Applied Research Journal of Environmental Engineering
Vol 1(1), pp. 1-13, December, 2018
Article number: se-j-arjee-2018.0101001
https://skies.education/journal-arjee/

International Institute for Applied Research
Skies Educational

Performance Evaluation of Selected Surface Irrigation Schemes in Kachabira Woreda, SNNPRS, Ethiopia

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This study was conducted to evaluate the comparative performances of two community-managed small scale irrigation schemes at Gemesha and Ufute with command area of 48 ha and 40 ha using internal performance indicators. In order to evaluate the irrigation water use efficiency at field level, nine farmer fields were selected from each irrigation schemes in relation to their location (from the head, middle and tail end water users). The internal performance indicators namely, in conveyance efficiencies, application efficiencies, deep percolation, storage efficiencies and irrigation uniformity shows (61.15 and 65.63%), (58.75 and 71.7%), (41.25 and 28.3%), (36.91% and 23.9%) and (98.32 and 97.79%) for Gemesha and Ufute respectively. The irrigation ratio results for physical sustainability indicator shows 0.32 and 0.4 for Gemesha and Ufute irrigation respectively. The result of relative Irrigation Supply for both irrigation schemes was higher than one, this shows that there were over supply of water in both irrigation schemes for Gemesha and Ufute respectively. Based on the assessment carried out, Ufute irrigation scheme performed better than Gemesha irrigation scheme. But there is still a room for improvement of the performance of both irrigation schemes.

Keywords: Internal indicators, efficiency, deep percolation, irrigation,

INTRODUCTION

Irrigation is of major importance in many countries in terms of agricultural production and food supply. To meet the demand of the ever-increasing population in Ethiopia (presently ~ 100 million), 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 irrigable area in Ethiopia is 197,225 ha around 3 % of the irrigation potential (MOWR). Moreover, much of the increase in irrigated area had come as a result of expansion of small-scale irrigation. Yet, the existing irrigation development in Ethiopia, as compared to the resource the country has, is negligible. Despite their promise as engines of agricultural growth, irrigation projects have typically performed far below their potential (Small and Svendsen, 1992). International Fund for Agricultural Development (IFAD, 2014) and (Hess, 2010) reported as only 20% of the world's total croplands are irrigated. However, these lands contribute to some 40% of the global agricultural harvest. The figure indicates that irrigated agriculture on average is roughly more than two and half times as productive as rain fed agriculture. Agriculture depending on rainfall has failed to produce enough food and with increasing rainfall variability, productivity of rain fed agriculture is expected to diminish.

Ethiopia has an estimated irrigation potential of 3.7 million hectares (ha) of land (Awulachew *et al.,* 2007). During 2006, the total estimated area of irrigated agriculture in the country was 625, 819 ha, which, in total, constitutes about 17% of the potential (MoWR, 2006). Despite its enormous potential to boost the country's economy irrigated agriculture is facing a number of problems. One of the major concerns is the generally poor efficiency with which water resources have been used for irrigation. A relatively safe estimate is that 40 percent or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface runoff (FAO, 1989).

This research deals with two community managed small-scale irrigation schemes namely Gemesha and Ufute specifically located in Kachabira Woreda, Kembata Zone in South Nation Nationality and Peoples Regional State (SNNPRS) of Ethiopia. The key stakeholders of these schemes are smallholder farmers. The schemes are community managed, because farmers are responsible for management of irrigation water and maintenance of their infrastructure through their Water Users Association (WUA).

The question – how is irrigated agriculture performing with limited resources? – has not been satisfactorily answered in our study area. We have not been able to compare irrigated land, water use, financial investments and crop production to learn how irrigation systems are performing relative to each other and what the appropriate targets for achievement are. Moreover, the results of individual improvement efforts have often not been satisfactorily measured and documented.

The study has the potential benefit of improving irrigation efficiency and reducing stress on water resources and losses of water and nutrients to groundwater and surface water resources. Furthermore, findings from the study would serve as a guide in the implementation of future surface irrigation systems for irrigating larger areas with a given volume of water. This study would also contribute to knowledge in the field of irrigation practice in Ethiopia at large.

MATERIALS AND METHODS

General Description of the Study Area

Kachabirra Woreda is one of the Seven Woredas in Kembata-Tembaro Zone Administration of Southern Nations, Nationalities and Peoples Region (SNNPR) State. The Woreda comprises 21 Kebele Administrations (all of them are Rural Kebeles).The mean annual rainfall of the project area (as measured at Durame meteorological station for the period of 1984-2013 (30years) is 1115.8mm.

In order to illustrate the potential use of irrigation performance indicators in evaluating efficiency of irrigation systems, two schemes Gemesha and Ufute small scale irrigation were considered. The availability of secondary data and organizational set up of the irrigation projects were considered as a primary criterion for both irrigation projects in the study area.

Description of the Schemes

Gemesha Irrigation Project

Establishment: Before construction of Gemesha irrigation project, the life of the farmers in the study area relied on the production of rain fed crops and livestock. The Gemesha irrigation scheme was established by NGO called World Vision Ethiopia in 2000 G.C. Gemesha Small scale irrigation Project is found in Gemesha Kebele Administration in which command area

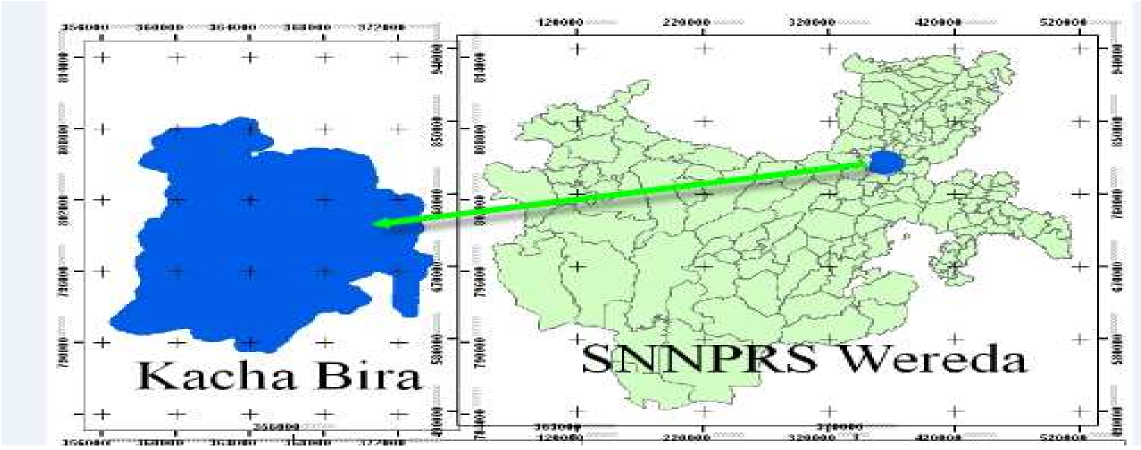

Figure 1: Location map of study area

located at 25 km far from Durame Town. The Project area is situated on geographical grid of $7^0$15`N Latitude and $37^0$45`E Longitude. Initially the area was designed to cover gross command area of 75 ha. Up on the development of the project, each farmer was cultivating his own land separately. This has created disputes among farmers. The source of water for the irrigation project is Senbeta River. The Senbeta River is diverted to the canal by constructing a diversion wall at a location where there is small natural protruding land in the river. The diverted water is then blocked by a weir near the main gate to raise the head of the water in the canal.

Ufute Irrigation Project

Ufute irrigation scheme was established by SNNPRS Water Resource Development Bureau in 2012 G.C and the project is found in the Woreda particularly in Mino Kebele Administration and the head work is located 3 km South West of the Gemesha irrigation scheme. Initially the project was designed to cover gross command area of 70 ha. The source of water for the irrigation project is Ufute River. The Ufute River is diverted to the canal by constructing a diversion wall at a location where there is small natural protruding land in the river. The diverted water is then blocked by a weir near the main gate to raise the head of the water in the canal.

Major Crop Types and Production Practices in the Area

There are different sources of household income. Sources of household income in both schemes can be classified as income from grain production and income from cash crop production. The production from grain crop includes Maize and Sorghum in both irrigation systems. Cash crop refers to vegetable crops produced through irrigation for the purpose of market to increase household cash income. Therefore, farmers in both irrigation schemes produce high value horticultural crops such as Onion, Tomato and Cabbage.

Data Collection Methods

Based on the survey made and information gathered; two irrigation projects were selected. Availability of organizational set up, nearness to weather station, and the availability of secondary data were the primary criteria for site selection. Data collected include primary sources at field level in the irrigation project. Three farmers' fields were selected from the head, middle and tail water users of each irrigation projects.

CLIMWAT 2.0 for CROPWAT, CROPWAT VERSION 8.0 was used for determining ET and water demand of the crop. Formal and informal survey was used for primary data collection. A formal survey was carried out with the help of standard questionnaire designed to obtain information from selected representative households. Discussion were made with key farmers including committee members of local irrigation water user's, executive members of peasant associations, Developmental Agent (DAs) and Kacha Bira district irrigation development desk representatives and experts from cooperative desk.

Determination of the Amount of Water Applied to the Fields

Floating method

Floating methods was used to calculate the surface velocity of the stream. An orange, partially filled with water, or waterlogged stick was used as float just below the surface and minimize the effects of air currents. It was done by making marks off a known length of the reach of at least 20m. Introduce the float just upstream of the first mark so the float has time to reach the stream's velocity. Measure the time it takes to pass between the two marks. Three passages of the float were ideal and averaged. In order to correct the effect of the streams bottom there is a correction factor, K = 0.85 based on the bed roughness it ranges from 0.8 to 0.9(Liggett, 2001).

$$\text{Velocity of the Float} = \frac{\text{Known Distance(m)}}{\text{Time required to pass this known Distance (s)}} \quad (1)$$

$$\text{Average velocity of flow} = \text{measured velocity of float} * 0.85 \quad (2)$$

$$\therefore Q = \frac{\text{Average c}}{\text{s area}} * \text{Average velocity of flow} \quad (3)$$

Sample Selection and Sampling Techniques

The total household heads that are using irrigated agriculture at Gemesha and Ufute small-scale irrigation systems are 432 and 323 respectively. Although the size of the population of the two study sites differs, equal number of sample water user was selected from each for the convenience of the study. Generally, irrigation users can be classified according to their location with respect to water source viz.., farmers located at head, middle and tail of the system. The classification was made based on idea that the head user uses more water and the tail users use less water. These approaches help to obtain different insights, thoughts and attitudes from farmers concerning the practice of irrigation. Simple random sampling technique was employed to select 3 water users from each group in both study area.

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 metrological station. Durame metrological station center was the source of the climatic data for both Gemesha and Ufute irrigation scheme.

Laboratory analyses

Bulk Densities (BD), soil textures, Field Capacity (FC), Permanent Wilting Point (PWP) of the soils of the selected farmers' fields at different depths were determined in the laboratory. To determine these soil parameters with their respective laboratorial procedures, recommendation manuals of Kamara and Haque (1991) and Sahlemedhin and Taye (2000) were followed. Then the values of the parameters determined were applied where they are appropriate for the analyses of the study.

Infiltration characterization

Double ring infiltrometer with 30 and 60 cm inner and outer ring diameters respectively was used to determine infiltration characteristics of the soil in the scheme of selected representative three fields (from head, middle, and tail ends of the schemes). Double ring infiltrometer was driven to the depth of 15 cm into the soil by hammer. Depths to water levels were measured at increasing time intervals from the datum established on the edge of each cylinder.

Gravimetric sampling for moisture content determination

Gravimetric samplings were made by collecting more than 9 soil samples from each farmer's fields with an interval of 40 to 150 cm of soil depth. It is presumed that this depth is deeper than the effective root zone of the irrigated vegetable crops. The maximum effective root zone of small vegetables, like onion, is 60 cm (Allen *et al*, 1998). The soil samples were placed in a container of known weight and then weighed. The samples were then placed in an oven dry 105° C for 24 hours. The dry weight fraction of each sample was calculated using the equation (FAO, 1989; Kamara and Haque, 1991).

$$W\theta = \frac{Ww - Wd}{Wd} * 100 * Bd \tag{4}$$

where,

$W\theta$- is gravimetric soil moisture content (% volume bases),

Ww- is wet weight of the soil (g),

Wd- is dry weight of the soil (g) and

Bd-bulk density of soil (g cm^{-3})

Then the moisture contents of the soils collected from the selected fields at different depths were determined.

Crop water requirements and irrigation scheduling

Crop water requirements, irrigation scheduling and irrigation water requirement of the irrigated crops at field levels of the irrigation project as a whole were estimated using CROPWAT 8 system by (FAO, 1992).This program uses the FAO (1992) Penman-Monteith equation for calculating reference crop evapotranspiration. The determination of IWR was carried out after estimation of effective rainfall by USDA soil conservation service method (Clarke, 1998). The irrigation requirements of each irrigation projects were calculated with CROPWAT 8 using the climatic data, cropping pattern, planting dates, and area of each crops.

Internal Performance Indicators

The internal performance indicators for each scheme were computed based on field measured data. Accordingly, the conveyance efficiency of the scheme was computed by taking discharges measurement at different points. The measurements points were taken at a diversion and initial and final points of main canals. It was computed as the follows (Ramulu, 1998):

$$\mathrm{Ec} = \frac{\mathrm{Wf}}{\mathrm{Ws}} * 100 \quad (5)$$

The conveyance efficiency of the scheme was computed as:

$$\mathrm{Ec} = \mathrm{Em} * \mathrm{Es} * \mathrm{Et} * \mathrm{Ef} \quad (6)$$

where Ec is conveyance efficiency (%), Em is conveyance efficiency of main canal (%), Es is conveyance efficiency of secondary canal (%), Et is conveyance efficiency of tertiary canal (%), Ef is conveyance efficiency of field canal (%), Ws is depth of water diverted from the source (m^3) and Wf is depth of water applied to the field (m^3).

The application efficiency was computed as the ratio of moisture added to the soil profile due to irrigation to the total water supplied to the farm or the ratio of moisture retained due to irrigation with total water added to the field. In this particular research soil samples were collected from different fields at depths of (0-40, 40-70, 70-110 and 70-150cm) and the amount of water stored in the root zone was determined by gravimetric method. Application efficiency was computed as follows (Ramulu, 1998):

$$\mathrm{Ea} = \frac{\mathrm{Zr}}{\mathrm{D}} * 100 \quad (7)$$

where Ea is application efficiency (%), Zr is average depth of water applied to the root zone as storage (mm), and D is average depth of water applied to the field (mm).

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

$$\mathrm{DPR} = 100 - \mathrm{Ea} - \mathrm{RR} \quad (8)$$

where:

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

The storage efficiency is an index used to measure irrigation adequacy. 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. Based on the moisture content at field capacity, permanent wilting point and bulk density of selected irrigation fields and the root depth, the depth of irrigation water required by maize was calculated at 50% moisture depletion level i.e. MAD of 0.50 (Hillel, 2004). After determining the storage and the required depths, the storage efficiency was calculated using the following formula (Ramulu, 1998):

$$\mathrm{Er} = \frac{\mathrm{D_{sr}}}{\mathrm{W_n}} * 100 \quad (9)$$

where: Er is storage efficiency (%), Dsr is water stored in the root zone (mm), and Wn is water desired to be stored in the root zone (mm).

Depth of water stored in the root zone

Pre and post irrigation soil moisture analysis method was employed for calculating water stored in the crop root zone. The soil samples for moisture content before and after irrigation were taken at three randomly selected points in each plot. The samples were collected at three depths i.e. 40, 70 and 130 cm. The maize crop has root depth greater than 1m; therefore, soil samples were collected down to 130 cm depth. Moisture content of samples was measured on dry weight basis. The procedure adopted by Imark *et al.* (2011) was used to calculate the depth of water stored in the root zone

$$\mathrm{Dsr} = (\mathrm{M.C} * \mathrm{Sp.G} * \mathrm{Zr}) \tag{10}$$

where:

Dsr = Depth of water stored in root zone M.C = Moisture content of soil (%)
Sp.G = Apparent specific gravity of soil Rz = Depth of root zone of crop, m

Apparent specific gravity

The ratio of weight of volume of different solid soils to the volume of water both being measured at zero degree temperature is presented in Table 1.

Table 1: Apparent specific gravity of different soils

Soil type	Quartz sand	Silt soil	Clay soil	Chalk	Loess	Peat
Specific gravity	2.64-2.66	2.67-2.73	2.7-2.9	2.6-2.75	2.65-2.73	1.3-1.9

Source: Salgado (2008).

Root zone depth of crops

Usually root zone is either assumed or estimated because its accurate measurement is not easy due to several varying conditions. This is the soil depth from which the plants take nearly 80 percent of their water needs, mostly from the upper part where the root system is denser. The rooting depths depend on the plant physiology, the type of soil, and the water availability (kind of irrigation) (FAO, 1992). In general, vegetables (beans, tomatoes, potatoes, onions, peanuts, cucumbers, etc.) are shallow rooted, about 50–60 cm; fruit trees, cotton and some other plants have medium root depths, 80–120 cm. Alfalfa, Sorghum, and Maize have deeper roots. Moreover, rooting depths vary according to age (Hillel, 2004). Distribution uniformity was determined by recording advance time and recession time at three equal points of the selected furrows. The depth of water infiltrated during the opportunity time was derived from measurement of the infiltration rate of the soil, which was determined using double ring infiltrometer. The irrigation distribution uniformity was computed using the following formula (Ramulu, 1998):

$$\mathrm{Ed} = \left(1 - \frac{\bar{y}}{d}\right) * 100 \ldots\ldots 3.9\bar{y} = \sum_{i=1}^{n}\left(\frac{(|y-d|)}{n}\right) \tag{11}$$

where:
Ed is distribution uniformity (%), d is average depth of water infiltrated (mm), $\bar{y}$ is average absolute deviation depth of infiltrated water from the mean d (mm) and y is depth of water infiltrated at a given point (mm). Finally the overall scheme efficiency was calculated as the product of conveyance and application efficiency. It was computed using following formula (Ramulu, 1998):

$$Ep = Ec * Ea \quad (12)$$

where:
Ep is overall scheme efficiency (%), Ec is conveyance efficiency (%) and Ea application efficiency (%).

RESULTS AND DISCUSSION

Gemesha Irrigation Project

The discharge in the canal is controlled by manually operated gate. The discharge of the main canal varies from time to time, along with the parent source, Senbeta River. The discharge lies in the range of 150 and 420 liters per second with an average discharge of 210 liters per second. The maximum discharge capacity of the main canal of the Gemesha irrigation project is 150 liter per second.

Ufute Irrigation Project

The discharge in the canal is controlled by manually operated gate. The discharge of the main canal varies from time to time, along with the parent source, Senbeta River. The discharge lays in the range of 98 and 215 liters per second with an average discharge of 125 liters per second. The maximum discharge capacity of the main canal of the Ufute irrigation Scheme is 98 liter persecond.

Internal Process Indicators

Conveyance efficiency

The results of the conveyance efficiency evaluation revealed that there is variation within a farm at different points, between farms, within and between schemes. The average conveyance efficiency values indicate the amount of water lost during transportation from the diversion point or source to field canal of Gemesha, and Ufute irrigation schemes were found to be 61.15 and 65.63%, respectively (Figure 2).

The conveyance efficiency of the Ufute irrigation scheme is better than the Gemesha. This is probably associated with length of main canals and technical and managerial facilities ofWater control. In Gemesha irrigation about 2500 m length of the main canal is lined which cause high water loss due to evaporation. Head loss, high silt accumulation along the canal, leakage in some parts of the canal, ‘poaching’ by people and to livestock watering and over-topping of water in the main canals was common. In the case of Ufute irrigation scheme the main canal is 1037m lined; all the division boxes works properly and the main canal and secondary canals size is enough to convey the water and no over topping of water on field canals. However, the values of conveyance efficiency for both schemes are below the recommended value i.e.70% unlined poorly managed main canals (MoAFS, 2002).

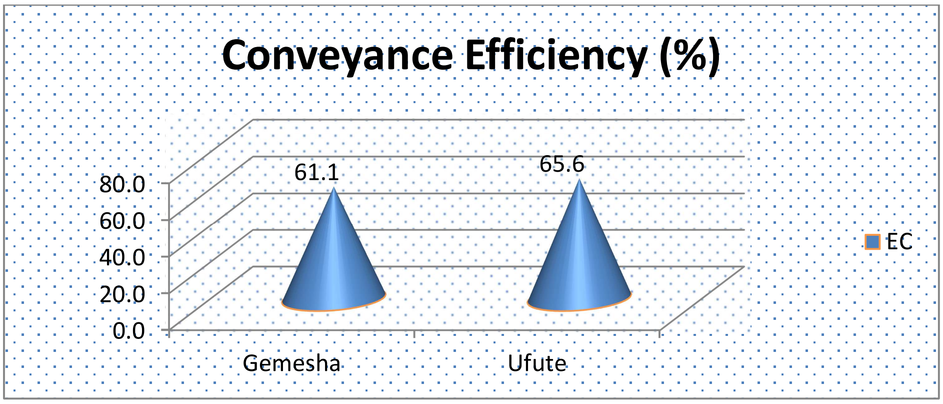

Figure 2 .Average Conveyance Efficiency of Gemesha and Ufute

Application efficiency

Water application efficiency provides a general indication of how well an irrigation system application efficiency of selected fields at the Gemesha irrigation scheme was found to vary from 43.39% to 75.22% with an average of 58.75% but the same parameter for selected fields at the Ufute irrigation scheme vary from 55.98 to 87.50% with an average application efficiency of 68.8% (Figure 3). The finding indicates that the application efficiency of Ufute scheme was slightly better than Gemesha irrigation scheme. This may be associated with the institutional set up of Ufute irrigation scheme which is stronger than that of Gemesha and non-beneficial use such as leaching is high in Gemesha scheme. The study is in congruent with study conducted on application efficiency of schemes by (Savva and Frenken, 2002. Kandiah (1981) also reported an application efficiency of 70% for furrow irrigation.

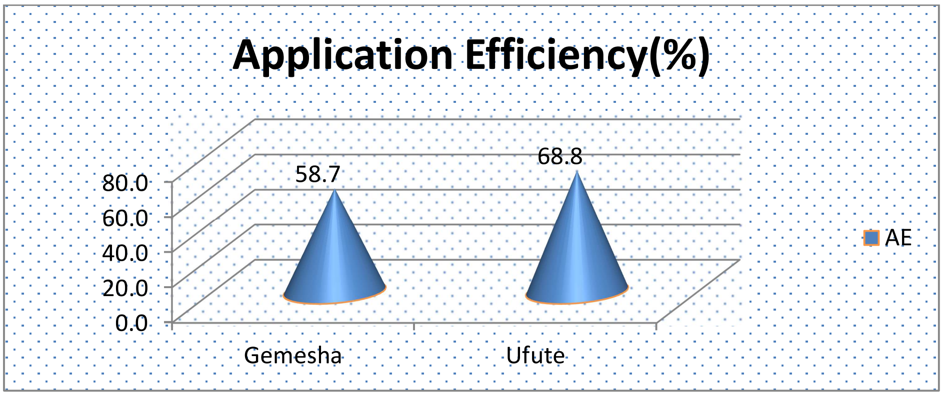

Figure 3. Average Application Efficiency of Gemesha and Ufute

Deep percolation ratio

Since the irrigation schemes considered in this study is blocked end furrows, the main source of water loss was deep percolation. Higher deep percolation ratio values are indications of over irrigation. Average deep percolation ratios at Gemesha irrigation scheme were found to be 41.25% and that of Ufute irrigation scheme was 31.2%. From the result obtained a higher deep percolation ratio was observed in lower application efficiency. During the study period it was observed that some irrigators in Gemesha scheme were trying to drain out excess water from their fields by digging traditional drainage ditches. Hence, it was an implication of over irrigation which is resulted in water logging problem. In both schemes; there is high deep percolation ratio which indicates over irrigation.

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. The water storage efficiencies (Er) were computed by monitoring soil moisture before and after irrigations. The result of storage efficiency of selected fields from Gemesha irrigation scheme was found to vary from 27.48 to 45.59% with an average storage efficiency of 36.91% and that of selected fields from Ufute irrigation scheme varied from16.63 to 29.98 % with an average storage efficiency of 23.9%.

As shown in Table 2 the storage efficiency at Gemesha irrigation scheme was slightly greater than Ufute, but in general the storage efficiency 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.

Table 2: Average irrigation efficiencies at Gemesha and Ufute irrigation projects

Internal Indicator	Project Efficiencies (%)	
	Gemesha	Ufute
Conveyance Efficiency	61.15	65.63
Application Efficiency	58.75	68.8
Deep percolation Ratio	41.25	31.2
Storage Efficiency	36.91	23.91
Irrigation uniformity	98.32	97.79
Overall scheme Efficiency	35.9	45.18

Irrigation uniformity

Irrigation uniformity is used to express the variation in depths of application or supplied volumes. Irrigation uniformity of the scheme was evaluated by monitoring the depth of water infiltrated into the root zone depth using soil moisture content. When irrigation water is applied uniformly in a field it helps to get uniform crop stand and uniform crop growth on the field. In this particular study the irrigation uniformity for Gemesha varies from 96.78 to 99.84% with an average value of 98.32% and on the fields in Ufute scheme it varied from 93.08 to 99.69% with an average of 97.79% (Figure). The irrigation uniformities of both schemes were very good, which may be due to the short furrow length commonly 12 meter, closed furrow ends and large stream flow used. The irrigation uniformity figures observed in both schemes of present study are much higher than the advanced furrow irrigation systems, which is 70% reported by Raghuwanshi and Wallender (1998) and the modern Amibara Project irrigation uniformity of 93% as reported by Kandiah(1981).

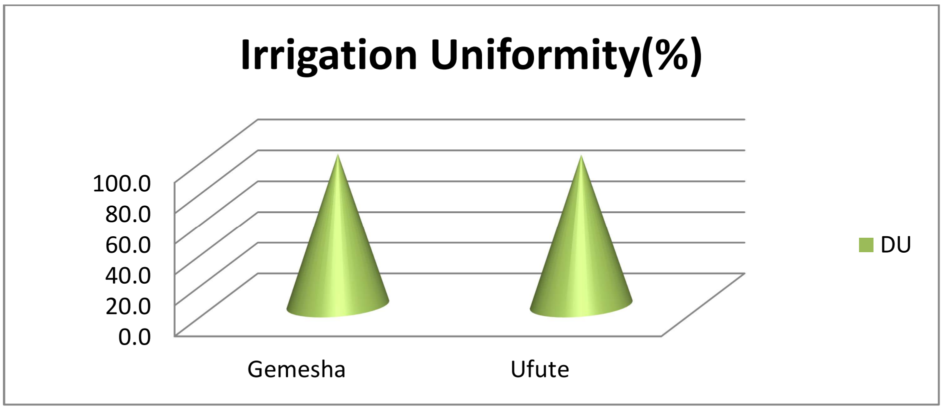

Figure 4.Average irrigation uniformity of Gemesha and Ufute

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

Gemesha and Ufute were found to be 35.9and 45.18%, respectively. The details of overall scheme efficiency of both schemes and the average overall irrigation scheme efficiencies of both schemes are shown in Table 2.

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

CONCLUSIONS

For both irrigation schemes values of water delivery and supply performance indicators presented in this paper are based on data sets of one production season. It doesn't show how adequately, uniformly, efficiently and timely the water distributed over the field and field units throughout the season and it is difficult to indicate exactly where the problems responsible for low performance of the system lie. The relative water supply for both irrigation supplies was higher than one this indicates that there was high water supply in both schemes. The output per cropped area in Ufute irrigation was higher than Gemesha irrigation scheme. This means that the irrigation practice in Ufute irrigation scheme was good as compared to Gemesha irrigation scheme. The return from one meter cube of irrigation water for Ufute irrigation scheme was higher than that of Gemesha irrigation scheme. There was a marked deficiency in irrigation water management at both irrigation projects. Low efficiencies were achieved because applications far exceed farmers' management know-how. This was due to the fact that the system permitted farmers to apply large volumes of water to their plots combined with poor knowledge about the crop water requirements. In both irrigation schemes the values of application efficiencies at field levels were reflected on the values of relative water supply of the irrigation projects as a whole. So there is some common ground to use them integrally. Even if it needs intensive data collection and close monitoring, irrigation efficiencies evaluations were good for farmers' field.

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