Hydraulic Performance Evaluation of Hare Community Managed Irrigation Scheme, Southern, Ethiopia

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Abstract

Performance based management is a principal approach to improve the scheme performances. However, in Ethiopia performance evaluation of irrigation schemes is rarely conducted. The potential benefits of Hare community managed irrigation scheme are hardly realized the required benefits. The objective of this study was to assess the hydraulic performance of Hare irrigation system. The study was carried out during the irrigation season from September to December, 2014. Hydraulic performance of the irrigation system was evaluated by nine process performance indicators. The results indicate that, the values of adequacy, dependability and equity are found to be 0.64, 0.21 and 0.34 respectively. The equity ratio of water distribution of head to tail is 3.52; which depicts the head reach farmers are received more water than the tail. Average water deficit of the system is 36 percent; the main canal supplies less water than the demand to the delivery points.As per the results of the study, water delivery performance of the scheme can be considered as poor. The values of water surface elevation ratio, effectiveness of infrastructure and delivery duration ratio are found to be 91,15.9 and 133.36 percent respectively. It displayed that high system maintenance is required. Generally, the performance of the irrigation system is poor. Therefore, capacity building of users, adequate operation and maintenances of the system, improving diversion capacity of the scheme and providing flow control and measurement structures are required to improve the irrigation system performance.

Keywords:*Hare irrigation scheme,Hydraulic performance, irrigation service, process indicators; water delivery and maintenance indicators.*

1. INTRODUCTION

Water scarcity is a potential constraint to produce more foods to meet the demands of increasing world population. One possible approach to conserve this scarce resource might be through improving the performance of existing irrigation schemes [1].

Ethiopia has enormous cultivable land, but only current irrigation schemes covering about 640,000 ha [2]. The government is undertaken development of several new irrigation projects, yet the performance of existing irrigation schemes are given less consideration. In many of these schemes, water management activities are performed by the farmers themselves, however they lack technical expertise to manage their water effectively [3]. The performance of many irrigation systems are significantly below their potential due to a number of shortcomings; including poor design, construction, operation, maintenance, and ineffective water control and measurement structure installation [4 and 5].

Hare irrigation scheme is allowed to the farmers applying irrigation and has enabled them frequently to harvest twice per year. However, due to lack of frequent training for water application and management, farmers spent water more hours per day. The water distribution approach in the scheme is fixed rotational water delivery scheduling, yet the water control and regulating mechanisms are traditional using barriers like leaves and stones. With increased population growth and the erratic nature of rain fall, the computation of water users in the area is increased from time to time. This limits the quality and quantity of agricultural productivities. The delivery of fair share of water to the user is not clearly understood, it was discovered that this situation could be artificially created to benefit few (corruption). Besides, due to urbanization breaching through and high economic escalation agricultural activities began to decline and the

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irrigation water is shared with municipalities and other purposes. In this condition appraisal of the performance of water delivery system and maintenance requirement of the scheme becomes vital to ensure good functioning of the irrigation system. Therefore, this study was conducted on hydraulic performance assessment of Hare community managed irrigation scheme using process performance indicators. It was addressed to analyze the performance of irrigation system in relation to water delivery performance indicators and maintenance requirements of the scheme. The study provides to the system managers, farmers and policy makers a better understanding of how a system can be operated.

2. MATERIALS AND METHODS

2.1 Descriptions of the study area

Hare irrigation scheme is located in the Abaya-Chamo sub-basin of Gamo Gofa Zone, Southern regional state of Ethiopia. The topography of the command area is described as flat to gently sloping plain. The watershed is situated between 6o03' and 6o18' North and 37o 27' and 37o 37'East and has an area of 187 km2. The average elevation is about 1169 m am.sl; and its command area lies between 6o06'40" and 6o06'28" North and 37o 33'53" and 37o36'48" East. The scheme abstracts water from Hare River. Smallholder agriculture is the dominant land use in the watershed; irrigated cash crop is the predominant. The designed and actual command area in irrigation was 1336 and 1131.87 ha respectively.

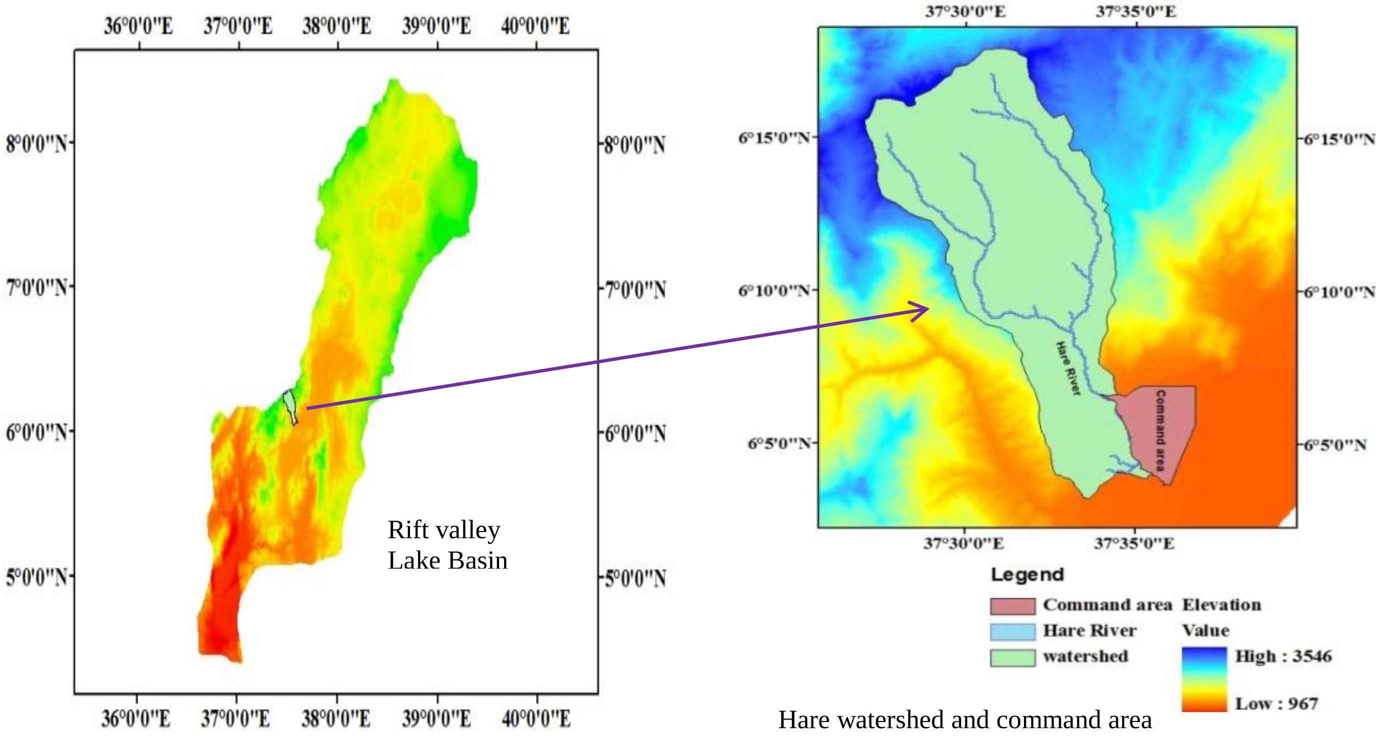

Figure 1 Location map of Hare irrigation scheme

2.1.2 Back ground of the scheme

The modern diversion irrigation scheme was intended to serve around 1798 households of Chano Chelba and Chano Mille Kebeles. The design capacity of the intake structure is 2 m^3/s with a maximum discharge capacity of 2.4 m^3/s. The networking system of canals in the irrigation area consists of one main canal with eight branch canals. A small portion of the main canal is rectangular masonry and the major portion is trapezoidal lined and unlined canal. The length of the main canal was about 5.31 km long and totally had 23.85km length of branch canals. The main canal length which actually gives service to the beneficiary is 3.89 km. The design layout of the scheme consists 162 various structures which includes turnouts, lateral gates, aqueduct, control and recession gates, bridges, flumes and drop structures [6].

2.2 Methods

2.2.1Data sources and methods of data collection

In this study the data were collected from primary and secondary sources. The primary data were collected in direct measurement from fields. Such activity includes: measurements of discharging through the branch off take canals, measurement of actual water surface elevation in the main canal, filed observations, hydraulic design of Parshall flume and volume of water required in the irrigation system. The secondary data were collected from agricultural and rural development offices and Arba Minch metrology station. Climate data, irrigated crops, actual command areas and designed features of the scheme are major data which were utilized in the study.

Discharge Measurements

In the study two methods were used for measuring canal irrigation water supply. These are calibrated Parshall flume and Current meter. The flow measurements were taken on the seven branch off take canals. A GEOPACKS Current flow meter was used to measure the flow velocities in the canals. Two and six inch Parshall flumes were installed at the flow measurement location and frequent readings were taken. The discharge of canals resulting from the depth-flow relationship in parshall flumes were calculated in free flow conditions. The measurements were taken at the branch off take canals just after abstraction points along the distribution or branching canals. Based on the settled water delivery plan, the measurement of actual discharges in each branch off take canals were taken on 15 days per three months (five days/month) and then converted into an average monthly rate.

Water surface elevation measurements (WSE)

Water surface elevation of the main canal was measured in the reaches of the canal. In middle and tail reach, actual WSE data were taken from eight monitoring stations classified with the canal length in 0.162 km interval, yet the data were taken in nine monitoring stations in the head reach. Generally, actual WSE data were taken on 25 inspection stations along the main canal.

2.2.2 Data analysis

Hydraulic performance of the irrigation system was evaluated using nine performance indicators. Performance evaluation using process indicators consists specifically measuring the extent to which the goals and required benefits are being achieved. It was investigated based on the data that were collected during September to December, 2014 in one irrigation season. While, water delivery performances were analyzed using the observed data in October to December, 2014. The choice of these months was arranged due to the fact that, it is hardly rain and almost all fields are irrigated. A water delivery performance was designated to evaluate on the main canal at head, middle and tail reaches. The main canal system performance with respect to water delivery indicators was estimated based on the monthly required and delivered discharge.

Water delivery performance indicators

The water delivery performance parameters like adequacy, equity and dependability have been proposed by Clemmens and Bos [7]; and Molden and Gates [8]. According to Molden and Gates [8], the performance of the system was classified as good, fair or poor.

Dependability (PD): It is defined as the temporal uniformity of the ratio of delivered amount of water to the required or scheduled amount over a region. Such parameter is defined as:

$$PD = \frac{1}{R}\sum_{S} CvT\frac{QD}{QR} \qquad (2.1)$$

Where, Cv_T is temporal coefficient of variationof the ratio Q_D/Q_Rover a region S and a time T.

Adequacy (PA): Adequacy displays the extent to which the total water deliveries are sufficient to fulfill the needs of the crops in a specific growing season. It relates to the actual delivery to required amounts of water needed for the crop irrigation [8].

$$PA = \frac{1}{T}\sum_{T}\left(\frac{1}{S}\sum_{S}\frac{QD}{QR}\right) \qquad (2.2)$$

Where, PA $=Q_D/Q_R$, if $Q_D \le Q_R$, otherwise PA=1, S is the site where canals are located. $Q_D$is actual amount of water delivered by the system and Q_R is required discharge.

Equity (PE): Equity as related to water delivery system can be defined as the delivery of the fair shares of water to the users throughout the system. An appropriate measure of the performance of the system with equity would be the average relative spatial variability of the ratio of amount delivered to the amount required over the time period of interest. The measure is given by:

$$PE = \frac{1}{T}\sum_{T} CvR(\frac{Qd}{Qr}) \quad (2.3)$$

where CV_R is the special coefficient of variation of the ratio of delivered water to required water over the region R andt is the time period.

Equity Ratio for Head and Tail (ERHT): This indicator focused on the equity of water distribution for head and tail at different levels of a system. It can assist to identify head and tail difference at the level of the system; and to address problems as a result. The ratio is defined as:

$$ERHT(MDR) = \frac{\frac{1}{n}\sum_{t=1}^{t=n} MDR\ (head)}{\frac{1}{n}\sum_{t=1}^{t=n} MDR(tail)} \quad (2.4)$$

The value of MDR is described as the ratio of Q_D with Q_R, n is the number of periods monitored

Deficiency: The value of deficiency is a quantitative measure of the dissatisfaction's of users. The parameter will help the system managers and users to take corrective measurements for system improvements in deficit areas. A measure of deficiency is given as the ratio of temporal and spatial average of water deficiency to the required amount (Q_R) [10].

$$PDF = \frac{1}{T}\sum_{T}(\frac{1}{S}\sum_{S}\frac{QR - QD}{QR} \quad (2.5)$$

$PDF = \frac{QR-QD}{QR}$, if $Q_R > Q_D$, Otherwise =0

Table 3.1 Range of water delivery performance indicators [8]

Performance indicators	Range			
	Poor	Fair	Good	Excellent
PD	>0.20	0.11-0.2	0.00-0.10	
PA	<0.80	0.80-0.89	0.90-1.00	
PE	>0.25	0.11-0.25	0.00-0.10	
ERHT(MDR)	<0.7 or > 1.3	0.7-0.79 and 1.21-1.3	0.8-0.9& 1.1-1.2	0.90-1.10

Maintenance indicators

Maintenance performance inspection of the irrigation scheme would provide to insight the feature of maintenance situations. Hydraulic performance of the scheme was also evaluated with maintenance performance indicators. It was estimated through the indicators recommended by Shafique [9], Bos [11]; Kloezen and Garces[12] and Bos *et al.* [13]. Maintenance requirements of the system were observed according to the maintenance indicators of water surface elevation ratio, effectiveness of infrastructure, delivery duration ratio and sustainability of irrigable area. The physical structures in its operational condition were categorized as operative, nearly operative, nearly inoperative and inoperative. If at least one of the following conditions are in effect: broken and damaging of the structure, change of canal cross-section, scouring of canal section, missing of flow control and measuring structures, sedimentation and weed growth [14].

Effectiveness of infrastructure (EI): The study was focused on the irrigation system components with the spillway and weir; yet the drainage and field application systems did not considered. The existing condition of the main and branch canals were inspected in its operating length alone. The ratio is:

$$EI = \frac{\text{Number of functioning structures}}{\text{Total number of structures initially installed}} \quad (2.6)$$

Water surface elevation ratio (WSER): This indicator provides to predict the impact of sedimentation and erosion problems on the physical irrigation system[9].

$$WSER = \frac{\text{Actuall water surface elevation at FSL}}{\text{Intended water surface elevation at FSL}} \quad (2.7)$$

Delivery Duration Ratio (DDR): are both maintenance and water utility performance indicator's, it is described as the ratio of actual and intended duration of supply in day.

$$DDR = \frac{Dac}{DI} \quad (2.8)$$

Sustainability of irrigated area (SI): Is measured as the ratio of existing area under irrigation to the planned irrigated area[15]:

$$SI = \frac{\text{Actuall irrigated area}}{\text{Designed irrigated area}} \quad (2.9)$$

Amount of water required in the irrigation system

The amount of water needed for the irrigated crop fields was determined using CROPWAT version 8 program. Crop water requirements, irrigation requirements (IR) and scheme water supply for varying crop patterns was estimated based on the soil, climate, and crop patterns. Daily and monthly reference Crops Evapo-transpiration (ETO) were estimated by the Penman-Monteith method. The soil composition based on the textural triangle classification is clay loam with 41.91% sand, 27.97% silt and 30.12% clay [16]. The hydraulic properties of the soil were determined based on the soil textural inputs from the percent sand; silt and clay using SPAW model [17]. The CWR were then computed from the crop factor (Kc) and the ETO values for the crop planted. The value of effective rainfall was determined using USDA soil conservation service method [18]. The volume of water required (QR) to feed the main and branch canals were estimated with the product of IR and the command area (ha) served for irrigation practice by assuming an irrigation efficiency (IE) of 31 per cent [16].

3. Result and Discussions

3.1 Evaluation of Water delivery performance

Adequacy

The adequacy value is calculated using equation (2.2). The spatial and temporal mean values of adequacy in the irrigation scheme system are given in Table 2. Average spatial and temporal values of adequacy are 0.69, 0.71 and 0.52 in October, November and December, and 0.9, 0.59 and 0.5 at head; middle and tail reach of the system respectively. The overall adequacy value of the system is found to be 0.64. The spatial and temporal average adequacy of the scheme is poor except in the head reach of the distribution system. The temporal adequacy in the head reach falls in the good range. However, the overall average adequacy during the season for the entire command of the main canal is found to be poor.

Dependability

The measurement of dependability was computed using equation (2.1). The results of dependability are presented in Table 3. The average dependability (temporal coefficient of variation) values of head, middle and tail reach of a system are ranging from 0.05 to 0.27 with an overall average dependability of 0.21. The average dependability of the first branch canal is zero. As it can be seen from the result BR_1 represents a reliable delivery of water (Table 3). Accordingly, the dependability of water distribution in the scheme at middle and tail reaches are poor (>0.2), while good in head reach of the distribution system. The performance of the entire system in terms of dependability of water distribution is found in the unsatisfactory range; it has been performed poor over the season.

Equity

Equity of water distribution was calculated as the coefficient of variation of the adequacy values between different locations using equation (2.3). The results of spatial coefficient of variation (PE) of water distribution over the investigation period are given in Table 3. Equity of water distribution in November and December is perceived above the standard of the faire rage; which is said to be poor. But, the distribution of water in October is fair. The head reach users received more water than the middle and the tail reach, however tail reach users are most disadvantaged in the delivery of water. Average overall equity of the delivery system is found to be 0.34 (Table 3). The result shows that equity of water distribution is poor over the entire system. Belete [16] and Mekonen [19] also found similar results in the study and suggested that almost upper end outlets were received more water than the tail end.

Table 1 Average adequacy of water distribution in the system

	Head		Middle			Tail		
Month	BR_1	BR_2	BR_3	BR_4	BR_5	BR_6	BR_7	Spatial Ava. PA
October	1.00	0.80	0.63	0.60	0.64	0.53	0.63	0.69
November	1.00	0.87	0.68	0.80	0.76	0.43	0.39	0.71
December	1.00	0.73	0.37	0.43	0.43	0.34	0.36	0.52
Temporal	1.00	0.80	0.56	0.61	0.61	0.43	0.46	
Ava. PA	0.90		0.59			0.50		0.64

Note: B_R refers to branch canal and Av. is average

Table 2 Dependability of water supplied and Equity of water distribution on the system

	Head		Middle			Tail				
Month	BR_1	BR_2	BR_3	BR_4	BR_5	BR_6	BR_7	Average	Std.	CV,(PE)
October	1.00	0.80	0.63	0.60	0.64	0.53	0.63	0.69	0.16	0.23
November	1.00	0.87	0.68	0.80	0.76	0.43	0.39	0.71	0.22	0.32
December	1.00	0.73	0.37	0.43	0.43	0.34	0.36	0.52	0.25	0.48
Average	1.00	0.80	0.56	0.61	0.61	0.43	0.46			0.34
Std.	0.00	0.07	0.17	0.19	0.17	0.09	0.15			
CV,(PD)	0.00	0.09	0.30	0.30	0.28	0.21	0.32			
	0.05		0.30			0.27		0.21		

Equity Ratio for Head and Tail (ERHT)

The ERHT was calculated using equation (2.4). It intends to estimate how water was managed and delivered fairly in head and tail reach of the main canal. Table 4 displayed the equity ratio for head and tail and the values of management delivery ratio (MDR).

Table 3Equity ratio for Head and Tail (ERHT (MDR)) reach of the system

	Head			Tail		
	BR_1	BR_2	BR_5	BR_6	B_7	
Month	MDR	MDR	MDR	MDR	MDR	ERHT(MDR)
October	3.13	0.80	0.64	0.53	0.63	2.18
November	7.00	0.87	0.76	0.43	0.39	4.96
December	3.13	0.73	0.43	0.34	0.36	3.41
Average						3.52

The value of ERHT ranges from 2.18 to 4.96. The overall average value of ERHT is found to be 3.52. The results of ERHT obtained here are poor. All the values of the ratio (ERHT) in the table are greater than one, indicating that the MDR of the head reach of the system is higher than the tail reach. The performance of the main canal is not found in a reasonable level with respect to ERHT (MDR). The head delivery systems receive more water than the tail in all months.

Deficiency of Water

The delivery of water less than the adequate supply of water to the delivery points in the system results shortage. The deficit of water delivery was calculated by equation (2.5). The results of spatial and temporal average value of deficit are presented in Table 5.

Table 4 Average spatial and temporal Deficiency (PDF)

	Head		Middle			Tail		
Month	BR_1	BR_2	BR_3	BR_4	BR_5	BR_6	BR_7	Spatial Ava. PDF
October	0.00	0.20	0.37	0.40	0.36	0.47	0.37	0.31
November	0.00	0.13	0.32	0.20	0.24	0.57	0.61	0.29
December	0.00	0.27	0.63	0.57	0.57	0.66	0.64	0.48
Temporal	0.00	0.20	0.44	0.39	0.39	0.57	0.54	0.36
Average PDF	0.10		0.41			0.46		

The average temporal deficits in head reach are relatively lower. Yet, shortage of water is not emerged in the first branch canal (Table 5). The deficits of water in the tail reach delivery system had been highest.

Average spatial deficit in the conveyance system has been observed in all months. The spatial deficit is advanced in December mainly in branch canal six (BR_6). As a result, high spatial average deficit is happened in December. Average overall deficiency of the entire system is found to be 0.36 (36 percent). It shown that, the delivery system supplied less water than the required in generally.

3.2 Maintenance performance of the system

Effectiveness of infrastructure

Effectiveness of infrastructure was estimated using equation (2.6). According to the design document, the total number of structures that were installed in the irrigation scheme was 113, however only 18 structures are currently functional. Hence, the value of effectiveness of infrastructure is estimated to be 15.9 percent. The value suggested that the maintenance activity of a system was very poor.

With regarding to canal operating condition, the physical states of canal length inspection are shown in Table 6. The main canal section is found to be operative, nearly operative, nearly inoperative and inoperative with the corresponding value of 4.86, 67.50, 0.90 and 26.74 percent respectively. Whereas, 0.08, 79.63, 9.07 and 11.23 percent of the branch canals are operative, nearly operative, nearly inoperative and inoperative respectively. In the view of the survey demonstrated, nearly larger percentage of the main and branch canal length were found to be inoperative in the tail reach.

Table 5 Physical condition of canal length inspection

Location	Total length of canal(km)	Operative length (%)	Nearly operative (%)	Nearly inoperative (%)	Inoperative length (%)
Main canal	5.31	4.86	67.50	0.90	26.74
Branch canals	23.86	0.08	79.63	9.07	11.23

Water surface elevation ratio (WSER)

The parameter of WSER was computed using equation (2.7). The results are given in Table 7. As per the design document the intended water depth of the main canal from the canal bottom was 0.8 m at FSL with the discharge capacity of 2 m^3/s. whereas, the current average water surface elevation at FSL is found to be 0.73 m. Even though, overall average WSER was found to be 0.91. This shows a seven percent of WSE at FSL was reduced in the intended water depth of the main canal.

The parameter of average WSER at head, middle and tail reaches of the main canal during the monitoring period is generally less than one, thus the main canal is infected by weed and sedimentation problem (Table 7).

Table 6Average Water Surface Elevation (WSE) statuses of the main canal

Location	Head		Middle		Tail		Over all	
	Dev. WSE	WSER	Dev. WSE	WSER	Dev. WSE	WSER	WSER	Dev. WSE
Average	0.05	0.94	0.13	0.84	0.05	0.94	0.91	0.07

Note: the result is based on mean level measurement of water depth at FSL in various main canal sections and all measurements are in meter unit. Dev. WSE is deviation of water surface elevation.

Delivery Duration Ratio (DDR)

The value of DDR was calculated using equation (2.8). As per the design document the intended duration of water delivery was 18 hours per day. However, because of the silting up of the canal system, malfunctioning of control structure, defective of ender main and secondary canals

and due to shortage of water mainly for tail end beneficiaries, water delivery is neither timely nor reliable, since actual duration of water delivery is elongated to 24 hours per day. Therefore, DDR is 133.33 percent; showing the water distribution system is not dependable and the system maintenance is insufficient. The system needs further maintenance requirement.

Sustainability of irrigated area (SI)

As per the design document the intended command area that a scheme could potentially irrigated were 1336 ha, while the actual irrigated area in a cropping season are 1131.87 ha. Hence, SI is found to be 85 percent using equation (2.9). The irrigated areas of the irrigation scheme are reduced compared with the planned; however the reductions of command area were not due to the inability of the scheme water supplied to the farm with insufficient maintenance activity.

4. CONCLUSIONS AND RECOMMEDATIONS

Performance assessment is a practical solution to providedifferent stakeholder with a better understanding of how the system can be effectively implemented to improve irrigation system performance. It helps to identify problems and management practice of irrigation system. In the main canal system, the performance of water delivery was found to be poor in terms of adequacy, dependability, equity and equity ratio for head to tail. Likewise, the delivery system supplied less water than the required, which is considered as unsatisfactory with respect to deficit. This unsatisfactory performance of irrigation system could reduce the productivity of the farm and brings water related conflicts.

Maintenance performance indicators were considered the parameter of water surface elevation ratio, effectiveness of infrastructure, canal operating condition and delivery duration ratio. Generally, it was found that the maintenance performance of the system was very poor. Some parts of the structures are affected by sedimentation; weed growth, flooding and erosion problems. The main causes of low maintenance performance of the scheme have been due to technical, social, managerial, institutional and financial issues.

In general, according to the result perceived, the performance of irrigation system is low. Therefore, a system to be performing well;thoughtful system management is required so as to achieve the required objectives of the scheme. Moreover, improving water management, adequate maintenance of irrigation infrastructures, capacity building of users in different aspects which can be support for improving irrigation water utilization, soil and water conservation practice is required to provide manifold benefits.

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