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Performance Assessment of Community Managed Irrigation Practices in the Wesha Small-Scale Irrigation Project, Southern Ethiopia

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Abstract

Field assessment to evaluate the performance of small-scale irrigation projects plays a vital role in improving the existing projects and assist engineers in designing new systems so that irrigation practice becomes sustainable. This study was initiated to investigate the causes of under-performance of the Wesha small-scale irrigation project. The performance indicators that were used to evaluate the irrigation project are technical that directly or indirectly affect water deliveries and water spreading effects. Seven technical performance indices used; namely, conveyance efficiency, application efficiency, water storage efficiency, water distribution uniformity, deep percolation fraction, runoff ratio and sustainability. The evaluation was done using nine irrigation events on three representative farmers' fields (selected from the head, middle and tail of the command area). During each irrigation event, water inflow and tail water outflow measurements; determination of soil moisture before and after each irrigation event; interviewing of irrigators; field observations and collection of secondary data were made. The results show that performance of the irrigation project is unsatisfactory in terms of conveyance efficiency, application efficiency, deep percolation fraction and sustainability with mean values of 65.39%, 46.78%, 48.43% and 30%, respectively. This shows that large volume of water is lost as steady-state and transient losses from canals and from irrigated fields. However, the distribution uniformity, water storage efficiency and runoff ratio are satisfactory with mean values of 88.3%, 97.63% and 4.45%, respectively indicating high deep-percolation loss. During the study period, on-site soil erosion, temporary water logging and illegal canal breaching are the observed major problems associated with the farmers' irrigation practices. Weak operation and maintenance of the project is also witnessed and thus its sustainability is uncertain.

Keywords: Small-scale irrigation project; Performance assessment; Technical evaluations; Irrigation efficiency; Irrigation practices; Water management

Introduction

Although the global rate of irrigation expansion is declining, in the last quarter, largely because most of the economically feasible opportunities for large-scale irrigation development had already been exploited [1], the world's irrigated area grew by 3 percent in the third quarter of the 20th century both in the humid and arid regions [2]. Among the many methods of irrigation, surface irrigation is seen to be the most widely used practice in the world. According to Reddy and Clyma, widespread use of surface irrigation method reflects its feasibility under many circumstances, low energy requirements and simplicity of operation [3].

In order to address the main challenges caused by food insecurity and rainfall uncertainty for rainfed agriculture, irrigation development is an important means for achieving food self-sufficiency by many countries including Ethiopia [4-6]. However, irrigation projects have also the potential to degrade the land, the soil and waste the valuable resource - water, if they are mismanaged [7]. When irrigation water is excessively applied to the field, runoff could occur that erodes the soil and deposits the sediment down to the field (on farm and off farm effects), the plant nutrients are washed out, temporal waterlogging condition occurs which causes insufficient aeration and root rot, and the depth of water table together with harmful salts rise to the surface [8]. Some farmers waste water when they irrigate, which means that other farmers may not have enough water for their fields. Careless maintenance of canals can result in weed, silt, or erosion problems, and not having water where it is needed. The final consequence of all these will be degradation of the ecosystem and the land and the normal growth and development of the plants is retarded so production and productivity is much reduced [1].

On the contrary, when farmers apply less water to their fields than is required by their crops (unless intentionally done so to use deficit irrigation), crops cannot get the water amount that is sufficient for their normal growth and development and so yield is reduced too. Therefore, improper irrigation practices lead to inefficient water distribution, non-uniform crop growth, excess leaching in some areas, and insufficient leaching in others, all of which decrease the yield per unit of land area against per unit water applied [9]. In contrast, efficient farm irrigation practices achieved through improving the efficiencies lead to improvement in crop production and economic viability of the irrigated farm [10].

In recent years, the agricultural sector is coming under pressure to make more efficient use of water. It has been blamed for being the greatest water user and having the lowest water use efficiency and lowest output per unit of water used of all sectors. Especially irrigated agriculture, the greatest water user of all, has been made responsible for inefficient water use and land degradation [11]. In response to the challenges exerted on irrigated agriculture, Pereira noticed that researchers have achieved enormous progress in modernizing irrigation methods, which include numerous equipment and automation tools, field evaluation techniques and models for design and analysis [12]. Field evaluation techniques play a major role in

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improving surface irrigation performance, as they provide information required to improve systems and practices. However, because they are very demanding, they are very seldom performed [13].

To address the problem of irrigation system performance, a large number of field assessments have been conducted by different researchers all over the world, though to a limited extent in Ethiopia [14]. The researchers focused on different aspects of irrigation performance: some of them on quantitative description of performance criteria while others focused on qualitative description of the effects of irrigation systems and water management on socio-economic indices. Field assessment and evaluation of irrigation projects has now become a paramount importance not only to point out where the problem lies but also to identify alternatives that may be both effective and feasible in improving system performance [7].

Despite the poor performance of many of the irrigation projects in the country, field assessment to evaluate their performances is a new exercise in Ethiopia. The Wesha small-scale irrigation project, located in the Sidama zone of Southern Region, though it has been in existence for the last 20 years, there has never been any formal and systematic field study conducted to assess its performance. In view of the above problems associated with irrigation water management, information on the performance of surface irrigation method (i.e., furrow) on farmers' fields has a significant importance for improving the existing irrigation system and assist engineers in designing other systems in the area. The irrigation project is also currently commanding less area than that was initially developed to irrigate. Hence, the possible causes for this underperformance of the project needed to be systematically and objectively investigated. This field assessment was therefore conducted to evaluate the current performance of the surface irrigation project using quantitative technical performance parameters.

Materials and Methods

Description of the Wesha small-scale irrigation project

The irrigation project is located in the Southern Regional State of Ethiopia, Sidama Zone. It is located some 260 km away from the Capital Addis Ababa at 03° 08' N latitude and 38° 35' E longitudes and at an altitude of 1880 m above sea level. According to the data obtained from the nearby meteorological station, the area receives 1141 mm of annual rainfall with mean monthly maximum and minimum temperatures of 27.25°C and 11.97°C, respectively.

Construction of the Wesha small-scale irrigation project was concluded in the late 1980s for satisfying the demands of the farmers located within the peasant association. Prior to the construction of the diversion weir, farmers in the area had been practicing irrigation by diverting the Wesha River traditionally. Construction of the new diversion weir was done under the authority of a Lutheran Church organization called 'Mena', which in turn was funded by the World Vision Ethiopia.

The diversion weir has a crest length of 12.45 m and 1.7 m top width. The weir height, up to the crest level, is estimated to be 2.2 m. The main canal is branched into secondary canal after a length of 300 m. About 240 m length of the main canal is lined with masonry and concrete works having a rectangular shape of 1.08 m width and 1.12 m depth. The irrigation project can be categorized as partially modern. Only the headwork and 240 m canal length are designed and constructed carefully, while the rest of the project is left to be operated traditionally. Canal structures are constructed only at few spots despite the existence of a number of canal branches and crossroads. Therefore,

Page 2 of 10

the irrigators normally use bund breaks as a mechanism to divert and deliver water to their fields.

Layout of sample fields

Three farmers' fields were selected to undertake evaluation of the irrigation project performance. These three farmers' fields were selected from the top, middle and bottom end of the command area. The assumption behind the selection criteria of the farmers' fields is that there is a tendency of the head-end users (farmers at the top) to over-irrigate their crops while the tail-end users (farmers at the bottom) are in short supply of irrigation water [15,16].

The size and slope of the selected fields were measured and field preparations made according to the existing farmers' practices; some used oxen ploughs while others used hand digging. At the end of each field, runoff collection channels and pits were dug to collect the tail water. Suunto Clinometer was used to measure the general slope of the selected farmers' fields. To achieve a relative accuracy, each slope of the fields was measured along the flow direction in the furrows at three positions-one at the center and two at the opposite sides of the fields. The average of the three measurements was taken to be the general slope of the fields. The evaluation was done on farmers who planted potato crop.

Measurements of soil and water in the field

Real performance is based on water uses over a specified period, rather than observation of a single irrigation event [17]. Taking this into account, the field assessment on water utilization efficiency, and therefore, the performance of the selected farmers' fields in the project was made on three irrigation events for each farmer.

As measuring water use and soil moisture is crucial for calculating irrigation efficiencies [18], during each irrigation event, water flows into the fields, moisture contents of the soil profile (before and after each irrigation) and runoff volume at the end of each field were measured carefully.

Inflow and tail water measurements: The flow of water into each field was measured using Parshall flume installed at the entrance of the water flow to the field. Before taking measurements, the Parshall flume was calibrated using volumetric method of discharge measurement. Discharge and the irrigation time were based on farmers' practices and irrigation was allowed to continue until the farmers perceive that enough amount of water is applied to their fields.

To collect the tail water, a pit and runoff collecting channel were excavated and known volume of runoff collector bucket was put inside the pit. To prevent seepage of the tail water into the runoff collector channel, plastic sheet was laid. In cases large tail water was expected, one-inch Parshall flume (which was made of prefabricated plastic) was installed to measure the depth of tail water flow.

Measured soil parameters: The soil parameters measured include moisture content, bulk density, field capacity (FC), permanent wilting point (PWP), soil texture and soil pH as discussed below.

Soil moisture

The moisture status was measured to determine how much water depleted below the field capacity before irrigation and how much water applied to the root zone after irrigation.

To collect representative soil samples, three rows were selected along each field (one row from the center and two rows from opposite sides) and three sampling points were identified starting from the beginning to the end of each row at regular interval. Then, at each selected points of the rows, soil samples were collected from two depths (i.e., at 0-30 cm and at 30-60 cm). These depths were preferred because root distribution of Potatoes is heavily concentrated near the soil surface. Therefore, from each field, a total of 36 samples, 18 from the top soil (i.e., 0-30 cm) and 18 from the sub-soil (i.e., 30-60 cm) were collected before and after irrigation at each time. This procedure was repeated in each of the three farmers' fields with three replications for each field (because three irrigation events).

Therefore, 108 from each field, a total of 324 soil samples were collected to measure the moisture status of the fields.

To this end, soil samples of each field were collected using manually driven soil auger. Though numerous techniques have been developed for evaluating soil moisture content, the standard method known as the gravimetric moisture determination method was used [19]. To achieve a relative accuracy, initial weights of the collected soil samples were immediately measured in the field using digital sensitive balance to determine moisture contents before oven-dry.

Bulk density, field capacity (FC), Permanent wilting point (PWP), soil texture and pH

For the determination of bulk densities, undisturbed soil samples from two depths (i.e., 0-30 cm and 30-60 cm) were collected diagonally at three points of each field using soil core samplers and taken to oven. Additional soil samples were taken to the National Soil Testing Center (at the capital city Addis Ababa) and pressures of 1/3 bar and 15 bars were exerted on saturated soil samples of the respective depths to determine the field capacity (FC) and permanent wilting point (PWP) respectively. To determine pH and texture of each farmer's field, soil samples from the same depths mentioned above were collected and taken to the same laboratory at Addis Ababa.

Determination of irrigation system performance indicators

The performance indicators that were used to evaluate the Wesha small-scale irrigation project are oriented toward items that directly or indirectly affect water deliveries and water spreading effects, rather than indicators like crop yields that are also affected by other factors [20].

In order to assess how efficient was the water utilization technique of the selected farmers, the amount of water each farmer diverted to his field, the amount of tail water loss, the amount of moisture retained in the root zone of the crop and how uniformly the water was spread over the fields were measured directly in the field.

Based on data obtained from measurements of inflow, tail water and soil moisture, project performance was evaluated based on conveyance efficiency, application efficiency, water distribution uniformity, water storage efficiency and water loss indices such as runoff ratio and deep percolation fraction. Sustainability of the irrigated area was also calculated to determine the trend of yearly shrinkage of total area put under irrigation.

Irrigation efficiencies:

Conveyance efficiency (Ec): Conveyance efficiency (Ec) parameter is used to evaluate how efficient are the water delivery and conveyance systems.

To determine conveyance efficiency, flows at the field canals were measured using the three-inch Parshall flume. Since the flume was not big enough, float (Velocity-Area) method was used at the primary, Page 3 of 10

secondary and tertiary canals to measure the corresponding discharges.

After determining the amount of water supplied by the conveyance system and total inflow into the conveyance system, the conveyance efficiency of each canal section was then calculated as [21]:

Conveyance efficiency,
$$E_c(\%) = \frac{\text{Total water supplied by the conveyance system } (m^3)}{\text{Total inflow into the conveyance system } (m^3)}$$
 (1)

Application efficiency: As a measure of how much of the water that is applied is actually retained in the root zone after irrigation, application efficiency was calculated. It is a function of design and effective management. The depth of water applied to each field (Da) was measured using a 3-inch Parshall flume and considering the overall size of the field [22]. Two days after irrigation, the depth of water stored in the root zone (Ds) was determined as the difference between the after- and before- irrigation moisture contents of the soils from 18 soil samples (9 samples each from the top and sub soil layers) taken at regular intervals over the entire field.

Then neglecting the leaching requirement, the application efficiencies (Ea) of irrigation at the selected fields were calculated using the equation [18]:

$$E_a(\%) = \frac{\text{Depth of water stored in the root zone } (D_s, \text{ cm})}{\text{Total Depth of water applied to the field } (D_a, \text{ cm})} \times 100$$
(2)

The depth of water retained (stored) in the soil profile of the root zone, Ds, and the total depth applied to the field, Da, were determined by using the following equations [23]:

$$D_{s} = \sum_{i=1}^{n} \frac{(W_{ai} - W_{bi})}{100} \times AS_{i} \times D_{i}$$
(3)

$$D_a = \overline{\mathcal{Q}} \Delta t /_A \tag{4}$$

Where:

 W_{ai} =moisture content of the ith layer of the soil **after** irrigation on oven-dry weight basis, %

 W_{bi} =moisture content of the ith layer of soil **before** irrigation on oven-dry weight basis, %

 AS_i = apparent specific gravity of the ith layer of soil (unit less)

 $D_i\!=\!{\rm depth}$ of ${\rm i}^{\rm th}$ layer of the soil (D $_1$ and D $_2$ are 30 cm each for this study)

n=number of layers in the root zone (n=2 for this study)

 \overline{Q} = average stream size during the irrigation (cm³/s)

 Δt =duration of the irrigation (s)

A= area irrigated (cm^2).

Distribution uniformity: Distribution (application) uniformity is used to measure the variation or non-uniformity of water applied to the entire field. For calculating distribution uniformity, the effective root depth of the crop (i.e., up to 60 cm) was taken as the zone of water distribution. After calculating the depth of water stored (as the difference between the after and before moisture contents) in the top soil (0-30 cm) and sub-soil (30-60 cm), the depth of water stored at each particular sampling point was calculated as the sum of the two.

Distribution efficiency of the irrigation project was evaluated using the Distribution Uniformity (DU) parameter and the determination was based on mean values of the total soil moisture contents stored at the nine sampling points. The depths of water stored at each sampling

RK

point were arranged in descending order and the Distribution Uniformity (DU) parameter was determined.

The Distribution Uniformity (DU) is defined as the percentage of average application amount received in the least-watered quarter of the field. It is the ratio of the average depth infiltrated in the lower quarter of observations to the average depth of all observations [19,24].

$$DU(\%) = \frac{X_{Lq}}{\overline{X}_{m}} \times 100$$
(5)

Where: \overline{X}_{Lq} is the mean of lower-quarter depth of water stored

(mm) and $X_{\rm m}$ is the mean depth of all water stored (i.e. the average of all the nine points) (mm).

Adequacy of irrigation (Water storage efficiency): To evaluate how effectively the irrigation practices satisfied the water requirement of the soil to compensate the moisture depleted by evapotranspiration, the evaluation parameter called water storage (requirement) efficiency (Es) was calculated.

While the amount of water added to (stored in) the root zone (Ds) was calculated for each field using equation 3, the amount of water potentially required to fill the root zone to field capacity (Dreq) was estimated using equation 7.

After knowing the values of Ds and Dreq, eqn. (6) was employed to calculate the water storage efficiency (Es), which is sometimes referred to as water requirement efficiency (Es) [25]:

$$E_s(\%) = \frac{D_s}{D_{req}} \times 100 \tag{6}$$

$$D_{req} = SMD = \sum_{i=1}^{2} 1000 \left(W_{fci} - W_{bi} \right) \times AS_i \times D_i$$
(7)

D_s=Amount of water added to (stored in) the root zone during the irrigation (mm)

 D_{req} =Amount of water potentially required to fill the root zone to field capacity (mm)

SMD=Soil moisture deficit within RZ below field capacity before irrigation (mm)

 $W_{\rm fci}$ =Moisture content of the ith layer of the soil at field capacity (FC) on oven-dry weight basis (in fraction)

 $W_{\rm bi}$ =Moisture content of the ith layer of soil before irrigation on oven-dry weight basis (in fraction)

 D_i =root depth (m).

Irrigation water losses

Evaluation of the irrigation project considered the amount of water lost from the field during irrigation applications of the farmers. The water applied to fields was lost in the form of evaporation, runoff and deep percolation. The evaporation loss was accounted as evapotranspiration of the crop. But the relative amounts of runoff and deep percolation losses were estimated through runoff ratio and deep percolation fraction, respectively. Evaluation of these losses is essential for identifying the loss that is primarily contributing to the low efficiency.

Runoff ratio (RR): The amount of runoff from each field was collected and measured using known volume of buckets and one-inch Parshall flume installed at the lower end of each field and RR was calculated using the following equation [19]:

$$R(\%) = \frac{Depth \ of \ runoff \ (Dr, mm)}{Depth \ of \ water \ applied \ to \ the \ field \ (Da, mm)} \times 100$$
(8)

Page 4 of 10

Deep percolation fraction (DPF): Deep percolation fraction (DPF) was calculated using the following equation [19]:

$$DPF(\%) = \frac{Volume of deep percolation (m^3)}{Volume of water applied to the field (Va,m^3)} \times 100$$
(9)

Deep percolation fraction (DPF, %) can be calculated indirectly from the measured values of application efficiency (Ea, %) and runoff ratio (RR, %) as [26]:

$$DPF=100 - E_a - RR \tag{10}$$

Sustainability of Irrigation Project

The simplest measure of sustainability that quantifies the cumulative effect of negative impacts (like salinity, water logging, urbanization, etc.) is Sustainability of the Irrigated Area (SIA) that was calculated using the following equation [20]:

$$SIA(\%) = \frac{AC}{4I} \times 100 \tag{11}$$

Where: AC=current total irrigated area (ha)

AI=total irrigated area when the system development was completed (ha)

This should be near one for the project to be categorized as sustainable.

Results and Discussions

Climatic water balance of the study area

Figure 1 shows the monthly climatic water balance of the study area based on CLIMWAT data and average rainfall data of 20 years (1989-2008). The potential evapotranspiration of the study area, calculated using CROPWAT Model, is more than the effective rainfall in most of the months calling for supplemental irrigation.

The effective rainfall is more than ETo by 2.7 and 9 mm/month during July and September, meaning that no irrigation is required during these months. Therefore, those farmers who grow crops on July, August and September are less likely to apply supplemental irrigation. On the other hand, extensive irrigation is essential for crops planted particularly on November, December, January, February and March (with 84.6, 91.7, 87.4 and 49.2 mm of irrigation water requirements, respectively).

Major slope and furrow lengths

The results of slope and furrow length measurements are presented



in Table 1. These results show that the general slope of the command area ranges from 0.002 to 0.005 m/m. The upstream field is relatively steepest, whereas the bottom (tail end) field is flattest. The middle field has slope value between the two. Since furrow lengths of the study fields are so short, an application efficiency of more than 70% can be obtained [27].

Laboratory analyses of soil samples

Results of physical and chemical analyses of the soils in the study area are presented in Table 2. It shows that the top 30 cm soil depth of the fields located at top and tail end of the command area has a sandy loam textural class while the middle one is characterized as loamy soil. The textural class of the subsoil was variable from Sandy Clay Loam, Loam, and Sandy Loam at top, middle and tail end, respectively. From this analysis, we can conclude that the first 30 cm soil profile of the command area is dominated by sandy loam.

Table 2 also shows that the top and tail end fields have relatively higher bulk densities than the middle one. This is true because (1) the textural class of the middle field is loam soil that has higher total porosity than the other fields; and (2) during the field observation, the middle farmer applied lots of cow dung and crop residues as organic manuring. Therefore, this result shows that the average bulk density up to 60 cm soil depth of the command area is 1.05 g/cc.

The soil pH value increased in magnitude with depth (7.0 to 7.7) indicating the presence of active leaching. Almost all the top 30 cm soil depth of the command area has neutral soil acidity. This shows that the pH value was higher than the FAO recommended value for potato production, which is between 5 to 6 [28].

Field position	Field size (m ²)	Slope (m/m)	Furrow length (m)
Тор	400	0.005	17
Middle	1200	0.003	34
Bottom	1000	0.002	33

Table 1: Slopes and furrow lengths of the selected fields.

Average moisture content before and after irrigations

The average moisture contents of the three irrigation events before and two days after irrigations are presented in Table 3.

As seen in Table 3, the average moisture contents within the two soil layers (i.e., 0-30 cm and 30-60 cm) showed an increasing trend with depth, which is typical of the moisture characteristics after irrigation or rainfall.

Though irrigation of potato should be initiated to maintain the soil water within the root zone in the upper 35% of the available water [29], all of the farmers allowed the soil moisture to drop below the critical water content, which is an indicator of poor irrigation scheduling (Table 4). During the evaluation period, the irrigation interval was in the range of 17 to 27 days with an average of 19 days.

The higher the depletion fraction, the drier is the soil prior to irrigation. Table 4 shows that the middle farmer has the least moisture deficit before irrigation. This is because the soil is characterized as loam, which has the highest water holding capacity than the others (predominantly sandy loam). Therefore, the middle field had better moisture content before irrigation. The relatively low water holding capacity of the head and tail end fields caused the soil to be drier more than recommended for potato production.

Depths of inflow water and tail water

Table 5 presents the amount of water applied and runoff generated by each field during each irrigation event. As seen in the Table, the middle and tail end fields generated runoff that has flown out of the fields.

We can also see from Table 5 that though the head farmer seems to have applied the smallest amount of water to his field, he used rather the highest amount on a hectare basis. The middle and the tail farmers used in the decreasing order of water volumes per hectare basis. Perhaps this is what is expected as outlined by FAO [15] and Levin et al. [16] who stated that farmers at the head end of a command area receive more water than farmers at the tail end.

	Soil depth (cm)							
Soil characteristics	0-30				30-60			
	Head end field	Middle field	Tail end field	Head end field	Middle field	Tail end field		
Sand (%)	59	33	57	53	27	59		
Silt (%)	26	44	24	26	48	22		
Clay (%)	15	23	19	21	25	19		
Textural class	SL	L	SL	SCL	L	SL		
Average bulk density (g/cc)	1.13	0.9	1.11	1.14	0.87	1.13		
Field capacity (%)	18.71	33.09	18.45	23.77	35.22	24.11		
Permanent wilting point (%)	14.45	25.17	14.96	15.16	24.19	14.44		
pH (H ₂ O)	7.1	7	7	7.7	7.3	7.3		

Abbreviations: SL: Sandy Loam; L: Loam; SCL: Sandy Clay Loam

Table 2: Physical and chemical properties of soil samples.

Field position	Soil donth (cm)	ail donth (am) Average bulk density (g/ac		ss wetness, w (%)	Average moisture content within root zone (mm)	
Field position	Son depth (cm)	Average buik density (g/cc)	Before irri.	After irr.	Before irri.	After irri.
Head	0-30	1.13	15.47	18.47	52.54	62.74
	30-60	1.14	17.68	23.58	60.46	80.63
Middle	0-30	0.90	28.51	32.89	76.64	88.40
	30-60	0.87	29.84	35.03	78.05	91.63
Tail	0-30	1.11	15.95	18.44	53.21	61.54
	30-60	1.13	17.97	24.26	61.06	82.46

Table 3: Average soil moisture contents of the three irrigation events.

Page 6 of 10

Field position	FC (mm)	Average moisture content before irri. (mm)	SMD before irri. (mm)	TAW (mm)	Depletion fraction (%)
Head	144.83	113	31.83	43.91	72.49
Middle	181.07	154.69	26.38	50.14	52.61
Tail	143 51	114 27	29.24	44 51	65.69

		3			
Field position	Field size (m ²)	Irrigation event	Vol. of applied water (m ³)	Depth of applied water, D _a (mm)	Depth of runoff, D _r (mm)
		1st	34.22	85.55	0
Hed	400	2nd	32.18	80.44	0
		3rd	31.23	78.08	0
Total			97.63	244.06	0
		1st	129	107.5	7.4
Middle	1200	2nd	44.73	37.28	4.15
		3rd	52.24	43.53	12.68
Total			225.97	188.31	24.23
		1st	60.71	60.71	0
Tail 10	1000	2nd	37.54	37.54	0
		3rd	43.92	43.92	1.34
Total			142.17	142.17	1.34

Table 4: Average soil moisture deficit (SMD) within the root zone before irrigation.

 Table 5: Depths of inflow water and tail water.

This study further concluded that even if farmers may receive more water, it does not mean more runoff would be generated from the fields. As seen in Table 5, the head farmer applied more water than the other two, but the amount of runoff generated was negligible. He completely blocked the lower end of the furrows so no water was flowing out of the field. The nature of his soil, which is coarse, also initiated high deep percolation than runoff.

The other possible reason for negligible runoff for the top farmer is that the size of the field is so small compared to the other two farmers. The larger the size of the irrigated field, the higher is the possibility of runoff occurrence unless irrigators have sufficient work force while irrigating. This is particularly seen on the middle farmer who has the largest field size and observed to generate the largest runoff volume. This is because he could not be able to manage his field size with the available work force during irrigation application.

As was discussed above, the tail enders receive relatively the least amount of water. Because of this, many farmers at the tail of the command area shift their land use from irrigated cropland to 'Enset' land. The local 'Enset' plant is perceived by the farmers as drought resistance which does not need irrigation.

Project water delivery and conveyance evaluation

The Wesha small-scale irrigation project uses the water diverted from the perennial river called Wesha. The mean water flow into the main supply canal was measured to be 20.4 l/s. However, as there is high seepage of water through the network of supply canals, the amount of water being delivered to the tail end fields is lower than the fields located nearer to the main inlet. As a result, competition for water and conflicts among irrigators are common scenes. If farmers need water anytime, they have to pay money illegally to the water committee members.

Canal conveyance efficiency: Due to lack of canal-crossing structures and division boxes, the water flowing in the canals is wasted at several spots when heavy trucks that frequently come to the command area to transport agricultural products, bicycles of the community members residing in the project and passengers who pass-by on foot frequently disturb the normal course of water in the

canals. Much water spills over the broken canals that contribute to the minimized irrigation water amount to the tail end users.

Water is rotated from one farmer to the other by means of bundbreak. They 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. This by itself has contributed to the low share of water to tail enders and the associated low conveyance efficiency (Table 6 and Figure 2).

Table 6 shows that the average conveyance efficiency of the project was 65%. The general texture of the soil where main canal efficiency measured was found to be sandy and the efficiency was 77%. This result is higher than FAO which recommend an efficiency value of 70% for canal length 200-2000 meters on sandy soils [30]. This shows that the main canal is relatively efficient because 240 m of it is lined with concrete and masonry works that minimized seepage of water.

FAO recommends 80% on sandy soils and 85% on loam soils as indicative values for canal conveyance efficiencies. Compared to these indicative values of FAO, conveyance efficiencies of the secondary and tertiary canals are so small (42% and 53%, respectively) indicating that a lot of water is lost as steady-state and transient losses [30,31]. During the study period, water is seen to be lost at several spots signifying that the water delivery structures are inadequate and poorly maintained.

However, though the field channel efficiency was found to be relatively high, the overall conveyance efficiency of the project has become 65%. The main canal and the field channel efficiencies appear to be high because, (1) 240 m length of the main canal is lined so the water loss through the canal bed and wall is low, and (2) field channels are usually so short that water travels only short distances inducing only little amount of seepage loss.

Field evaluation of farmers' irrigation practices

Water application efficiency and uniformity: The measurements of depth of water applied to each field (Da) and the depth of water stored in the root zone (Ds) are presented in Table 7. The water application efficiency and uniformity computations are made based on the results of Table 7.

Page 7 of 10

Canal type	General soil type	Canal length category (m)	Average canal inflow (I/s)	Average canal outflow (I/s)	Conveyance efficiency, E _c (%)
Main canal	Sandy	200-2000	20.4	15.67	76.80
Secondary canal	Sandy	<200	15	6.3	42.00
Tertiary canal	Loam	<200	14.8	7.84	53.00
Field channel	Sandy Loam	<200			89.78
Scheme E (%)					65.39

Table 6: Evaluation of the water conveyance efficiencies of different canals.



Water application efficiency: FAO suggested 60% as attainable water application efficiencies for surface irrigation system. Value below this limit would normally be considered unacceptable [26]. In this study, the water application efficiencies (Ea) in the three fields were in the range of 37.31% - 62.63% that is considered as inefficient because farmers applied excess water to their fields that caused high deep percolation and runoff losses (Table 7).

Considering three farmers' irrigation practices at the top, middle and tail end of the command area, the average application efficiency of the irrigation project was found to be 46.78%. The result obtained agrees with Environmental [32] who concluded that in most traditional irrigation projects the application efficiency is typically less than 50% and often as low as 30%. However, according to the studies of Solomon [33] and FAO [26,34], the water application efficiency of the command area is considered as lower than the acceptable range of 60-85%.

From the field observations and measurements, the major cause for the low water application efficiency is the existence of high deep percolation losses. This can be proven from the field observations of the farmers' shallow water wells scattered at several spots over the entire command area. During the irrigation season, the water table in the shallow wells had a depth of 1.5-2 m below the surface and suddenly dropped below 2.5 m after the irrigation season and in the middle of rainy season.

Table 7 also shows that the application efficiency of farmers increases as the shortage of water increases from head to tail end of the command area. This is because as the supply of water decreases, farmers tend to become more efficient in their water use. The application of water by many farmers is generally more than the required depth for crop use and leaching of excess salts. Therefore, slight decrement of water supply can improve the application efficiency particularly by decreasing the deep percolation and runoff ratios as excessive application of water generally entails losses due to surface runoff from the field as well as to deep percolation below the root [32]. If water is expensive, then a most efficient system with minimum loss can be ascertained. Similar results can be expected when labour is expensive [3].

However, it should be noted that decrement of the water supply less than the perception of farmers as sufficient for their crops results in abandoning of crop production using irrigation and shifting the land to non-irrigated local crops like 'Enset' (according to their attitude). During the field assessment period, many farmers located at the bottom (tail) of the command area are seen to abandon their irrigation practice and shift to 'Enset' crop which they consider the crop as drought resistant that does not need any irrigation application. Many tail enders also constructed houses on such lands.

Water spreading uniformity

The evaluation of water spreading uniformity of each field was carried out using three irrigation events. The average of the three was taken to compute the distribution uniformity and the result is summarized in Table 8.

The DU at the head, middle and tail end fields are 90.34, 86.15 and 88.41%, respectively. From this, it can be concluded that 86-90% of the irrigation fields received and stored equal amount of water at their rooting depths. The higher the value of DU, the better the uniformity of water application and the higher is the distribution efficiency.

The results indicate that the distribution uniformities of all the three fields are by far higher than the value categorized as sufficient (i.e., 65%) by FAO [35].

Compared to others, the head end farmer applied water more uniformly (90.34%). This is because he had an access to apply more water than the others did only because he is located nearest to the main intake (weir site). The extra large volume of water he applied helped him to water much of his field uniformly. The middle farmer applied water least uniformly to his field (86.15%). The reason behind, in

Page 8 of 10

Field position	Field size (m2)	Irrigation event	Vol. of applied water (m3)	Depth of applied water, Da (mm)	Mean depth of root zone storage, Ds (mm)	Application efficiency, Ea (%)
		1 st	34.22	85.55	23.79	27.81
Тор	400	2nd	32.176	80.44	33.69	41.88
		3rd	31.23	78.075	33.58	43.01
Total			97.63	244.07	91.06	37.31
		1st	129	107.5	27.64	25.71
Middle	1200	2nd	44.73	37.275	30.78	82.58
		3rd	52.236	43.53	17.66	40.58
Total			225.97	188.31	76.08	40.4
		1st	60.71	60.71	23.75	39.12
Bottom	1000	2nd	37.54	37.54	33.47	89.16
		3rd	43.92	43.92	31.82	72.45
Total			142.17	142.17	89.04	62.63

Table 7: Depths of water applied (Da) and stored in the root zone (Ds).

Field position	Distribution Uniformity, DU (%)
Head	90.34
Middle	86.15
Tail	88.41

Table 8: Distribution uniformity of the fields.

Field position	Mean depth of moisture stored, D _s (mm)	Mean depth of moisture required to refill to FC, D _{reg} (mm)	Storage efficiency, E _s (%)	
Head	30.35	31.81	95.43	
Middle	25.36	26.26	96.57	
Tail	29.68	29.42	100.90	
Scheme Average, E _s (%) 97.63				

Table 9: Storage efficiencies over the fields.

addition to others, is that his field size was the largest so he could not be able to manage to spread water uniformly over his field.

Water storage efficiency: The evaluation of E_s for each field was done based on the mean value of the three irrigation events, and results are summarized in Table 9. From Table 9 we see that the storage efficiency of the sample fields ranges from 95-100% with an average of 97.63% for the project. Generally, storage efficiency values are the maximum attainable values worldwide [31]. The storage efficiencies of the middle and tail end fields are found to be high because the depletion fractions of the fields before irrigation were lower than the head end field (Table 4).

The overall water storage efficiency of the irrigation project (i.e., 97.63%) was in line with the range of 85-100%, which is assumed to be the potential achievable value for furrow irrigation [31]. This shows that irrigation water application successfully met its objective of refilling the root zone to field capacity.

Irrigation water losses

Runoff ratio (RR): The amount of runoff measured is summarized and presented in Table 10 considering the mean values of the three irrigation events for each farmer.

The majority of water lost from the field as runoff was from the middle farmer. The field size of this farmer is largest than the other two farmers. Therefore, the size is beyond his management capacity that he could not control the water flow effectively. As it was indicated in Table 5, the head end farmer yields negligible amount of runoff because his field size was 3 times less than the middle farmer that helped him to

manage the water flow to his field. The overall runoff ratio of the Wesha small-scale irrigation project (i.e., 4.45%) is therefore acceptable (since it is below 20%) as by Ley et al. meaning that only little water is lost from the croplands in the form of runoff [31].

Deep percolation fraction (DPF): The amount of runoff collected and the application efficiencies of each field were used to calculate the deep percolation fraction and the results are presented in Table 11.

Though the head end farmer was described to be the most efficient in preventing the occurrence of runoff, he is the least efficient in terms of deep percolation fraction. In Table 5, it is mentioned that he applied the largest volume of irrigation water per hectare on his field. Therefore, the majority of water was lost from his field was in the form of deep percolation (62.69%). Farmers usually tend to evaluate their skill of irrigation practice in terms of runoff loss even if they waste great quantity of water in the form of deep percolation. As water is relatively scarce to the tail end farmers, they tend to use water more efficiently by minimizing the deep percolation losses. This was particularly seen on the tail end field on which the deep percolation loss was only 36.43%.

The overall deep percolation loss of water from the project, taken as the average value of the three sample fields, was therefore found to be 48.43%. As a result, the deep percolation loss is considered as unacceptable by both FAO [28] and Ley [31], who put the acceptable DPF figures as <10% and 5-25%, respectively, based the analysis of a number of properly designed irrigation system evaluations.

Sustainability of the irrigation project

In many irrigation projects, it is a common practice to see if the total irrigated area decreases from year to year because of several reasons like abandoning of previously irrigated lands due to the problems of water logging, salinity, continuous water shortage, urbanization, etc.

Sustainability of the Wesha small-scale irrigation project is evaluated to be declining because the total size of the project initially designed to irrigate in 1989 was 200 ha; but currently only 60 ha of land is under irrigation. From the quantitative evaluation using equation 11, sustainability of the project is greatly endangered (now decreased to only 30% of the design size). This reveals that the project is not sustainable, because according to David [20], for an irrigation project to be categorized as sustainable, SIA should be near one. Settlement expansion and shortage of water to the tail end of the command area are the major reasons observed in the field as threats to the sustainability of the project. Due to increasing population residing in the command area, many previously irrigated lands are used for house constructions.

Page 9 of 10

Field	Total doubt of water enabled D (mm)	Total donth of supoff D (mm)	Runoff ratio,
position	Total depth of water applied, D _a (mm)	Total depth of runon, D _r (mm)	RR (%)
Head	244.07	0.00	0.00
Middle	188.31	24.23	12.87
Tail	142.17	1.34	0.94
Scheme average RR (%)			4.45

Table 10: Total depth of applied water and water lost as runoff.

Field position	Application	$Pupoff_{rotio} PP(\mathscr{Y})$	Deep percolation fraction, DPF (%)	
	efficiency, Ea (%)	Runon fatto, RR (%)		
Head	37.31	0.00	62.69	
Middle	40.40	12.87	46.73	
Tail	62.63	0.94	36.43	
Scheme average DPF (%)			48.43	

Table 11: Fraction of water lost as deep percolation.

In addition, long existing conflict between the two major ethnic groups inside the project causes fast expansion of house constructions. During the field evaluation period, it is observed that each group encourages immigration and high birth rate as a mechanism to overpopulate the other group.

Irrigated lands located at the bottom of the command area are abandoned and shifted to 'Enset' croplands because the farmers do not irrigate 'Enset' fields. Farmers want the emergence of new 'Enset' shoots to be delayed until the onset rainfall season. According to perception of the farmers, if new shoots are emerged as initiated by the irrigation water, they will be exposed for diseases during the coming rainfall season. This has also contributed to the declining of irrigated lands.

Conclusions

Performance of the Wesha small-scale irrigation scheme was considered as unsatisfactory in terms of water conveyance efficiency of the canals (65.39%), water application efficiency of the farmers (46.78%), deep percolation fraction (48.43%) and sustainability of irrigated area (30%). This means a lot of water was lost as steady-state and transient losses from the canals. Once reached to fields, the water was also lost as deep percolation during application by farmers due to their poor water management practice that depended mainly on preventing of runoff loss. Because of the rapid expansion of urbanization and relative water shortage to the tail end farmers, the total area put under irrigation showed sign of declining; meaning that the sustainability of the irrigation scheme is endangered.

However, the irrigators performed well in uniformly spreading water over their fields (average distribution efficiency, DU=88.3%); meaning that more than 88% of the field received equal amount of water to the root zone. The farmers also performed well in terms of water storage efficiency (97.63%) and runoff ratio (4.45%). The result of water storage efficiency tells us that about 98% of the moisture depleted below FC by evapotranspiration was refilled by irrigation water. Similarly, the irrigators have appreciable technique to prevent runoff loss by using block-end furrow irrigation practice.

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Page 10 of 10

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