and the same for selected fields at the Kokono irrigation scheme 76.13%, 58.35% and 63.31% for upper users, middle users and lower users respectively with a mean application efficiency of 65.93%.

The finding indicates that the upstream irrigators of Golina scheme were inefficient by applying excess water to their fields. As seen in Figure 4 , water was applied to the field by flooding type irrigation and water was lost by runoff. The application efficiency was, however, high at downstream plots. This indicates that those irrigators, who were getting less water, were able to efficiently utilize what they have got. But at Kokono scheme some farmers prepare their fields in a special way. As a result of this, the application efficiency of selected fields was very good and no water lost by runoff. For this and related reasons, the application efficiency of Kokono small scale irrigation scheme was slightly better than Golina scheme.

a) Golina b) Kokono

Figure 4 Water application at Golina and Kokono schemes

Generally, the obtained application efficiency of both schemes (52.51% and 65.93%) for Golina and Kokono respectively were between the recommended value reported by Savva and Frenken (2002) which is recommended as 50-70% for properly designed furrow irrigation. Kandiah (1981) also reported an application efficiency of 70% for furrow irrigation. But according to Yusuf (2004), the application efficiency 30% - 60% was considered as inefficient and indicated that the farmers were applying excess water to their fields.

c. Storage efficiency

Storage efficiency refers to how completely the water needed prior to irrigation has been stored in the root zone during irrigation water application. Based on the FC, PWP, Bd of the soils of the selected irrigation fields and the root depth of the crop irrigated, the depth of irrigation water required by the crop was calculated at the 75% moisture depletion level (Allen et al., 1998). After determining the storage and the required depths, the storage efficiency was calculated as described under the methodology part.

The obtained result of storage efficiency of selected fields from Golina irrigation scheme was 56.47 %, 33.78% and 54.87 % at upper, middle and lower users respectively with an average storage efficiency of 48.38% and that of selected fields from Kokono irrigation scheme were 48.49%, 47.25% and 38.91% with an average storage efficiency of 44.89%. The storage efficiency at Golina irrigation scheme was slightly greater than Kokono scheme, but in general, the storage efficiencies of both schemes were very poor as compared to 63% storage efficiency usually found in typical furrow irrigation systems (Raghuwanshi and Wallender, 1998). This normally shows over irrigation of the field and this might be associated with the intention of the farmers on high return from high irrigation depth.

d. Overall scheme efficiency

The overall efficiency of the scheme is the ratio of water made available to the crop to the amount released at the headwork. In other words, it is the product of conveyance efficiency and application efficiency. In the present study, the overall efficiencies of the irrigation schemes at Golina and Kokono were found to be 40.21% and 25.07%, respectively.

The result indicated that the Kokono irrigation scheme was worse than Golina scheme. The overall efficiency of the Golina irrigation scheme was within the range of values (40-50%) commonly observed in other similar African irrigation schemes (Savva and Frenken, 2002).

3.5.2. External Performance Indicators

a. Irrigated agriculture performance indicators

Under this comparison, land and water productivity levels and major constraints were analyzed. This includes performance indicators, which are associated with the production. To compare the two selected irrigation schemes in terms of their output per area and water supply, four comparative indicators (output per cropped area; output per unit command area; output per unit irrigation supply and output per unit water consumed) were used.

As shown in Table 2 and 3, the crop production for the year 2017/2018 of Golina was about 40,944.7 quintals. The cropped area was 779.5 ha with a gross income of 866,549 US$. And the crop production of Kokono scheme was 2,904 quintals; the cropped area was 81.6 ha with a gross income of 61,475.4 US$. The cropped areas of both irrigation schemes were greater than the command area because some areas were irrigated more than once in the same year.

The total volume of water diverted to the Golina irrigation scheme for 779.5 ha of land during the season (Nov. - Jun, with an average discharge of 394.338 liters per second was 8,245,134 m^3. And the total volume of water diverted to the Kokono irrigation scheme during the same season with an average discharge of 34.325 l/s was 717,695 m^3.

i. Output per unit cropped area

The output per unit cropped area shows the response of each cropped area on generating a gross return. This parameter gives a clue about the management practice in every scheme. According to the data collected from each irrigation schemes, there was a big difference in irrigable area between the two schemes; the total production value obtained from Golina was 14.1 times higher than Kokono's irrigation scheme. Based on the data obtained, the outputs per unit cropped area were 1111.67 and 753.38 US$ ha^{-1} for Golina and Kokono schemes respectively. There was a difference of 358.29 US$/ha, which was a high value per unit area. It is possible to say that the response or income per cropped area at Golina is better than at the Kokono irrigation scheme. This is mainly due to the improved irrigation management in Golina scheme. This can be associated with the input use and strong institutional set up at the Golina irrigation scheme.

ii. Output per unit Command area

This indicator expresses the average return per design cropped area. It is an indication of whether all the cropped areas are generating returns or not. The outputs per unit command area of Golina and Kokono irrigation scheme were 2166.37 and 768.44 US$ ha^{-1}, respectively. The irrigated area for Golina was 383.1 ha at first season and 396.4 ha at the second season. That means 95.775% and 99.1% of the command area was under irrigation at first and second season. For Kokono scheme 39.4 ha and 42.2 ha area were irrigated at first and second season respectively. When these areas are compared to designed command area, in the first irrigation season, 49.25% and 52.75% in the second season were under irrigation.

Output per unit area irrigated and output per unit command area performance indicators was called land productivity indicators.

iii. Output per unit irrigation supply

The output per unit irrigation supply shows the revenue from the agricultural output for each meter cube of irrigation water supplied. The output per unit irrigation water supply for Golina was found to be 0.11 US$ m^{-3} and that of Kokono was 0.1 US$ m^{-3}. The result of output per m^3 of water supply for both schemes was nearly the same.

Table 2 Crop yields and output production values for Golina SSI scheme in the year 2017/2018

Crop	Season I						Season II					
	Area (ha)	Yield (ku/ha)	Yield (ku)	Ave. price birr/ku	Total income (birr)	Total income (US$)	Area (ha)	Yield (ku/ha)	Yield (ku)	Ave. price birr/ku	Total income (birr)	Total income (US$)
	(1)	(2)	(3) = (1)*(2)	(4)	(5) = (3)*(4)	(6) = (5)/(27ETB)	(7)	(8)	(9) = (7)*(8)	(10)	(11) = (9)*(10)	(12) = (11)/(27ETB)
maize	28.3	17	481.1	1000	481100	17819	27.1	16	433.6	1100	476960	17665
Chick pea	20.2	18	363.6	1100	399960	14813	12.4	15	186	1000	186000	6889
Pepper	5.4	12	64.8	800	51840	1920	9.4	13	122.2	700	85540	3168
Tomato	25.6	60	1536	900	1382400	51200	34.6	63	2179.8	1000	2179800	80733
Onion	165.8	75	12435	450	5595750	207250	189	70	13251	500	6625500	245389
Cabbage	49.2	80	3936	300	1180800	43733	41.3	81	3345.3	350	1170855	43365
Teff	58.4	15	876	1400	1226400	45422	52.1	13	677.3	1550	1049815	38882
Mango	20	-	-	-	-	-	20	35	700	1200	840000	31111
Banana	10.2	-	-	-	-	-	10.2	35	357	1300	464100	17189
Total	**383.1**		19692.5		**10318250**	**382157**	**396.4**		21252		**13078570**	**484391**
				Grand Total = Season I + Season II							**23396820**	**866549**

Qu: represents quintal, 1US$=27ETH birr, average currency exchange rate for 2017/18 production year.

Table 3 Crop yields and output production values for Kokono SSI scheme in the year 2017/2018

Crop	Season I						Season II					
	Area (ha)	Yield (ku/ha)	Yield (ku)	Ave. price birr/ku	Total income (birr)	Total income (US$)	Area (ha)	Yield (ku/ha)	Yield (ku)	Ave. price birr/ku	Total income (birr)	Total income (US$)
	(1)	(2)	(3) = (1)*(2)	(4)	(5) = (3)*(4)	(6) = (5)/(27ETB)	(7)	(8)	(9) = (7)*(8)	(10)	(11) = (9)*(10)	(12) = (11)/(27ETB)
maize	8.3	13	107.9	1000	107900	3996.2963	22.6	12	271.2	1100	298320	11048.9
Chickpea	2.5	20	50	1000	50000	1851.8519	-	-	-	-	-	-
Pepper	1.3	9	11.7	700	8190	303.33333	1.1	10	11	800	8800	325.9
Tomato	4.6	55	253	600	151800	5622.2222	2.6	60	156	900	140400	5200.0
Onion	19.5	58	1131	400	452400	16755.556	14.2	55	781	450	351450	13016.7
Cabbage	1.2	65	78	300	23400	866.66667	0.1	60	6	350	2100	77.8
Teff	1.5	11	16.5	1450	23925	886.11111	1.1	12	13.2	1500	19800	733.3
mango	0.3	-	-	-	-	-	0.3	35	10.5	1200	12600	466.7
banana	0.2	-	-	-	-	-	0.2	35	7	1250	8750	324.1
Total	**39.4**				**817615**	**30282.037**	**42.2**				**842220**	**31193.3**
Grand Total = Season I + Season II											**1659835**	**61475.4**

Qu: represents quintal, 1US$=27ETH birr, average currency exchange rate for 2017/18 production year *iv. Output per unit of water consumed*

The output per unit of water consumed is used to describe the return on the water actually consumed by the crop. This indicator gives due attention to the water consumed by each scheme and tells us how water is efficiently utilized by the scheme from an economic point of view. The outputs per water consumed for Golina irrigation scheme was 0.2 US$ m^{-3} and that of Kokono irrigation scheme was about 0.18 US$ m^{-3} of water. This result shows that the water use efficiency is slightly better at Golina than at the Kokono irrigation scheme. The reason for this may be institutional set up of Golina which is stronger than that at the Kokono irrigation scheme.

Through using two indicators, water productivity performances were evaluated at both irrigation schemes; output per unit irrigation water supplied/diverted/ and output per unit water consumed. At both irrigation schemes the output per unit water consumed was higher than the output per unit water supplied. This implied that the consumed amount of irrigation water was more productive than diverted irrigation water.

b. Water Supply indicators

i. Relative water supply

Relative Water Supply (RWS) showed the availability of water in relation to crop water demand that means the relative water supply depicts whether or not there is enough irrigation water supplied. Both the relative water supply and relative irrigation supply relate supply to demand and give some indication as to the condition of water abundance or scarcity, and how tightly supply and demand are matched. The relative water supply value below one normally indicates that the water applied is less than the crop demands. A value of RWS less than one may not represent a problem; rather it may provide an indication that farmers are practicing deficit irrigation with short water supply to maximize returns on water. And a value of RWS above one indicates that extra water is added to the root zone beyond plant demands which means that the total water applied met the crop needs.

Based on equation 12, the indicator was determined for both schemes. In addition to delivered irrigation amount, total crop water demand, effective rainfall, and crop irrigation demand were determined by CROPWAT model for a given cropping pattern and irrigation seasons. The relative water supply values in Golina and Kokono irrigation schemes were 1, which indicated that the supplied water was sufficient for the crop water demand, i.e. neither surplus nor deficit. This implied that the supplied water was sufficient for crop water demand for the irrigated land. However, it couldn't irrigate additional farmland with this delivery amounts and available effective rainfalls.

ii. Relative irrigation supply

The relative irrigation supply shows whether or not the irrigation demand is satisfied. The interpretation of the computed value is similar to RWS. At both irrigation schemes, the computed values of RIS were 4 for Golina and 1.7 for Kokono. These values indicated that there was a generous supply of water and the sole water provider was irrigation. It is better to have RIS close to 1 than a higher or lower value (Molden *et al.,* 1998).

c. Physical performance indicators

Physical indicators are related to changing or losing irrigated land in the command area for different reasons. Irrigation ratio for the Golina irrigation scheme was 0.974, which means that 97.4% of the command area of the scheme was under irrigation during the study period, but the irrigation ratio of Kokono irrigation scheme was 0.51 which means about 49% of the command area of the scheme was not under irrigation during the study period. The main reasons for this were the discharge of the scheme was decrease because of the new diversion structure was constructed on the upper Kokono River, which is the source of Kokono irrigation scheme.

4. Conclusion

In this study, an attempt was made to evaluate the performance of two small scale irrigation schemes in Eastern Amhara Regional state under North Wollo administrative zone, Kobo and Habru districts by using the process and comparative performance indicators. The process performance indicators computed were conveyance efficiency, application efficiency, storage efficiency, and overall efficiency. The standardized performance indicators established by the international irrigation management institute (IIMI) were taken as comparative indicators. The comparative indicators included in this study were agriculture, water use, and physical performance. Because of data limitation, economic performance was not included.

The conveyance efficiency of Kokono scheme at the main canal showed low value because the canals are unlined and due to leakage and lack of management. The conveyance of Golina small scale irrigation scheme at main, secondary and tertiary canals also low value; But as a general, the conveyance efficiency of Golina irrigation scheme was more than the recommended value 70 % for unlined poorly managed canals observed in other African countries. The application efficiency of both schemes was, found to be good compared to the application efficiency of 50-70% for furrow irrigation observed in other African countries. But the application efficiency of Kokono scheme was higher than that of Golina irrigation scheme.

The relative irrigation supply for Golina schemes shows that there is a high ratio, which implies the amount of water applied during irrigation events was much higher than what was required by crops. The output per cropped area at Kokono was low as compared to Golina, implying that the irrigation practice in Kokono was relatively poor. The output per unit command area was also observed to be relatively low in Kokono. This implies that a large amount of command area was not under irrigation during the study season in Kokono due to a shortage of water. The returns from the one-meter cube of irrigation water were almost equal in both schemes. This implies that water utilization in both schemes was the same.

In general, based on the assessment carried out, it can be concluded that the Golina irrigation scheme performed better than the Kokono scheme but it cannot be said the Golina scheme does not need improvement so measures should be taken to improve the performance of both schemes. As there is no shortage of water, Golina scheme has room to expand and to provide irrigation opportunities to the surrounding community relying on rain-fed agriculture. The comparison of the performance of irrigation systems will help to know the present status of these systems.

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