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Evaluation of Failures and Design Practices of River Diversion Structures for Irrigation: A Revisit of Two SSI Schemes in Ethiopia

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Abstract: *In this paper, the design practices and failure mechanisms of two small scale irrigation (SSI) schemes (Awushoana and Kecha) in Ethiopia were evaluated. An attempt was made to understand the design problems with respect to hydrologic, hydraulic and structural design aspects. The main constraints that contributed to the malfunctioning of the irrigation system in the schemes associated with planning, institutional, social, operational and economic parameters were also assessed. The main problems observed in Kecha scheme were sedimentation at the headwork, damage of intakes and sluice gates, clogging of intakes, damages of distribution systems and ram body. Whereas accumulation of boulders, structural failures of diversion weir, damages of the intake gates, main canals, and absence of the under sluice were observed in Awushoana scheme. Some of the problems attributed to the institutional, social and operational problems due to lack of adequate community participation, the absence of Water Users Associations (WUA's), proper handing over and lack of training and maintenance, evaluation and monitoring issues. Finally, the rehabilitation measures are suggested for the failed SSI schemes. Therefore, this study will help for the SSI schemes to perform better and efficiently to increase agricultural productivity in the study region as well as other SSI schemes in Ethiopia.*

Keywords: *Evaluation; Design Practices; Failure Mechanism; Hydraulic Ram Pumps; Rehabilitation; SSI*

1. Introduction

Ethiopia has considerable development potentials and its land and water resources are adequate relative to its population (Haile [1]). However, crop production is not enough to fulfill the food requirements of the country and most of the agricultural production is based on rainfed farming (Lambisso [2]). Variable rainfall and frequent drought conditions have adverse effects on rainfed dependent farming, which has negative impacts on Ethiopia's economy (Hagos et al. [3]). It is reported that due to floods, droughts and lack of water infrastructures Ethiopia at risk of chronic food shortage (CARE [4]). One of the best alternatives for achieving food security is expanding irrigation on various scales through river diversion, constructing micro-dams and water harvesting structures etc (Lambisso [2]; Awulachew et al. [5]; Awulachew et al. [6]; Teklay and Ayana [7]).

Enhancing public and private investment in irrigation development has been identified as one of the core strategies to enable sustainable growth and development (MoWR [8]; World Bank [9]; MoFED [10]; Hagos et al. [3]). However, the performance of the large-scale irrigation schemes and its investment has been decreased. Therefore, it is needed to find other ways to improve the productivity and livelihoods of small scale irrigation (SSI) schemes. The SSI schemes have been identified a strategic target to achieve the sustainable food security in the country due to its relatively small investment, easy in construction and operation and maintenance (O&M) (Lambisso [2]). However, some of the schemes are not giving a satisfactory performance and failed to serve the purpose for which they are intended (Lambisso [2]; Fikru [11]). Therefore, Performance of these schemes needs to be analyzed to assess the efficiency of the system (Molden and Sakthivadivel [12]).

The productivity of these schemes fully depends on the hydraulic functioning of intake weirs and main canal structures. However, follow-up of these schemes with regard to technical, social, O&M, water utilization, economic and financial issues have not been well studied in the study area. Therefore in the present study, the main objective was to assess and evaluate the failures and design practices of SSI schemes (i.e. Awushoana and Kecha) which are found in Soroworeda of Hadiya zone, Southern Nations, Nationalities, and Peoples' Region (SNNPR), Ethiopia.

In addition, institutional planning, social, operational and economic problems contributing to the failures of the schemes were also identified and remedial measures are suggested. Eventually, the present study will serve to meet the requirements of the failed schemes with the best rehabilitation works.

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2. Materials and Methodology

2.1 Study area

Awushoana and Kecha SSI schemes are located at Soroworeda in the south-western parts of Hadiya zone in the southern administrative region, Ethiopia. The geographical location of these schemes extends between 7°44'54"N latitude and 37°50'41'E longitude (Fig. 1). The woredas altitudinal variation ranges from 800 m to 2880 m above mean sea level (a.m.s.l). The woreda allocated areas fall into high land, mid highland, and lowland agro-climatic zonation based on altitude and rainfall (Table 1). They have bimodal rainfall condition with annual precipitation ranging from 900 to 1200mm. Generally, the rainfall distribution is fair in highland regions. However, in lowland areas occurrence of erratic rainfall distribution is hard to regulate the ecosystem of certain areas within watersheds (Source [13]).

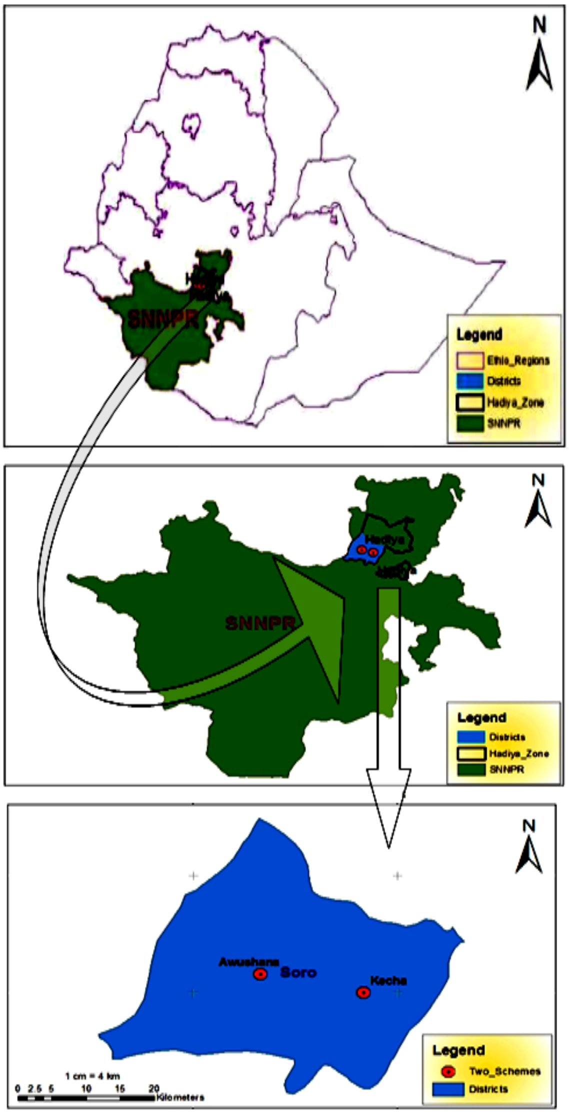

Fig. 1: Geographical location of the study area

The implementation of Awushoana SSI project was started in 1996 and completed in 1998. It is a gravity type irrigation system and diversion weir site is located about 20km from the woreda town Gimbichu and 45km from zone town, Hossaina. The length of the main canal starting from the headwork to the field is about 2 km (i.e. 1.25 km is unlined and 0.75 km is lined canal). The headwork was designed to irrigate 100 ha of land for 125 households (HH) beneficiaries. The main source for this scheme is Awushoana River which is the tributary of Gibe river basin. Fairly level or slightly undulating soil tends to be located mostly in low-lying areas and generally have deep and medium to heavy texture soils. They have also fewer limitations for the cultivation of agricultural crops and generally found easy to irrigate, but have a drainage problem on some parts of sub-catchments. The main drainage pattern that contributes Awushoana River is Sheshacho, Shapa and Unifule streams (Table 2).

The implementation of Kecha SSI scheme was started in 2001 and completed in 2002 by World Vision, Ethiopia (WVE). The diversion weir site is located about 10 km from the woreda town Gimbichu and 40 km from zone town Hossaina. The main source for this scheme is Kecha River which is the tributaries of Gibe river basin. This scheme is a hybrid system possessing both gravity and Hydraulic Ram Pump (HRP) type water delivery mechanism. The soil in the irrigable area is clay loamy and wheat, bean, potato and vegetables (i.e. carrot, onion, garlic, and cabbages) are mostly grown. This scheme is characterized by a combination of civil works like diversion weir and gated intake at the upstream side and supply source and HRP at the downstream side. The HRP operates on the principle of creating pressure surge, water hammer in the drive pipe by the sudden stoppage of water flow (Fig. 2). The gated intake at the upstream side is connected to the supply source at the downstream via 10 cm diameter buried concrete pipe. The supply source and ram body are also fitted through drive pipe which is a very rigid galvanized iron pipe at the drive head difference of 2m. Also, the ram body is fitted to header tank at utilization point through the delivery pipe. The diversion weir and intake structures are constructed at the upstream of HRP displaced about 100 m. There is also concrete pipe connected from the intake structure up to a reservoir which is connected to the ram body by rigid galvanized iron pipe. There are valves and air chambers which are very important for the movement of water in the ram body. The water is moved to field reservoir through the delivery pipe and irrigates the agricultural field. The HRP is designed to irrigate 10 ha of land for 25 HH beneficiaries.

Table 1: *Agro-climatic zonation of Soroworeda, Hadiya zone*

No	Agro-climatic zone classification	Altitude(m)	Areal coverage		Annual rainfall, mm	Daily average temperature, °C
			Km	%		
1	Dega/cool highland	2500-3500	81.34	14	1000-1400	12-18
2	Woyna-dega/warm highland	1500-2500	307.93	53	900-1400	18-25
3	Kolla/lowland	500-1500	191.73	33	900-1000	>25

(Source: [13])

Table 2: *The drainage pattern of Awushoana river catchments*

Main river	Sub-drainage patterns	Estimated area in ha	Bounded kebeles/ridges
Awushoana river	Sheshacho drainage	2900	Meta-bira, Agosha, Balamo,
	Shapa drainage	1000	Jukera, Sibo,
	Umfile drainage	3000	Mesera Jukera Hankota
Total		4200	

(Source: [14])

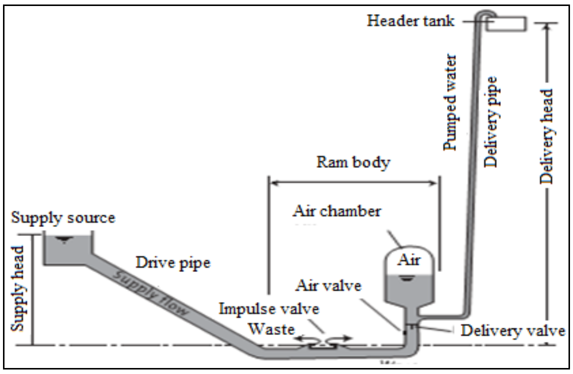

Fig. 2: *Installation of hydraulic ram pump (Watt [15])*

2.3 Data used

The primary data was collected from field observations, users and Key Informant (KI) interviews, Focused Group Discussion (FGD). The different data were collected from the field which includes the functionality of irrigation schemes, structural design, damages of weir components, upstream and downstream condition of the weirs, stability of the river banks, intake conditions, upstream and downstream protection works, carrying capacity, condition of distribution structures, problem of flooding, erosion, siltation of canals, weed growth in the canals, farm irrigation practices and types of crops grown. The photographs of the failed structures were also taken as aiding tools.

Structured questionnaires which are focusing on physical, technical, socioeconomic and institutional problems were used in the interviews. For this study, 40 farmers were interviewed from two schemes. The socio-economic conditions of the community were also obtained through KI discussions at the site level. The FGD based on semi-structured questionnaires with a total of 20 participants were selected from two schemes and divided into 4 groups (2 in each irrigation system) and each group 10 members were involved from the head end, middle and irrigators from the tail end. The KI were conducted to generate an understanding of irrigation systems. In addition, this information was also used for developing more focused questionnaires for HH interviews. The scheduled interview was carried out with 16 KI. The informants were Development Agents (DA's), Peasant Association (PA's), District officials pertinent to irrigation issues and NGO's. Secondary data was collected from various sources (i.e. zonal and district water bureaus, Bureau of Irrigation development and Rural Development, Cooperative, Land management and natural resources). Daily meteorological data (1968-1999) was collected from Hossaina meteorological station.

2.4 Methodology

The problems of SSI such as hydrologic, hydraulic, structural, socioeconomic, planning and institutional aspects, social and operational problems were investigated by reviewing the design documents, field visits and interviewing of the water user's. The current design practices for the irrigation structures were examined and type of problems in each scheme identified. The data generated through HH interview was analyzed using statistical analysis software (i.e. SPSS). The detailed methodology adopted in the present study is presented in Fig. 3.

2.4.1 Review of current design practices of irrigation schemes

Hydrologic analysis: The maximum design discharge was estimated using United States Department of Agriculture (USDA) Natural Resources Conservation Service Curve Number (NRCS-CN) method. This was used to determine the backwater curve results from constructing the weir in order to predict the highest water level for the 50 years return period. The maximum rainfall data was used for the hydrologic analysis to determine the maximum design discharge and checking the consistency of the structures constructed for the design period.

Hydraulic analysis: In general, the hydraulic analysis consists of the estimation of the shape and height of the weir, clear waterway, discharge, and head over the weir, length of the weir, flood and energy level, afflux and scour depth. To design a weir, all external forces acting on it were calculated. The length of the waterway (L) is calculated from Lace's regime formula:

$$L = 4.75\sqrt{Q} \tag{1}$$

Where, L is the length of the waterway in 'm' and Q is the discharge in m^3/s.

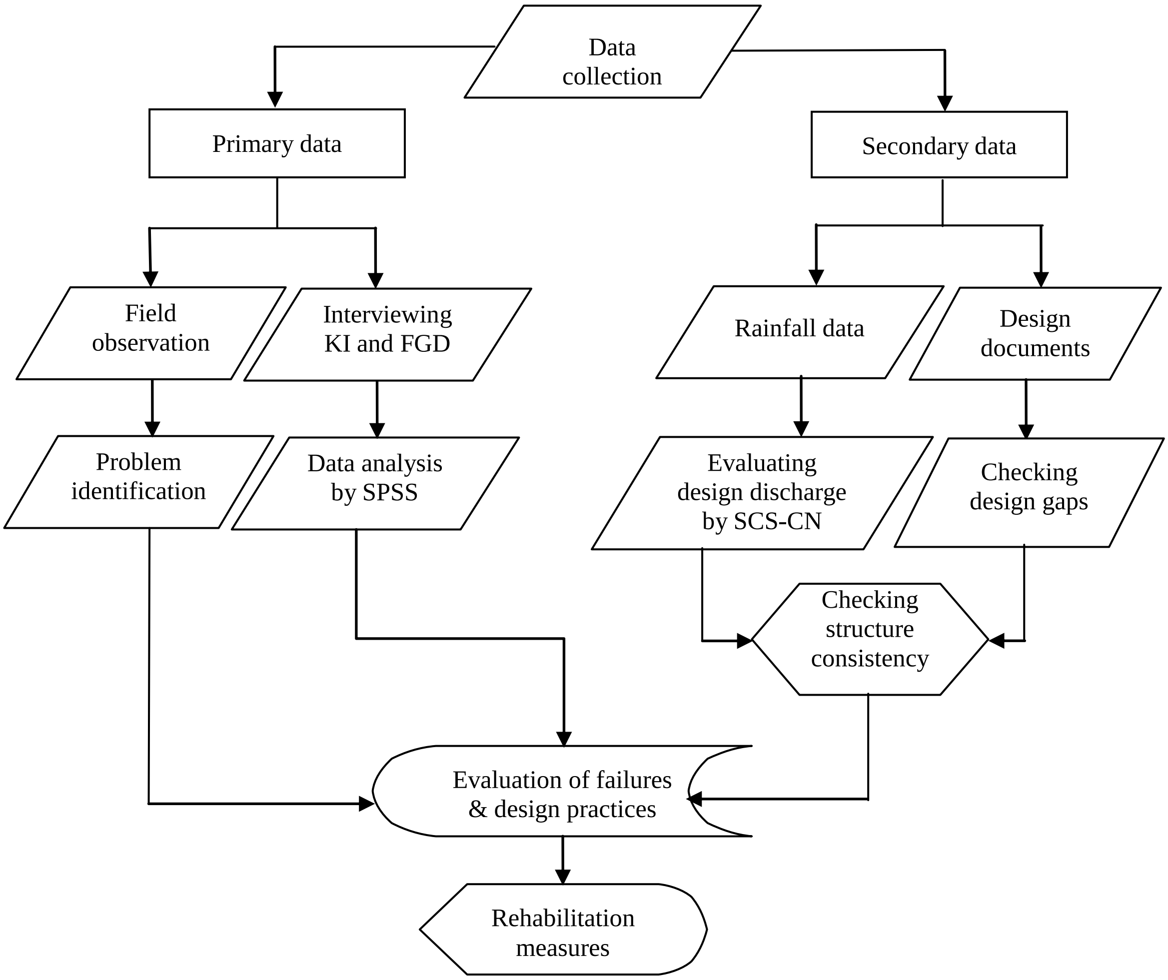

Fig. 3: *The methodology adopted in the present study*

$$q = Q/L \tag{2}$$

Where, q is the discharge per unit width of the river. The regime scours depth (R) is calculated from Laces formula

$$R = 1.35\left(q^2/f\right)^{\frac{1}{3}} \tag{3}$$

Where 'f' is the silt factor

The regime velocity and velocity head are calculated from the expression:

$$V_a = \frac{q}{R} \quad \text{and} \quad h_a = \frac{V^2}{2g} \tag{4}$$

Where, h_a is velocity head, m, and V_a is the approach velocity, m/s

The total energy level (TEL) and high food level (HFL) at upstream (U/s) and downstream (D/s) are given as follows:

D/s TEL=D/s HFL+h_a (5)

U/s TEL= D/s + afflux (6)

U/s HFL=U/s TEL-h_a (7)

Crest level of weir=U/s HFL-h_d (8)

Weir height=crest level- river bed center (9)

Pond level = Full supply level (FSL) of off taking canal + head loss through head regulator (10)

Depth of u/s and d/s sheet piles are fixed based upon the maximum scour depth

Depth of u/s sheet of piles =1.5R (11)

Depth of d/s sheet piles =2R (12)

Where, TEL=total energy level (m); HFL=high flood level (m); h_d=the depth of water above the crest (m).

Structural stability analysis: In general, it includes stability analysis of the guide wall and weir body for both ponded and overflows conditions.

a) Factor of safety against overturning

Overturning failure occurs when the overturning moment exceeds the resisting moment (Aziz [16]). Thus, failure of the weir by overturning is usually preceded by tension failure or crushing failure. Therefore, a weir may be considered safe against overturning if the criterion of no tension at any point in the weir body is satisfied and also the maximum compressive stress does not exceed the allowable limit. To be on the safer side the resisting moment should exceed the overturning moment at least by 100%.

$$F_{OT} = \frac{\sum M_R}{\sum M_{OT}} \geq 2 \qquad (13)$$

Where, F_{OT} = Factor of safety against overturning; M_R= resisting moment; M_{OT} = overturning moment.

b) Factor of safety against sliding

The sliding failure occurs when the weir slides over its base or when part of the weir lying above the horizontal plane slides over that plane. To avoid this failure at any horizontal section or at the base, the weir should be designed so that the sliding forces do not exceed the resisting force.

$$F_S = \frac{\sum V}{\sum H} \geq 1.5 \qquad (14)$$

Where, F_s = Factor of safety against sliding; V = vertical forces; H = horizontal forces,

c) Check for the development of tension failure

The resultant force should pass through the middle third section of the base if not tension cracks develop and worsen the risk of failure by overturning. Masonry sections are very weak in resisting tension stress.

$$e \leq \frac{B}{6} \quad or \quad e = X - \frac{B}{2} \quad or \quad X = \frac{\sum M_n}{\sum V} \qquad (15)$$

Where, M_n= Net amount $(= \sum M_R - \sum M_{OT})$;

e = Eccentricity developed; B = Bottom width, m

3. Results and Discussion

The major problems, design practices, and their rehabilitation works are presented as follows:

3.1 Major Problems

3.1.1 Damage of headwork: The field survey at Awushoana SSI indicates that weir is collapsed due to improper hydrologic, hydraulic analysis and structural design of weirs and inappropriate mortar mix ratio. In addition, use of very poor construction materials was also responsible for damage of headwork.

3.1.2 Hydrologic analysis: The estimation of flood magnitude is an important parameter for the design and analysis of structures to be constructed on the river. In the present study area, the flood estimation was not done accurately using long-term rainfall data. The feasibility study of the project carried out in the year 1996 revealed that annual daily maximum rainfall data from the year 1968 to 1990 (22 years) from Hossaina meteorological station was used. The peak annual discharge was obtained by the designers from the log-Pearson type III distributions and it was found to be $68m^3/s$. However, it may be noted that the long-term rainfall data could be considered to estimate the accurate annual peak design discharge. Therefore, rainfall data of the same station was collected and revised estimates of the peak annual rainfall and peak discharge were estimated using rainfall frequency analysis and curve number (CN) method, respectively.

Due to lack of flow data, it is forced to analyze the peak daily rainfall for the computation of peak discharge. The probability of occurrence of point rainfall was estimated for the recurrence interval of 50 years for diversion weir. Therefore, after the necessary goodness of the fit test was carried out and the peak rainfall (i.e. 75.52mm) was determined using the log-Pearson type III distribution method for the 50 years returns period. For drainage basins, where no runoff has been measured, the curve number method (NRCS-CN) can be used to estimate the depth of direct runoff from a measured rainfall amount over the study area (Brebbia [17]). This method was originally developed by the Soil Conservation Service for the management of water resource in the United States for agricultural development (Mishra et al. [18]). Using this method, the peak discharge was found to be $122.66m^3/s$. However, there is a discharge difference of $54.66m^3/s$ which can destabilize the structure. It is also revealed from the design document of this project that backwater computation was not performed and proper bank protection works were not included.

3.1.3 Geology of the headwork site: Geological information related to the stability, workability, water tightness and bearing capacity of the various foundation materials needed in the design of irrigation system. The field survey revealed that the plain area of the river is covered by an alluvial deposit of boulders and cobbles with sandy soil materials where the foundation of the weir site located. In addition, two sides of the river bank at the upstream and downstream are not stable. Stream deposits at the river center are characterized by high transmissibility and should be completely controlled. This may be caused because the project did not consider the geological condition of the project area.

3.1.4 Upstream flooding: The field study indicates that the siltation of headwork in both of the schemes, and damages of the main canal and weir proper in Awushoana SSI scheme (Fig. 4). The field survey was also revealed that Awushoana river basin having mountainous, undulating to rolling, steep to very steep slopes. This characteristic supplemented with the meandering of river terrain insisted to high runoff which results flooding with silt and sediments deposition at river course. In addition, the main causes of weir failure were found weir site foundation problem and instability of the side banks at the upstream of the weir.

3.1.5 Damage on downstream protection works: There was no proper design of downstream protection works like a downstream impervious apron, cut-off wall, downstream block protection, launching apron and a downstream sheet of piles and their length and thickness were not properly designed. This results in failure of downstream work in the case of Awushoana scheme (Fig. 5). The improper hydraulic design arises from poor knowledge of energy dissipation and impact of sediment on the structure (Baban [19]; Novak et al. [20]). The impervious floor is designed in all cases to reduce surface flow action that causes scouring due to unbalanced pressure in the hydraulic jump tough. The stilling basin is seldom designed to confine the entire length of a free hydraulic jump on the paved apron because such a basin would be too expensive. The main purpose of such control is to shorten the range within which the jump will take place and thus to reduce the size and the cost of stilling basin (Hoffmans and Verheij [21]).

3.1.6 Seepage problem: The problem of seepage through foundation was observed in the headwork site of Awushoana scheme. This is mainly caused due to subsurface flow which comprises of rupture of the floor due to uplift pressure and piping due to exit gradient.

Fig. 4: *Accumulation of boulders upstream of weir of Awushoana*

Fig. 5: *Damages on downstream protection work at Awushoana SSI scheme*

The observations indicate that water is flowing beneath the foundation of the structure results total failure of the scheme. Also, it was found the absence of upstream and downstream sheet piles to control the sub-surface flow which induces failure due to uplift pressure or piping.

3.1.7 Damages in the main canal: In Awushoana, the structures were deteriorated due to a failure of the diversion weir resulting from upstream flooding. Canals are not protected against livestock and are frequently damaged. The result reveals that 42.2% of the selected farmer's perception for the damage of the main canal was due to the collapse of diversion weir and intake structure at the upstream (Table 3). It resulted in the stoppage of the water coming to the field through the main canal and results in complete damage to the main canal and other distribution systems. The poor coordination of maintenance resulted (22.2%) from the absence of properly organized WUA's and follow up their contributions to conduct the O&M work. The study also revealed 17.7% weak enforcement of group-based a rule which was the result of the absence of the WUA's and 15.5% was damage from the livestock (Table 3). As a result, it poses a threat to the safety and sustainability of this scheme. In addition, it was also observed that the main canals were damaged due to the absence of proper cutoff drains at the upstream sides of the main canals.

Table 3: *Perceptions of selected farmers for the failure of the Awushoana scheme*

Sl.No.	Causes of failures	Frequency	%
1	Collapse of diversion weir and intake structure	19	42.2
2	Weak enforcement of group based rules	9	20.0
3	Damaged by livestock	7	15.6
4	Poor coordination of maintenance	10	22.2
	Total	45	100

3.1.8 Failure of HRP: The field survey revealed that the civil works i.e. diversion weir, intake, and sluice gate were constructed in Kecha PA. The different pipes, storage structures, and the ram body were constructed and installed. However, there was no proper monitoring and evaluation of those structures for their sustainability. The problems contributed to the failure of HRP's are as follows:

Sedimentation at headwork: It refers to the overall submergence of the weir proper, wing walls, upstream protection works, and gates due to the settlement of sediment and the bed level rise of the river channel (Lambisso [2]). The clogging of intake by the silt makes the amount of water not to flow into the intake. According to FGD, the amount of water was decreased during the dry period affects the pump functioning and could not work properly. Therefore, sedimentation in the headwork is the major problem for the Kecha SSI scheme. The sediment was found to be completely filled at headwork and, the intake and under sluice gates was totally clogged and jammed. The FGD revealed the provision of adequate training, proper handling, and follow-up of the scheme was not proper and there was no formation of WUA's.

3.1.9 Operation & Maintenance problem: The survey on the O&M of the Awushoana and Kecha SSI schemes were conducted, and response from the selected target community was reported. The 66.7% and 52% of the respondents confirmed that the irrigation schemes were completely damaged due to very poor O&M of the scheme. Failure to deliver sufficient water was found due to improper adjustment of the waste valves and insufficient delivery of water to the pump. More than 90% of the respondent confirmed that O&M activities of the schemes were not proper. The 16% Kecha and 22.2% Awushoana respondents revealed that poor O&M activities were taken at these schemes (Fig. 6).

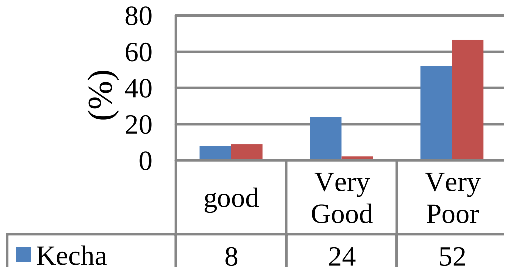

Fig. 6: *The response of selected target community on maintenance and evaluation of the two schemes*

Table 4: *The response of target community on the training after implementation of the schemes*

Sl. No.	Condition of raining was ffered or not	Frequency and their %			
		Kecha		Awushoana	
		Frequency	%	'requency	%
1	Yes	2	8	10	22
2	No	19	76	35	7.8
3	None	4	16	-	-
	Total	25	100	45	.00

The survey results indicated that about 96% of the target community did not know how the HRP pump is operated and it's functioning. As far as the capacity building was concerned, only 8% and 22% community of Kecha and Awushoana agreed that they were getting training. The rest 76% and 77.8% of Kecha and Awushoana schemes respectively responded that they were not getting training about irrigation scheme and its management and O&M (Table 4). As a result, the system became completely failed and stopped its functions. The valves are blocked due to debris and floating materials which were entering into the pump body through the drive pipe from the source of water. Due to the absence of strainer at the intake of the drive pipe, the functions of the valve stopped. The problems related to pipe fitting, exposure and leakage of concrete pipe that directs the water from stream to the reservoir and drive pipe with no strainer at the intake was found.

3.2 Key constraints related to SSI development

3.2.1 Planning problem: The satisfactory performance of the scheme is directly related to the level of involvement of community members in the planning process (Lambisso [2]). According to the FDG, it was revealed that very poor participation of water user community (WUC) in planning, designing, construction and evaluation of the irrigation schemes. At present time, both schemes were completely deteriorated due to poor planning processes.

3.2.2 Institutional Aspect of the Schemes: Generally, various institutions were involved in the process of planning, designing, implementation, and operation of the irrigation schemes. The expected level of participation of these institutions was not observed in both schemes. Handling over irrigation systems to farmers upon completion of construction has been a standing procedure in SSI development (Elias [22]). However, 80% of the respondent said that there was no formal handling over of the project to the beneficiaries and 20% said there was formal handing over the project to the beneficiaries. The KI interviews revealed that the institutions did not consider the participation of the WUC's. The 82.2% (Awushoana) and 58.33% (Kecha) of the respondents indicated that WUA's was not established (Table 5). Beneficiaries had no role in scheme maintenance even the canal was damaged in Awushoana SSI. The effective organizational structure of the WUA's creates the ability to facilitate working relationships between various entities and to improve the working efficiency within the organizational units. By strengthening the management capacity of WUA, the legal and smooth handover of schemes is critical for the sustainable performance of the schemes (Ulsido and Alemu [23]).

3.2.3 Problems with irrigation water distribution: The absence of established water rights makes water distribution difficult for irrigation development. Since the intervention, farming communities have been trying with more or less success to craft socially acceptable and applicable water distribution rights (FAO [24]). The main reason for the scarcity of water in the Awushoana SSI scheme was found to be structural failure of the diversion weir and intake structure (62.2% responded), poor water management (22.2% responded) and non-functioning of the water distribution system (11.1% responded) from target community survey (Table 6). However, the main cause for the scarcity of water in the Kecha SSI scheme was found to be sedimentation of the diversion weir (28% responded), less pump efficiency (24% responded) and not functioning of the distribution systems (20% responded). Therefore, both of the schemes were damaged due to problems in water distribution system (Table 6).

3.2.4 Social and operation problem: For sustainability of the scheme, one of the important steps in irrigation system design has been farmer's participation in all stages of the project cycle (Makadho 1990 [25]). Otherwise, this leads to dependency on the government which decreases farmer's sense of ownership and responsibility for O&M. More than 95% of the respondents in both schemes were confirmed that they did not undertake even minor repairs for the structure. All respondents confirmed that no attempts were made to encourage participation of the beneficiaries. According to the respondents, 95% (Awushoana) and 92% (Kecha) community did not participate in planning and 53.3% (Awushoana) and 56% (Kecha) participated during the construction phase (Fig. 7).

3.2.5 Economic problem: Only access to irrigation water is not enough to the small land holding farmers in the area, but also requires a broad range of support services (access to inputs, credits, and market) and knowledge of farming. Two scheme water user farmers revealed that productivity decreased due to a shortage of credit and very small supply of inputs. Therefore, scheme beneficiaries have not used fertilizers at right time to increase the productivity. Also, less utilization of improved crop varieties and seeds were observed. The study area marketing system did not always facilitate outcomes desired by the farmers, which indicates reduced returns and less incentive to invest in the use of irrigation. According to the FGD, there is no generation of resources for the sustainability of schemes, which could be used to conduct minor maintenance and rehabilitation activities.

Table 5: *Selected Farmer's response on the establishment of the WUA on both of the schemes*

S.N.	Condition of WUAs	Frequency of the respondents and their %			
		Awushoana		Kecha	
		Frequency	%	Frequency	%
1	Established	3	6.7	2	8
2	Not established	37	82.2	15	60
3	Not known	5	11.1	4	16
4	None	-	-	4	16
	Total	45	100	25	100

Table 6: *Reason for the scarcity of water on both of schemes, Awushoana and Kecha*

Types of the problems	Frequency of the respondent and their %			
	Awushoana		Kecha	
	Frequency	%	Frequency	%
shortage of water	2	4.4	4	16
Structural failure of diversion weir and intake gate	28	62.2	-	-
Poor water management	10	22.2	3	12
None functioning of water distribution systems	5	11.1	5	20
Sedimentation of diversion weir	-	-	7	28
Less pump efficiency	-	-	6	24
Total	45	100.0	25	100

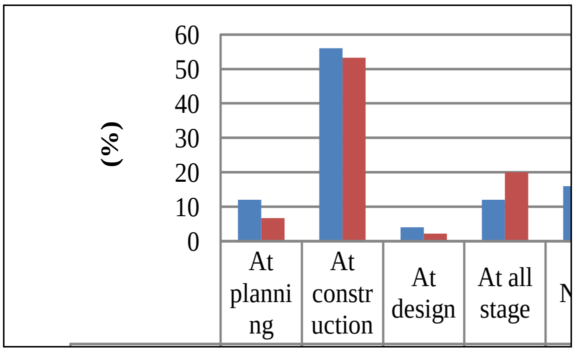

Fig. 7: *The response of target community on irrigation development phases*

3.3 Mechanisms of Rehabilitations for the Failed Irrigation Structures

3.3.1 Damage on intake and sluice gate: The field survey revealed that the intake gates of two schemes were damaged and could not be moved due to structural failures and jammed. For future utilization, another gate of the same size is required as amended design work. Therefore, it is possible to make a flexible and movable gate using different smoothing materials and removal of sediments that are stored in front of intake gates and sluice gates. This operational problem can be improved by offering training to the users and carrying out proper handing over and follow up in operation of these schemes.

3.3.2 Seepage through foundation: Seepage can destabilize the structure by removing soil particles. Seepage flow returning to the river downstream of the weir can cause a piping failure, in which the river-bed loses all strength. This problem was mainly observed in Awushoana SSI diversion headwork. This can undermine the weir apron and leads to complete structural failures. This problem can be avoided by providing cut-offs (sheet piles) in the riverbed at the upstream and downstream ends. The cut-offs extend the seepage path and reduce the hydraulic gradient that causes piping. Also, the structure can be equipped with vertical cut-offs which hinder the water flow along and underneath the structure. The cut-offs are part of a structure and can be driven into the bed and the embankments of a canal.

3.3.3 Downstream scouring and damage of downstream apron: From the hydraulic analysis, Awushoana weir indicated that failure corresponds to the position of the hydraulic jump due to variation occurring in the bed of the river. The proposed solution to this problem is to create a stable hydraulic jump within the limited stilling basin. It is useful means of dissipating energy in the supercritical flow.

Its merit is preventing possible erosion below overflow spillways, chutes, and sluices. The bottom of the basin is paved to resist scouring. In practice, the stilling basin is seldom designed to confine the entire length of a free hydraulic jump on the paved apron, because such a basin would be too expensive (Wei [26]; Mohamed Ali [27]; Rageh [28]). Accordingly, proper design of both impervious and pervious apron are required to control the excessive upstream energy and control structures should be provided to manage the problem of receding jump. Consequently, accessories to control the jump are usually installed in the basin (Mohamed Ali [27]). To prevent such problems additional thickness of the impervious floor can be provided at the point where the hydraulic jump is formed to counterbalance the suction pressure. There is also the proper design of launching apron should be provided at u/s and d/s ends to provide a cover to the main structure against scour. The piles (or cut off the wall) at u/s and d/s end of the impervious floor should be provided up to the maximum scour level to protect the main structure against scour (Johny [29]).

3.3.4 Failure of HRP systems: Damage on HRP in Kecha SSI can be rehabilitated by proper planning, installation, and O&M of the system through WUC and offering successive training. Before the proper installation of HRP, there must be proper planning and designing of the civil works like diversion weir, intake and sluice gate etc. The details of the O&M activities are presented in Table 7.

3.3.5 Hydraulic design of the weir: An attempt has been made to assess the design of hydraulic components of the proposed weir structure. The shape of the weir has been decided based on its practicability and economy of the structure.

Table 7: *The operation and maintenance activities of the RPS*

SN	Actors	Roles	Skill required
1	Caretaker	Check and restart the pump clean the pump	Awareness raising and give training activities
2	Water committee	supervises the caretaker and collects the contribution	basic skills
3	Area mechanic	Replace the valve	Technical skill
4	External support	Check the water quality motivate and guide the local organization	Highly qualified

The selected shape of the weir at Awushoana river cross section must be reinforced concrete broad crested weir. But the constructed weir was masonry type with poor construction materials. The reinforced concrete weir was selected due to the river is at the huge boulder stage and expected maximum design discharge was found to be 122.66m^3/s for a return period of 50 years. Considering, land to be irrigated, the weir height should be sufficient to divert the water at the required level. Hence, the height of the weir is determined to be 2.59m. Shorter the weir less will be the cost of the main structure but on account of the increase in discharge per unit run (Web [30]). Dynamic action on the river be downstream will be severed, guard against which the thickness and the length of the impervious and pervious floor will have to be increased. Therefore the length of the waterway is determined from the lacey's wetted perimeter is 23.67m. The discharge per unit length for this diversion structure is estimated to be 5.18m^3/s/m when these values occur at high flood conditions. When the natural waterway of the river is contracted, the waterway scours the bed both on upstream and downstream of the structure. These phenomena occurred when there is a high flow of water over the structure without the design of the hydraulic jump. This causes structural failure and the regime of the scour depth is estimated to be 4.04m. Therefore to prevent the failure of this structure the piles should be provided at the upstream and downstream of the structure and estimated to be 1m and 3.25m, respectively.

The water profile of the weir at the upstream and downstream for the Awushoana scheme should be determined which can be used in the design of energy dissipating structures of the weir and fixing the dimensions of these structures. The backwater effect due to the construction of the weir is required to determine the level of the water surface at different length upstream of the weir (Fig. 8). This computation is needed to determine whether the flood over tops the river bank and to provide protection measures. In this particular site, river bank is more than the depth created during the design floods, there is an effect on the river banks. Therefore, protection work should be provided. Construction of the weir increases the total energy level and this energy has to be dissipated before the flow reaches the river channel. Since the flow over the weir is supercritical, the energy can be dissipated by the formation of the hydraulic jump. Therefore, this jump must be constructed at the downstream of the Awushoana weir section to prevent the surface flow damages.

Stability analysis of the weir under dynamic condition involves the following forces (Fig. 9):

- Uplift pressure is considered for weir wall (UP1, UP2)
- Water wedge weight is considered (Ww1, Ww2)
- The weight of the weir itself (W1, W2, W3)
- Horizontal forces (PH1, PH2, PH3)
- Unit weight of water and concrete is taken to be 10KN/m^3 and 24KN/m^3, respectively (Mohamed Ali [27])
- The moment is taken about the toe per m width.

Table 8 indicates that it is necessary to keep the stabilizing moment more than destabilizing moments.

In the case of Awushoana diversion weir structure, this criterion is analyzed and the result implied that the stabilizing moment (ΣM_R=1562.45) is greater than a destabilizing moment (ΣM_O=265.87) for the high flood condition (Table 8). The factor of safety against overturning for the weir section is 4.136 ($F_O=\Sigma M_R/M_O$=1562.45/268.87 =5.87>1.5 OK) which is between the recommended values (i.e. 1.5-2.0). This implies that the structure is safe against overturning. It is also necessary to keep the summation of vertical forces greater than the summation of the horizontal forces. In this case, the factor of safety against sliding for the weir section is 0.06 which implies that the structure is safe against sliding ($F_s=\Sigma H/\Sigma V$ = 20368.2 =0.05).

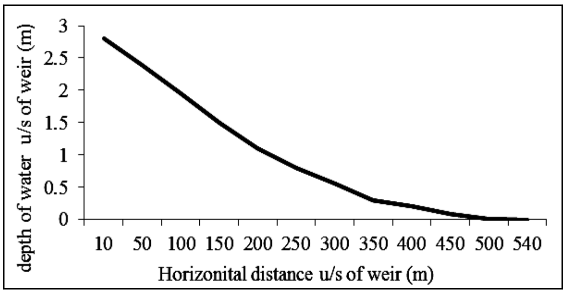

Fig. 8: *The backwater curves upstream of the Awushoana scheme*

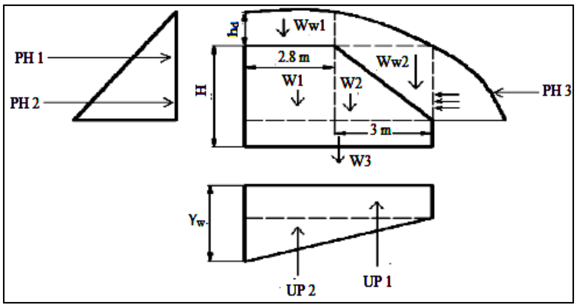

Fig. 9: *The forces acting upon weir wall of Awushoana scheme*

Table 8: *Force analysis for diversion weir at Awushoana River*

Types of load	Force computed	Lever arm (L) toe (m)	Moment about toe	Remark
W1	174.05	4.2	731	Self-weight of weir
W2	33.6	1.87	+62.72	″
W3	134.5	2.8	+376.32	″
PH1	25	0.5	12.5	Horizontal hydrostatic pressure
PH2	10	1/3	3.33	″
PH3	14	0.33	-4.62	″
WW1	72.52	4.2	304.58	Vertical weight of weir
WW2	37.5	1.93	72.5	″
UP1	56	2.8	-156.8	Uplift pressure
UP2	28	3.73	-104.44	″

4. Conclusions

Many irrigation schemes were implemented by the Governments and NGO's for the purpose of food security and food self-sufficiency. However, some of the schemes are performing successfully and some of them are failed to serve the purpose for which they are intended [2], [11]. The selected schemes Awushoana and Kecha were implemented by WVE in Hadiya zone, Soroworeda, Ethiopia. However, these are failed as the result of improper design, planning, O&M, and absence of legal WUA's. It is needed to revise the approaches towards irrigation development by:

Proper hydrologic, hydraulic and structural analyses are very important which contributes to the good performance and sustainability of the small scale irrigation schemes.

According to the FGD and KI interview, the main causes of failures from selected schemes were found very poor participation of target community in irrigation development stages, the absence of WUAs, lack of proper training and absence of proper supervision, monitoring and evaluation of the schemes.

Increasing irrigation development activities for the farmers through education, training, and community participation.

Building the capacity of the technical personnel involved in the subject so that better skills can be gained in planning, designing, installation, and implementation of projects.

One of the problems with hydram technology is that a majority of potential users were not aware of this pumping device. Therefore, promotion and dissemination of hydram technology should increase and give training for the WUC and DAs of Kebele and detail technological information must be generated and disseminated (in the case of Kacha SSI). Continuous monitoring and evaluation are necessary to provide feedback and information for the future planning and management of new irrigation schemes.

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