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TECHNICAL PERFORMANCE EVALUATION OF MADA BATU SMALL SCALE IRRIGATION SCHEME, WEST ARSI ZONE OF OROMIA REGION

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ABSTRACT

The technical performance evaluation of Mada Batu Small Scale Irrigation Scheme was made in order to identify management practices of farmers' implementation to improve the performance of the irrigation system. The scheme was evaluated using performance indices such as conveyance efficiency (Ec), application efficiency (Ea), runoff ratio (ROR), deep percolation fraction (DPF), water storage efficiency (Es), overall efficiency (E_o), distribution uniformity (DU) and water productivity. For this study three farmers' fields were selected each from the upper, middle and lower stream of the irrigation scheme. The results obtained showed that the average conveyance efficiency (Ec) of main canal was 64.77% and many of the secondary and tertiary canals are poorly maintained and many of the structures were not functional, Due to this farmers' diverted water to its own way by from division box reaching to their farms. The application efficiency (Ea), runoff ratio (ROR), deep percolation fraction (DPF), water storage efficiency (Es), overall efficiency (E_o) and distribution uniformity (DU) were 64.54%, 12.10%, 23.29%, 82.33%, 41.47%, and 93.10% respectively. The average of three farmers' field water use efficiency was 1.03 kg/m^3 whereas, irrigation water uses efficiency was values of 2.12 kg/m^3. In conclusion, the average of overall efficiency of the scheme is rated poor require sustainable maintenance of structures.

Key words: Ethiopia, small scale irrigation scheduling, performance evaluation, efficiency

1. INTRODUCTION

With steady increase of the global population, the contribution of irrigation towards boosting agricultural production is enormous. Particularly, in some emerging and least developed countries irrigation development and use is a backbone to the extent that it is responsible for the nations' welfare and feeding the vast majority of their population (FAO, 2005).

Irrigation is essential in overcoming the rainfall deficit and stabilizing agricultural production especially in arid and semi-arid areas. For this reason developing countries have made huge investments in infrastructure for irrigation in the form of irrigation schemes over the last half century, realizing its importance for food production for the growing population. This investment, together with improved crop production technologies such as use of fertilizers, hybrid varieties, plant protection techniques etc, has enabled many countries to move towards achieving self-sufficiency in food production. Nevertheless there is also a perception that many irrigation schemes do not perform up to expectations or achieve the goals (Gorantiwar and Smout, 2005).

Considering the current Ethiopian situation with growing population pressure in the highland areas and a rapidly declining natural resource base has necessitated irrigated agriculture and in line with this irrigation is given prime attention on the country's development agenda. The irrigation potential of the country is estimated to be about 3.7 million hectares. Of the total potential, only about 20 to 23% of this potential is put under irrigated agriculture (both traditional and modern irrigation systems) (NRMD, 2011).

From the existing irrigation, small-scale irrigation is dominant in Ethiopia. These schemes play a vital role in improving the livelihoods of the smallholder farmers. However, existing small-scale community managed irrigation schemes face various problems related to operation and maintenance, water management and sustainability. These problems have greatly reduced their benefits and challenged their overall sustainability (Zeleke, 2015). Whether traditional or modern, public agency or community managed many of the existing irrigation systems are deteriorating in their physical structures, operation and management. Performance assessment is used to identify the present status of the scheme with respect to the selected indicators and will help to identify 'why the scheme is performing so which in turn imply means of improvement. Of course performance evaluation needs relevant and reliable data which is rarely measured in Ethiopia (Mekonnen and Seleshi, 2007).

Performance evaluation for any irrigation system is essential to assess how far the goals and objectives set forth at the time of project formulation of the system have been achieved. This is a useful tool to provide necessary feedback for improving the systems management by initiating remedial measures (Rani *et al.,* 2011).

Although performance evaluation of irrigated agriculture has gained momentum since late 1980s worldwide such attempt is rarely carried out in Ethiopia (Mekonnen and Seleshi, 2007). Many irrigation schemes do not perform as much as they should, due to considerable constraints and setback. The performance evaluation conducted on 26 existing small scale irrigation scheme in south region of country and identified the major frailer and performing below their capacity (Robel, 2005). Identifying the areas in which they fall short of potentials is essential. To this effect, it is important to measure and evaluate their success or failure objectively and identify specific areas that need improvement. Hence, reliable measures of system performance are extremely important for improving efficiency and management decisions.

One of such failed scheme selected for this study to identify the major frailer and performing below their capacity is Mada Batu Irrigation Scheme. This scheme, provided with excellent quality of irrigation water from a spring with virtually no silt problem, was expected to operate with minimum technical problem. However the scheme has not been able to live up to the expectations. Hence, this study was made to evaluate the problems of scheme for its technical underperformance.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

Mada Batu small-scale irrigation scheme was located in Gedeb Asasa district, West Arsi zone of the Oromia Region of Ethiopia. It has a longitude of 39°25′51′′E and latitude of 7°21′49′′N with an elevation from 2200 to 4180 meters above sea level. The mean annual temperature of the district is found between 12-25.3^{0}C and annual mean rainfall 995.6 mm. This district is situated on Addis Ababa to Bale road at a distance of 285 km and 110 km from Asella town.

2.2 Data Collection

Three canal locations were selected along the scheme for canal evaluation and three farmers' field and the garlic crop were selected for on farm evaluation. The criteria for selection of a plot were location of stream that is upper, middle, and lower, their similarity with irrigation practices, crop grown and willingness of the farmers to collaborate. The data collected were physico-chemical properties of soil, discharge measurement of water at head works, in main canals, at three field inlets and water application practices related to water management on the selected field. For analysis of soil physico-chemical properties 54 soil samples were collected diagonally from farmers fields.

Soil Physico-chemical properties

The bulk densities of the soil were determined from undisturbed soil samples taken with core sampler of 98.13 cm^3 at 0-30 and 30-60 cm soil depths. Each wet samples were weighted and dried in an oven at 105^{0}C. The dried soil samples were re-weighed. Then, bulk density was determined as stated by (Majumdar, 2002):-

$$B_d = \frac{Ms}{Vt} \quad (1)$$

where, B_d = dry soil bulk density (g/cm^3)

Ms = dry weight of the soil (g)

Vt = volume of the core sample (cm^3)

The moisture content of the soil at Field capacity and Permanent wilting point were determined using pressure plat in laboratory by applying pressure at 1/3 and 15 bars. The texture of the soil was determined using hydrometer method and soil textural classes were determined from the textural triangle of USDA system as described by Sahlemedhin and Taye (2000).

Titration method, which is oxidation under standardized condition with potassium dichromate in sulpheric acid, was followed for organic carbon determination. Finally, conversion of organic carbon to organic matter was, therefore, obtained by multiplying percentage organic carbon by 1.724 (Stanley and Yerima, 1992). The pH of the soil and electrical conductivity values were measured in laboratory using 1:2.5 soil-water extracts as per the procedure recommended by Sahlemedhin and Taye (2000).

The infiltrations of soil were measured using double ring infiltometer of 30 cm inner diameter and 60 cm outer diameter. The two ring inserted 15 cm into the soil to prevent lateral movement of water then water were filled into the two rings then the decrease in head were recorded by 5-10 minute interval up to continually constant reading were obtained.

To determine the soil moisture content and the adequacy of an irrigation events, the soil moisture content just before and 48 hr after irrigation events were determined using gravimetric method. For this purpose, a total of 432 soil samples were collected at depth of 0-30 and 30-60 cm using soil auger from upper, middle and lower locations of the scheme on four irrigation stage at initial, development, mid and late stage of the crop and the weight of each soil were taken immediately on the farm by digital balance. The soil samples were placed in an oven and dreid to 105^{0}C to a constant weight. Then the dried soil and the container were again weighed and the weights of water present were determined by subtracting the initial from the final weight. The water contents were determined on such a way on weight and volume basis as stated (Michael, 2008):

$$\theta_w = \frac{W_w - W_d}{W_d} \times 100 \quad (2)$$

where, θ_w = soil water content on dry weight basis, (%)

W_w = weight of the wet soil (g)

W_d = dry weight of the soil (g)

To convert the dry weight soil moisture fraction into volumetric moisture content (θ), the dry weight fraction (θw) was multiplied by its respective bulk density (γ_b) and divided by the specific weight of water (γ_w) as follows;

$$\theta = \frac{\gamma_b}{\gamma_w} \theta w \quad (3)$$

Soil moisture content is also expressed in terms of equivalent depth mm/m as:

Equivelent depth (mm/m) =10*θ (%) (4)

The actual moisture storage or retention (AMS) after irrigation was computed as:

$$AMS\ (mm/m) = 10*[\theta_{AI}(\%) - \theta_{BI}(\%)] \quad (5)$$

Total available water (TAW) which is an estimate of the amount of water a crop can use from the soil for the selected fields were computed from the moisture content in volume percent at field capacity and permanent wilting point as:

$$TAW\ (mm/m) = 10 *[\theta_{FC}(\%) - \theta_{PWP}(\%)] \quad (6)$$

Flow measurement

The flow of water was measured at different point of the scheme. These are: - at the diversion (off take) from the reservoir to canal and at the three field site (upper, middle and lower) of the canal by using area velocity method, the water diverted to the farmers' fields measured by installed 3″ Parshall flume and water flow out from the fields in the form of runoff were measured by volumetric methods.

The velocities of flow were measured by mini type propeller current meter at 0.6 of water depth of the water flow from surface water. To measure flow velocity of water the tail vanes of current meter were aligned in reverse direction of water flow. The flow velocity of the water, after current meter is inserted at a point was obtained by starting a stop watch on a click and stopping it on another click after about 45 seconds. Then the average number of revolution and velocity were read from the current meter.

The discharges of canal at the three entrance of irrigation farm were determined by Area-Velocity method using Mean-Section Method. First the canal cross-section was divided into number of vertical segments or strips (by 5% interval of water width) and average velocities of each segment were measured at depth of 0.6 of water depth. The discharges in each segment were calculated by multiplying the area of the segment with the mean velocity of flow. The total discharge in the canal was computed as the sum of the discharges in various segments as stated (Mushtaq *et al.,* 1997).

$$q = a * v \tag{7}$$

$$Q = \sum_{i}^{n} a * v \tag{8}$$

where q = discharge from an individual section

a = individual section area

v = mean velocity of the flow normal to the section

Q = total discharge from the cross- section

The amount of water applied by farmer to the field, three inches (3") Parshall flumes were installed at the entrance of study field. Frequent measurement of water depth were taken at 2/3 distance from the crest (converging section). Irrigation was continuing until the farmers' thought that enough amount of water is applied to their field. After farmers completed irrigating the study field, the average depth of water passing through the flume was calculated and the discharge was reads from three inches (3") Parshall flumes table. The total discharge entered the field were calculated by multiplying discharge read from table with total time taken to irrigate.

2.3 Technical Performance Indicator Analysis

(a) Water conveyance efficiency

The discharge of water diverted from the reservoir to off take canal and discharge reached at three study sites were measured using Area-Velocity method as indicated in equation 7 and 8. Then conveyance efficiency was calculated as expressed as (Irmak *et al.*, 2011):

$$E_c = (V_f/V_t) \times 100 \tag{9}$$

where E_c = water conveyance efficiency (%)

V_f = volume of irrigation water that reaches the farm or field (m^3)

V_t = volume of irrigation water diverted from the water source (m^3)

(b) Water application efficiency

The evaluations of the application efficiency were the ratio of stored water to the applied water. The water applied to field was determined using three inches Parshall flumes and depth of water stored in the root zone of selected field was determined from the soil moisture content before and two days after irrigation by gravimetric method. The depth of water retained in the soil profile in the root zone was determined using equation given by Mishra and Ahmad (1990):

$$Z_r = \sum_{i=0}^{n} \frac{(\theta_{AI} - \theta_{BI})}{100} iD_i \tag{10}$$

where Zr = depths of water stored in the root zone of selected field

θ_{AI} = moisture content of the ith soil compartments after irrigation on oven dry volume basis (%)

θ_{BI} = moisture content of the ith soil compartments before irrigation on oven dry volume basis (%)

Di = thickness of i^{th} soil compartments and

n = number of compartments in the root zone.

The application efficiencies of the fields were calculated this using equation.

$$E_a = (V_s/V_f) \times 100 \tag{11}$$

where E_a= water application efficiency (%)

V_s= volume of irrigation water stored in the root zone

V_f = volume of irrigation water delivered to the farm or field

(c) Overall irrigation efficiency

It was calculated by multiplying the efficiencies of water conveyance and water application (FAO, 1989; Irmak *et al.*, 2011).

$$E_o = (E_c \times E_a) \times 100 \tag{12}$$

where E_o = overall irrigation efficiency (%)

E_c = water conveyance efficiency (decimal)

E_a = water application efficiency (decimal)

(d) Water storage efficiency

The water storage efficiencies were computed by monitoring soil moisture before and after irrigations. After determining the water stored in the root zone of the plants and water needed in the root zone prior to irrigation, the storage efficiency Er (%) could be computed as:

$$Er = \frac{Zr}{Wn}*100 \qquad (13)$$

where Zr is depth of water retained in the soil compartments of the root zone computed by equation and Wn is water needed in the root zone prior to irrigation and estimated by the following equation:

$$w_n = \sum_{i=0}^{\infty} \frac{\theta FC - \theta BI}{100} * i * Di \qquad (14)$$

where, θ_{FC} and θ_{BI} are soil moisture content at field capacity and moisture content of the soil before irrigation in volume percent, respectively, i, is the number of soil layers and D_i is the depth of soil profile in root zone.

(e) Distribution uniformity coefficient (DUC)

This was computed by arranging moisture content in descending order then finding average of them and least quarter then distribution uniformity were calculated stated given as Terry and Howell (2002)

$$D_{up} = 100\ (Vp/Vf) \qquad (15)$$

Where D_{up} = is the distribution uniformity in % for lowest "p" fraction of the field or farm (lowest one-quarter p= ¼)

V_p = is mean application volume lowest one quarter (m^3)

V_f = is the mean application volume (m^3) for whole farm or field.

(f) Runoff fraction (ROF)

During the study time the water runoff from the farm were collected at the end of the field. Then losses from the irrigation system via runoff from the tail of the field were calculated as:-

$$TWR = \frac{\text{Volume of runoff } (m^3)}{\text{Volume of water applied to the field } (m^3)} \qquad (16)$$

(g) Deep percolation ratio (DPR)

Deep percolation fraction (%) can be calculated indirectly from the measured value of application efficiency (E_a) and run off ratio (RR) as given by FAO (1989).

$$DPR = 100-E_a-RR \qquad (17)$$

Estimation of Water Productivity

Crop water and irrigation water requirement were determined using CROPWAT computer program by entering climate data of station. After attaining the maturity stage of the crop, grain yield of the crop was collected and weighted on weight balance for water productivity analysis. Using the equations 9 and 10 water use efficiency and irrigation water use efficiency were calculated as stated (Tanner and Sinclair, 1983).

$$WUE = \frac{Ya}{ETc} \qquad (18)$$

where WUE is water use efficiency (kg/m^3)

Ya is actual yield (kg/m^2)

ETc is seasonal crop evapotranspiration (m^3/m^2)

$$IWUE = \frac{Ya}{IW} \qquad (19)$$

where *IWUE* is irrigation water use efficiency (kg/m^3)

Ya is actual yield (kg/ha)

IW is irrigation water applied (m^3/ha)

3. RESULTS AND DISCUSSION

3.1 Measurement of Physico-Chemical Properties of Soil

From the laboratory results, textures of the soil in the three study fields of irrigation scheme were loamy soil and bulk densities 1.44-1.46 g/cm^3, permanent wilting point 15.90-18.15%, field capacity 28.25-30.90%, Organic matter contents 2.95-3.65%. The pH and EC of soil in the range of neutral and non saline (less than 2 mmhos/cm). This shows that the pH and EC of the area were suitable for crop productions.

Table 1. Laboratory result of soil Physico-Chemical Properties

Soil properties	Soil sampling location		
Soil depth (cm)	US	MS	LS
Texture	Loam	Loam	Loam
pH	7.44	6.73	7.15
EC mmhos/cm at 25^{0}c	0.48	0.14	0.21

% C	1.81	1.71	2.12
OM (%)	3.13	2.95	3.65
Bulk density (g/cm^3)	1.44	1.45	1.46
FC (% Vol)	30.90	29.15	28.25
PWP (%Vol)	18.15	15.90	15.90
TAW (mm/m)	127.50	132.50	123.50

US=upper stream MS=Middle stream LS=Lower stream

The infiltration rate of the study area was found to be 12 mm/hr. According to Israelsen and Hansen (1962) the infiltration rate of a soil is in the range 10-20 mm/hr, it is classified as a soil with moderate infiltration rate which is the typical characteristics of loam soil.

3.2 Irrigation Scheme Performance

a) Conveyance efficiency

From Table 2 main canal conveyance efficiency were found as 88.6%, 58.6% and 47.1% and water loss at the interval of 400 m, 800 m and 1200 m from off take canal as 7.98 l/s, 28.98 l/s and 37.03 l/s were determined at upper, middle and lower respectively. This shows at interval of 400 m 7.98 l/s, 21 l/s and 8.05 l/s water loss from upper, middle and lower stream respectively. At middle stream there was high loss (21 l/s) of water in canal. This is due to the cracks developed in the canal by tree roots at different places.

Table 2. Conveyance efficiency of main canals at upper, middle and lower stream of the scheme

Position of canal	Canal type	Length from off take (m)	Discharge (l/sec)	Conveyance efficiency (%)	Conveyance loss	
					l/s	l/s /m
Off take	Lined	-	70	-	-	-
Upper	Earthen and lined	400	62	88.6	7.98	0.02
Middle	Earthen and lined	800	41	58.6	28.98	0.04
Lower	Earthen and lined	1200	33	47.1	37.03	0.031
Average				**64.77**	**24.66**	**0.03**

b) Farmer's fields evaluation

The data collected from selected farmers fields train shows that average amount of water applied to field per irrigation stage as 89.80, 89.33 and 70.70 mm but the depth of water needed in the root zone prior to irrigation or soil water depletion at different growth stages were 66.98 mm, 62.93 mm and 63.86 mm at the upper, middle and lower of irrigation scheme respectively. From this water applied the, water stored at crop root zone at upper, middle and lower of irrigation scheme as 55.71, 53.40 and 50.64 respectively.

Application efficiency

Table 2 shows the application efficiency of irrigation scheme. The average application efficiency of the three fields were 62.08%, 59.78%, 71.76% at upper, middle and lower respectively. The water application efficiency of lower side of scheme was greater than the two even though the amount of water application was lower than the two fields. This is due to the farmer at lower side of study site who properly used water and applied to field without more loss.

Over all irrigation efficiency

This efficiency was 55.18%, 35.4%, and 33.84 at upper, middle and lower stream of irrigation scheme respectively. The overall average was 41.47% which is reasonable according to FAO (1989) overall scheme efficiency around of 40% is reasonable.

Water storage efficiency and distribution uniformity

From Table 2 water storage efficiency of irrigation scheme at three farmers field were 83, 85 and 79% and distribution uniformity (DU) were 96.39, 91.01and 91.82% at the upper, middle and lower respectively

Runoff fraction (ROR) and Deep percolation ratio (DPR)

Runoff percentage was calculated after collecting water at the tail of the field. The average runoffs registered at upper, middle and lower were 12.55, 13.13 and 10.62% and deep percolation percentage was 25.37, 27.09 and 17.42 % for upper, middle and lower of irrigation scheme respectively. From this result the high deep percolation ratio was observed at the middle and upper stream. The average percentage of water loss on the farm (deep percolation + runoff) was 37.92, 40.22 and 28.04% at upper, middle and lower of irrigation scheme respectively.

Table 3. Efficiency of irrigation scheme

Stream location	Water applied	Water need (wn)	Water store at root zone	Application efficiency (%)	Runoff (%)	Deep percolation (%)	Over all efficiency	Water storage efficiency (%)	DU in %
US	89.80	66.98	55.71	62.08	12.55	25.37	55.18	83	96.39
MS	89.33	62.93	53.40	59.78	13.13	27.09	35.4	85	91.01
LS	70.70	63.86	50.64	71.76	10.62	17.42	33.84	79	91.82

3.3 Water Productivity

The crop water requirement of Garlic was determined using CROPWAT. The seasonal crop water requirement and irrigation requirement of garlic crop were 649.6 mm and 365.6 mm respectively. Using seasonal water requirement (ET_c) of garlic crop (649.6 mm), irrigation water use and product collected from the three study area water productivity and irrigation water productivity were calculated using equation 18 and 19. The water productivity of the upper and middle was the same but water productivity at the lower stream was greater than the two study fields and irrigation water use efficiency of the upper and middle was the same but the lower irrigation water use efficiency was greater than the two study fields.

Table 4. Water productivity of garlic crop

Field location	Water productivity (kg/m^3)	IWUE (kg/m^3)
Upper	0.74	1.34
Middle	0.74	1.34
Lower	1.61	3.68

4. SUMMARY AND CONCLUSION

Performance evaluation for any irrigation system is essential to assess how far the goals and objectives set forth at the time of project formulation of the system have been achieved. This is a useful tool to provide necessary feedback for improving the systems management by initiating remedial measures.

The performance evaluation made on Mada Batu small scale irrigation scheme at three farmers' fields evaluation shows that, average conveyance efficiency was 88.6%, 58.6% and 47.1%. Application efficiency (Ea), runoff ratio (ROR), deep percolation fraction (DPF), water storage efficiency (Es), overall efficiency (E_o) and distribution uniformity (DU) were determined and their average values of scheme were found to be 64.54%, 12.10%, 23.29%, 82.33%, 41.47%, and 93.07% respectively.

The conveyance water loss of main canal at the middle stream is higher than the two streams due to same trees root crake's canal bed resulting seepage loss. Due to this surge flowing of water from the main canals affecting by some farmer's farm by water logging. The result of the study also showed that the irrigation water applied to the farmer's fields was higher than the required depth to be applied per irrigation event. Even though water was not a free resource, farmers were applying excess amount of water to their fields without considering the crop water requirements of the crop. The average of overall efficiency of the scheme is rated poor require sustainable maintenance of structures.

5. ACKNOWLEDGEMENTS

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