Design Development of Spate Irrigation Structures in Raya Valley, Ethiopia

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Abstract- Spate irrigation is a resource system, whereby flood water is emitted through normally dry wadi and conveyed to irrigable fields. Modernization of spate structures has been taking place in Raya valley since 1998 even though the efficiencies are not as intended. Initially the design standard was directly adopted from the conventional irrigation systems. Farmers were complaining that the implemented design standard was not appropriate with regards to their experiences. According to the professional’s perception, the reason for schemes failure could be poor management and lack of maintenance. Spate irrigation design development in Raya valley shows significant changes through time; like widening of intake, increasing of deflection angle, excluding of rain fall during design and reduction of irrigation time. The spate schemes with relatively best performance still have problems like; sedimentation around intakes, less spate flow and low performances. Therefore, understanding of the experience, wisdom and tradition of farmers is necessary during design and construction of spate irrigation.

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I. Introduction

According to FAO and UNDP, (1987) spate irrigation define as “an ancient irrigation practice that involves the diversion of flashy spate floods running off from mountainous catchments where flood flows, usually flowing for only a few hours with appreciable discharges and with recession flows lasting for only one to a few days, are channelled through short steep canals to bunded basins, which are flooded to a certain depth”. Mehari et al. (2007) also defines spate irrigation in the simple way as “a resource system, whereby flood water is emitted through normally dry wadi and conveyed to irrigable fields”. Moisture stress resistant crops, often sorghum and maize are grown in the spate irrigated agricultures and planted after the first flood irrigation water has occurred. In many areas crops can get matured and give reasonable yield using two or more floods depending on the water holding capacity of the soil.

According to Van Steenbergen et al. (2010) rough estimates, global spate irrigation coverage extends up to 3.3 million hectares even though uncertainty is there. According to the reference made by Mehari et al. (2011) spate irrigation is frequently practiced in the Middle East, North Africa, West Asia, East Africa and parts of Latin America. Although spate irrigation is uncertain type of investment economically it is very important practice in countries such as Yemen, Pakistan, Eritrea and Ethiopia where agriculture is a vital component of their economy (Ratsey, 2011). Even though spate irrigation contributes a lot for food security enhancement in the drought prone areas little concern and emphasis had been given in its developments.

In Ethiopia spate irrigation is a common practice in midlands as supplementary and in lowland area used as dominantly full irrigation. According to Van Steenbergen et al. (2011) in Ethiopia both farmer’s initiative and public investments are the driving forces for spate irrigation development. Currently the cultivated areas under spate irrigation estimates to be 140,000 ha of which 20,000 ha is modern spate irrigation and 70,000 ha still need improvements and other 50,000 ha are under design and construction phases (Van Steenbergen et al., 2011).

Spate irrigation system in Ethiopia is increasing in arid areas particularly; south Tigray (Raya valley), Oromia (Bale, Arusi, West and east Hararghe), Dire Dawa Administrative Region, Southern Nations, Nationalities and Peoples Region (Konso), Afar and Amhara (Mehari et al., 2011).

Raya valley is one of the areas where spate irrigation is being practiced for long times. Farmers were diverting flood water to their farm land using traditional spate irrigation system. During the past decades many governmental and non-governmental organizations were trying to improve and modernize the traditional spate irrigation systems. Many traditional spate schemes were modernized while they did not perform as expected due to several problems. Among this problems are over sedimentation in diversion and canal, failure of structures, inappropriate design and poor participation of farmers during design and construction.

II. Methodology

a) Study area

The Raya Valley is located in the south-east part of the Tigray Regional State between 39°02’ to 39°05’ east longitude and 120°17’ to 120°15’ north latitude. It is bordered by Hintalo Wajerat Woreda to the north, Afar Region to the east, Endamekon and Ofa woredas to the west and Amhara Region to the south. It comprises the total area of Raya Azebo and Alamata Woredas and
some eastern high lands of Endamekoni and Ofia Woredas (REST, 1996). Figure 1 shows the location map of Raya valley. The total population of the Raya Valley Area is about 227,431 (136,039 for Raya Azebo and 85,359 for Alamata woreda).

Topographically the Raya Valley is divided in to two major zones: low land areas with an altitude less than 1500 m.a.s.l which mostly covers large part of the central part of the valley; and the high land areas having altitude above 1500 m.a.s.l which covers the western and eastern edges of the valley. According to the moisture index criteria provided by REST, (1996) the Raya Valley area is classified as dry climates of semi-arid and arid types.

b) Data collection

Secondary data mainly study design report, design specification and scheme locations were collected from relevant organizations of Tigray Water Resources, Mines and Energy Bureau, Mekelle University, Raya Alamata and Raya Azebo weredas or districts. After having this secondary data rough evaluation on the design development in time was made and seven schemes namely Hara, Tirke, Fokissa, Beyru, Tengago, Dayu and Oda were selected for field observation and assessment. Hara, Tirke and Oda modern spate irrigation schemes did not have any report. Therefore analysis was made to this sites based on the current condition in the field and farmers perceptions.

An intensive scheme visit and observation was made for the seven selected schemes so as to envision the current situations in the ground. Headwork structures measurement was also made to Hara, Tirke, Fokissa, Beyru, Tengago, Dayu and Oda modern spate irrigation schemes. The field observation was aimed to measure the headwork structures and to observe the practical problems in the field. Structures like intake size, weir dimensions, sluice gates and main canals were measured. This data are used for comparison of design development with other scheme designs. Discussion with local farmers and experts were held in all visited schemes to determine the perception of the beneficiaries.

III. Result and Discussion

Modernization of spate irrigation schemes in Raya valley starts in 1998. Hara was the first modernized spate irrigation scheme in the area and that leads to many improvements in the designing and constructions of modern schemes in Tigray. Tirke spate irrigation scheme was also modernised in 2004 following to Hara scheme. In 2005 four schemes namely Fokissa, Beyru, Utu and Burka was designed and constructed while Ula-ulula, Buffie, Tengago and Dayu schemes were constructed in 2006.

The design standard of Hara and Tirke was directly adopted from the conventional irrigation schemes which have low sediment concentration. The headwork of this two spate schemes has gated off take or intake with broad crested weir and all the structures were made up of concrete masonry. Hara and Tirke schemes were failed in one rainy season due to problem of sediment in both intakes and canal systems. Figure 2 shows the modernized headwork structures of Hara and Tirke spate irrigations.

According to the farmers perception the main reason for failure of these schemes was the inappropriate design structure of intakes. During construction the farmers were complaining about the size, shape and deflation angle of the gate. According to field observation the intakes of Hara and Tirke has 900 deflection angles from the river flow direction and less than one meter diameter of gate.

In 2005 when Fokissa, Beyru, Utu and Burka was designed and constructed the design engineers took key lesson from the failure of Hara and Tirke. They came to realize that the incoming sediment or bed material load was too high. Hence, they decided that gated intake, narrow canal and siphons cannot work as structures of spate scheme. At that time the designers tried to know the indigenous knowledge of farmers for sediment managements and they observed some traditional irrigation schemes in the valley.
The major findings of farmer’s knowledge were wide open gate intake with an angle of deflection greater than 90° and wide size of canals. To some extent experts tried to understand and incorporate farmers traditional knowledge during design and construction. They took good lesson on size and deflection angle of intake and they tried to give attention for sediment problems.

The major changes of the design include:

- To change the gated intakes to open gate
- To increase the width of the intakes and canals
- Improving of diversion angle from 900 to 1200
- Avoiding of crossing structures

The main problems or limitations during these designs are:

- The crop water requirement (CWR) was calculated for 24 hours while flood occurrence is too short
- Effective rainfall was considered during irrigation water requirement calculation (IWR) which leads to underestimation of net irrigation water requirement (NIWR) but rain fall is not reliable.
- As the width of the gates ranges from 1m to 3m depending to size of irrigable area but the farmers were still complaining as they were thinking even 3m gate is small.

In 2006 four spate schemes were designed and constructed namely Ula-ula, Buffie, Tengago and Dayu schemes. In addition to the design improvement takes place in 2005 some improvements were made based on recommendations of supervision. These improvements try to solve the limitations and problems occurred in the design of schemes made in 2005. Figure 3 presents the headwork structures of Tengago and Dayu modern spate irrigation scheme. The main design improvements for Ula-ula, Buffie, Tengago and Dayu schemes are:

- The calculation of crop water requirement was minimized to 4 hours
- Effective rainfall was neglected during net irrigation water requirement calculation
- The schemes design was limited to headwork and main canals.
In 2011 Oda spate irrigation was designed with some improvements to traditional spate system, it was designed as a simple intake using gabion and only cut offs built to reduce the risk of bed level lowering around the river bed and intake (Embaye et al., 2012).

During the field visit to Oda spate irrigation it was found that the weir or cut off structure was completely destroyed by flood hazard. According to the farmers perception Oda scheme was failed before handed over to users just during completion of construction work. Now farmers are using in traditional way using forest and shrub embankment Figure 4 shows the failed weir axis and reconstruction of scheme in traditional systems.

From 2011 to 2013 there was no sound change in design development of spate irrigation schemes. Few schemes were constructing by the wereda or district of Raya Azebo and Raya Alamata bureau of water resources, mines and energy. Most of these schemes are simple and small structures and they are exposed to flood hazards. In 2014 two spate irrigation schemes were designed by Mekelle University. The headwork of these schemes was designed to have 50 centimeter high slant barrage across the river. This design was aimed to convey limited amount of water and during medium and high flood occurrences the flood will over flow above the barrage and sediments will flashed away. This spate scheme is still under construction and its performance and applicability was not assessed.
The major design development made for spate irrigation systems in Raya valley are summarised as shown in Table 1. The relatively best performed modern spate irrigation system in Raya valley was the one designed and constructed in 2006 namely Ula-ula, Buffie, Tengago and Dayu schemes. Renovations have been taking for these schemes to minimize the structural damages and sedimentation problems. Among this schemes Dayu spate irrigation scheme were found relatively best performing scheme. Therefore, this scheme was selected for further study.

Comparing Tengago and Dayu spate irrigation schemes Dayu is relatively best performing. The reason for this could be the difference of river flood discharge. As we can see from Table 2 the design flood discharge for Tengago is 50.0m³/s while 358.89 is flood discharge of Dayu. Even though the river discharge is small but Tengago was designed to irrigate 500 ha with two intakes in one diversion structure. The structures of Tengago are still in good conditions while there are accumulations of sediments around both intakes. Therefore designing of 500 ha to a river which has 50m³/s is not optimum and this could be the reason for poor performance.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Hara</th>
<th>Tirke</th>
<th>Fokissa</th>
<th>Tengago</th>
<th>Dayu</th>
<th>Mersa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design flood discharge</td>
<td>-</td>
<td>-</td>
<td>220.5</td>
<td>50.0</td>
<td>358.89</td>
<td>-</td>
</tr>
<tr>
<td>Weir length</td>
<td>35</td>
<td>34</td>
<td>35</td>
<td>23</td>
<td>29</td>
<td>-</td>
</tr>
<tr>
<td>Intake type</td>
<td>Closed gate</td>
<td>Closed gate</td>
<td>Open gate</td>
<td>Open gate</td>
<td>Open gate</td>
<td>Open gate</td>
</tr>
<tr>
<td>Gate size</td>
<td>0.8X0.8 both sides</td>
<td>0.9m diameter</td>
<td>3 m</td>
<td>2.5m right &amp; 2m left</td>
<td>3 m</td>
<td>3 m</td>
</tr>
<tr>
<td>Deflection angle</td>
<td>900</td>
<td>900</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>Main canal system</td>
<td>Concrete</td>
<td>Concrete</td>
<td>Concrete</td>
<td>Concrete</td>
<td>Concrete</td>
<td>Concrete</td>
</tr>
<tr>
<td>Crossing structures</td>
<td>Available</td>
<td>Avoided</td>
<td>Avoided</td>
<td>Avoided</td>
<td>Avoided</td>
<td>Avoided</td>
</tr>
</tbody>
</table>

Table 1 : Summary of spate structures design development


### Design Development of Spate Irrigation Structures in Raya Valley, Ethiopia

<table>
<thead>
<tr>
<th>Assumed irrigation time</th>
<th>24 hrs</th>
<th>24 hrs</th>
<th>24 hrs</th>
<th>4 hrs</th>
<th>4 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of rainfall</td>
<td>Considered</td>
<td>Considered</td>
<td>Considered</td>
<td>Neglected</td>
<td>Neglected</td>
</tr>
<tr>
<td>Designed ha</td>
<td>400</td>
<td>380</td>
<td>500</td>
<td>500</td>
<td>Neglected</td>
</tr>
<tr>
<td>Current ha</td>
<td>0</td>
<td>0</td>
<td>100-150</td>
<td>&lt;50</td>
<td>150</td>
</tr>
<tr>
<td>Over all status</td>
<td>Failed</td>
<td>Failed</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
</tbody>
</table>

ii **Designers and experts perception**  
According to the discussion held with designers and professional experts of spate irrigation system the main cause could be lack of good operation and maintenance in addition to lack of inappropriate design. As there is no known standard for spate irrigation system most the decisions for all structural design are by trial and errors. The experts are still not confident on the size and angle of intakes which they have been designing for years. In the other way round the experts are not convinced by the farmers complaining about the existence and functionality of sluice gate. Sluice gate is important parameter for sediment control. Opening of sluice gate during high flood helps to erode the accumulated sediments around intake. In low flood is must be closed so as to rise the water level and divert more water. Therefore the existence of intake could not be a problem but it needs care full management and frequent supervision.

c) **Remedial solutions for the problems**

i **From farmers point of view**
Based on the farmers indigenous knowledge most of traditional irrigation system are characterized as wide intake width up to 6 meter wide, the angle of deflection are greater than 1200 in some area they can make it near to 1800 which is parallel to the river flow and mostly they use temporary and small solid weir or barrage to clot the flow along the river and divert to earthen canal. For the modernized schemes the farmers put the following remedial actions;

- Width of intake have to be up to 5 meter
- Angle of deflection have to be more than 1200 deflected
- The weir must be without sluice gate

ii **From expert point of view**
The design experts of spate irrigation system are keen to know the impact of different deflection angle and width length on sediment management and spate flow. Therefore the possible remedial solution in relation to sediment management and spate flow could be;

- Width of intake 3m or 5m
- Deflection angle 1200 or 1500

### IV. Conclusions
Modernization of spate irrigation was started in 1998. Hara and Tirke schemes were the first to modernize. The design parameter of these schemes was directly adopted from the conventional design system without consideration of the sediment income and extreme flood events. Nevertheless, these schemes were failed in one rain season and went out of use due to high sedimentations.

- Inappropriate design parameters of intakes and canals are the main cause of failure.
- Sedimentation and less spate flow are still the major problem in spate irrigation schemes.
- Farmers are complaining to experts for not considering their willing and construction of inappropriate designs. Experts were also complaining to farmers for their poor management and lack of maintenance.
- The design of main intakes has significantly improved over the past years. The intake dimensions were changed from closed intake, 900 deflection angles and narrow (90 cm wide) gates to 3 meters wide open intake with 1200 deflection angle and this improvement gives relatively good performance for modern spate irrigation schemes.
- The latest design of diversion structure is however, far below optimum. This design is irrigating about 50% of the intended area. The main reason for the poor performance could be lack of optimum intake designs
- Understanding the experience, wisdom and tradition is necessary during design and construction of spate irrigation.

### References


