Sedimentation of Reservoirs in Amhara Region: The Case of Adrako Micro-Earth Dam

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Abstract

Sedimentation of reservoirs has direct and indirect effects on irrigation practices. The susceptibility of a reservoir to sedimentation depends on the sediment delivery of the source watercourse, the retention characteristics of the reservoir and the manner in which the flow is delivered from the natural source to the reservoirs.

Major constraints of Adrako micro-earth dam on design, construction and operation and maintenance were assessed in order to relate them to sedimentation, seepage and other structural problems. Study from sedimentation of 9 reservoirs in the Amhara Region shows reduction of 7 ha annually from 1997 – 2018. This implies that about 1.887 MCM sediment will be accumulated in all reservoirs displacing equal volumes of irrigation water. This will be equivalent to abandoning of about 151 ha of irrigable land before achieving their economic life. When we consider Adrako micor-earth dam 1.4 ha of irrigable land reduction is expected annually. This implies that 0.362 MCM of sediment will be accumulated in 21 years, which displaces equal volume of irrigation water. About 29 ha of irrigable land will be lost before achieving the economic life.

The socio- economic survey of Adrako micro-earth dam irrigation project was conducted by structured questionnaire. The social, economical and environmental impacts were reported by the local people as: The main problems reported in the area were shortage of rainfall,, irrigation water shortage, fuel wood problem and farmland shortage. All respondents (100%) expect that the project was very important for them to secure their food self-sufficiency; 70% and 13.3% of the respondents report that the main cause of failure of the dam is sedimentation and design problem respectively and 16.7% do not know the causes of failure.

***Key words*:** Irrigable land, Reservoirs, Sedimentation, Seepage

1. INTRODUCTION

Adrako micro-earth dam irrigation project is constructed by Commission for Sustainable Agriculture and Environmental Rehabilitation of Amhara Region (COSAERAR) in 1998-2000. The project was implemented to irrigate 75 ha of land (60 ha by supplementary irrigation and 15 ha dry irrigation). It is located at $12^{0}06^{'}30^{''}$ N latitude and $38^{0}07^{'}30^{''}$ E longitude. It was expected to fulfill the food self-sufficiency of the local community by using irrigation. The reservoir harvests water from 1221 ha catchment area and Adrako stream, which is intermittent. The project is a micro-earth dam with an ogee spillway. No study has been conducted specific to the status of Adrako irrigation project except that the general assessment of irrigation projects in Ethiopia was done by MOWR at different times and sedimentation of micro-earth dams in relation to soil and water conservation measures were studied by Sisay (2004). So this study tries to evaluate the status of this project and its impacts. The project failed due to various reasons. The main cause of failure is sedimentation due to effect of untreated and unstabilized catchment. The socio-economic evaluation and the project document shows that the sediment yield of the catchment was very high as a result watershed planners recommended that the construction of the dam should be delayed. If need arises after heavy treatment of the catchment, it may be possible to construct the dam. However, violating these recommendations of the watershed planners, the dam was constructed.

2. METHODOLOGY

Major constraints of Adrako micro-earth dam on design, construction and operation and maintenance like technical constraints, handing over, theft and vandalism of control structures and lack of monitoring and evaluation activities were assessed in order to relate them to sedimentation, seepage and other structural problems. These were done by detail reviewing of the design document of the COSAERAR such as hydrology, geology, headwork and infrastructure and physical observation of the scheme including the catchment.

Runoff and sediment yield of Adrako micro-earth dam irrigation project was calculated by Samuel Jose's formula during this study and compared with the methods used on the design document (Rational formula and Universal Soil Loss Equations respectively). Hydrological investigations have shown that the rates and amounts of runoff are dominantly influenced by physical conditions of watersheds. It is impractical to gauge every small watershed. Therefore, statistical sampling procedures are used to extend the finding from one area to another by use of rainfall-runoff relationships and by evaluation of climatic and physiographic factors influencing runoff. Samuel Jose's formula was selected for estimation of runoff and sediment yield because there is no any hydrological and meteorological data recorded in the watershed.

3. RESULTS AND DISCUSSION

3.1. Watershed

In principle, watersheds of small reservoir have to be treated ahead of the construction of the headwork structures. This helps to reduce the siltation hazard, which would be deposited in the reservoirs. Practically this scientific procedure was violated in the region i.e. construction of earth dams have been started before the treatment of catchments. In all watersheds, implementation was done parallel to/after the headwork construction but this was not effective to control the sediment load carried to the reservoirs. The implementation of watersheds by physical and biological conservation techniques and headwork construction procedures were not integrated and result in sediment problems of the reservoirs. This problem was common in the reservoirs fed by the watersheds and was not improved even in the recently constructed reservoirs such as Gomit and Enguamesk. Major problems and constraints encountered on the implementation of the watershed projects in the region in general and Adrako in particular were:

- Little attention given to watershed treatment
- Conceiving that watershed documents are primarily used for fulfilling hydrological computations and formulation for searching funds
- Resource constraints, money, manpower and logistics
- Participation of watershed inhabitants
  - The absence of concerned experts in the office
  - Unchanged attitude of the community about the project. Bad/false rumors in the area that their land may be taken by the state.
- Period of implementation
  - Delay of catchment treatment tasks
  - Too much tasks handled both by farmers and experts
- Coordination problems
  - Integration with Woreda agricultural office and COSAERAR regarding the fund disbursement.
  - Untimely supervision, planning and performing activities
  - Poor professional combination

3.1.1. Effects of untreated watersheds

Treating watersheds of micro-earth dams and diversion structures brings sustainability to the downstream and upstream lands. It also creates economic equilibrium between upstream and downstream landholders. However, watershed based development plans require a sort of integrated management of natural resources. It must not neglect and violate any natural system or must not break the natural cycle in the environment. This implies that multidisciplinary studies and participation are necessarily required to tackle the past cumulative problems observed today. On the other hand adverse effects of watershed management degradation are serious in both upland and lowland. Accelerated soil erosion from degraded upland affects the people in both lowland and upland. Sedimentation analysis of the dams in the region by Sisay (2004) including Adrako showed that there existed a great loss of reservoir capacity annually due to siltation.

Sedimentation of reservoirs has direct and indirect effects on irrigation practices. Increasing of siltation brings reduction of reservoir capacity thereby reducing hectares of irrigable lands. As shown from the table there will be a reduction of irrigable land of 7 ha per annum on average from 1997 to 2018 in nine reservoirs. This implies that about 1.887 MCM sediment will be accumulated in all reservoirs displacing equal volumes of irrigation water. This will be equivalent to abandoning of about 151 ha of irrigable land before achieving their economic life. When we consider Adrako specifically 1.4 ha of irrigable land reduction is expected annually. This implies that 0.362 MCM of sediment will be accumulated in 21 years, which displaces equal volume of irrigation water. About 28.97 ha of irrigable land will be lost before achieving the economic life.

The removal of fertile topsoil from cultivated lands in the watersheds is another threat of agricultural practices. Controlling about 1.887 MCM soil in situ would result in saving of 376 ha of land (optimistic) assuming average soil depth is taken as 50 cm (Sisay, 2004). For Adrako case retaining 0.362 MCM of soil in situ would result 72.41 ha of land being saved on the same soil depth above. Siltation problems are worse than the above explanation; that Adrako is now silted up; Dana may be silted up within these few years time or may be silted up this year and others are ready for action.

3.1.2. Adrako catchment characteristics

3.1.2.1. Climate

The main limiting climatic factors are rainfall and temperature. For analysis of the Adrako irrigation project the nearest meteorological station, Addis Zemen was chosen during the construction of the dam (COSAERAR, 1996). For prediction of runoff and sediment loss analysis the station's monthly rainfall data since 1974-1995 excluding 1991 and 1992 and 24 hr peak rainfall of these years were used.

3.1.2.2. Watershed hydrological conditions

Adrako watershed is best described using hydrologic assessment and analysis of the general drainage, land use and other features. The most important of these are hydrologic parameters, hydrologic soil group and hydrologic cover conditions. These values and coefficients are the results of direct and/or indirect analysis of the field data.

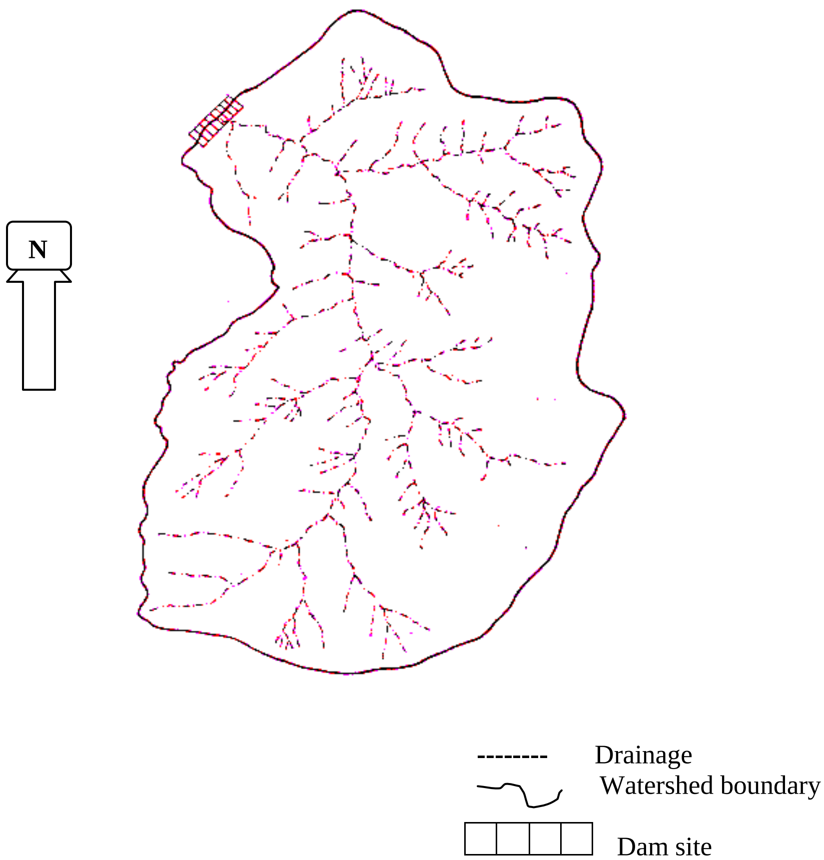


Figure 1: Drainage pattern of Adrako watershed

3.2. The Dam and its Appurtenant Structures

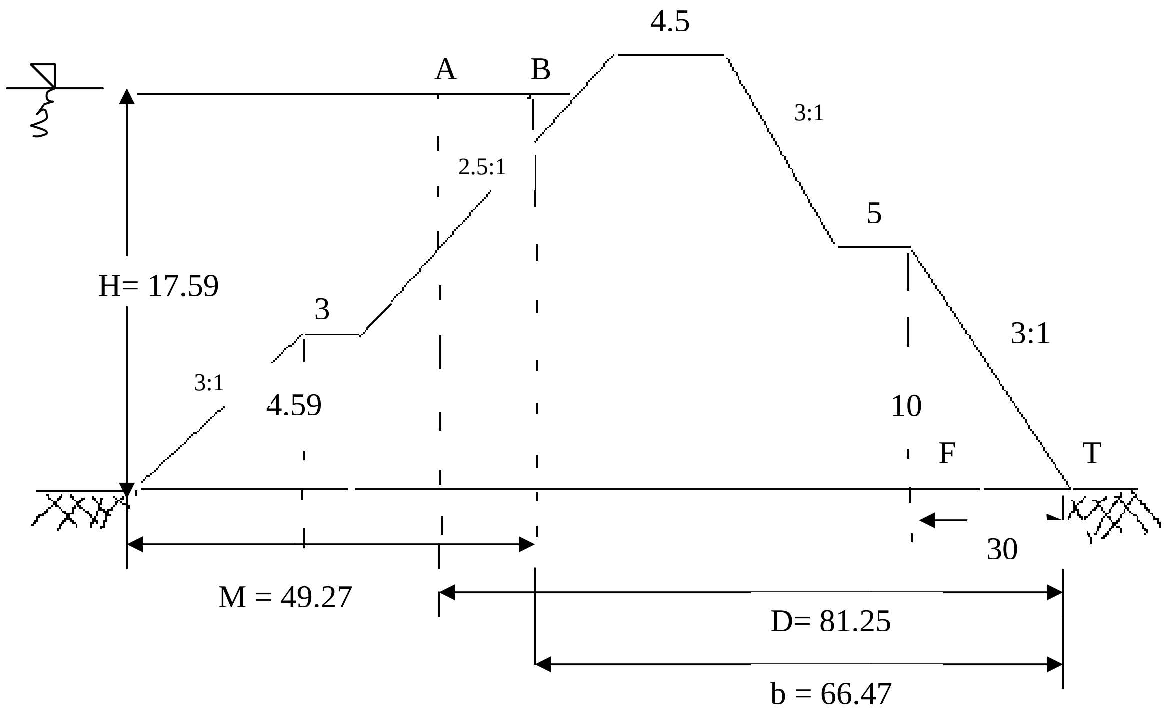
3.2.1. Adrako micro-earth dam

The dam is a homogeneous earth dam constructed by soil and has a crest length of 196 m, maximum height of 20 m and crest width 4.5 m. The dam is already stabilized and has a reservoir with a design capacity of 0.39 Mm^3 at Maximum Water Level (MWL), 0.33 Mm^3 at Normal Water Level (NWL) (0.28 Mm^3 excluding the dead storage) and 0.05Mm^3 of water at Minimum Drawdown Level (MDDL) and it submerges 7.5 ha of land at an average depth of 4.4m (COSAERAR, 1996). But now the submergence is reduced to less than 7 ha and average water depth of 0.4 m that yields a capacity of 0.028Mm^3 (10%) of water excluding the dead sediment volume. Within the short period of time (2000-2004) total capacity reduction of 0.078 Mm^3 (24%) is clearly observed. The reservoir is fed by 12.21km^2 catchment area and its design flood and dependable yield was 109.195 m^3/sec and 3.99 Mm^3 respectively. Based on the design the reservoir's water level was 2090.40 m a.s.l at MWL, 2089.00 m a.s.l at NWL and 2076.00 m a.s.l at MDDL. The dam has an ogee spillway with crest level of 2089 m a.s.l, length of 25 m and its maximum height is 0.8 m. The spillway has a discharge capacity of 86.969 m^3/sec and its tail water level is 2087.495 m a.s.l. Revised area capacity was considered for the reservoir operation study and it was found that the reservoir is successful in 15 years out of 20 years, which is 75% to irrigate the command area.

Figure 2: Adrako Micro-earth dam

Based on the design document the embankment was formed with locally available soils and definitely water seeps through it. Therefore proper measures had taken to drain the seeping water to the downstream side of the dam. To serve the purpose a horizontal filter, which extends up to 12.40 m from the toe is provided. Its principal function is to facilitate drainage of seeping water and protect the lower part of the downstream slope from tail water erosion. Commonly the height of the rock toe equals H/5, where H is the depth up to the Normal Pool Level (NPL) and for Adrako earth dam a slope of 1:1 from inner and 2:1 from outer rock toe was recommended (COSAERAR, 1996).

The sloping side of an earth dam shall be protected from erosion due to wave action, velocity of flow, rain wash, wind action etc. A hand placed riprap and graded gravel which have 0.5 m thick each and grassing in addition to surface drains and toe drain at its toe was recommended for the upstream side slope and downstream slope respectively.



Units are in meter.

AB = 0.3 HB = 0.3*49.27 = 14.78m, AT = 81.25, BT = 66.47m, AF = 51.25

Figure 3: Sectional View of Adrako micro-earth dam

3.2.2. Appurtenant structures

It includes the intake structure, conveyance conduit, control devices and other provisions. The intake structure is a box-like concrete structure with openings at the top and front side and its bottom fixed at the minimum drawdown level. The conduit is mild steel covered with reinforced cement concrete lining. To control the flow two valves are provided at the downstream side. The first valve is for closing and opening while the second one is to regulate the flow. At the outlet of the pipe an impact type stilling basin is provided to dissipate the energy of the flow before it enters to the irrigation canal. The sill level of the outlet structure is at 2074.938 m.a.s.l with the vent size/pipe diameter of conduit as 40 cm and it has also discharging capacity of 0.1103 m^3/sec. By applying energy equation between the reservoir maximum water level and the exit point of the steel pipe and datum at the center of the pipe the exits velocity of the conveyance pressure pipe is 7.07 m/sec.

As it was observed, these structures do not have any defect to function as designed but the intake is closed at upstream due to huge sediment load. This sediment load comes from the farmland, a degraded forestland, active and passive gullies and the query site that was used for source of soil for construction of the dam. Based on the design document in order to lengthen the seepage path through the dam along the outside of the conduit, projecting collars are provided. The total length of the conduit inside the dam body is 81 m.

3.3. Seepage

Seepage occurs through the body of all earthen dams and also through their pervious foundations. The amount of seepage has to be controlled in all conservation dams and the effects of seepage (i.e. position of phreatic line) has to be controlled in order to avoid the failure of the structure. In the design document seepage analysis was conducted based on the normal design procedure and collars were introduced at 4.5 m interval in order to increase the seepage path. Seepage was not observed in most parts of the dam except on the side of the outlet. Water seeps between the reinforced cement concrete lining of the outlet conduit and the fill at a discharge of 0.005 lt/sec. There is no indication of seepage like development of springs in the downstream, which was not present before the project.

The infrastructure of the project is more or less safe since there was no irrigation practice starting from the completion of the project. But the main canal is blocked by the active gully that is produced by spillway of the dam. Efforts were made to maintain the canal with PVC pipes by Woreda Agricultural Office experts in order to use the main canal for water drawn by siphon from the dam. Figure 1. shows main canal of Adrako, which is damaged by active gully.

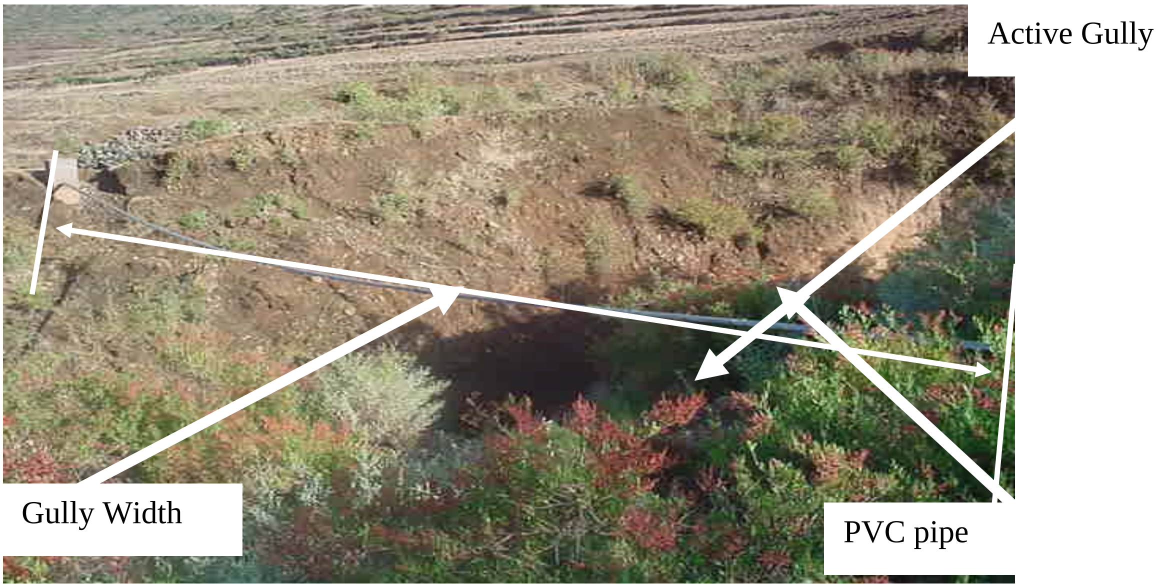


Figure 4: Main canal of Adrako damaged by active gully

3.4. Prediction of Run-off and Sediment Yield

Water, sediment and many water quality constituents for reservoirs are typically derived from upland contributing watersheds as well as from lower-elevation streamside zones and banks. This is particularly evident for the topographically complex landscapes of Adrako irrigation project. Comprehensive, successful river and watershed management and simulation model application requires adequately understanding hydrologic and ecosystem characteristics of the source watershed.

3.4.1. Prediction of runoff

Runoff prediction is directly and indirectly related to the sediment yield, which would come up to the reservoir. It helps in designing recommended structures in soil and water conservation. The rational formula was used in the design since it is applicable to small watersheds due to rainfall data availability. But in the design the same rainfall intensity is used for the whole watershed. Using 6 hours storm duration and taking the value of runoff coefficient C = 0.379 the runoff yield of the watershed in volume was estimated as 475.37 ha-m and an empherical formula developed by Samuel Jose estimates the runoff yield of the catchment as 48.07 cm which is equal to 586.93 ha.m.

Adrako watershed is best described using hydrologic assessment and analysis of the general drainage, land use and other features. The most important of these are hydrologic parameters, hydrologic soil group and hydrologic cover conditions. These values and coefficients are the results of direct and/or indirect analysis of the field data. Hydrologic parameters include the values, which shows the shape, ridgeness, dissectedness and other characteristics of the watershed.

Total watershed area	1221 ha
Watershed perimeter	15 km
Total number of streams	96
Longest stream length	5.4 km
Total length of streams	33.44 km
Stream density	2.87 /km
Drainage density	2.94 km/km^2
Length of overland flow	182.56 m
Form factor	0.43 km^2/km^2
Watershed shape	Fan shape
Average mainstream slope	8.7%
Average watershed slope	32.02%
Average daily rainfall (P)	60.17 mm
Runoff coefficient (C)	0.379

When we compare the above two results there is variation, this is due to the variation of parameters used in these two methods. The second method (Samual Joes) over estimates the runoff but the rational formula underestimates the runoff when we compare them each other. Based on the Samual Joes formula the dam was expected to flood but the amount of water that is beyond the capacity of the reservoir is reduced by the spillway. So we did not expect flooding. The Rational Formula underestimates the amount of runoff that is entering to the reservoir and the expectation is the amount of sediment and runoff in the reservoir should be less. But practically we saw the reservoir is full in sediment and water. This is because the outlet is clogged and the water below the spillway level is forced to stay on the reservoir.

3.4.2. Prediction of sediment yield

Estimating sediment yield in the catchment is an important procedure for watershed management in any micro- earth dam irrigation project. The value tells what should be done in the future to control reservoir siltation problem, but it is impossible to get the actual value of sediment yield without on site experimentation. Though there are different models to predict sediment yield, they are difficult to apply directly on any watershed. The sediment yield estimation of this watershed was done by using universal soil loss equation (USLE) method (eq.5) and another empherical model developed by Samuel Jose (eq.6) was used during the study. With these models the amount of sediment produced was estimated as 0.855 ha-m/yr and 4.069 ha.m/100km^2/yr which is equal to0.49 ha-m/yr respectively.

Data used for the calculation of the annual soil loss of the catchment is based on the characteristics of the watershed such as rainfall amount, soil condition, slope, land use etc. Rainfall erosivity factor (R) expresses the agressivity of rainfall. Traditionally the rainfall erosivity factor for a station is calculated from continuous RF records over a large number of years to calculate the long term average values. The value obtained was R = 642.3

K – soil erodibility factor that is taken based on the characteristics of the soil of the catchment.

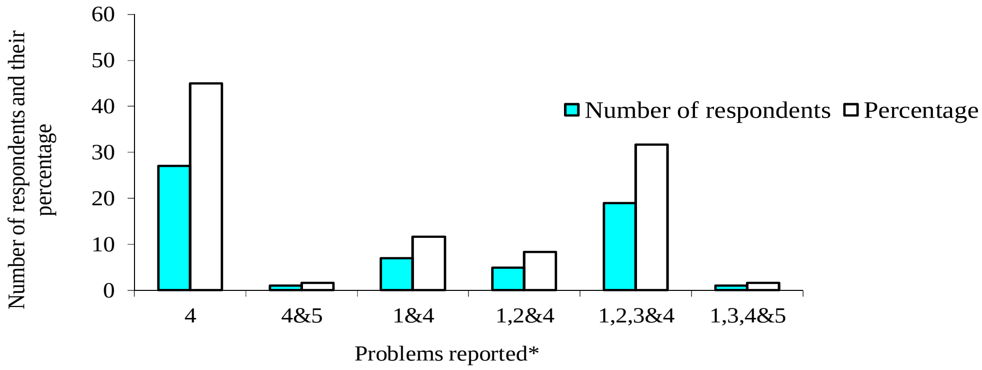
Parameters	Values	Description
K	0.2	Value is taken as 0.2 based on soil color, which is brown
L	182.56	Length factor was taken was L = 2.84
Slope	32.02%	Slope factor was taken as S = 3.14
C	0.15	Land cover (cereals)
P	0.8	Land management (strip cropping)

These two methods universal soil loss equation and Samuel Jose formula estimate the sediment yield with a difference of 0.36 ha-m/yr, which is relatively good estimate when we compare each other.

4. SOCIO-ECONOMIC EVALUATION OF ADRAKO IRRIGATION PROJECT

Adrako irrigation project socio-economic evaluation was done at the project site by interviewing 60 households with structured questionnaire. The questionnaire stresses on the environmental, social and economic impact of the project for the users or local community. Respondents were selected randomly from 300 households over which the project was enclosed. The respondents were 14 (23.3%) in the upstream of the dam, 41 (68.3%) in the downstream, i.e. in the command area, 4 (6.7%) both upstream and downstream and 1 (1.7%) outside the project. From all respondents the majorities are illiterate (48.3%), those under informal education are 24% and primary education is 11.7%. All but 1(1.7%) has farmland on the project.

The main problems reported in the area were shortage of rainfall, potable water, irrigation water, and fuel wood with a decreasing order. Generally there is shortage of potable water in the project area. In conjunction with the failure of the project the downstream water condition is poor and farmers who practiced traditional irrigation are forced to stop due to water shortage.

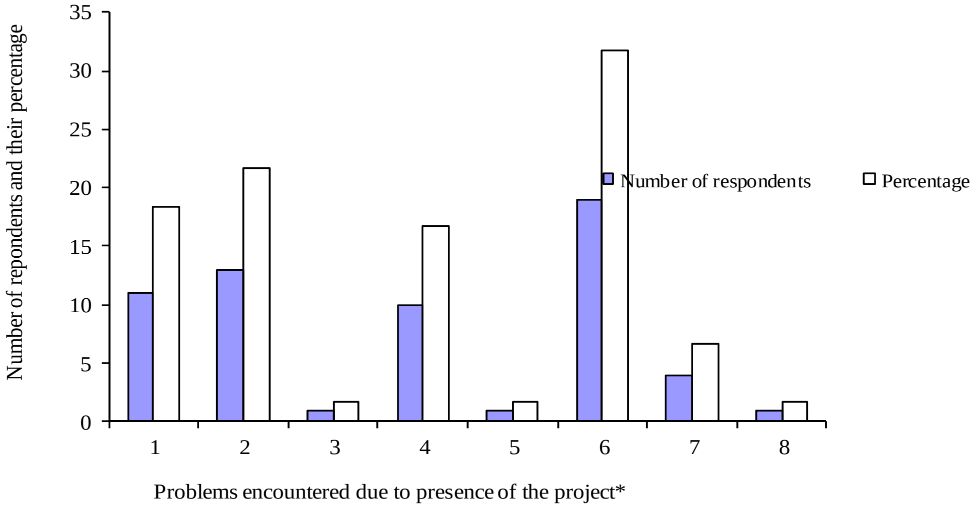


*1 = Irrigation water, 2 = Fuel wood shortage, 3 = Potable water shortage, 4 = Rainfall shortage 5 = Shortage of farmland

Figure 5: Problems reported at Adrako irrigation project

There is no clear distinction on response of farmers who have farmlands on the upstream and downstream of the dam. This is checked by the response of farmers on the importance of the project. The data shows all respondents (100%) expect that the project was very important for them to secure their food self-sufficiency. This leads to the conclusion that the communities' awareness about advantages of irrigation was very good. Before the introduction of the project the idea of using irrigation was very low. The data of practicing traditional irrigation before the implementation of the project shows that only 10 (16.7%) of the respondents were using the traditional irrigation and the rest 50 (83.3%) did not practice it. These traditional irrigation practitioners were using furrow irrigation system. As far as training is concerned only 8 (13.3%) were getting training and 52 (86.7%) did not get any training regarding irrigation. The idea of constructing the dam on the site was completely the initiation of the government but agreement was made between the government and the local community. Participation of the community on planning and implementation of the project is 70% and 96.7% respectively.

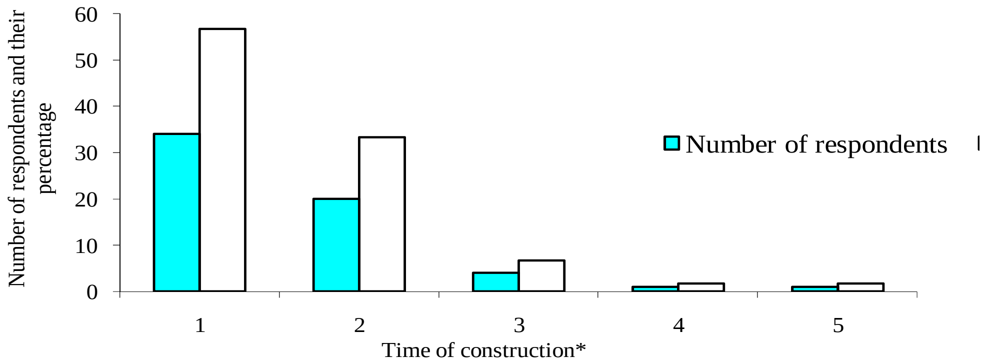
Farmers' response shows that problems faced due to the presence of Adrako irrigation project was introduction of disease commonly malaria, wastage of farmland and grazing land, introducing crop damaging birds, water shortage at downstream and child death.(Figure 6).



*1 = No problem, 2 = Introduction of disease, 3 = Environmental disturbance, 4 = Life loss, 5 = Introduce crop damaged birds and insects, 6 = (1&3), 7 = (1, 3 & 4) and 8 = (1,3 & 2)

Figure 6: Response of farmers' on problems encountered due to the presence of the project

Dams should be constructed after catchment treatment on which the sediment load decreases to required level of dead storage capacity. But construction of Adrako micro-earth dam is undertaken before the catchment treatment.



*1 = Before the catchment treatment, 2 = Parallel to the catchment treatment, 3 = 3-4 years after the catchment treatment, 4 = (1 & 2), 5 = (1 & 3)

Figure 7: Response of farmers for time of construction of the dam in relation to catchment treatment

The Adrako irrigation project failed immediately after construction. Little efforts were made by the implementing organization to make the dam functional. Farmers (98.3%) told that the project is failed immediately after construction and 1.7% a year after construction.

As to causes of failure of the dam, 53 (83.3%) of farmers consider that the cause of failure of the dam is problem of sediment from the catchment and 10 (16.7%) of them report as sedimentation and design problem including the site selection.

Figure 8: Response of farmers about causes of failure of Adrako project

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

Sedimentation of reservoirs is the common problem in Ethiopia in general and Amhara region in particular. Adrako irrigation project is a failed project due to violation of the technical procedures that should be followed. Adrako is a bowl shaped watershed with a highly rugged and dissected topographic terrain and most part of it is a farmland, because of this high sediment yield from the watershed reservoir sedimentation resulted and led to outlet clogging. The project failed as a result of sedimentation, which should have been protected by watershed management. Based on report by experts and design document review the dam should have not been constructed at that period. But political intervention has taken the great responsibility of the failure of the project. This is because experts were forced to construct the project without the consideration of the study document. Therefore, for future irrigation project development watershed management should be given due attention before the construction of diversions and dams.

The Adrako watershed before the construction of the dam was degraded and active gullies were developing. Because the dam was constructed before and parallel to the catchment treatment the unstable soil from the catchment fills the reservoir and clogs the outlet. For future use of the project there should be great effort on maintaining the watershed and proper land use based on its land capability classes should be used and other mechanisms also should be devised to use the ponded water.

The socio economic survey of Adrako irrigation project was conducted by structured questionnaire and the following results were found:

- All respondents (100%) expect that the project was very important for them to secure their food self-sufficiency.
- 70%, and 13.3% of the respondents report that the main cause of failure of the dam is sedimentation, sedimentation and design problem respectively and 16.7% do not know the causes of failure.
- The main problems reported in the area were shortage of rainfall (45%), rainfall and farmland shortage (1.7%), irrigation water and rainfall problems (11.7%), irrigation water, rainfall and fuel wood (8.3%), irrigation water, rainfall, fuel wood and potable water (31.7%), and irrigation water, rainfall potable water and farmland shortage (1.7%).
- Farmers' response shows that problems faced due to the presence of Adrako irrigation project was introduction of disease commonly malaria, wastage of farmland and grazing land, introducing crop damaging birds, water shortage at downstream and drowning child. From these results one can conclude that the project has social, economical and environmental impact on the local community and efforts should be made in order to avoid these impacts.

Irrigation planning should be treated seriously with full farmers' involvement. The following is a summary of the recommendations that have come out of the study of the twelve schemes and case study project. These are important for the implementation of viable and sustainable projects.

5.2. Recommendations

Recommendations regarding sedimentation of SSI schemes in Amhara region:

- Designers should consider secondary outlet when they expect high sediment laden in the respective watersheds.
- Measures for sediment flushing should be considered to prolong the life of the reservoirs and preserve a long-term useful storage capacity.
- Installing bottom outlets for sediment discharge by considering the amount of sediment entering the reservoir.
- To accommodate more silt deposition increasing dam height is also an alternative.

Recommendations specific to Adrako micro-earth dam irrigation project:

- Since the reservoir is containing water it is better to use pumps as well as siphons in order to irrigate some parts of the irrigable area.
- The concerned agencies should organize the farmers, which are found at the side of the reservoir in order to practice irrigation by cans to vegetable crops.
- Designers and decision makers should give due attention on watershed planning in order to increase the life of the reservoir.
- It is advisable to train farmers in using the water in the reservoir for other alternatives like fish production.
- Back flushing technologies in order to flush the clogged sediment should be practiced.

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