academicJournals

Vol. 9(11), pp. 254-263, November 2017
DOI: 10.5897/IJWREE2017.0728
Article Number: 5F3C45D66439
ISSN 2141-6613

http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Hydraulic performance assessment of Tahtay Tsalit small scale irrigation scheme, Tigray, Ethiopia

Efriem Tariku Kassa[1]* and Mekonen Ayana[2]

[1]Abergelle Agricultural Research Center, P. O. Box 44, Abiy Adi, Tigray, Ethiopia.
[2]Adama Science and Technology University, Institutional Development and Business Vice President, Adama, Ethiopia.

Received 26 May, 2017; Accepted 10 July, 2017

Assessment of irrigation performances is very essential while planning and chalking out management strategies for various irrigation. However, in Ethiopia, especially Tigray, performance evaluation of irrigation schemes is rarely conducted. The performance of Tahtay Tsalit irrigation scheme was not assessed yet and hence, this research was undertaken to assess the hydraulic performance of the irrigation scheme. The study was carried out during the irrigation season from September to November, 2016. The field measurements on canal dimensions, water flow measurements and water surface elevation were undertaken at selected sampling points. Simple descriptive statistics was employed for analysis of the data collected from field measurements and observations. However, hydraulic performance indicators were used to evaluate the performance of this irrigation scheme. Several factors such as flooding, sedimentation, design problems, damage of sluice gates, abstraction of irrigation water by unwanted plants has been identified in this irrigation scheme for mal-functional of different irrigation structures. Hydraulic performance of the irrigation system was evaluated using ten hydraulic performance indicators. There was no problem in irrigation adequacy (0.84 fair), equity (fair), dependability (0.057 good) and efficiency (0.77 fair) of irrigation water in this irrigation scheme. The average water surface elevation ratio, delivery performance ratio, and delivery duration ratio of the main canal during the monitoring period was less than one, greater than 5 and 150%, respectively. The highest sediment accumulation was observed at head and middle reaches of the irrigation scheme than the tail reaches. Generally, in this irrigation scheme there were a number of irrigation structures which had mal-functioned, and now required to be remodeled with sustainable solution to improve the performance of the irrigation scheme. Hence, it has been recommended that capacity building and awareness creation for irrigation water users, water committee, Woreda and Kebelle expertise are the main key factor to bring a change in irrigation water managements.

Key words: Hydraulic structures, hydraulic performance, small scale irrigation scheme.

INTRODUCTION

Ethiopia has abundant rainfall and water resources, its agricultural system does not yet fully benefit from the technologies of water management and irrigation (Awulachew et al., 2010). Since it is already suffering

*Corresponding author. E-mail: ephri32@gmail.com.

from food shortage because of the increasing population and chronic drought occurrence in most part of the eastern and northern part of the country. There is a dire need of utilizing these resources on emergent bases particularly, in those areas where the duration of the growing period is short and the precipitation is erratic.

Hence, improving the performance of irrigation schemes through various interventions is considered a key issue for addressing the need for increased productivity of irrigated lands under pressure on water resources. Though much study has been done in Ethiopia on irrigation performance assessment of schemes focusing mainly on the hydraulic, structural, water service and maintenance issues of the irrigation system (Seid, 2012; Henok, 2014; Dejen et al., 2011, 2012, 2015, 2016; Tebebal and Ayana, 2015) such kind of studies are limited in Tigray, particularly in the area where this study has been done.

The farmers found Tahtay Tsalit (T.Tsalit) irrigation scheme is able to irrigate and harvest crops twice per year. However, due to lack of frequent training for water application, management, operation and maintenance, for the Water users and water committee. Additionally, expertise of Woreda and/or development agent didn't estimated the appropriate crop water requirements and irrigation scheduling. Based on these problems farmers spent more hours per day to watering the irrigate field. Therefore, this study was conducted on hydraulic performance assessment of T.Tsalit small scale irrigation (SSI) scheme using internal performance indicators.

The study provides important information to the system managers, farmers, Woreda expertise, scientific community, funding agency and policy makers for better understanding of how a system can be operated and maintained the irrigation structures. Moreover, policy makers can take this opportunity to benefit other farmers who are not part of this study area.

Study objectives

The objectives of this study were:

i) To assess the hydraulic performance of the irrigation scheme.
ii) To evaluate the physical (area based) sustainability of the irrigation scheme.
iii) To identify the main causes and effect of failed hydraulic structures.

MATERIALS AND METHODS

Description of the study area

Tahtay Tsalit irrigation scheme is a perennial flow river which is located at Kola Tembien Woreda Tabia Adiha, at a specific site called Laelay Skein. It is about 120 and 23 km away from the regional town of Mekelle and Woreda town of Abi Adi, respectively and the catchment size is 130 km^2. Geographically, it is situated at latitude 13.740N, and longitude: 39.087E (Figure 1). The average elevation of the area above mean sea level is 1675 m (Tigray Region Water Resource, Mine and Energy Bureau (TRWRME), 2003). Tahtay Tsalit irrigation scheme was constructed in 2003 till 2005 between Laelay Tsalit and Mychew SSI schemes. It covers about 265 ha of which the irrigation potential is 178.5 ha while the remaining 86.5 ha is unsuitable land for irrigation purpose. The total length of the lined canal was 4.25 km and the unlined canal was about 1.05 km. The total irrigation beneficiaries was 269 household head and out of these 20.82% were female and 79.18% was male (Wereda Kola Tembien Agricultural Rural Development Office, 2016). The main crop type sown in this irrigation scheme include fruit trees such as orange (*Citrus sinensis*), and mango (*Mangifera indica*), vegetables (pepper (*Piper nigrum*)), and cereals (maize (*Zea mays*)).

Data collection and sources

For this assessment the data was collected from primary and secondary sources. The primary data was collected through direct measurement from fields. For example overview of the irrigation structures together with their water control and measurements, discharging through the branch off-take canals, actual water surface elevation in the main canal were measured from the field. Comprehensive field survey such as transect walk was held through the different components of the scheme to understand the irrigation practices, sources of irrigation water, its water distribution system and their cropping patterns. Moreover, discuss with the focused group and key informants was undertaken to identify the root causes and effect of failed irrigation structures.

The secondary data were collected from Tigray Regional Water Resource, Mines and Energy Bureau, Woreda Kola Tembien Water Resource, Mine and Energy office, Woreda Kola Tembien Agricultural Rural Development office and National Meteorological Agency of Ethiopia. Design document of the irrigation scheme, irrigated crops, actual command areas and climate data are major data which were utilized in the study.

Irrigation water delivery measurements (IWD)

In the study, the irrigation water in the canal was measured by calibrated Parshall flume and 90 degree V notch. The flow measurements were taken from nine off-take canals which were located at head, middle and tail reach of the irrigation system. 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 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 (WSE) measurements

The actual water surface elevation (AWSE) data was taken along the main canal. The main canal length was divided proportionally in to three segments for analysis. The left and right side of the irrigation canals, AWSE were measured at interval of 300 m for head and middle and 250 m interval for tail reach. Generally, AWSE data were taken from thirty inspection stations along the main canal and secondary canal on both side of the irrigation scheme and these aggregated into fifteen inspection points.

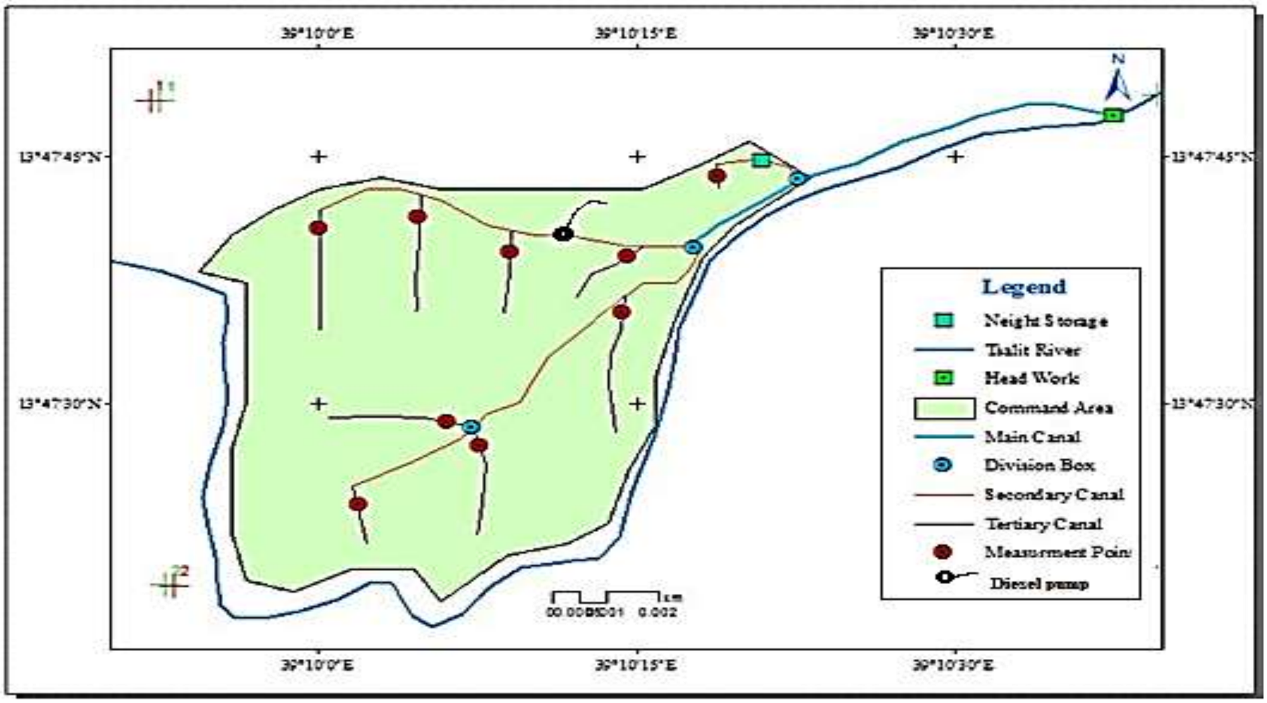

Figure 1. Layout of T.Tsalit SSI scheme.

Measurements of sediment accumulation

Initial depth was measured before cleaning of the canal, while final depth of the canal was taken after cleaning the silt or sedimentation from September 10 to 12, 2016.

Data analysis

Hydraulic performance of the irrigation system was evaluated using ten performance indicators. Performance evaluation using internal indicators contains specifically measuring the extent to which the intended demand required benefits are being achieved. It was investigated based on the data that were collected during September to November, 2016 in one irrigation season. The choice of these months was arranged due to the fact that, in this irrigation scheme most of fields are irrigated. A water delivery performance indicator was designed 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.

Hydraulic performance indicators

Water delivery performances at field level were determined according to the indicators of adequacy, equity, dependability and efficiency. The coefficient of variation (CV) was estimated through the ratio of standard deviation to mean. In estimating these indicators, the values of delivered (Q_D), required (Q_R) and intended (Q_{In}) for irrigation scheme were taken as basic variables. The number of irrigations in one season (T) was taken as the time period; and the number of fields (R) was taken as the sub-region. These indicators have been proposed by (Molden and Gates, 1990). The results where compared with Performance standards.

Maintenance indicators

Maintenance performance assessment of irrigation schemes would provide an insight to the future of maintenance situations. It was estimated through the indicators recommended by Bos (1997), Kloezen et al. (1998) and Bos et al. (2005). Maintenance requirements of the system were evaluated by water surface elevation ratio, delivery performance ratio, delivery duration ratio and effectiveness of the infrastructures.

Physical sustainability (Area based) indicators

Sustainability is the performance measure related to upgrading, maintaining, and degrading the environment in the irrigation schemes. Aspects of environmental/physical sustainability that can be affected by irrigation managers and farmer's practices relate primarily to over or under-supply of irrigation water. This leads to negative effect of the irrigation practices that is water logging or salinity. For this study, irrigation ratio and sustainability of irrigated area physical sustainability indicators were used.

RESULTS AND DISCUSSION

Hydraulic performance indicators

There were many different factors that affect irrigation water deliveries in the study area. The community in T.Tsalit SSI scheme both irrigation beneficially and no beneficially use water from Tsalit River, diversion and canals of the irrigation scheme for all water demand purposes particularly in the dry period (Figure 2). As a

Figure 2. Water used for other purpose than irrigation.

Table 1. Average required (Q_R) and delivered (Q_D) discharge on the main canal (m^3 s^{-1}).

Month	T.Tsalit SSI scheme																	
	Head						Middle						Tail					
	Q_{R1}	Q_{D1}	Q_{R2}	Q_{D2}	Q_{R3}	Q_{D3}	Q_{R4}	Q_{D4}	Q_{R5}	Q_{D5}	Q_{R6}	Q_{D6}	Q_{R7}	Q_{D7}	Q_{R8}	Q_{D8}	Q_{R9}	Q_{D9}
Sep	0.14	0.14	0.12	0.10	0.20	0.19	0.19	0.11	0.13	0.12	0.15	0.14	0.11	0.10	0.11	0.10	0.09	0.08
Oct	0.14	0.13	0.12	0.10	0.20	0.16	0.17	0.11	0.13	0.11	0.15	0.13	0.11	0.09	0.11	0.09	0.09	0.09
Nov	0.14	0.12	0.12	0.11	0.20	0.15	0.16	0.11	0.13	0.10	0.15	0.14	0.11	0.09	0.11	0.10	0.09	0.09

Where: Q_{R1}, Q_{R2}, Q_{R3} … Q_{R9} and Q_{D1}, Q_{D2}, Q_{D3} … Q_{D9} required and delivered discharge at 1, 2, 3… 9 of the supply canal incoming across the off -taking canal. N.B: The delivery discharge measurements were taken twice per day and average as the delivery of one day. A total of five days per month was taken.

result, loss of irrigation water from the intended purpose was high in this irrigation scheme.

Based on the investigation, from September to November, 2016 the average values of actual monitored discharge and required in the secondary and branch off-take canals are summarized in Tables 1 and 2, respectively.

Adequacy indicator (P_A)

The adequacy of irrigation water at T.Tsalit irrigation scheme was average temporal value of adequacy are 0.86, 0.80 and 0.87 at head, middle and tail reach of the system, respectively (Table 3). The spatial values of adequacy based on the Table 3 with an average values 0.87, 0.84 and 0.83 in September, October and November, respectively. From these results the spatial and temporal average adequacy of the scheme was 0.84 (fair).

Similar results were obtained by Dejen et al. (2015). The temporal indicators shows that the level of adequacy of water delivery was generally satisfactory at the head and tail reach off-takes, both for 2012 and 2013. However, it was worse at the middle off-takes , which could be explained by the following two factors. First, there was inadequate operation of the night storage reservoir, which causes significant temporal water level fluctuation in the outlet canal from which middle off-takes were supplied. Secondly, off-takes in the middle reach except for one lateral have over flow structures, while the water level regulators were under flow, which makes these off-takes hyper-proportional. Hence any hydrodynamic perturbation in the parent canal generates relatively larger changes in flow of these off-takes.

Equity

Based on the Table 3, equity of water distribution in T.Tsalit SSI scheme at September was fair whereas in the October and November irrigation time equity was good. This is because the irrigation canal in these months were completely cleaned. The water committee as well as the sub leaders started proper function or control the irrigation canal based on the irrigation scheduled.

Dependability

The average dependability values at the head, middle and tail reach of a system is ranging from 0.03 to 0.08 with an overall average dependability of 0.057 (Table 3). Generally, the dependability value of T.Tsalit irrigation scheme lay within the range of 0 - 0.1 (good). When compare on each reaches the tail reach was good reliable than the middle and head. This result shows that, the commitment or agreement of the water committee

Table 2. Average delivered and required discharge in the branch off-take canals ($m^3 s^{-1}$).

Reach / Month	Head						Middle						Tail					
	Q_{R1}	Q_{D1}	Q_{R2}	Q_{D2}	Q_{R3}	Q_{D3}	Q_{R4}	Q_{D4}	Q_{R5}	Q_{D5}	Q_{R6}	Q_{D6}	Q_{R7}	Q_{D7}	Q_{R8}	Q_{D8}	Q_{R9}	Q_{D9}
Sep	0.009	0.015	0.009	0.016	0.01	0.014	0.006	0.008	0.006	0.008	0.004	0.009	0.006	0.008	0.007	0.009	0.006	0.006
Oct	0.009	0.015	0.009	0.014	0.01	0.016	0.006	0.008	0.006	0.009	0.004	0.009	0.006	0.009	0.007	0.008	0.006	0.006
Nov	0.009	0.015	0.009	0.013	0.009	0.015	0.006	0.008	0.006	0.008	0.004	0.009	0.006	0.008	0.007	0.008	0.006	0.007

Where: Q_D and Q_R is the delivered and required discharge in the branch off-take canals and in branch off-take of R_1 till R_9 respectively.

Table 3. Average adequacy of water distribution, dependability of water supplied and equity of water distribution on the system.

Month	Head			Middle			Tail			Spatial Average (P_A)	STDEV	CV_R (P_E)
	R1	R2	R3	R4	R5	R6	R7	R8	R9			
Sep	0.96	0.84	0.96	0.56	0.95	0.91	0.85	0.9	0.86	**0.87**	0.12	**0.14**
Oct	0.88	0.83	0.84	0.65	0.89	0.88	0.83	0.86	0.91	**0.84**	0.08	**0.09**
Nov	0.8	0.87	0.75	0.67	0.83	0.89	0.81	0.87	0.94	**0.83**	0.08	**0.1**
Average (Temporal)	0.88	0.85	0.85	0.63	0.89	0.9	0.83	0.88	0.9	0.84		
Average Reach (P_A)		**0.86**			**0.8**			**0.87**		**0.84**		
STDEV	0.08	0.02	0.11	0.06	0.06	0.02	0.02	0.02	0.04	0.02		
CV_T (P_D)	0.09	0.02	0.12	0.09	0.07	0.02	0.03	0.03	0.04			
Ave.CV_T (P_D)		**0.08**			**0.06**			**0.03**		**0.057**		**0.11**

with their irrigation water users (IWUs) to distribute irrigation water was proportional and the communication between them was very stronger.

Gorantiwar and Smout (2005) explained that farmers may be happier with a water delivery system in the irrigation scheme that delivers an inadequate supply which is reliable, than with the adequate supply which is not reliable. If the farmers are sure that the deliveries are according to the schedule communicated to them, they can plan their activities accordingly resulting in higher productivity.

Efficiency

For T.Tsalit irrigation scheme the spatial and temporal average values of irrigation efficiency (P_F) are illustrated in Table 4. The temporal irrigation efficiency was poor at the head in all months; however, good and fair temporally at the tail and middle of the irrigation scheme. This problem was happened due to uncontrolled delivery of water in the first, second and third branch canals. The spatial irrigation efficiency of T.Tsalit SSI scheme was under fair at all months 0.77, 0.78 and 0.77 during September, October and November, respectively.

Generally, similar results were found from different sites; for example, Dejen (2015) aggregated all monthly efficiency indicators values concern the tendency of the whole system to save water for the downstream off-takes. Moreover, Tebebal and Ayana (2015) found similar results at the middle and tail reach of the system over the observation period; while the efficiency of water supplied in the head reach was poor. This problem was transpired due to uncontrolled delivery of water in the first branch canal.

Maintenance indicators

Maintenance performance inspection of irrigation scheme would provide an insight to the feature of maintenance situations. According to Mateos et al. (2002) objectives of maintenance indicators are to keep the system in proper operating conditions, to maximize the life of the system's

Table 4. Average spatial and temporal irrigation efficiency.

Month	Head			Middle			Tail			Spatial Av. P_F
	R1	R2	R3	R4	R5	R6	R7	R8	R9	
Sep	0.61	0.57	0.68	0.78	0.73	1	0.82	0.8	0.94	**0.77**
Oct	0.6	0.67	0.61	0.8	0.68	1	0.75	0.88	0.99	**0.78**
Nov	0.61	0.68	0.61	0.78	0.71	1	0.8	0.91	0.86	**0.77**
Average P_F	0.61	0.64	0.63	0.79	0.71	1	0.79	0.86	0.93	
Temporal Av. P_F		**0.63**			**0.83**			**0.86**		**0.77**

Table 5. Water surface elevation ratio (WSER).

Linear distance (m)	Head				Linear distance (m)	Middle				Linear distance (m)	Tail				Overall	
	IWSE (m)	AWSE (m)	DEV. WSE	WSER		IWSE (m)	AWSE (m)	DEV. WSE	WSER		IWSE (m)	AWSE (m)	DEV. WSE	WSER	DEV. WSE	WSER
20	0.8	0.65	0.15	0.81	2020	0.6	0.59	0.01	0.98	4020	0.4	0.31	0.09	0.78		
420	0.8	0.72	0.08	0.9	2420	0.6	0.51	0.09	0.85	4420	0.4	0.36	0.04	0.90		
820	0.75	0.63	0.12	0.84	2820	0.55	0.51	0.04	0.93	4820	0.4	0.36	0.04	0.90		
1220	0.75	0.62	0.13	0.83	3220	0.55	0.53	0.02	0.96	5220	0.4	0.39	0.01	0.98		
1620	0.75	0.69	0.06	0.92	3620	0.55	0.48	0.07	0.87	5300	0.4	0.35	0.05	0.88		
Average		0.66	0.11	0.86			0.52	0.05	0.92			0.35	0.05	0.89	**0.07**	**0.89**
Maximum		0.72	0.15	0.92			0.59	0.09	0.98			0.39	0.09	0.98		

Linear distance is the distance from the intake canal to the monitoring station, DES.WSE = deviation of water surface elevation, DEV.ESE = IWSE – AWSE, and WSER = water surface elevation ratio. N.B: The result was based on average level measurement of water depth at FSL in various main canal sections and the linear distance was the distance from the intake of the irrigation canal.

facilities, and to prevent interruptions in water deliveries. Therefore, maintenance study helps to reflect the management performance of an irrigation schemes.

Water surface elevation ratio (WSER)

The results of WSER are given in Table 5. It was derived from the average value of the ratio of water surface elevation in the prescribed monitoring locations on head, middle and tail reach of the main canal and represents the average WSE below the full surface level (FSL) of the main canal as per the design document. The intended water depth of the main canal from the canal bottom was 0.8 m at FSL with design discharge of 2.3 $m^3 s^{-1}$.

The current average water surface elevation at FSL were 0.66 m, 0.52 m and 0.35 m at the head, middle and tail reach, respectively. The overall average of WSER was 0.89; this shows a seven percent of WSE at FSL was reduced from the intended water depth of the main canal (Table 5). The average WSER of the main canal during the monitoring period was generally less than one, thus the main canal was ineffective by weed and sedimentation problems. Similar result was found by Tebebal and Ayana (2015). The overall average WSER was found to be 0.91. From their estimation, about seven percent of WSE at FSL was reduced from the intended water depth of the main canal.

Delivery performance ratio (DPR)

The delivery performance ratio of irrigation scheme was illustrated in Table 6. The head

Table 6. Delivery performance ratio of canal reach.

Month	Head			Middle			Tail			Spatial average
	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	
Sep	0.05	0.04	0.05	0.07	0.05	0.05	0.05	0.06	0.07	**0.06**
Oct	0.05	0.08	0.04	0.07	0.05	0.04	0.05	0.06	0.07	**0.06**
Nov	0.04	0.04	0.39	0.07	0.05	0.05	0.05	0.06	0.07	**0.09**
Average (Temp)	0.05	0.06	0.16	0.07	0.05	0.05	0.05	0.06	0.07	
Average		**0.09**			**0.06**			**0.06**		**0.07**

R_1 till R_9 represents samples of off-take canals from which discharge measurements were taken.

Figure 3. Mal-functioned hydraulic structures.

reach of the hydraulic structures DPR was estimated to be 0.09 which is greater than 5%, which needs maintenance and this also agrees with the field observation (Figure 3) and response from the focus group discussions. Part of diversion nearest to the inlet of the main canal was damaged and two sluice gates were flushed by flood during 2011.

The result at head reach was greater than middle and tail which have the same value 0.06 for each reach, this show the head reach of the canals was affected by siltation of the irrigation canals and scouring the downstream of the diversion. Tahtay Tsalit SSI scheme need more maintenance in November than the remained months (September and October).

Delivery duration ratio (DDR)

The value of delivery duration ratio for T.Tsalit SSI scheme as per the design document, the intended duration of water delivery was 16 hours per day. However, because of the expanding of the irrigated land, silting up of the canal systems, mal-functioning of control structures, inappropriate watering of main and secondary canals and shortage of water; mainly for tail end beneficiaries, actual duration of water delivery was increased to 24 h per day. Therefore, DDR for this irrigation scheme is 150%; showing the water distribution system was not dependable and the system maintenance also insufficient. Tebebal and Ayana (2015) at Hara irrigation scheme similarly demonstrated that the water distribution system was not dependable (133.33%) and the system maintenance was also insufficient.

Effectiveness of infrastructure

In Tahtay Tsalit irrigation scheme both the spill way sluice gates at the weir nor the flow control gates at the off-take were functional and hence, are not effective yet. On the other hand, no failure was observed at the main and branch canals. Beyond the mal-functionality of sluice gates, off-takes and other hydraulic structures were also mal-functioned (Table 7).

Based on the design document, the total number of structures that were constructed in T.Tsalit SSI scheme i.e. diversion, intake gate, spillway gate and other irrigation structures built on the main and branch canals were 155, however only 94 structures are currently functional (Table 7). The values of effectiveness of infrastructures was estimated to be 60.65%. This value suggests that the maintenance activity of the system was poor. Similar results and expression given by Tebebal and Ayana, (2015) in Hare irrigation scheme, SNNPR, Ethiopia from 113 constructed irrigation structures only 18 structures were functional and its position was 15.9%.

Table 7. Functional and mal-functioned irrigation structures.

		T. Tsalit SSI scheme			
S/N	Infrastructures	Functional	Mal-functioned	Total No. of infrastructure	Effectiveness of infrastructure (%)
1	Spill way gate	0	3	3	0
2	Drop structures	45	3	48	93.8
4	Diversion box	3	2	5	60.0
5	Off-take	46	7	53	86.8
6	Sluice gate at the off-take	0	46	46	0
	Total	94	61	155	48.11
	Position (%)	**60.65**	39.35		

Table 8. Environmental sustainability of irrigation scheme (WKTARD, 2016).

SSIS	Irrigable area (ha)	Design capacity (ha)	Irrigated land (ha)	IR	SIA
T.Tsalit	178.5	149.5	161.75	**0.91**	**1.08**

Physical (area based) sustainability indicators

Based on the focus group discussion the physical sustainability of irrigation scheme could be affected by IWUs and irrigation managers. This was related primarily to over or under supply of irrigation water leading to mal-functioning of the hydraulic structures, water logging or salinity.

Irrigation ratio (IR)

In Tahtay Tsalit irrigation scheme from the total irrigable land about 91% was irrigated (Table 8). This is because the irrigation scheme was constructed in 2003 and has relatively the required irrigation infrastructures. Eventhough, it was to expand beyond this value, but shortage of irrigation water was the limiting factor not to irrigate the potentially irrigable land. Moreover, there is no irrigation water fee that promotes farmers to use the irrigation water efficiently so as to increase the irrigable land in the scheme.

Dejen et al. (2012) have similar reasons for the greater irrigation ratio found at Golgota which could be explained by three factors; these are, generous water availability, absence of irrigation water fee and better land productivity encouraging farmers to invest on more areas.

Sustainability of Irrigated Area (SIA)

According to the estimated value of SIA for this irrigation scheme has sustainable irrigated land (Table 8) which can be explained by the expansion of irrigated area from what has been designed initially. Nearly similar result and reasons found in Dejen et al. (2012) that, for Golgota scheme with a value of 1.22; the irrigated area has expanded by about 20% since commissioning. The same reason applies for irrigation ratio. These factors encourage more farmers to come to the area and irrigate lands by leasing or renting from local land owners.

Causes and effect of failed hydraulic structures

The main causes of failure of the hydraulic structures in T.Tsalit SSI scheme could be attributed to the occurrence of high flooding in 2011. During that time a number of sluice gates were damaged by the flood and also more amount of sedimentation entered in to the irrigable lands. After the damage, maintenance was being done routinely using temporary materials such as sand bag, mud and stone to the structures and this further adds siltation to the canals.

Based on the filed observation and focus group discussion; the failure of some irrigation structures was observed to be design problem (Figure 4c). For example, due to the high slope difference between the constructed off-takes and irrigable farm lands (the variation of the off-take and the irrigable land was averagely about 0.5m). As a result, farmers didn't use this irrigation off-takes as it could erode their farm land and hence, use other alternative off-take faraway from their farm land. This leads into soil erosion, siltation, seepage, deep percolation and mal-functioning of the irrigation structures.

Improper operation and maintenance of canals which was strengthened by poor awareness on water users and water committee were also mentioned as problems, and leads into illegal manipulation of canals and structures.

Figure 4. Main causes of hydraulic structure mal-functioning of T.Tsalit SSI scheme.

Table 9. Sediment deposition of T.Tsalit SSI scheme.

Reach	Sample	Sedimentation (m^3 per 5 m)
Head	S1	1.214
	S2	0.965
Middle	S3	0.931
	S4	0.850
Tail canals on the left side	S5	0.701
	S6	0.483
	S7	0.268
Tail canals on the right side	S8	0.525
	S9	0.532
	S10	0.406
	Average	**0.687**

Due to the stealing of flow control gates from the off-take irrigation canals farmers were forced to use soil and wooden logs (Figure 4a) to control flows of water and this creates siltation problem mainly at the canals. The tertiary unlined canals which were constructed by the individual farmers has a problem in its dimension (very wide) which creates an opportunity of water loss through percolation, evaporation and even flow to unwanted areas (Figure 4b) and additionally leads soil erosion.

Deforestation, free grazing and non-treating the upper catchments by different soil and water conservation structures due to the existing disagreements between *Hagere Selam* and *Kola Tembien* Woredas were also mentioned as the most important source of siltation in the irrigation scheme.

Apart from the structure mal-functioning factors, there were some unwanted plants.these are *Pterolosium stellatum* (Konteftefe), *Ziziphus spinachristi* (geba), *Acacia sieberiana and Acacia seyal* (Tsaeda cheia and Tselim cheia), *Ficus sur* (Sagla), *Balanites eagyptica* (Meki'a), *Syzygium guinensis* (Li'ham) and *Ficus vasta* (Da'ero) where as the planted trees were *Euphorbia tirucalli* (Knchib), *Eucalyptus camaldunesa* (keyh kelamitos), *Gravilia robusta* (Gravila), Susbanyia, and Lusinya) in the farm land that absorbed the irrigation water and they are agents of the irrigation canal to become cracked.

Sediment deposition in the irrigation canals

From the measurements in this irrigation scheme as illustrated Table 9, the sedimentation in T.Tsalit near head canal (main canals) has more amount of sedimentation than the middle and tail canals, that is, (S_1) 1.214 $\frac{m^3}{5m}$ into (S_4) 0.850 $\frac{m^3}{5m}$ and as the distance increases from the head into the tail canals sedimentation decreased from (S_5) 0.701 $\frac{m^3}{5m}$ to (S_7) 0.268 $\frac{m^3}{5m}$..

Moreover, the sedimentation of the right side canal has more sediment accumulation than the left side canals of the irrigation S_8, S_9, and S_{10}0.525$\frac{m^3}{5m}$, 0.532 $\frac{m^3}{5m}$ and

$0.406\frac{m^3}{5m}$, respectively. Because, there was large amount of cultivation land above the canal and the topographic features are undulating.

Conclusions

Improving irrigation water management through identification of factors that hinder for efficient utilization is compulsory. Several factors such as flooding, sedimentation, cracking, stealing of flow control gates, improper operation and maintenance, abstraction of irrigation water by unwanted plants, deforestation, free grazing, lack of watershed treatment/soil water conservation have been identified in this irrigation scheme. The overall irrigation water delivered performance indicators, adequacy value was fair both spatially and temporally. The overall equity value of the delivery system was fair. Regardless of its fair classification, there was high temporal variability. Dependability was classified as good but, there was spatial variation in the canal reach that is tail reach was good and for the head and middle was fair classification. The estimated delivered performance ratio was greater than 5% which needs maintenance. Delivery duration ratio of this scheme has 150%; showing the water distribution system was not dependable and the system maintenance was insufficient. In T.Tsalit irrigation scheme neither the spillway sluice gates at the weir nor at the flow control gates at the off-take were functional and are not effective yet. Beyond the mal-functionality of sluice gates, a considerable number of off-takes were also mal-functioned. On the other hand, no failures were observed at the main and branch canals. There was high irrigation ratio and sustainability of irrigate area in T.Tsalit. Since, sustainable irrigate land which could be explained by the expansion of irrigated areas in this sites from what has been designed initially. Generally, in this irrigation scheme there were a number of irrigation structures which were mal-functioned due to many different reasons and now needs sustainable solution to improve the performance of the irrigation scheme.

RECOMMENDATIONS

i) Awareness creation and capacity building should be given to local administrations, development agent, irrigation water users and farmers on management of irrigation water and irrigation structures.

ii) There should be integration between *Hagere Selam* and *Kola Tembien* Woredas in the watershed development.

iii) All tertiary off-take flow control gates should be constructed so as to control the discharge of the irrigation water and minimized the sedimentation accumulation of the next off-takes.

iv) There should be water fee by-laws for all the irrigation water users; which will later used for maintenance of failed irrigation structures.

v) Watering procedure should be based on the crop water requirement and irrigation scheduling.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Awulachew S, Erkossa T, Namara R (2010). Irrigation Potential in Ethiopia- Constraints and Opportunities for Enhancing the System, International Water Management Institute.

Bos MG (1997). Performance indicators for irrigation and drainage. Irrigation and Drainage Syst. 11(2):119-137.

Bos MG, Burton MA, Molden DJ (2005). Irrigation and drainage performance assessment practical guidelines. Journal of Centre for Advanced Biomedical Imaging, 22, Wallingford, UK, pp. 28-59.

Dejen ZA (2015). Hydraulic and operational performance of irrigation schemes in view of water saving and sustainability: sugar estates and community managed schemes In Ethiopia: CRC Press/Balkema.

Dejen ZA, Haileslassie A, Sally H, Erkossa T, Schmitter P, Langan S, Hoekstra D (2016). Analysis of water delivery performance of smallholder irrigation schemes in Ethiopia: Diversity and lessons across schemes, typologies and reaches.

Dejen ZA, Schultz B, Hayde L (2012). Comparative irrigation performance assessment in community-managed schemes in Ethiopia. Afr. J. Agric. Res. 7(35):4956-4970.

Dejen ZA, Schultz B, Hayde L (2015). Water Delivery Performance at Metahara Large-Scale Irrigation Scheme, Ethiopia. Irrigation Drainage 64(4):479-490.

Dejen ZA, Schultz B, Hayde LG (2011). Irrigation performance in community-managed schemes: Assessment using comparative indicators and utility analysis. In Proceedings of the ICID 21st International Congress on Irrigation and Drainage, Tehran, Iran 15-23:17-17.

Gorantiwar S, Smout IK (2005). Performance assessment of irrigation water management of heterogeneous irrigation schemes: 1. A framework for evaluation. Irrigation Drainage Syst. 19(1):1-36.

Henok F (2014). Performance Assessment of Diversion Headwork Implemented for Irrigation (Case Study on Fantale Irrigation Based Integrated Development Project). (MSc.), AAU.

Kloezen WH, Kloezen WH, Garces-Restrepo C (1998). Assessing irrigation performance with comparative indicators: the case of the Alto Rio Lerma Irrigation District, Mexico (Vol. 22).IWMI.

Mateos L, Lopez-Cortijo I, Sagardoy JA (2002). SIMIS: the FAO decision support system for irrigation scheme management. Agric. Water Manag. 56(3):193-206.

Molden DJ, Gates TK (1990). Performance measures for evaluation of irrigation-water-delivery systems. J. irrigation drainage eng. 116(6):804-823.

Seid S (2012). Assessment and evaluation of the performance of diversion structure for small scale irrigation. (MSc.), Arbaminch University.

Tebebal M, Ayana M (2015). Hydraulic Performance Evaluation of Hare Community Managed Irrigation Scheme, Southern, Ethiopia.

Tigray Region Water Resource, Mine and Energy Bureau (TRWRME) (2003). Feasibility Study Tahtay Tsalit Diversion scheme (Engineering head work), Irrigation development department.

Wereda Kola Tembien Agricultural Rural Development Office W (2016). Annual Report . Abiy Adi, Tigray, Ethiopia.