

Technical Performance Evaluation of Small-Scale Irrigation Scheme at Wondo Genet, Ethiopia

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Abstract: Expanding efficient irrigation development on various scales is one of the best alternatives to provide reliable and sustainable food security. However, many irrigation schemes in developing countries in general and particularly in Ethiopia are performing below capacity. This study was conducted to evaluate the performance of wosha soyama irrigation scheme at Wondo Genet South Nation Nationality and People Regional State, Ethiopia. The evaluation carried out using standard technical performance indicators including conveyance, application, water storage, water distribution uniformity efficiency and deep percolation loss were used at the head, middle and tail reach of the scheme. The study shows that application efficiency was very low which is 48.2% due to higher water loss through deep percolation. Conveyance efficiency, water storage, water distribution uniformity efficiency, and deep percolation loss were revealed 55.6, 89.8, 91.7 and 51.8%, respectively. The overall efficiency was also below the desired level which is 26%. Based on the above observation, adoption of water saving practices such as deficit irrigation, surge and cutoff application to improving application, frequent maintains of water conveyance system can enhance the conveyance efficiency of the scheme.

Keywords: Irrigation Scheme, Performance, Evaluation and Technical Indicators

1. Introduction

Water is the most limited resource, which is widely used by different sectors like agriculture, water supply and industrial. Due to the rapid increase in the world population, food demand also increased as well. The competition for this scarce resource is increasing from time to time due to increasing food demand from the highly consuming agricultural sector [1, 2].

Worldwide, the cost of water insecurity to the irrigation sector is estimated at about US\$94 billion per year, and hence the total value of water insecurity to the global economy is about US\$500 billion annually [3]. In addition, increasing stress on water resources could inhibit an adaptation effort that increases irrigation development by maintaining the current level of the irrigation system.

Modern irrigation systems in Ethiopia started in the 1960s with the objective of producing industrial crops in Awash Valley [4]. The total irrigable land area in the country is estimated as 5.3 Mha. However, only about 4 to 5 percent is cultivated under irrigation from the existing cultivated area of

the country. Which implies that based on the irrigable land potential, only 12% is under irrigation currently [5]. However, about 90% of the irrigation potential in terms of land and water resources has not been developed so far. In recent years, there are many irrigation developments progresses in medium and large-scale. Whereas about 47% of the developed area is under large-scale public irrigation schemes, mainly industrial crops like cotton, sugarcane, and fruits were grown [6].

According to Food and Agriculture Organization of the United Nations (FAO) [7] report, irrigated agriculture is the most inefficient and much water consuming sector, which contributes globally about 70% of water withdrawal from different sources like aquifers, streams, and lakes and it is over 90% in most of the least developed countries. Without improved efficiency measures, agricultural water consumption is expected to increase by about 20% globally by 2050 [8].

The comparative estimate is 40 percent or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface runoff [9]. As a

result, the performance evaluation of irrigation schemes plays a fundamental role in improving the productivity of irrigation schemes by identifying where the critical problem occurred. Therefore, it is reasonable to evaluate the performance of Wosha Soyama small scale Irrigation Schemes found in Wondo Genet District of southern nation, nationality and people regional state (SNNPRS), Ethiopia.

2. Material and Methods

2.1. Description of the Study Area

The study irrigation scheme is found in Wondo Genet district, SNNPRS of Ethiopia which is located at about 263

km south of Addis Ababa. Geographically lied from 6°54'0" to 7°7'45" N and 38°31'33" to 38°41'20" E and covers an area with an altitudinal range of 1600 to 1950 m. a.s.l. The scheme has designed to develop 180 ha of irrigated area at wosha soyama kebele.

Long-term (1986-2015) climatic record of Wondo Genet College of forestry and natural resources meteorological station, average annual rainfall in the area is 1069.2 mm. The area receives more than 70% of the total annual rainfall between Aprils and September. The monthly maximum and minimum rainfall values are 147.0 mm and 18.3 mm occurs in the month of August and December, respectively (Table 1).

Table 1. Long-term climatic data of the study area.

| Month | T max (°C) | T min (°C) | Relative humidity (%) | Wind speed (m/s) | Sunshine hour | Rainfall (mm) |
|-----------|------------|------------|-----------------------|------------------|---------------|---------------|
| January | 24.2 | 12.6 | 47.4 | 3 | 8.7 | 28 |
| February | 25.7 | 13.8 | 42.0 | 3.2 | 8.4 | 54 |
| March | 26.2 | 15.1 | 46.4 | 3.3 | 7.9 | 95.6 |
| April | 24.6 | 14.9 | 60.5 | 3.0 | 7.3 | 128.5 |
| May | 23.1 | 14.5 | 71.4 | 2.4 | 7.4 | 115.0 |
| June | 20.9 | 13.8 | 78.8 | 2.9 | 6.7 | 110.9 |
| July | 19.5 | 13.1 | 81.6 | 3.3 | 4.7 | 143.5 |
| August | 19.8 | 13.0 | 81.5 | 3.1 | 5.1 | 147.1 |
| September | 21.0 | 13.1 | 77.9 | 2.3 | 5.5 | 125.2 |
| October | 22.0 | 12.3 | 70.6 | 2.4 | 9.2 | 77.2 |
| November | 23.0 | 11.8 | 58.0 | 3.0 | 9.0 | 26.0 |
| December | 23.2 | 11.9 | 52.1 | 3.1 | 7.2 | 18.3 |

2.2. Data Collection

All necessary secondary and primary data were collected during of 2017/18 irrigation season. To evaluate the study irrigation scheme using technical performance indicators three fields have been selected from the head, middle and tail end water users with respect to the water source. The selection of fields was done in considering similarly crop and growth stage and the dominance of crop, which most of the schemes land is covered with it.

2.2.1. Soil Texture and Bulk Density

For textural analysis disturbed soil samples and undisturbed soil for bulk density were collected from three locations along diagonal of the selected fields of (head, middle, and tail end) using soil auger and core sampler with the depths 0-30cm, 30-60 cm, 60-90 cm, and 90-120 cm.

Hydrometer method was used for textural analysis. The bulk density was determined using the following equation [10].

$$BD = \frac{W_s}{V_c} \quad (1)$$

Where: BD is soil bulk-density (g/ cm³),

W_s is mass of dry soil (g) and

V_c is volume of soil in the core (cm³)

2.2.2. Field Capacity and Permanent Wilting Point

Soil sample for determination of moisture content at field capacity (FC) and permanent wilting point (PWP) was

collected at 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm from three locations along the diagonal of the selected field. The FC and PWP were determined using pressure pate apparatus at 1/3 and 15 bars pressure for field capacity and permanent wilting point, respectively.

The volumetric total available water (TAW) was calculated based on the data of FC, PWP and root depth using the following equation [11].

$$TAW = 1000 \sum (\theta_{FC} - \theta_{PWP}) * Z_d \quad (2)$$

Where TAW is volumetric total available water in the root zone (mm/m),

Z_d: - root depth (m),

θ_{FC}: - volumetric moisture content at field capacity (m³/m³), and

θ_{PWP}: - volumetric moisture content at permanent wilting point (m³/m³).

Soil Moisture Determination

Determine the moisture content of the soil before and after irrigation was determined by the gravimetric method. Soil samples were collected with a 30 cm interval up to 120 cm. The water content in the soil was determined in the volume base using the following equation [10].

$$\theta_v = \theta_m \times BD \quad (3)$$

Where:

θ_v: - volumetric moisture content in (%),

BD: - soil bulk density (g /cm³), and

2.2.3. Flow Measurement

Two-inch Parshall flume was used to determine the amount of water applied by the irrigators to the field where at the head, middle and tail during an irrigation event. Parshall flume was installed at the entrance of the selected farmers' field at the part, which is straight and uniform.

The relationship between the head of irrigation water and its discharge is based on the following equation [12].

$$Q = C * H^n \quad (4)$$

Where:

H:- is water depth measured at one third from in late of converging,

C and n are constants to be determined for flume with two-inch throat

Determination of flow velocity through main, secondary and tertiary canals was obtained by floating methods then discharge of the flow was determined by the continuity equation as follows.

$$Q = AV \quad (5)$$

Where:

Q:- Discharge of the flow (m³/s)

A:- cross-sectional area (m²)

V:- Velocity of the flow (m/s)

However, the measured velocity was multiplied by correction factor 0.85 for rough or rocky bottoms and 0.9 for smooth, muddy, sandy or smooth bedrock conditions as illustrated by Harrelson *et al.* [13].

2.3. Technical Performance Indicators

Technical performance evaluation of the scheme was done on farm using the following standard indicators.

1. Conveyance Efficiency (Ec)

To determine the conveyance efficiency, the flow at main and secondary canals at hundred-meter interval recorded using area velocity method. The second measurement was also taken at a fixed distance above the downstream end of the main and secondary canal.

The conveyance efficiency was computed using the following equation [14].

$$Ec = \left(\frac{Q_{in}}{Q_{out}} \right) \times 100 \quad (6)$$

Where:

Ec:- conveyance efficiency (%)

Q_{in}:- Discharge at the inlet

Q_{out}:- Discharge at the outlet

The overall conveyance efficiency of the schemes was computed using the following equation.

$$Ec = Em * Es \quad (7)$$

Where:

Ec:- conveyance efficiency (%),

Em:- conveyance efficiency of the main canal (%),

Es:- conveyance efficiency of secondary canal (%),

Losses in conveyance system were computed as;

$$Lc = Q_{in} - Q_{out} \quad (8)$$

Where:

Ec:- conveyance efficiency (%)

Lc:- conveyance loss (m³/sec)

Q_{in} and Q_{out}=are the inflow and outflow discharge in specified canal length (m³/sec)

2. Application Efficiency (Ea)

Application efficiency was computed using the following equation [14]:

$$Ea = \frac{W_s}{W_f} * 100 \quad (9)$$

Where:

Ea:- application efficiency

W_s:- average depth water stored in the root zone of the plant

W_f:- average water delivered to the field (water depth applied to the field)

3. Storage Efficiency (Es)

The distribution uniformity was obtained by the relationship given below [14].

$$Es = \frac{W_s}{W_n} * 100 \quad (10)$$

Where:

Es:- storage efficiency (%)

W_s:- water stored in the root zone during irrigation (mm)

W_n:- water needed in the root zone prior to irrigation (mm)

The water needed in the root zone prior to irrigation was computed using the following equation [14].

$$W_n = \sum_{i=1}^n \left(\frac{M_{fci} - M_{bi}}{100} \right) * BD_i * D_i \quad (11)$$

Where:

W_n:- net amount of water to be applied during an irrigation (mm)

M_{fci}:- field capacity moisture content in the ith layer of the soil (%)

M_{bi}:- moisture content before irrigation in the ith layer of soil (%)

BD_i:- bulk density of the soil in the ith layer

D_i:- depth of the soil layer within the root zone cm, and

n:- number of soil layers in the root zone

4. Water Distribution Uniformity (DU)

The moisture content collected from different location was arranged in descending order, then the least quarter and the mean computed. Finally, the distribution uniformity was determined by using equation [15].

$$DU = \frac{\bar{x}_{Lq}}{\bar{x}_m} * 100 \quad (12)$$

Where:

DU:- Water distribution uniformity (%),

\bar{X}_{Lq} : - the mean of lower-quarter depth of water stored and
 \bar{X}_m : - the mean depth of all water stored
 5. Deep Percolation Ratio

The Furrow that practiced in the scheme is closed-end, therefore runoff ratio also neglected, and the evaporation from the soil neglected because it is only a short period after irrigation. The loss of irrigation water beyond the root zone is only through deep percolation. Therefore, deep percolation ratio was calculated by using the following equation [16].

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

Where:

DPR: - Deep percolation ratio (%),

Ea: - application efficiency (%) and

RR: - runoff ratio

Then after, the overall scheme efficiency calculated as the product of conveyance and application efficiency. It was computed using the following formula [17]:

$$Ep = Ec \times Ea \quad (14)$$

Where:

Ep: - overall scheme efficiency (%),

Ec: - conveyance efficiency (%) and

Ea: - application efficiency (%)

3. Results and Discussion

3.1. Soil Physical Characteristics of Study Scheme

The soil textural class of the scheme revealed that clay, sandy loam, and sand at the head, middle and tail, respectively was dominant soil textural class at Wosha Irrigation Scheme (Table 2). Physical soil analysis of Wosha Irrigation Scheme showed that average moisture content on a mass base at field capacity (FC) was 37.2, 24.4 and 13.1% at the head, middle and tail reach, respectively. On the other hand, the mass base moisture content at the permanent wilting point (PWP) was 24.3, 12.6 and 7.4% at the head, middle and tail reach, respectively,

The bulk density values ranged from 1.04 to 1.25 g/cm³, the result indicated that as the depth goes down the bulk density increased, which implies the soil compactness increased as goes down to deep. The volumetric total available water content (TAW) at 120 cm of soil depth is ranges from 86 to 172 mm. TAWs of the study irrigation scheme is with the range of FAO [18] recommendation for the particular soil type.

Table 2. Selected soil physical characteristics of Wosha irrigation scheme.

| Soil properties | Field Location | | |
|-------------------------|----------------|------------|------|
| | Head | Middle | Tail |
| Texture | Clay | Sandy Load | Sand |
| FC (%) | 37.2 | 24.4 | 13.1 |
| PWP (%) | 24.3 | 12.6 | 7.4 |
| Bd (g/cm ³) | 1.04 | 1.22 | 1.25 |
| TAW (at 120 cm) | 161 | 172 | 86 |

3.2. Technical Performance Indicators

3.2.1. Conveyance Efficiency (Ec) and Losses

The result showed that the conveyance efficiency in the lined main canal of Wosha Irrigation Scheme is 92.3% (Table 3). The current finding is in line with former reports of Gashaye and Tena [19] who reported conveyance efficiency of Geray irrigation scheme as 92%. On the other hand, the average conveyance efficiency in the unlined secondary canal wosha irrigation scheme was 60.2%, this is due to loss through seepage loss in the side and bed of the earthen canals. Bayan [20] reported a similar finding that unlined conveyance efficiency of Mada Batu small-scale irrigation scheme canals ranged from 47.1 to 88.6%. In contrary, the conveyance efficiency in the main unlined canal of Midhegdu small-scale irrigation scheme was 88.8% as reported by Worku [21]. This might be due to the difference in soil property and structural stability of the earth canals.

Overall, the scheme has a conveyance efficiency of 55.6%, which is very low efficiency recorded in the scheme due to the secondary canals are unlined. According to FAO [9] reports, the conveyance efficiency for earthen canal could be 80 and 95% for the lined canal; therefore, unlined canals of the scheme was under the desired efficiency.

Losses through conveyance system, which is in the main and secondary canal at Wosha irrigation scheme, were 0.06 and 0.093 l/s/m, respectively. As per the field observation during field data collection in canals, the conveyance loss in the lined canal was due to linkage through division boxes. However, loss of irrigation water in the unlined canals associated with seepage losses. This was exacerbated by the flat slope of canal, which leads to the higher contact surface and poor structural stability of earthen materials of the canals. The current finding is greater than the loss in the unlined canal of Mada Batu small-scale irrigation scheme, which is ranged from 0.02 l to 0.04 l/s/m as reported by Bayan [20].

Table 3. Conveyance efficiency of the irrigation scheme.

| Canal | Conveyance Efficiency (Ec) (%) | Conveyance losses (l/s/m) |
|-----------|--------------------------------|---------------------------|
| Main | 92.3 | 0.060 |
| Secondary | 60.2 | 0.093 |
| Scheme Ec | 55.6 | |

3.2.2. Application Efficiency (Ea)

The study revealed that the average application efficiency of wosha irrigation scheme was 48.2 (Table 4). The efficiency has a trend of decreasing as it moves from head to tail of the scheme. This might be due to the physical property of the soil, which indicates that water-holding capacity at the head is better than at middle and tail of the scheme. According to FAO [17] reports, the application efficiency of furrow irrigation could range from 50 to 70%. However, Wosha irrigation scheme was found to be below the range.

From mean application efficiency, the least contributed

from the tail reach of the scheme it was because of typically the soil categorized in sand textural class with high deep percolation loss. According to Ayele [22] report, application efficiency of Guder irrigation scheme was nearly similar to Wosha irrigation scheme, which is 49.7%.

Table 4. Application efficiency of wosha irrigation scheme.

| Field location | Applied depth (mm) | Stored depth (mm) | Ea (%) |
|---------------------------|--------------------|-------------------|--------|
| Head | 100.2 | 59.9 | 59.7 |
| Middle | 86.9 | 45.2 | 52.0 |
| Tail | 71.3 | 23.4 | 32.8 |
| Scheme average efficiency | | 48.2 | |

3.2.3. Storage Efficiency (Es)

Water storage efficiency at Wosha irrigation scheme was varies 92.5% from head to 83.8% at the tail of the scheme and the maximum efficiency recorded in the middle of the scheme which is 93.2% whereas, the average storage efficiency was 89.8% (Table 5). Storage efficiency has the advantage to know the applied irrigation water is satisfied the moisture deficit of the crop root zone. The result implies about 89.8% of the soil moisture deficit of scheme satisfied. Farmers practiced water conservation techniques by mulching the soil with sugarcane straw. This helps them to stay without irrigation by minimizing evaporation loss up to one to two months. The current finding is in line with Korkmaz and Avcı [23] who reported the storage efficiency varies from 54% to 97% over the scheme at Menemen Left Bank irrigation system.

Table 5. Storage efficiency of the irrigation scheme.

| Field Location | Stored water at root zone (mm) | Required Water (mm) | Es (%) |
|---------------------------|--------------------------------|---------------------|--------|
| Head | 59.9 | 64.7 | 92.5 |
| Middle | 45.2 | 48.5 | 93.2 |
| Tail | 23.4 | 27.9 | 83.8 |
| Scheme Storage Efficiency | | 89.8 | |

3.2.4. Water Distribution Uniformity (DU)

The computed result indicated that the average water distribution uniformity of wosha irrigation scheme was 91.7% (Table 6). In addition, the result revealed that water distribution uniformity at three reaches of the irrigation scheme has small variation from 90 to 93%, which implies that the irrigated water distributed uniformity throughout the same. This is due to the sugar cane fields were lay-outed by keeping the farm leveled.

According to the recommendation of FAO [24], the studied irrigation scheme had adequate irrigation water distribution over the entire farm field. The current finding revealed that distribution uniformity was above sufficient, in which 30 and 65% were taken as poor and sufficient, respectively [24]. Similar findings were reported by many authors, which the water distribution uniformity was greater than 90 % [17, 21, 25, 26]. However, Dinka [27] also reported conflicting results that average water distribution uniformity of the Ketar medium Scale irrigation Scheme was 61.6% due to the scheme operating

at flow rates below or above the design flow rates. This could lead to inefficient and non-uniform water distribution in the whole farm field.

Table 6. Water distribution uniformity of the irrigation scheme.

| Field Location | Mean stored water (mm) | least quarter mean Stored water (mm) | DU (%) |
|-------------------|------------------------|--------------------------------------|--------|
| Head | 60.0 | 55.1 | 91.9 |
| Middle | 45.2 | 42.2 | 93.2 |
| Tail | 23.4 | 21.1 | 90.1 |
| Scheme efficiency | | 91.7 | |

3.2.5. Deep Percolation Ratio

Majority of water loss during every irrigation event was deep percolation as farmer practice ended tied furrow. The average scheme deep percolation loss was found as 51.8%. The highest deep percolation loss recorded at the tail of scheme as 67.2%. In which the sandy property of the soil contributes to the lion share of the loss. The deep percolation ratio at head and middle of Wosha irrigation scheme was 40.3 and 48.0% of the applied water, respectively (Table 7). According to FAO [9], the water loss through deep percolation and surface run off could be about 40% and above.

Table 7. Deep percolation ratio of the irrigation scheme..

| Field location | Ea (%) | Runoff ratio, RR (%) | Deep percolation ratio, DPR (%) |
|---------------------------|--------|----------------------|---------------------------------|
| Head | 59.7 | 0 | 40.3 |
| Middle | 52 | 0 | 48 |
| Tail | 32.8 | 0 | 67.2 |
| Scheme average efficiency | 48.2 | | 51.8 |

3.3. Overall Efficiency

The study revealed that the overall efficiency of Wosha irrigation scheme was 26.8% (Table 8). This indicates that the scheme is performing with poor efficiency. Poor efficiency for the scheme was due to its poor application efficiency. The schemes overall efficiency was nearly similar with the overall efficiency of Dodicha irrigation scheme, which is 28.6% as reported by Eticha [28].

According to Tesfaye *et al.* [29] report the scheme is expanding the irrigated command area beyond the design capacity without modifying the amount of water diverted, in this regard efficient irrigation water management options should be introduced.

Table 8. Overall scheme efficiency of the scheme.

| Internal indicator | Scheme efficiency (%) |
|---------------------------|-----------------------|
| Conveyance efficiency | 55.6 |
| Application efficiency | 48.2 |
| Storage efficiency | 89.8 |
| Distribution efficiency | 91.7 |
| Deep percolation ratio | 51.8 |
| Overall scheme efficiency | 26.8 |

4. Conclusion

The current study revealed that the overall performance of wosha irrigation scheme has performing in poor efficiency.

According to the internal indicators, the application efficiency was very low due to losses through deep percolation during irrigation events. In addition, conveyance efficiency in the unlined section of the scheme was very low due to leakage loss. Storage efficiency and water distribution uniformity were in good condition. The deep percolation loss was greater in tail reaches of the irrigation scheme, moreover in the scheme. Poor application efficiency and high seepage losses in secondary canals were responsible for the lion share of low overall efficiency at Wosha Irrigation Scheme.

5. Recommendations

Generally, based on the evaluation carried in the irrigation scheme would needs improvement measures to maximize the performance. Therefore, for the improvement of application efficiency deficit irrigation, surge and cutoff application shall be adopted. Proper irrigation scheduling should be used because the application efficiency can be improved by applying the right depth of water in the right place at the right time. The conveyance efficiency can be improving through regular maintenance of the canals and water controlling metal sheet gates in the intake structures and conveyance systems especially in the division box. Finally, frequent performance evaluation should be conducted to identify the performance level of the scheme.

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