



Assessing Farm Water Management and Performance of Koga Irrigation Scheme: a Case Study of Inguti Unit, Amhara Regional State, Ethiopia

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Abstract

The principal objective of this study was to assess field water management and performance of Koga irrigation scheme specifically Inguti unit using performance indicators based on the selected performance indicators such as conveyance efficiency, application efficiency, distribution efficiency, storage efficiency, and deep percolation ratio. Primary data such as discharge, soil moisture content, field surveys, and group discussions among the farmers/beneficiaries and Water User Associations (WUA) and secondary data such as crop data, climate data, and design documents were collected. CROPWAT 8.0 models and GIS were used for data analysis in this research. Average conveyance efficiency values ranged from 81 to 86.5% for lined (secondary and tertiary canals) and about 64% for unlined tertiary canals. The maximum water losses observed were 0.19 and 0.2 l/s/m on lined (secondary and tertiary) canals, respectively. The maximum water loss observed in unlined tertiary canals was 0.26 l/s/m. The average distribution uniformity, field storage efficiency, and field water application efficiency were 79.6%, 78.9%, and 53.5%, respectively. Average values of the scheme, cropped area ratio, and infrastructural effectiveness were 94% and 96.2%, which was good sustainability based on the standards. The overall efficiency of scheme in the Inguti unit was found to be 46.3%. In general, the performance of the irrigation scheme was weak due to poor field water managements as indicated by the above indicators due to illegal water abstraction, unequal distribution of irrigation water, sedimentation of canals and lack of institutional support service, and inadequate operation and canal maintenance.

Keywords Koga irrigation scheme · Performance indicators · Water User Association

Introduction

Agriculture remains the basis of Ethiopia's economy employing 85% of the population and contributing to 45% of the GDP [1, 2]. The majority of the population has a subsistence mode of crop and livestock production. Despite its economic and social benefits, production and productivity of different agricultural crops in Ethiopia are mostly on a small scale and average crop yield is very low, as compared to other developing countries [1, 3].

The majority of Ethiopian population is dependent on rain fed agricultures. 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 [4]. Irrigation is one means by which agricultural production can be increased to meet the growing food demands in the country [5]. Irrigation can be defined as an artificial application of water to soil for the

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purpose of supplying the moisture essential in the plant root zone to prevent stress that may cause reduced yield and/or poor quality of harvest of crops. Water is an irreplaceable resource used for numerous economic, social, spiritual, and representative purposes, on which the existence of life depends [6].

The aim of performance evaluation and irrigation water management is to keep the water level at the root zone and assess its effectiveness of irrigation infrastructures within a range where crop yield and quality are not damaged due to either inadequate or excess water [7]. And also performance evaluation is carried out for the purpose of improving system management [8]. Therefore, optimum irrigation water uses, appropriate allocation of irrigation water, appropriate operation of irrigation structure, and regular follow-up and maintenance of irrigation infrastructures are energetic for durability of cultivation in water-scarce areas and irrigation sustainability [9].

Koga irrigation scheme highly benefited the farmers in the scheme to harvest twice per year by supplying irrigation access with full infrastructures. However, due to lack of awareness and frequent training about irrigation water application and managements, farmers' irrigation management is poor and with highly water wastage. Therefore, this study was conducted to assessing the farm water management and performance evaluations of Koga irrigation scheme in the case of Inguti unit using selected performance indicators.

Materials and Methods

Description of the Study Area

Koga irrigation scheme is found in Mecha Woreda in the Amhara regional state which is located about 30 km South of Bahir Dar, which is located $11^{\circ}20'N$ to $11^{\circ}30'N$ (latitude) to $37^{\circ}3'E$ to $37^{\circ}9'E$ (longitude). The scheme has an average elevation of about 1980 m above mean sea level. Koga irrigation scheme is a large-scale scheme designed initially to irrigate 7000 ha command area and is divided into 12 units. For the purpose of measurement and detail sample collection of the study, one of the 12 irrigation units, called Inguit, was selected as a study site (Fig. 1) (Inguti unit was designed to irrigate total command areas of 391 ha and is associated with 473 total households).

The annual rainfall of the study area ranges from 800 to 2200 mm, with a mean of 1420 mm [10, 11].

The average daytime temperature of the study area is $24^{\circ}C$. Mean maximum temperature varies from $30.1^{\circ}C$ in April to $24.3^{\circ}C$ in July and August; mean minimum temperature varies from $8.9^{\circ}C$ in January to $15.5^{\circ}C$ in May. The mean monthly relative humidity is 58.4%. The value of relative humidity is highest during the humid rainy season from July to August; it becomes 75% and lowest during March 42.9%. Mean monthly sunshine hour varies from a low value of 4.4 h/d during the month of August

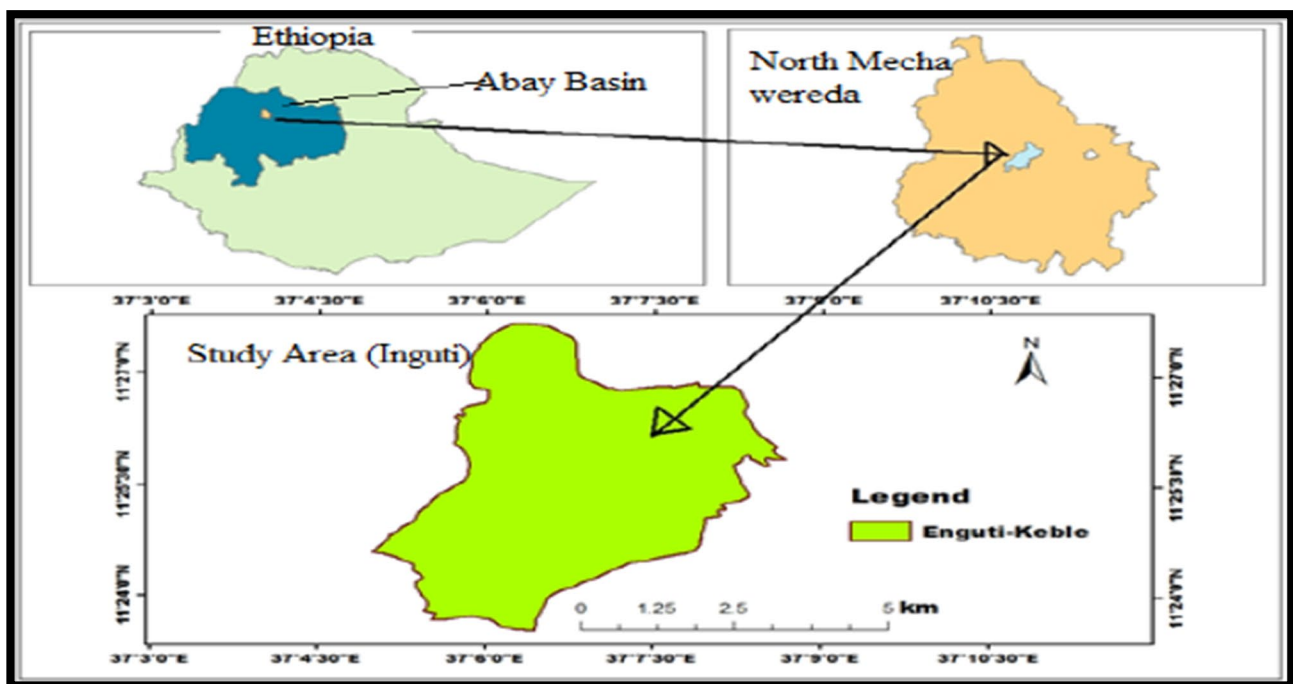


Fig. 1 Location of the study area

(rainy season) to as high as 9.9 h/d during the month of December [12].

Inguti irrigation scheme is one of the twelve irrigation blocks of Koga irrigation scheme and it is located at 11.9 km from main canals and about 0.8 km from secondary canals with one night storage with a capacity of 18,144 m³. The scheme consists of a number of irrigation infrastructures such as control gates/shutters, cross regulator, division boxes, culverts, sediment traps, and drop structures. The most common irrigation infrastructures are described in Fig. 2.

In the study unit, there are three tertiary canals in the unit which have a total length of 3.37 km and they deliver water to unlined quaternary canals and there are 26 quaternary canals which deliver water from tertiary canals to the fields. The areas served by quaternary canals are generally 8–16 ha. Field canals are sometimes used to serve areas smaller than 2 ha (Fig. 3).

Materials Used

Augers were used to collect disturbed soil samples at the required depth for soil moisture and bulk density determination whereas core samples were used to collect undisturbed soil samples for determination of soil texture field capacity and permanent wilting point.

Sensitive weight balance was used to measure weight of soil samples and crop yield samples. Drying oven was used to dry soil for soil moisture content determination. Tape meter was used to determine the length of field and canal sections where the measurement was done. In addition, stopwatch and floating materials were used to determine flow rate using float method in both in earthen and lined canals. RBC (Replogle-Bos-Clemmens) flumes were used to measure field discharge at earthen sections of field channels at the field inlet of the selected farm plot. Standard gaged type flumes were used to directly read the measurements of applied water depth in millimeters and field channel flow rates in liters per second. Finally, careful data recording was done using note books.

Data Collection Methods

Most of primary data were collected through field observations and experimentation and secondary data were also collected from key representatives such as the scheme operator, experts, and concerned bodies of the unit. Relevant information regarding infrastructural performance and managerial issues that affects scheme performances and farm water managements was gathered.

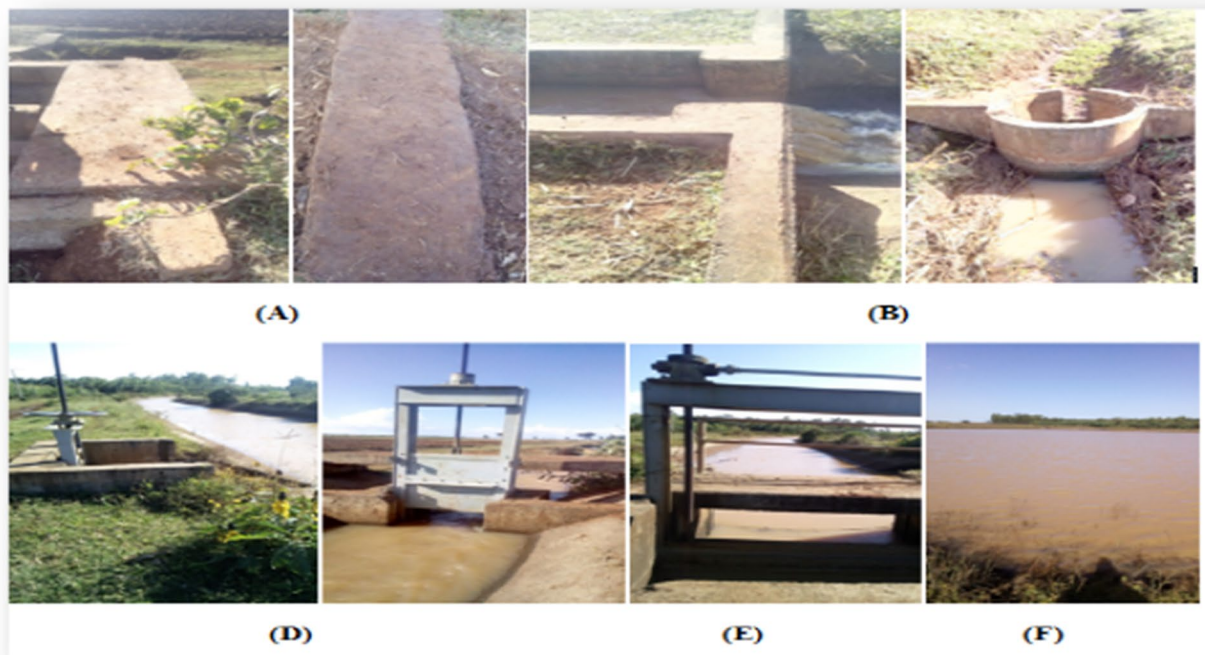
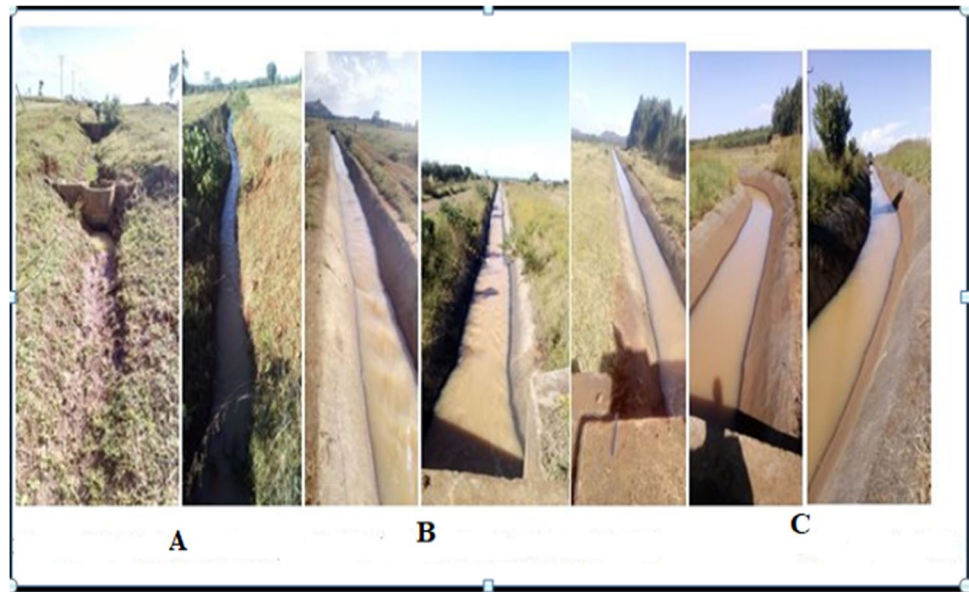


Fig. 2 Irrigation infrastructures **A** culvert, **B** drop structures, **D** control gate/shutters, **E** cross regulator, and **F** night storage

Fig. 3 Irrigation canals at the unit. **A** Unlined tertiary canals. **B** Lined tertiary canals. **C** Lined Secondary canals



Data Analysis Techniques

The collected data were analyzed using excel (for calculations and graphs). Cropwat8.0 (to determine reference evapotranspiration and crop water requirement) and GIS (for geo referencing and mapping of study area) were used. Finally, the selected performance indicators were computed for evaluations of its performances and farm water management.

Disturbed and undisturbed soil samples were collected at a depth of 30 cm up to 60 cm depending on the root depth of the irrigable crop in each area of representative irrigation sites and at the experimental site (head, middle, and tail) for the purpose of moisture content, bulk density field capacity, and permanent wilting point determinations. The collected soil samples were determined and characterized in terms of physical characteristics of soil such as soil moisture content before and after 24 irrigations and bulk density at the soil laboratory of Bahir dar polytechnic water treatment laboratory and soil texture, and FC and PWP at the soil laboratory of Amhara design and supervision enterprise soil laboratory.

The soil texture was determined using hydrometer analysis and the soil textural class is determined by USDA soil textural triangle method [13].

Bulk density was determined using 18 undisturbed soil samples collected from three pits using a 5-cm diameter and 5-cm height cylindrical core sampler at interval of 30 cm soil depth in each plots. Field capacity and permanent wilting point of the three selected fields were determined in the laboratory using a pressure plate apparatus

by applying a suction of 1/3 bar and 15 bar to a saturated soil samples, respectively.

$$Bd = \frac{Md}{Vc} \quad (1)$$

where

Bd is the bulk density of the soil (g/cm^3)

Md is the dry weight of the soil (gm), and

Vc is the volume of core samplers (cm^3).

Initial moisture content of the soil before irrigation and moisture content after irrigation were determined using gravimetric method (weight basis). The moisture content in volumetric basis was determined by multiplying the gravimetric water content (weight basis) by the soil bulk density. The soil samples were placed in airtight containers of known weight and then weighed. The sample is then placed in an oven for 24 h at 105 °C with the container cover removed. After drying, the soil and container were again weighed and the weight of water determined as the pre and post readings. The gravimetric soil water content ($W\theta$) was calculated as Eq. (1).

$$W\theta = \frac{Ww - Wd}{Wd} * 100 \quad (2)$$

where

$W\theta$ is gravimetric soil water content in weight basis

Ww is weight of the wet soil (gm), and

Wd is dry weight of the soil (gm). The volumetric moisture content was calculated using Eq. (3.2)

$$\theta V = W\theta * Bd \tag{3}$$

where

- θv is volumetric water content on a dry weight basis (%)
- $W\theta$ is gravimetric soil moisture content on a dry weight basis (%), and
- Bd is bulk density of soil (g/cm^3).

Total available water (TAW) in volumetric base was computed from the moisture content in volume percent at field capacity and permanent wilting point and the TAW in percent was also computed by subtracting from field capacity to wetting point [14]

$$TAW = 1000 \sum_1^n (\theta F_{ci} - \theta P_{wpi}) Z_{ri} \tag{4}$$

where

- TAW is total available soil moisture (mm)
- θFC is volumetric moisture content at field capacity in the layer of the soil (m^3/m^3)
- θpwp is volumetric moisture content at permanent wilting point in the soil layer (m^3/m^3)
- n is number of soil layers in the root zone; and
- Z_r is soil depth (mm).

The infiltration rate of the soil was determined using double ring infiltrometer. The inner and outer rings have 30 cm and 60 cm diameter, respectively. Water was added to the soil

with certain interval of time. The cumulative depth of infiltration and the time elapsed were recorded carefully. The constant value of the basic infiltration rate expressed in cm per hour obtained after a long time was used as an input data for the CROPWAT8.0 Model that was useful for the determination of crop water and irrigation water requirements (Fig. 4).

Canal flow rate measurement is a relevant data for irrigation scheme performance evaluation activities including computation of conveyance efficiency and losses. Frequent flow measurements have been taken starting from intake to referenced point of secondary and tertiary canal using float method.

The flow velocity was measure by the float method and it is multiplied by the areas of flow cross sections to change in to discharge. Since the velocity of the float on the surface of the water was greater than the average velocity of the stream, it was necessary to correct the measurement by multiplying by a constant factor (velocity correction factor) which was usually assumed to be 0.85 [15]. To obtain the rate of flow, this average velocity (measured velocity * correction factor) was multiplied by the average cross-sectional area of the stream. To compute the surface velocity, V_s , the selected length, L , was divided by the travel time, t :

$$V_s = \frac{L}{T_{av}} \tag{5}$$

where V_s is surface velocity (m/s)

L is length of canals (m)

T is average time taken of a float(s), and

Fig. 4 Infiltration test of the soil at field



C is flow coefficient. Then, the average velocity was determined by multiplying the average surface velocity by the coefficients ($V = 0.85 \times V_s$).

After determining the flow velocity, the discharge was calculated using the following equations (Walker & Skogerboe, 1987).

$$Q = A * V \quad (6)$$

where

Q is total amount of water applied to field (m^3/s)

A is cross sectional area of the trapezoidal lined canal (m^2), and

V is average flow velocity (m/s).

Applied irrigation water to the field was measured using RBC flumes with standard calibrated staff gage readings. RBC flumes were installed at the entrance of irrigation water to the field for the selected farm test plot within keeping the level of flume. The RBC flume has a short trapezoidal section with a contraction inserted in the flume bottom which is a simple and reliable instrument for the measurement of the quantity of irrigation water that flows towards a field channels. The standard RBC flumes with various measuring capacities to measure volume of water applied to the farm were 2.0–145 l/sec [16]. When they completed irrigating their plots, the average depth of irrigation water passing through the flume and time of application were carefully recorded (Fig. 5).

Determination of Crop Water and Irrigation Water Requirement

The amount of water needed for the irrigated crop fields was determining using CROPWAT computer programs. Crop

water requirements (CWR), irrigation requirements (IR), and scheme water demand for varying crop patterns were estimated based on the soil, climate, and crop patterns. FAO CROPWAT 8.0 computer model was used to determine the crop water requirements (CWR), and monthly ET of the irrigated crops at field levels during irrigation season (January to April). The value of Kc of each major crops was taken from FAO I & D 56 ([14] and 24 [17] papers (FAO [19]). Penman–Monteith method was selected to calculate the reference crop evaporation (ET_o) as indicated in Eq.[4]

$$ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (7)$$

where ET_o is the reference evapotranspiration [$mmday^{-1}$]; R_n is net radiation at the crop surface [$MJm^{-2}day^{-1}$]; G is soil heat flux density [$MJm^{-2}day^{-1}$]; T is air temperature [$^{\circ}C$]; u_2 is wind speed [ms^{-1}]; e_s and e_a are saturation and actual vapor pressures, respectively [kPa]; Δ is slope vapor pressure curve [$kPa^{\circ}C^{-1}$]; and γ is psychrometric constant [$kPa^{\circ}C^{-1}$].

Performance Evaluation of Irrigation Scheme Using Indicators

Farm Water Management Evaluation

Farm water management of the existing irrigation practice was evaluated using the following selected internal performance indicators for the study units called Inguti irrigation Block. The evaluation of the field application efficiency requires the measurement of water deliveries to each field and measurements of soil water content before each irrigation application.

Fig. 5 Field water application depth and discharge measurement with RBC flume



Field Irrigation Application Efficiency (E_a %)

Field irrigation application efficiency can be a useful performance indicator overtime that reflects losses of water below the crop root zone [20] and was determined by the ratio of depth of water added to the root zone to the depth of water applied to the field [21] as follows:

$$E_a = \frac{D_s}{D_f} * 100 \quad (8)$$

where D_s is the depth of water added/stored to the root zone and D_f is the depth of water applied to the field, both in millimeters.

The depth of water stored in the root zone (D_s) was calculated (Eq. 3.8.3.1) by subtracting the average soil–water content just before an irrigation event from the soil–water content 24 h after the irrigation event (cm^3) (moisture difference), multiplied by depth of root zone (mm) and bulk density in gm/cm^3 as per Israelsen et al. [22] and Imark et al. [23].

$$W_s = MC * Bd * Rz \quad (9)$$

Where

W_s is depth of water stored in root zone (mm)
 MC is average moisture content of soil (%)
 Bd is bulk density of soil (gm/cm^3), and
 Rz is depth of root zone of crop (cm). The root zone depth (Rz) for crops under study was taken from FAO depending on soil type depth to water table.

Application of irrigation water by farmers was also evaluated by comparing crop water demand and irrigation applied for water demands of selected crops (potatoes) was modeled using FAO Cropwat 8.0 using 10-year average (2009–2019) climate data collected from the stations and crop characteristics were obtained from 14.

Distribution Uniformity (D_u %)

The distribution uniformity is more commonly used to characterize the irrigation water distribution over the field in surface irrigation systems. This is important to evaluate the distribution of water on field and shows how uniformly water is applied to the field along the irrigation run. According to Merriam et al. (1983), distribution uniformity was calculated as:

$$DU = \frac{\text{Average Low quarter depth of water in filtration}}{\text{Average depth of water stored}} \quad (10)$$

Storage Efficiency (E_s %)

The amount of water needed in the root zone is the difference between moisture content corresponding to approximately the field capacity and the moisture content in the root zone before irrigation and the type of crop grown, which is the ratio of quantity of water stored in the root zone during irrigation event to that required to the field [18]. The water needed in the root zone prior to irrigation (depth of required) is calculated by at 75% moisture depletion level for most vegetable crops as per 14.

$$W_n = TAW * BD * RD * Df \quad (11)$$

Where

W_n is the depth of water required in the root zone prior to irrigation (mm)
 TAW is total available water in %
 BD is bulk density of soil
 RD is total soil depth in mm, and
 Df is depletion factor (%) and then storage efficiency (E_s %) was calculated as:

$$E_s = \frac{W_s}{W_n} * 100 \quad (12)$$

Where

E_s is storage efficiency (%)
 W_s is stored water depth (mm)
 W_n is required water depth (mm).

Deep Percolation Ratio (DPR)

The loss of water through drainage beyond the root zone is reflected in the deep percolation ratio, DPR. High deep percolation losses aggravate water logging and salinity problems and leach valuable crop nutrients from the root zone.

Field loss of water through drainage beyond the root zone is reflected only in the deep percolation ratio that expresses the ratio between the percolated water beyond the root zone to the volume of water applied to the field without considering ground water situations. Deep percolation ratio (field water loss in relation to field water application) could be calculated indirectly from values of application efficiency and runoff ratio as given by Feyen and Dawit [24]. The runoff ratio is normally considered for this particular study as zero as the farmers are using furrows whose tail ends are closed; runoff ratio is neglected.

$$DPR = 100 - E_a - RR \quad (13)$$

Where

DPR is deep percolation ration (%)
Ea is application efficiency, and
RR is runoff ration.

Scheme Performance Assessment Using Indicators

The scheme performance evaluations were made for the following internal and physical indicators, namely, conveyance efficiency, cropped area ratios, sustainability of irrigable area, and infrastructural effectiveness which were selected depending on the purpose of the assessment [25]. Internal indicators enable comprehensive understanding of the processes that influence water delivery service and the overall performance of a system [26]. Three efficiency indicators are considered to give the overall scheme efficiency (conveyance efficiency, application efficiency, water storage efficiency). Under scheme performance assessment, the following scheme performance indicators were used as follows [27].

Canal Conveyance Efficiency (CE%)

Canal conveyance efficiency (CE) was measured for selected defined canal segments both secondary and tertiary canals. Conveyance losses from lined and earthen sections of canal irrigation network are determined under existing situation and the scenarios for different management strategy were developed to utilize saved water for in irrigation scheme.

$$CE = \frac{Q_o}{Q_i} * 100 \quad (14)$$

Where

CE is the conveyance efficiency
Qi is total water diverted into the canal, and
Qo is total water outflow from the canal (m³/s).

In the study area, water loss was determined in the canal by using inflow-outflow methods after measuring of discharges at different sections of lined and earthen canals in the unit.

$$CL = Q_{in} - Q_{out} \quad (15)$$

where

CL is conveyance loss
Q_{in} is inflow, and
Q-out is outflow in specified canal reach in all units in m³/s.

Sustainability of Irrigable Area

Sustainability of irrigated area/crop area ratio is the ratio of currently irrigated area to initially irrigated area when designed [21]. It is a useful indicator for assessing the sustainability of irrigated agriculture. Lower values of this indicator would mean abandonment of lands which were initially irrigated and, hence, indicate contraction of irrigated area over time. On the other hand, values higher than unity indicate expansion of irrigated area and would imply more sustainable irrigation.

$$CAR = \frac{CIA}{PIA} \quad (16)$$

Where

CAR is crop area ratio
CIA is current irrigated area, and
PIA is planned irrigated area in ha.

Infrastructural Effectiveness (EI)

Effectiveness of infrastructure (also called structural performance) is used to quantify maintenance performance to analyze whether the maintenance system is operating as designed. It is obtained by dividing the number of functioning infrastructures by the total number of infrastructures. The total number of infrastructures was counted and cross-checked from the design report [28].

$$EI = \frac{NFS}{TNSI} * 100 \quad (17)$$

where

EI is effectiveness of infrastructures
NFS is number of functional structures, and
NSI is total number of structures initially installed.

Overall Scheme Efficiency (Et)

The overall irrigation efficiency (Et) represents the efficiency of the entire physical system and operating decisions in delivering irrigation water from a water supply source to the target crop. It was calculated by multiplying both component efficiencies of water conveyance and water application efficiencies [29] and FAO [30]. The project or overall efficiency of the scheme was calculated as the product of conveyance and application efficiency.

$$Et = \frac{Ea * Ec}{100} \quad (18)$$

where

- E_t* is overall irrigation efficiency
- E_c* is conveyance efficiency (%), and
- E_a* is average application efficiency.

Results and Discussions

Results of Soil Physical Properties

Based on laboratory analysis of particle size distribution, the textural class was found to be exclusively heavy clay at all depths (Table 1); the test results of the plots showed that the composition of sand, silt, and clay (average percentage) was 12.67%, 20.00% and 67.50%, respectively. According to USDA soil textural triangle textural classification, the soil is classified as heavy clay soil at the experimental units.

The bulk density of soil of the experimental area showed a variation with increasing the soil depth (Table 1). It varied between 1.15 and 1.25 g/cm³ and generally the top surface soil had lower bulk density than the subsurface. The top 0–30 cm has an average bulk density of 1.18 whereas the subsurface 30–60 has an average bulk density of 1.25 g/cm³. The weighted average bulk density of the soil in the experimental site was found to be 1.21 g/cm³. According to obtained result for subsurface bulk density of soil, it showed a little higher values for surface bulk density of soils. This might be attributed to relatively low organic matter content and compaction effect due to overlaying material at the depth of 30–60 cm compared to surface. According to Mekonnen et al. [31], recommended soil bulk density is 1.1 up to 1.6 g/cm³ for clays to get better plant growth. The result of the study area

shows that the bulk density is in the ranges of recommended bulk density which is better for plant growth. As the bulk density values of the soils at irrigation schemes were low as per the bulk density rating of Vanden Aker et al. (2003), hence Jones et al. (2003) indicated that there was no compaction that could limit infiltration of water into and through the soil and root penetration of such soils.

In the study area, the basic/constant infiltration rate of the scheme was 0.15 cm/h which was attained after 220 min. The obtained result was within the range of recommended value, which stated that the basic infiltration rate for clay soil is 0.1–0.5 cm/h.

As illustrated by Savva and Frenken [32], infiltration rate is highly influenced by the soil textural class. According to Dagadu and Nimbalkar [33], infiltration rate less than 5 mm/h is classified as a soil with low infiltration rate which is the typical characteristics of clay textured soil. Then the result is in the range of less than 5 mm/h. However, the textural class and average infiltration rate were agreed on the textural class of the scheme. For the determination of crop water requirement using the CROPWAT 8.0 model, the maximum recommended value of the basic infiltration rate for clay soil 0.15 cm/h was used.

Average water requirement of potato during the initial, developmental, mid-season, and late-season stages accounted for 5.3%, 22.6%, 41.7%, and 30.4%, respectively, of the seasonal water requirement of the crop. The crop had the highest crop and irrigation water requirement during developmental stage. Crop coefficient (K_c), maximum root depth (m), crop height, and yield reduction factor (K_c) values were adopted from FAO Irrigation & Drainage paper 24 and 56, the detailed values in growth stage based which was used as input values of CROPWAT.

Table 1 Soil physical properties

| Field | Soil depth | PH (H ₂ O) | Particle size distribution (%) | | | Soil textural class | Bulk density (g/cm ³) | FC (%) | PWP (%) | TAW (%) | TAW (mm) |
|---------|------------|-----------------------|--------------------------------|-----------|-------------|---------------------|-----------------------------------|-------------|-------------|------------|--------------|
| | | | Sand | Silt | Clay | | | | | | |
| Head | 0–30 | 4.76 | 9 | 15 | 76 | Heavy clay | 1.15 | 26.88 | 16.79 | 10.09 | 34.81 |
| | 30–60 | 4.98 | 17 | 19 | 64 | Heavy clay | 1.25 | 26.75 | 16.64 | 10.11 | 37.91 |
| Middle | 0–30 | 4.71 | 17 | 21 | 63 | Heavy clay | 1.23 | 27.35 | 18.05 | 9.3 | 34.32 |
| | 30–60 | 4.84 | 9 | 25 | 66 | Heavy clay | 1.24 | 27.23 | 17.91 | 9.32 | 34.67 |
| Tail | 0–30 | 4.72 | 13 | 25 | 62 | Heavy clay | 1.15 | 25.14 | 17.29 | 7.85 | 27.08 |
| | 30–60 | 4.89 | 11 | 15 | 74 | Heavy clay | 1.25 | 24.95 | 16.59 | 8.36 | 31.35 |
| Average | | 4.82 | 12.7 | 20 | 67.5 | Heavy clay | 1.22 | 26.4 | 17.2 | 9.2 | 33.36 |

Laboratory result (Appendix Fig. 1). Note: *FC*, field capacity; *PWP*, permanent wilting point; and *TAW*, total available water in millimeter and per meter. Head, upstream water user; Middle, middle stream water user; and Till, downstream water user. The soil moisture content at field capacity varied from 24.95 to 27.35% by volume. The soil moisture at permanent wilting point varied from a minimum value of 16.59% to the maximum value of 18.05% on volume basis. The average calculated value of total available water of the irrigation scheme was 111.32 mm/m within the acceptable range which was FAO (1998) recommended FC, PWP, and TAM values for clay soil ranges from 320 to 400 mm/m, 200 to 240 mm/m, and 120 to 200 mm/m, respectively

Characterization of the Scheme

The planned irrigable area of the scheme was 391 ha. However, the actual area developed for irrigation was 368 ha; currently, the actual irrigable area was reduced by 23 ha compared with initially planned irrigable areas. The numbers of beneficiary households that own irrigable land were 493 out of which 150 were members of the WUA and the remaining 343 were non-members. During this survey, the majority of the scheme infrastructures (drop structures, division box, gate shutters, and other structures) were functional. However, a number of problems were faced in the scheme illegal water abstraction, canal breaching, water theft, and damaged of earthen canals by donkey carts. Majority of farmers practice furrow irrigation with a length of 8 to 54 m. There is no restriction for the type of crop one grows by farmers, but the majority of crops grown by farmers were wheat, potatoes, and onion (40%, 35, and 25), respectively.

Field Water Application Efficiency (Ea)

Before determining the application efficiency of a field, we computed depth of water stored in the root zone and applied depth was stated (Table 2).

The flow measurements on field channels/furrows were measured and recorded by RBC flumes on the calibrated flume stilling well in liters per second and depth in millimeters and carefully recorded the flow values, the time that was taken until the irrigator completed irrigating test plot, and the average depth of irrigation water passing through

the flume then the total volume of water passing through the field were determine by multiplying the discharge/flow with time taken. The calculated applied depth of the scheme was (Table 3) 70 mm, 78 mm, and 68 mm at the head, middle, and tail reaches of the scheme, respectively, and the average applied depth was 72.39 mm.

Applied depth of water in the scheme (Table 3) shows relatively much water is applied at the middle of the scheme and lower water is added at the tail of the scheme compared to all reaches. Generally, the applied depth of water at middle was relatively higher than the other test plots that applied more water to the crops (Table 4).

The obtained average values of application efficiency were 54.3%, 53.5%, and 52.7% for head, middle, and tail users, respectively; the average was 53.5%. This indicates that the application efficiency of the schemes was inefficient from the expected values of surface irrigation due to poor managements of irrigation water to their fields that were applying excess water in the field. Application efficiency of all plots in the schemes was almost similar values compared from the head farm plots to the tail farm plots. This indicates that those irrigators who are getting water access to crops were not properly managed and over irrigating of the farms that reduce field application efficiency. The result was in line with Roger et al. (1997) was reported as, it is possible to have high application efficiency (50–90%) can be used for general system type comparison and Lesley (2002) was reported as, it could be in the range of 50–80%. But the result was disagreed from FAO (2003) that reported that the attainable application efficiency according to the USA (soil

Table 2 Determination of water stored (retained) depth in the root zone (Ws)

| Location of field | Soil depth (cm) | Sampling time | Average% of moisture (Wt base) | Moisture difference (%) | Average BD (g/cm ³) | Moisture content (vole, base) | Root depth (mm) | Stored depth (mm) | Total stored depth (mm) |
|-------------------|-----------------|---------------|--------------------------------|-------------------------|---------------------------------|-------------------------------|-----------------|-------------------|-------------------------|
| | | | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| | | | | | | (2*3) | | (4*5/100) | (sum) |
| Head | 0–30 | BI | 37.5 | 7.28 | 1.23 | 8.96 | 300 | 26.8 | 38.0 |
| | | AI | 44.78 | | | | | | |
| | 30–60 | BI | 37.12 | 3 | 1.24 | 3.72 | 300 | 11.2 | |
| | | AI | 40.12 | | | | | | |
| Middle | 0–30 | BI | 33.17 | 8.57 | 1.15 | 9.8555 | 300 | 29.57 | 42.1 |
| | | AI | 41.74 | | | | | | |
| | 30–60 | BI | 36.12 | 4.7 | 1.25 | 4.175 | 300 | 12.53 | |
| | | AI | 39.46 | | | | | | |
| Tail | 0–30 | BI | 34.16 | 7.29 | 1.15 | 8.3835 | 300 | 25.15 | 36.1 |
| | | AI | 41.45 | | | | | | |
| | 30–60 | BI | 33.22 | 2.91 | 1.25 | 3.6375 | 300 | 10.91 | |
| | | AI | 36.13 | | | | | | |
| Average | | | | | | | | | |

BI, moisture content before irrigation; AI, moisture content after irrigation for all reaches

Table 3 Average applied depth of water in (mm)

| Location of fields | Area (m ²) | Time (s) | Time (H) | Depth (mm) | Q (L/s) | Total volume (L) = (5*2) | Total volume (m ³) | Applied depth (mm) = (7/1) |
|--------------------|------------------------|----------|----------|------------|---------|--------------------------|--------------------------------|----------------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Head | 1500 | 14,200 | 3.94 | 96 | 7.4 | 105,080 | 105.08 | 70 |
| Middle | 752 | 9543 | 2.65 | 85 | 6.2 | 59,166.6 | 79.17 | 78.6 |
| Tail | 1115 | 11,740 | 3.26 | 88 | 6.5 | 76,310 | 76.31 | 68.4 |
| Average | | | | | | | | 72 |

conservation science) ranges from 55 to 70%; value below this limit would normally be considered unacceptable. In general, the schemes were below the recommended values due to poor scheme management activities.

According to Yusuf [34], the application efficiency 30–60% was considered as inefficient and indicated that the farmers were applying excess water to their fields. The potential cause of low application efficiency values may be due to the low level of farm water management at the field level (Table 5).

Field Storage Efficiency

The depth of the water retained in the root zone was computed using moisture content field capacity and permanent wilting point obtained. The average results of storage efficiency obtained were 77.4%, 80.2%, and 79.4% for head, middle, and tail locations of the test plots, respectively, with the average result 78.9%. According to Raghuwanshi and Wallender [36], the recommended storage efficiency is 87.5%, and Tedla (2007) at Bullinegero small-scale irrigation scheme, it was 92.8%. And depending on weather, type of soil, and time span considered, storage efficiency might be as high as 90% [19]. Thus, the storage efficiency of the system is below the recommended value. Generally, the irrigation system was not adequate in fulfilling the soil moisture. This was due to low frequency of water applied to all field and the water was infiltrated deeper. It shows over irrigation of the field and this might be associated with the intention of the farmers on high return from high irrigation depth.

Table 4 Farmer field application efficiency (Ea) in each plot

| Location of field | Average stored depth (mm) | Average applied depth (mm) | Average application efficiency (%) |
|-------------------|---------------------------|----------------------------|------------------------------------|
| Head | 38.03 | 70.05 | 54.3 |
| Middle | 42.11 | 78.68 | 53.5 |
| Tail | 36.06 | 68.44 | 52.7 |
| Average | 38.73 | 72.39 | 53.5 |

Distribution Uniformity (Du %)

The average distribution uniformity of the scheme was 79.5% which was similar result suggested by Irmak. S; William. L (2011) reports a low Du (< 60%) which indicates that the irrigation water is unevenly distributed, while a high Du (< 80%) indicates that the application is relatively uniform over the entire field. Generally, the obtained result of distribution uniformity in the scheme was near to the reports from Irmak and William (2011) which was good.

Deep Percolation Ratio

The deep percolation ratio calculated was 45.7%, 46.5%, and 47.3% for head, middle, and tail test plots, respectively. A higher deep percolation naturally results lower application efficiency. The averaged scheme loss due to deep percolation was 46.5% that means from the total depth of water applied, 46.5% water was lost due to deep percolations. During the study period, it was observed that some irrigators in the middle and tail fields of the scheme were trying to drain out excess water from their fields' excavated drainage ditches. Hence, it was an implication of over irrigation which resulted in water logging problem.

Conveyance Efficiency (CE)

The water conveyance efficiency for secondary canal was varied from 85.5 to 90.1% at different measuring points and the average value secondary canal conveyance efficiency was equal to 86.6%.

Water conveyance loss consists mainly of operation losses, evaporation, and seepage into the soil from the sloping surfaces and bed of the canal. The seepage loss in the irrigation canals accounts for the major portion of water conveyance loss (14.4%) of water lost due to seepages. The water conveyance losses L/S/M of secondary canal varied from 0.16 to 0.19 l/s/m with average value equal to 0.18 l/s/m. The lining of an irrigation canal has the advantages of reduction in seepage losses from canals

Table 5 Average storage efficiency in each plot (Es)

| Location of field | Average BD g/cm ³ | Average TAW in % | Average TAW | Total root depth mm | Depletion factor | Required depth mm | Stored depth mm | Average storage efficiency % |
|-------------------|------------------------------|------------------|-------------|---------------------|------------------|-------------------|-----------------|------------------------------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | | | | | | (1*3*4*5) | | (7/6)*100 |
| Head | 1.245 | 10.505 | 0.105 | 600 | 0.75 | 58.85 | 40.35 | 77.36 |
| Middle | 1.245 | 9.31 | 0.093 | 600 | 0.75 | 52.16 | 47.19 | 80.18 |
| Tail | 1.245 | 8.105 | 0.081 | 600 | 0.75 | 45.41 | 36.06 | 79.41 |
| Average | | | | | | 52.14 | 41.2 | 78.98 |

that were properly managed and maintained compared with unlined canals which are highly affected by seepage loss. However, better conveyance efficiency was on the 165-m canal section and the maximum water loss was observed at 0.19 l/s/m on the 251-m length canal section of secondary canal; this was compared to other sections of measuring points of canals. Reason being this section was highly cracked and malfunctioning of control gates which caused high seepage and leakage losses in the canals that affects the canal efficiency.

At the Inguti small scale irrigation scheme, about 2.1-km length of the tertiary canal was lined and the remaining 1.27 km is unlined, making a total length of tertiary canal at the unit both lined and unlined of 3.37 km. The estimated average value of inflow, outflow, water conveyance efficiency, and water conveyance losses for different sections of the tertiary canal in each blocks. The average water conveyance efficiency for tertiary canal both lined and unlined canal varied from 89.3 to 64.2% and the average value of both lined and unlined canal was 77.7%.

The maximum and minimum water conveyance loss observed in tertiary canals was varied from 0.23 l/s/m on TC (01) to 0.09 l/s/m on Tc(05) which were compared to other sections of measuring points of the canals.

The reason being in this section of canal was observed maximum water lost (Tc,01) due to the factors of canal type (earthen), poor maintenances (cleaning) and blocking of canals with crop residues/or other debris of the scheme (Fig. 6) which results side eroding of canal wall and re-growth of grass in the canals to reduces conveyance efficiency. The value of conveyance efficiency was different for each sections of canal which were measured and estimated along a respective length of canals. This indicated that the conveyance efficiency of lined canal is below the recommended 95% for lined canals while 80% unlined canals for clay soil [35]. The reasons behind high conveyance loss of earthen canals in the studied canals were poor management, improper design, rodent's holes, insufficient channel bed slop,

and overtopping the bank. Large amount of water was lost, which could have irrigated more lands that implies that a significant amount of irrigation water was lost in the earthen canal compared to lined canals (Fig. 7).

The users use mud, wood, and trashes of different plants to obstruct the flow of water and divert it to the next farmer. However, as this mechanism is not quite efficient in obstructing the flow of water, still much water leaks and flows to the undesired canals that reduces the efficiency of canal.

Sustainability of Irrigable Area

The sustainability of irrigated area of Inguti irrigation unit is relatively highest sustainability of irrigation land value were compared to the planned irrigable areas (Table 6).

Infrastructural Effectiveness (EI)

In Inguti irrigation scheme, no more severed infrastructures were observed in the secondary and tertiary canals. The total number of structures that were installed in the irrigation scheme was 199; from the total number of structures in the unit, 194 structures were currently functional. Hence, the value of effectiveness of infrastructure was estimated using Eq. 2.13 to be 96.2%. The suggested values of infrastructural effectiveness of the irrigation scheme were good which implies that the maintenance activity of a system was fair (Table 7).

Overall Scheme efficiency

In the present study, the overall efficiencies of the irrigation schemes were found to be 46.3%. The overall efficiency of the Inguti irrigation scheme was within the range of values (40–50%) commonly observed in other similar African irrigation schemes [32]. According to [35], the irrigation efficiency of the plan 50–60% is good and 40% reasonable,



Fig. 6 Application efficiency in each test plot

while the irrigation efficiency of the plan by 20–30% is considered poor. It should be kept in mind that the above values are only indicative values. Therefore, the result of overall irrigation scheme (46.3%) is between reasonable values [35].

Performance of the Water User Association

Inguti irrigation scheme is mainly administered by “YewuhaAbats” or “water fathers” who are elected by the beneficiaries of the scheme. However, during the study period, Inguti



Fig. 7 Poor canal maintenance (unclean canals)

Table 6 Cropped area ratio and (CAR) water level ratio (WLR)

| Design flow | Measured flow | | Current irrigated | | Planned irrigated | | |
|-------------|-----------------------|-----------------------|-------------------|---------|-------------------|-----------|-----|
| | Q (m ³ /s) | Q (m ³ /s) | WLR | WLR (%) | Area (ha) | Area (ha) | CAR |
| 0.4692 | 0.415 | 0.885 | 88.5 | 368 | 391 | 0.94 | 94 |

WLR water level ratio, CAR cropped area ratio

irrigation scheme/unit has weak WUA and it was administered by community representatives or leaders also called “Father of water.” The WUA within unit was established 10 years ago but now it is not well functional. This might cause poor sense of ownership, improper irrigation water operation and management, and also a lack of effective communication between the WUA/leaders and users of the scheme.

The feeling of respondents about performance of Water User Association within the irrigation unit was evaluated by well-prepared questions for 55 total respondents/farmers in the unit. About 56% of the respondent responded that the overall performance of the Water Users Association in terms of managing the schemes was poor and Water User Associations are not well organized structures and the range is weak to run the irrigation scheme facilitations that improve the performance of irrigations at the unit. Moreover, the cooperative committee manual lacks detailed operational guidelines and rules (such as entry, allocation, penalty, input rules) and organizational structure specifying that in the irrigation scheme. These definitely affected the performance since the success of irrigation to poverty alleviation, according to Bhattarai et al. (2002), depends on water management, input utilization, access to potential output market, and socio economic characteristics of users.

As the farmers responded that (34%) were no get trainings and extension services from governments and other respondents get some of training by development agents (DAs) for the selected model framers/users at the unit. The training, they said, was offered by Merawi Woreda and Keble level administrative councils are expected to mobilize the community, support the WUA, and provide administrative supports

in the course of the development. But most of the trainees that were given by development agents were members of the WUA and some selected model farmers.

Most of respondents responded (40%) that they had got input supply support and 29% of respondents responded that they had got technical advice for farmers on when to irrigate and how to irrigate for different crop varieties with relation to field water application. On the other hand, 13% of them responded that they have got no support on the government.

The results in Table 8 indicated that there is lack of cooperation/integrity between WUAs and other institutions working in Inguti irrigation unit. This constitutes the major factor influencing WUAs participation in Inguti irrigation scheme management.

Lack of transparency between WUAs and other institutions from one hand and between WUAs and their members from other hand constitutes real problem in irrigation scheme.

In general, in Ingutie small scale irrigation schemes, management problems were observed and interviewed at scheme levels. Lack of an efficient WUA; water management problems, such as equitable water use, high water loss due to seepage as a result of a poor maintenance strategy, uncontrolled water use, vandalism, and water theft; and scheme management issues, such as lack of structural maintenance, lack of proper operation of the structures, and lack of the ownership sense are the major constraints in all schemes. The result shows that the irrigation systems were poorly managed in terms of water allocation and distribution, conflict management, and system maintenance, because of lack of well-established organizational and institutional conditions. The Water User Associations are not well organized and found to be weak to run the irrigation scheme.

Table 7 List of infrastructures and its performances at the unit

| Infrastructures | | | | | |
|----------------------|-----------------|---------------|----------------------|--------------------------|-------------------------|
| Structures | Type | Total numbers | Functional (working) | Non-functional (damaged) | Problems |
| Division box | Concert | 26 | 26 | | Un-balanced opening |
| Division box shutter | Steel | 26 | 23 | 3 | Un-balanced opening |
| Division box culvert | Concert and PVC | 26 | 24 | 2 | Clogging with sediments |
| Drop structures | Concert | 91 | 91 | | Some of scoring |
| Cross regulator | Steel | 3 | 3 | | |
| Control gate | Steel | 14 | 12 | 2 | Un-balanced opening |
| | Total | 186 | 179 | 7 | |

All infrastructural effectiveness (%) 96.2%

Table 8 Responses of farmers about what factors influence the success of WUA in relation to scheme irrigation managements

| Responses of farmers/users | Frequency | Percent (%) |
|-----------------------------------|-----------|-------------|
| *1 Lack of cooperation/integrity | 21 | 38 |
| 2 Transparency and accountability | 15 | 27 |
| 3 Workload | 7 | 13 |
| 4 Low income | 4 | 7 |
| 5 Absence of training | 8 | 15 |
| 6 Total | 55 | 100 |

Responses of Farmers About Water Distribution Schedules in the Scheme

The water distribution in the scheme is managed by the beneficiaries themselves without any designed irrigation schedule being considered based on crop water demand and each growth stages. The result shows that only 15% of the respondent farmers confirmed that water supply to each farmer is decided by WUA and 38% farmers confirmed that the distribution was managed by beneficiary households. According to all respondents, every member in the scheme has the right to get irrigation water and is free to grow a crop he/she wishes but farmers do not know the specific time for irrigating and watering within irrigation time of 12 h. Conflict among the irrigation users was obvious in irrigation schemes due to the reason of water abstraction for different purposes that diverted to the command areas.

The common source of conflict that rises in the scheme is responded to by the scheme farmers; 40% of household respondents believe that the conflict is due to the problem of water management which is lack of responsible body to control the water distribution system and other conflicts were raised due to improper irrigation schedules and water theft that included poor water management activities.

Forty-two percent of respondents reported that problems that exist in the irrigation canals were deposition of sedimentation due to poor cleaning of the canals, which was the cause of weed invasion in the canal beds, and 31% of the respondents responded that the problems occurred in the canals were seepage loss due to cracking of concrete line canals and longtime stagnate water in earthen canals.

The responses of farmers shown that for poor maintenance of the canals due to poor work collaboration/integrity that mobilizing and facilitating the scheme users. However, the status of the secondary canals and their water control structures showed that no proper maintenance has been carried out for a long time and the cooperative was not effectively shouldering the scheme management. The beneficiary farmers also acknowledged that the scheme was poorly maintained, and they attributed the problem to lack of fund and poor organization for maintenance.

Conclusions

Assessing farm water managements and performances of irrigations is critical to evaluate the existing situations of farm water management and the levels of infrastructural performances.

The averaged water conveyance efficiency for lined secondary and tertiary canal was found to be 86.5% and 81%, respectively, and about 64% of water conveyance efficiency for unlined tertiary canals. The results imply that conveyance efficiency of the scheme was below the recommended values 95% for line [35] (Wachyan & Rushton, 1987). According to the result, most conveyance loss was observed in tertiary canals due to poor managements of canals, eroding off the canal, insufficient bed slop of the canal (backflow), leakage due to cracking, weed growing in the canals, and illegal water abstraction.

According to the result, most of infrastructures in the irrigation scheme at tertiary level was well functional and its infrastructural performance was 96%. But some of infrastructures at the unit was un-functional due to sediment clogging of division box culvert, unbalanced opening of some gates, and damaging of gate shutters which means the gate is not allowed to pass the required amount of water in the field.

From the results, the averaged irrigation application efficiency was 53.5% which indicates inefficient field water managements due to excessive application of irrigation water. This field irrigation application efficiency is below the standard of 60% for surface irrigation methods [27.]. The reason for lowering of field application efficiency was the farmers' sense that the crops are productive by applying excess water that leads to the crop not getting the required water based on the growth stages.

According to the results, the beneficiary participation in the irrigation schemes in canal clearing and regular maintenance was low due to poor performance of WUAs that facilitate and solve scheme managerial issues effectively and timely. The UWA lacks to conduct regular meeting and scheduling of activities for the effective operation of the irrigation scheme. There is also poor documentation and attendance of participant/users, maintenance planning, and reporting to irrigation managerial authority. Due to weak performances of WUAs, some of the canals were covered by weeds, side wall eroding, and deposition of sediments which allows irrigation water to spill out and be lost.

Data Availability The required data collected for analysis are included in the manuscript. The corresponding author is ready to clarify the data and provide all the necessary data set as per the request.

Declarations

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants involved in the study. I understand that journals may be available in both print and on the internet, and will be available to a broader audience through marketing channels and other third parties. Therefore, anyone can read material published in the Journal.

Conflict of Interest The authors declare no competing interests.

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