Research Article
Volume 9:4, 2020
DOI: 10.37421/idse.2020.9.245

Irrigation and Drainage Systems Engineering

ISSN: 2168-9768

Open Access

Evaluation of Water Delivery Performance in Robit Small-Scale Irrigation Scheme, Amhara, Ethiopia

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Abstract

Ethiopia has expanded irrigable areas by constructing many small-scale irrigation schemes. These are aimed to improve the productivity of agricultural crops. However, they commonly perform far below the intended objectives. This is mostly because the performance of the irrigation schemes has not been managed well. In the present study, the water delivery performance and the satisfaction of irrigation users for Robit small-scale irrigation scheme were evaluated. The water delivery performance indicators; adequacy, efficiency, equity, and dependability were evaluated by monitoring discharge at nine selected tertiary offtakes for three months during 2017. The irrigation water flow was measured using Current meter and 3-inch Parshall flume. Questionnaire was developed to assess the satisfaction level of irrigation users regarding the irrigation service received. Finally, the collected data were analyzed using STATA, CROPWAT, ARC GIS, and Microsoft Excel. The adequacy, efficiency, equity, and dependability values varied widely regarding location (from head to tail end of the scheme) as well over time (from April to June). Thus, when compared with Molden and Gates standards, the scheme was performing under a "fair" condition with adequacy and dependability and under "good" condition regarding efficiency and equity. The level of irrigation users' satisfaction with the irrigation service received was 57.33%, 48%, 42.67% and 49.33% at the head, middle, tail reaches, and the entire system respectively. Satisfaction of irrigation users was associated with the variation in the general availability of water, availability over time and farm location respective to the head canal.

Keywords: Robit; Small scale irrigation; Water delivery performance users' satisfaction

Introduction

Background

Rain-fed agriculture has failed to meet the increasing demand for food with in the rapidly growing population. Thus, significant investment in irrigation with improved performance of irrigation schemes is important. Even though irrigation schemes are constructed, large amount of irrigation water is lost because of poor water management, inefficient irrigation systems including the water delivery systems. The water delivery performance in conveying irrigation water of many irrigation schemes are significantly below their potential [1,2]. The shortcomings of low performance include poor design, construction, operation, maintenance, malfunctioning of control structures and weak management [3,4]. This is because; governments pay attention for the construction of new irrigation projects than the operation and maintenance of existing irrigation schemes. Similar to the other parts of the country the Robit irrigation scheme is performing poorly, and giving due consideration for the existing irrigation project and evaluating its performance is therefore, a crucial issue. Significance amount of irrigation water is lost when water is delivered from the source to the irrigation schemes through canal branches. Due to those losses irrigation users may not obtain the required amount of water equitably at the requested time and so that their satisfaction level can be decrease.

The level of dissatisfaction may result in some cases from the lack of awareness on the effect of excess water on crop production. Also dissatisfaction may arise from the unreliability of irrigation water supply to satisfy timely demands of the users. Many researchers conducted studies on water delivery performance evaluation of different irrigation schemes. The authors [5,6] evaluated the water delivery performance of different irrigation schemes using the four water delivery indicators. Tababal [7] was also evaluated the water delivery performance small scale irrigation scheme including the satisfaction level of irrigation users. Majority of the researchers obtained similar results and the performance of the irrigation schemes were found below the intended objectives. Therefore, the present study was aimed to address the water delivery performance of the irrigation scheme and to assess the satisfaction level of irrigation users from the service received [8-10].

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Received 05 June 2020; **Accepted** 11 June 2020; **Published** 18 June 2020

Research Methodology

Robit small-scale irrigation scheme

Robit small-scale irrigation scheme which is located in the dry lowland areas of Kewet Woreda, Ethiopia was constructed during 2012 and gives service 518 irrigation users. Geographically, the study area is located at 9° 57' 21'' latitude and 39° 51' 21'' longitude. It is situated in the Kola Agro Ecologic Zone, where irrigation is common. The initial command area of the small-scale irrigation scheme was 250 ha, currently; it is decreased to194 ha. The purpose of the irrigation scheme was to provide both productive and protective services; during the summer season (January to May), it gives productive service while during the winter season (June to September) it serves as protective service. The irrigation scheme has a main canal, two secondary canals and 13 tertiary canals. As reported in the design document, the flow duty for the command area was 1.14 $ls^{-1}ha^{-1}$ with design discharge of the main and two secondary canals 0.275 m^3s^{-1}, 0.045 m^3s^{-1} and 0.043 m^3s^{-1} respectively. The land holdingsof the farmers vary from 0.15-0.5 ha. The growing crops during the study period were Onion (*Allium cepa*), Maize (*Zea mays) and* Mung bean (*Vigna radiate*). The irrigation users apply the rotational way of water distribution system to irrigate their fields. The irrigation interval followed in the irrigation scheme was constant throughout the crop growing season and each irrigation user received irrigation water after six days. As shown in Figure 1 below, nine tertiary canals receive irrigation water directly from the main canal (Figure 1).

Sampling Techniques

Conducting measurement in all canal branches and each off take is a difficult task; time-consuming and costly. To simplify taking representative samples from the whole canal network was employed. Since the water supply and delivery varies from one part of the scheme to the other, the canal branch of

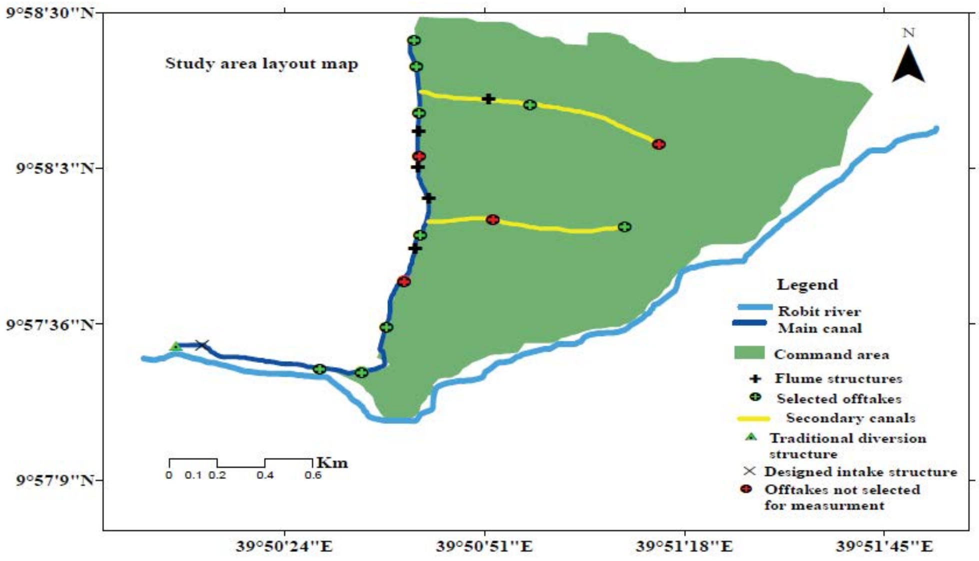

Figure 1: Layout of Robit SSI scheme.

the present study was stratified as head, middle and tail reaches. Nine tertiary off takes three each at the head, middle and tail reaches were selected from the total 13 tertiary off takes, and the selected off takes were symbolized as; L_1- L_9. Offtakes which grow a single crop per tertiary off takes were selected for the present study. The area covered by each crop in the remaining four off takes was not known and thus, estimation of crop water requirement for these off takes was difficult. Therefore, these four off takes were not selected for the present study. The total beneficiaries in the selected command area were 518. The representative sample size was determined using a simplified Equation 1. Finally, the representative respondents were selected randomly.

$$n = \frac{N}{1+N(e)^2} \quad (1)$$

Where: n=Sample size; N=Total irrigation users; e=Level of precision

The level of precision for 95% confidence interval (α=5% 0.05) with degree of variability (P)=50%.

Accordingly;

$$n = \frac{518}{1+518(0.05^2)}, \ n = 225$$

Therefore, to assess the satisfaction of irrigation users from the irrigation service received, questionnaire was collected from 225 irrigation users; 75 each from the head, middle and tail reach users.

Methods of Data Collection

The study was conducted for one irrigation season from April to June 2017. The data needed for the present study were collected from different sources using different data collection mechanisms. Direct field measurement, transect walk, questionnaire, focus group discussion and interview were used to collect the necessary data for the present study. Transect walk was conducted for observing the general condition of the study area and for proper selection of control points. After careful selection of the control points, direct field measurement was carried out to determine delivered flow to each tertiary off takes. Soil samples were also collected using core sampler, to estimate the total available moisture and soil textural class of the study area. The maximum infiltration rate of the soil was determined directly in the field using double ring in filtro meter. Additionally, questionnaires, focus group discussion and interviews were carried out to assess the perceptions of users regarding the irrigation service received and to identify the factors affecting water delivery performance of Robit irrigation scheme. The important secondary data collected for the study were:- crop coefficient (K_C) values for each growth stage for the crops grown in the study area, crop root zone depth, critical moisture depletion, meteorological data, total irrigated area, area irrigated under each off take structure and the total number of beneficiaries. These secondary data were obtained from different sources; from the Kewet Woreda agricultural office, design documents, development agents (DAs), irrigation users, National Meteorological Agency, related journals, and from FAO documents.

Method of data analysis

Discharge measurement: To determine the delivered flow to each tertiary off takes measurements were done fortnightly at nine locations, three each at head, middle and tail. In these tertiary off takes flow depth was measured and this flow depth was used to calculate the delivered amount of water (Q_D) to each fields. At the off take structures, measurement was taken following the irrigation interval during the crop growing season. The amount of crop water requirement (Q_R) for the crops grown in the study area was estimated using CROPWAT software. 3-inch Parshall flume was used to measure the delivered flow in each tertiary off takes. In the Parshall flume the flow depth was measured in the $\frac{2}{3}$ A measured from the crest. The delivered discharge was estimated using Equation 2.

$Q = KH^n$ (2)

Where: Q=Delivered discharge (m^3s^{-1}); H=Upstream flow depth in the converging inlet section (m); K=Free flow coefficient and; n=Free flow exponent

For 3-inch Parshall flume the values of the coefficients K and n are 0.1771 and 1.55 respectively. The validity of the coefficients (free flow coefficient, K and free flow exponent, n) for the study area was examined by measuring the water flow velocity at two control points using Current meter. The locations S1P5 in a first secondary canal and S2P3 on the second secondary canal were selected to cross check the delivered discharge measured using Parshall flume. The results obtained from Parshall flume and current meter for the selected control points were similar. Therefore, the selected values of the coefficient K=0.1771 and n=1.55 for the 3-inch size Parshall flume were correct and further calibration of these coefficients was not necessary. Thus the discharge estimated in each tertiary off takes during the study period was the delivered flow in the tertiary off takes.

Soil sample analysis

The soil textural class of the study area was determined during the study period using the hydrometer method. Six soil samples each at the head, middle and tail reach of the study area were taken using Core samplers of 5 cm height by 5 cm diameter. The soil samples were analyzed in the laboratory using hydrometer method. The total moisture available in the root zone of crops was also determined in the laboratory using the pressure plate apparatus. Moreover, the maximum infiltration rate observed in the soil was estimated in the field using the double ring in filtro meter.

Crop Water Requirement

The water required for different crops grown in the study area was determined by CROPWAT software using Equation 3.The input data for CROPWAT software were; average values of different climatic data, soil texture, crop type, total available moisture (mm/m), maximum basic infiltration rate (mm/day), rooting depth, crop coefficient (Kc) values of each crop for different growth stages, total number of days per growth stage for each crop, depletion fraction and overall irrigation efficiency. To accomplish the study 25 years (1990-2015) climatic data were collected from the National Meteorological Agency. The crop water requirement and the duty of each crop were determined from the CROPWAT Model. The duty of the crops was determined using Equation 3.

$$D = \frac{GIR}{8.64} \quad (3)$$

Where: D=Flow duty ($ls^{-1}ha^{-1}$); GIR=Gross irrigation requirement (mm/day); 8.64=Unit conversion factor

The gross irrigation water requirement considering the entire irrigation system may be expressed as

$$GIR = \frac{NIR}{Ei} \quad (4)$$

Where: GIR= Gross irrigation requirement (mm/day); NIR=Net irrigation requirement (mm/day); Ei=Over all irrigation efficiency (fraction)

The net irrigation requirement was determined using Equation 5.

$$NIR = ET_C - Ref \quad (5)$$

Where: NIR=Net irrigation requirement (mm/day); ET_C=Crop evapotranspiration (mm/day); Ref=Effective rainfall (mm/day)

Finally, the water required (Q_R) for each crop was determined by multiplying the cultivated area of each crop by the duty of each crop as expressed by Equation 6.

$$Q_R = D * A \quad (6)$$

Where: QR=Water required for the crop in each off take structure (ls^{-1}); D=Duty of each crop ($ls^{-1}ha^{-1}$); A=Area covered by each crop and irrigated by each off take (ha)

The estimated values of crop water required (Q_R) and water delivered (Q_D) in the study were expressed in liter per second (ls^{-1}).

Water delivery indicators

To evaluate the water delivery performance of the irrigation scheme, the water delivery indicators; adequacy, efficiency, equity and dependability were used. After estimation of the required discharge and discharge delivered to each tertiary off take, the water delivery performance of the irrigation scheme was evaluated as below.

Adequacy (P_A): For a single off take, Adequacy is the ratio of water delivered (Q_D) to water required (Q_R) in terms of flow rate or volume as expressed by Equation 7. Adequacy may, however, also be determined for an irrigation system as a whole or for a subsystem. In this case, it is aggregated for a service area (R) averaged over a time period of consideration (T).

$$P_A = \frac{1}{T}\sum_T \frac{1}{R}\sum_R \left(\frac{Q_D}{Q_R}\right) \quad (7)$$

If $Q_D < Q_R$ otherwise 1

Where: P_A = Adequacy indicator over an area R and time period T; Q_D = Delivered amount of discharge at each offtake for a specific time period, and; Q_R =Crop water required at a specific point during growing period.

Efficiency (P_F): Efficiency refers to the water conservation property of the irrigation system. The ratio of required to delivered flow $\left(\frac{Q_R}{Q_D}\right)$ indicates the offtake efficiency as expressed in Equation 8.

$$P_F = \frac{1}{T}\sum_T \frac{1}{R}\sum_R \left(\frac{Q_R}{Q_D}\right) \quad (8)$$

Where: P_F = Efficiency indicator over an area R and time period T

Equity (P_E): Equity is the spatial variation of adequacy. It refers to the fairness of water deliveries and reflects the spatial uniformity. The coefficient of variation (C_V) of the ratio of delivered to required flows $\frac{Q_D}{Q_R}$ over a region R and for time period T provides a measure of the fairness of the water distribution over Ras expressed by Equation 9.

$$P_E = \frac{1}{T}\sum_T CV_R\left(\frac{Q_D}{Q_R}\right) \quad (9)$$

Where: P_E=Equity indicator over an area R for a time period T and; CV_R=Spatial coefficient of variation of the ratio $\frac{Q_D}{Q_R}$ over a region R.

Dependability (P_D): Dependability is an indicator for the degree of conformity of water deliveries to prior expectations. It implies the achievement of temporal uniformity of the relative water delivery over a region R as expressed by Equation 10.

$$P_D = \frac{1}{R}\sum_R CV_T\left(\frac{Q_D}{Q_R}\right) \quad (10)$$

Where:

P_D=Dependability indicator over a time period T for a region R and; CV_T=Temporal coefficient of variation of the ratio $\frac{Q_D}{Q_R}$ over time period T.

User satisfaction

To assess the satisfaction of irrigation users,' questionnaire concerning the independent variables affecting satisfaction was prepared. The factors that were expected to have an effect on the satisfaction of the farmer and listed by the farmers were identified. The factors listed by the majority of the farmers, irrigation expert and water committees were; availability of adequate water, water availability in time, farm location from canal head, farm size and schooling years. The data collected from the questionnaire was uploaded to STATA software. The important outputs of the STATA software were the P-value, Logit regression coefficient and probability of chi square (X^2). In order to check whether the explanatory variables have real association with the dependent variable, the explanatory variables were regressed in the Logit model both in bi-variant and multi-variant cases. In the bi-variant, the dependent variable was regressed with the one independent variable. While in multi-variant case all the independent variables were regressed at the same time with the dependent variable. If there is an association between the variables, the P value would be least less than 10%. In addition to this, the probability chi square (X^2) value would be below 0.05. Therefore, the present study was done considering these conditions.

Results and Discussion

Determination of required and delivered flow

The required amount of discharge (Q_R) and the discharge delivered (Q_D) to each farmer's field was estimated both temporally and spatially. The spatial, temporal and reach wise variations of the required and delivered flow for the study area during the study period are given in Table 1 (Table 1). The spatial averaged value of the required discharge for the month of May was higher than the delivered discharge. During April and June, the spatial averaged required flow values were lower than the average values of delivered flow. The discharge requirement of each field was low during the first month, because, at the initial stage crops require small depth of water frequently. Similarly, during June some farmer's fields were reached at their late season stage and they need small amount of water. But during May, crops were mostly at the mid growth stage; greater discharge with larger irrigation interval was required.

The temporal variation of the required and delivered flow at different locations for the crop duration is given in Table1. The required and delivered flow of the nine off takes varied from month to month, from 0.97 to 18.33 $ls^{-1}$and from 1.15 to 20.49 ls^{-1} respectively. In the first four tertiary off takes the delivered flow were higher than the required flow. In the remaining five tertiary off takes, the required flow was higher than the delivered flow. This is because the first

Table 1. Estimated values of required (Q_R) and delivered flow (Q_D).

Reach location	Months	April		May		June		Temporal mean of Q_R (ls^{-1})	Temporal mean of Q_D (ls^{-1})
		Q_R	Q_D	Q_R	Q_D	Q_R	Q_D		
Head	L1	0.87	1.21	0.96	0.77	1.07	1.46	0.97	1.15
	L2	4.05	5.01	9.27	8.10	9.18	11.41	7.50	8.17
	L3	3.23	4.49	16.66	13.87	20.23	28.83	13.37	15.73
	Mean	2.72	3.57	8.96	7.58	10.16	13.90	7.28	8.35
Middle	L4	9.90	12.42	22.66	18.77	22.44	30.28	18.33	20.49
	L5	7.23	6.41	8.00	6.42	8.88	10.34	8.04	7.72
	L6	6.07	5.52	6.72	5.80	7.46	7.06	6.75	6.13
	Mean	7.73	8.12	12.46	10.33	12.93	15.89	11.04	11.45
Tail	L7	2.38	1.86	12.25	8.42	14.88	14.01	9.84	8.10
	L8	5.78	4.80	6.40	4.62	7.10	6.62	6.43	5.35
	L9	6.98	5.39	15.97	10.01	15.81	12.96	12.92	9.45
	Mean	5.05	4.02	11.54	7.68	12.60	11.20	9.73	7.63
Spatial mean		5.17	5.23	10.99	8.53	11.89	13.66	9.35	9.14

four tertiary off takes are located near to the water source and they abstract water easily as compared to the remaining five tertiary off takes. The variation of crop water requirement and the delivered discharge in the head, middle and tail reaches are all given in Table 1. The reach wise required discharge of the study area was higher than the delivered discharge at the middle and tail reaches. At the head reach, irrigation users were supplied with more than the required crop water demand. This may be, due to the difference in area coverage under each off take and the difference in crop water need between different crops. In general, in the study area, the overall mean required and delivered discharge values were 9.35 $ls^{-1}$and 9.14 ls^{-1}. Therefore, the overall mean delivered flow was slightly lower than the overall mean required flow. As reported in the design document, the design flow rate for each tertiary off take structure was higher than the currently delivered flow. This might be, due to the failure of the intake structure, canal sedimentation problem and lack of regular maintenance works.

Water Delivery Performance Indicators

Adequacy (PA)

The temporal adequacy of the study area varied from 0.74 to 0.96 in the nine off takes. As shown in Figure 2 below, temporal adequacy values were low at tail the end off takes while the higher values were at head and middle reach off takes. According to Molden and Gates [1] standards, the tail reach off take location L9 which has an adequacy value of 0.74 is categorized under poor condition and the locations L7 and L8 are grouped under fair performance conditions. Adequacy for the remaining six off takes located at the head and middle reaches were found in a good performance condition. The water delivered to the tail end tertiary off takes was lower than the required one. Consequently, the adequacy value was low at these off takes. The reverse was true, for the tertiary off take locations, L1, L2, L3 and L4 (Figure 2).

The reach wise adequacy values are presented in Figure 2 and the values were 0.95, 0.92, and 0.79 for the head, middle and tail reaches respectively. Therefore, average level of adequacy was good in the head and middle reaches but poor in the tail reach. The major problems for the poor level of adequacy in the tail reach were inequitable water distribution due to weak management of the WUAs, absence of water regulating structures, malfunctioned water control structures at the head and middle reaches. Hence, the irrigation users located at the head and middle reach abstracted more of the delivered flow and below the crop demand was supplied to the tail reach off takes.

The estimated spatial average values of adequacy for April, May and June months were 0.91, 0.78 and 0.96, respectively and the variation is presented in Figure 3. The amount of water delivered during May in each off take was lower as compared to April and June. The reason for the lower water deliverance during May was increase in crop water requirements and low flow in the river. While during June, discharged water from each off take was acceptable. Even

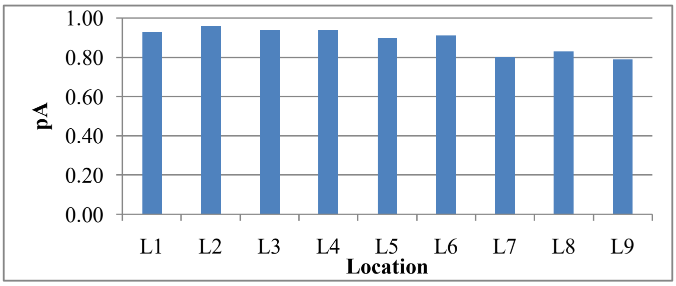

Figure 2. Average temporal adequacy of selected offtakes.

though there was no rainfall during the first two weeks of June in the study area, the river flow increased due to the incoming runoff from upstream catchments. In addition to this, it was harvest time for Mung bean (*Vigna radiate*) crop; and therefore, the water demand for this crop was minimal. As a result, Adequacy was in the acceptable range in April and June but poor in May. The overall adequacy level of the scheme was rated as fair with a mean value of 0.88 (Figures 3 and 4).

Efficiency (PF)

The temporal efficiency of the nine off takes varied from 0.81 to 1.0. Efficiency was lower at the head end off takes especially at locations L1 and L3, with respective values of 0.82 and 0.81, while high at all middle and tail end off takes. The variation of the temporal average values of efficiency for different locations is shown in Figure 4. According to Molden and Gates [1] standards, locations L1 and L3 were grouped under fair efficiency level, while the remaining offtakes were found under good performance level. The irrigation users located at the head end abstracted more water and used the supplied water less efficiently. But farmers located at tail end off takes received irrigation water below their demand and used the supplied water efficiently.

The reach wise variation in efficiency value sat the head, middle and tail reaches is shown in Figure 5 and the values were 0.83, 0.93 and 1.0 respectively. The irrigation water users located at head reach were grouped under fair performance condition, and the users located at middle and tail reaches were grouped under good performance condition (Figure 5).

The spatial variation in efficiency values during the crop season is shown in Figure 6. The average efficiency values observed during April, May and June were 0.89, 1 and 0.87 respectively. Since all the crops found in the nine off takes require more water during May month, there was high computation in water consumption for their plot of land. Thus the supplied irrigation water was used more efficiently than the April and June months. According to Molden and Gates [1] standards, the overall and the monthly performance level was found in good performance level (Figures 6 and 7).

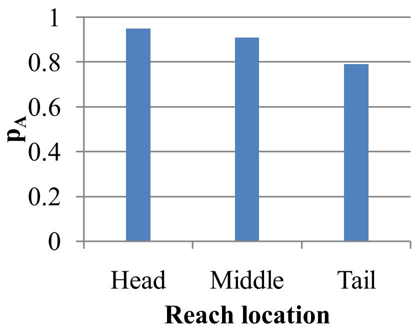

Figure 3. Reach wise average temporal adequacy.

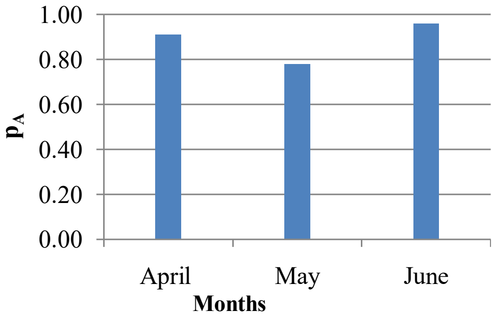

Figure 4. Average spatial adequacy values.

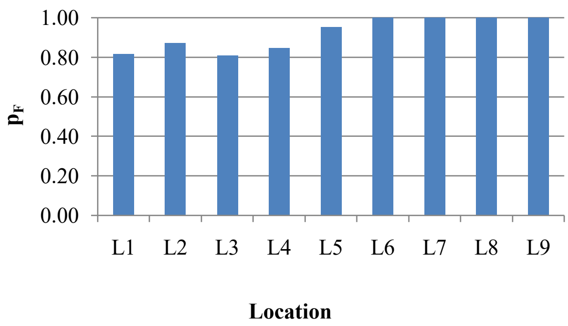

Figure 5. Temporal average efficiency at different locations.

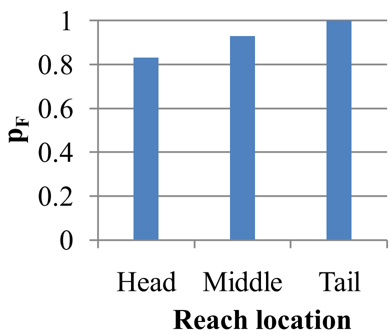

Figure 6. Reach wise average efficiency.

Equity (PE)

Equity indicator as given by Equation 7 was estimated for the nine selected tertiary offtakes during April, May and June months. The spatial coefficient of variation in equitable water distribution during April, May and June was 0.11, 0.11 and 0.06 respectively. The water stress was less during June month. Hence, variation in proportional share of water in the nine off takes was small during June. According to Molden and Gates [1], equitable share of water in the nine tertiary off takes was fair during April and May, but good in June. The overall average spatial coefficient of variation of the study area was 0.09 and it was grouped under good performance conditions in sharing irrigation water in the tertiary off takes during the study period (Figure 8).

Dependability (PD)

The temporal coefficient of variation for different off takes is shown in Figure 8. The estimated values varied from 0.05 to 0.16. The minimum and the maximum values were observed at locations L6 and L7 respectively. The delivered flow highly varied from one month to another month at location L7, while at location L6 temporal variation was low during April, May and June. As per Molden and Gates [1], locations L2, L3 and L6 were categorized under good performance in reliability of the delivered flow. The remaining tertiary off takes were found under fair performance condition. The assigned water committee locally called them "YewuhaAbat" in the three lactations (L2, L3 and L6) was follow up the timely water distribution in each field effectively. Thus the temporal coefficient of variation in these locations was minimal. The overall temporal coefficient of variation for the nine off takes was equal to 0.11. This indicates the irrigation scheme was under a fair performance condition with respect to reliability of water delivery (Figure 9 and Table 2).

Generally, the water delivery performance of Robit irrigation scheme was fair in delivering adequate amount of irrigation water and in its dependability with their time of expectation. However, it was found under good condition in the water conservation properties of tertiary off takes and their equitable distribution to all users.

Evaluation of Users Satisfaction

The five determinant explanatory variables selected to estimate the satisfaction of users were: i) availability of adequate water (X_1), ii) water availability at time (X_2), iii) farm location from canal head (X_3), iv) farm size (X_4) and v) farmer schooling years (X_5). The Logit model works for three significance levels: 1%, 5% and 10%. The explanatory variables have a very strong effect, strong significant effect and weak significance effect depending

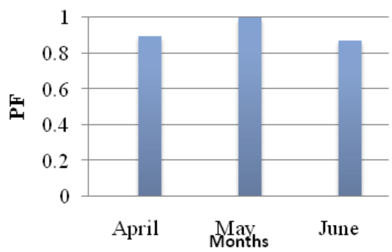

Figure 7. Time wise spatial average efficiency.

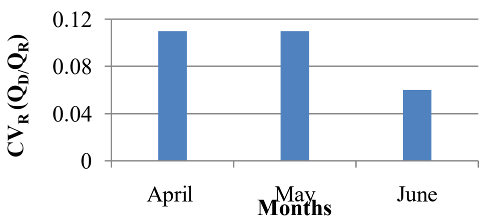

Figure 8. Equity (P_E) during three months.

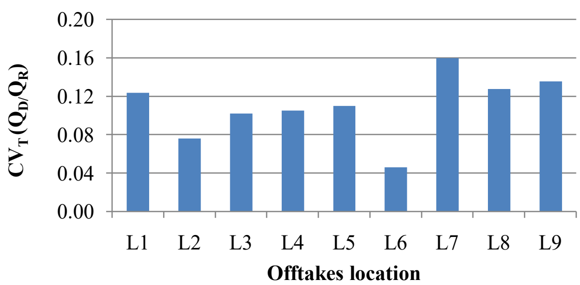

Figure 9. Temporal coefficient of variation (CV_T).

Table 2. Overall performance level of delivery indicators.

Indicators	Performance values	Performance level
Adequacy	0.88	Fair
Efficiency	0.92	Good
Equity	0.09	Good
Dependability	0.11	Fair

Table 3. Parameter estimates of Logit model for middle reach users.

	Head		Middle		Tail		Entire system	
Indep. variables	Coefficient β	P values	Coefficient β	P values	Coefficient β	P values	Coefficient β	P-values
X1	3.723	0.000***	0.909	0.106	3.895	0.000***	0.000***	0.000***
X2	0.981	0.156	1.897	0.001***	2.354	0.006***	0.000***	0.000***
X3	-0.920	0.165	-1.053	0.060*	-1.366	0.098*	0.005***	0.005***
X4	-1.435	0.567	-3.295	0.141	1.009	0.644	0.660	0.660
X5	1.083	0.223	0.083	0.25	0.063	0.507	0.058*	0.058*
Constant	-1.047	0.262	-0.733	0.362	-3.682		0.000	0.000

Note: *, *** indicates; weak significant effect and very strong significant effect.

on the P-value; less than 0.01, between 0.01 and 0.05, and 0.05 and 0.1 respectively.

The estimated values of different parameters of Logit model for the head, middle, tail and the entire system are given in Table 3. The availability of adequate water (X_1) had very strong positive association with the satisfaction of head users as the P-value for X_1 was less than 0.01. The model result indicated that, a unit increase in the adequacy of irrigation water increased the satisfaction of irrigation users by 3.723 units. Whereas the effect of the remaining selected explanatory variables (X_2, X_3, X_4 and X_5) on the satisfaction of irrigation users from the service obtained at head reach was not significant.

The satisfaction of irrigation users located in the middle reach was influenced by the explanatory variables water availability in time (X_2) and farm location from the canal head (X_3). However, availability of adequate water (X_1), farm size (X_4) and farmers schooling years (X_5) had no significant effect on the satisfaction of middle reach irrigation users. The Logit regression coefficient (values showed that; water availability in time (X_2) and farm location from canal head (X_3) had positive and negative effect on users satisfaction respectively. The water availability in time (X_2) had a very strong significant effect on the satisfaction of users (P-value, 0.001 ≤ 0.01). But farm location from the canal head (X_3) had weak significant effect (P-value, 0.05 ≤ 0.06 ≤ 0.1) on the irrigation users' satisfaction. A unit increase in availability of water in time (X_2) increased the satisfaction of users by 1.897 units. On the other hand, a unit increase in farm location from canal head (X_3) decreased users' satisfaction by 1.053 units.

The parameter estimates of the Logit model for the tail reach indicated that availability of adequate water (X_1), water availability in time (X_2) and farm location from the canal head (X_3) were the factors affecting irrigation users' satisfaction. Availability of Adequate water (X_1) and water availability in time (X_2) had a very strong level of significant effect and farm location from the canal head (X_3) had weak significant effect on the satisfaction of irrigation users. The satisfaction of irrigation users increased by 3.895 and 2.354 units with a unit increase in adequate water availability (X_1) and water availability in time (X_2) respectively. However, satisfaction of irrigation users decreased by 1.366 units with a unit increase in farm location from the canal head (X_3). The satisfaction of irrigation users was not influenced by the remaining two parameters (X_4 and X_5).

The satisfaction of irrigation users from the service received was also evaluated for the entire system. The Logit model regression coefficients for availability of adequate water (X_1), water availability in time (X_2) and farmer schooling years (X_5) were 2.31, 1.519 and 0.085, respectively. Therefore, a unit increase in the adequacy (X_1), water availability in time (X_2), and schooling years (X_5) increased the users' satisfaction by 2.31, 1.519 and 0.085 units respectively. But the satisfaction of users decreased by 0.972 units with a unit increase in farm location from the canal head (X_3). The availability of adequate water (X_1), water availability in time (X_2) and farm location (X_3) strongly affected the users' satisfaction. However, farmer schooling years (X_5) had weak levels of significance to the satisfaction of irrigation users. Even though the farm size (X_4) was taken as explanatory variable; its effect on the irrigation users was found insignificant for each reach as well as for the entire system (Table 3).

The estimated values of satisfaction at head, middle, tail reaches; and for the entire irrigation system are given in Table 3 and graphical variation is shown in Figure 10. The satisfaction level of irrigation users was 57.33%, 48%, 42.67% and 49.33% for the head, middle, tail reach and entire irrigation system respectively. The irrigation users situated at the head reach had higher satisfaction (57.33%) from the irrigation service obtained and the tail reach users were less satisfied (42.67%) with the service obtained. This was because the irrigation users located at head reach received more water and timely than the other reaches. As a result, the satisfaction level was higher in the head reach irrigation users. The level of satisfaction for the entire irrigation system was 49.33%. Thus, 50.67% users were dissatisfied with the irrigation services.

The selected explanatory variables of adequacy and dependability for the head, middle and tail reaches were substantiate with the findings evaluated quantitatively. In both cases, Adequacy and dependability were decreased from head to tail reaches. While the explanatory variables farm location from canal head, farm size and farmers schooling years were not interlinked in the study as they are not estimated quantitatively (Figure 10).

Factors Affecting Water Delivery Performance

The water delivery performance of Robit irrigation scheme was not according to the intended objective. During the study period, so many problems were observed. Non-existence of the designed intake structure, inadequate supply of water from the source, over-abstraction of water by the head reach users, poor management of the scheme, mal-functionality of water controlling structures, poor control and distribution of water, stolen tertiary offtake gates, and absence of supportive training concerning water management and irrigation scheduling were the main reasons for the low performance in water delivery of the irrigation scheme. All these problems were observed simultaneously during the data collection period. To divert the irrigation water, an intake with small diversion head work structure was constructed. But it was not given its planned service because it was covered with boulders and sand. Hence, water was diverted in traditional manner using locally available materials (Figure 11); adequate discharge was not diverted with this obstruction, moreover huge amount of sediment and sand particles entered into the main canal. As a result, the supply of water was not adequate to fulfill the demand of all irrigation users and the farmers near the source of water abstracted more water than the downstream users. This indicates that;

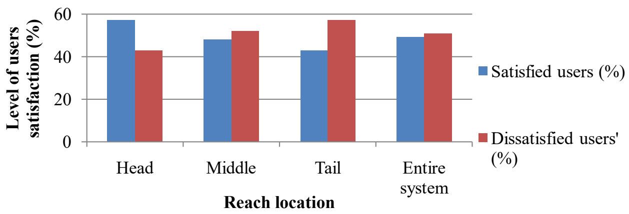

Figure 10. Level of users' satisfaction for Robit irrigation scheme.

(a) (b)

Figure 11. Traditional diversion structure and current condition of the designed intake structure.

the irrigation schedule and distribution of irrigation water was poorly managed. The management in the operation and maintenance of the irrigation scheme was also very weak. Except cleaning of some weeds and sediments in the canal system; regular maintenance, including the maintenance of the damaged controlling structures and protecting leakage and seepage were not carried out. Some of the water distribution and controlling gates were out of function and some of them were stolen. These all problems lead to the performance of the scheme to be below its design.

In order to solve the problems, discussion was held with the water committees and the irrigation users regarding the above issues: the irrigation users agreed to pay 5 birr per irrigation fee to facilitate the operation and maintenance activities; replace the damaged control structures and other maintenance activities. This fee was collected and will be collected in the future by the water committee of each group. To avoid the water abstraction out of the scheduled time, all irrigation users agreed and established bylaws that regulates all users. According to their agreement; if somebody abstracts water out of his or her schedule, he or she was to be punished 100 Birr for the first time, 300 Birr for the second time and 500 Birr if more than three times. This agreement was announced in the local village and was accepted.

Conclusions and Recommendations

Conclusions

I. The overall average irrigation water demand for the selected crops grown in the canal command area as compared to water delivered by the canal was high during month of May but low during June and April. But water delivered by the canal was more than a crop water requirement at head and middle reach and less at tail reach.

II. The water delivery performance of the irrigation scheme (as per Molden and Gates [1]) was found fair in adequacy and dependability, but good in efficiency and equity.

III. The main determinant factors affecting satisfaction of irrigation users were; availability of adequate water, water availability in time, and farm location from the canal head.

IV. The water delivery performance of Robit irrigation scheme was below the intended objectives; this was due to the failure of the small diversion weir and intake structure, canal sedimentation, broken and stolen water control structures, weak management of WUAs and water committees, illegal abstraction of irrigation water out of the planned schedule, absence of established bylaws in the irrigation scheme, and lack of regular maintenance activities.

V. Agreements were reached with the irrigation users; so that problems could be solved with their contribution.

Recommendations

The following recommendations may be drawn based on the finding of the performance evaluation of Robit small-scale irrigation scheme:

I. Supply of irrigation water should be increased by rehabilitating the irrigation scheme. Damaged physical infrastructures of the irrigation scheme should be repaired and maintained. The sediments, leaves and other unnecessary materials deposited in and around the canal system should be cleaned regularly.

II. The farmers in the command area of the irrigation scheme should follow a scientific irrigation schedule determined from the CROPWAT Model for each crop.

III. Formal trainings are necessary to enhance the knowledge of farmers regarding advanced water management techniques, irrigation scheduling, and negative impact of excess water application to the crops.

IV. The assigned water committee and WUA should work sincerely and discharge the responsibilities given by the irrigation users.

V. Appropriate fee collection mechanism should be established and the collected money should be utilized for relevant works in the irrigation scheme.

VI. Due attention should be given for installing irrigation flow control and water flow measuring structures at critical points for the success of fair water distribution and appropriate fee collection.

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How to cite this article: Abrha Ybeyn Gebremedhn and Pratap Singh. Matrix Evaluation of Water Delivery Performance in Robit Small-Scale Irrigation Scheme, Amhara, Ethiopia. *Irrigat Drainage Sys Eng* 9 (2020) doi: 10.37421/idse.2020.9.244