Small-scale reservoir sedimentation rate analysis for a reliable estimation of irrigation schemes economic lifetime (A case study of *Adigudom* area, Tigray, northern Ethiopia)

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Abstract

The research was conducted in Tigray, northern Ethiopia. The area is found in semi-arid agro-ecological zone where shortage and erratic nature of rainfall makes rain-fed agriculture difficult. Thus, surface runoff harvesting for irrigation using micro dams was taken as a strategy and many dams were built in Tigray. However, the fact that the region is characterized by deforestation and soil erosion that makes reservoir sedimentation a major treat for the economic lifetime of the projects. Thus, the main objective of the study is to estimate the rate of reservoir sedimentation in two selected irrigation small-scale dams, Filiglig and Grashito. The study was conducted after two years of their construction and during the time when both reservoirs were dry. To estimate the sediment deposit, pits (grid form) were dug to measure the thickness. The entire reservoir, which is being covered by sediment, was surveyed using a theodolite. Finally, a contour map was developed using the sediment depth of pits. Area of each depth class (contour) was computed using digital coordinator (planimeter). Volume of sediment (m^3) was then computed by taking the depth of pits and area. To compute sediment deposition (ton), average silt density was estimated in the laboratory. The result indicates that, the average volumes of sediment depositions in the reservoirs were 13856m^3 (annual sediment yield of 6928 m^3) and 23974 m^3 (annual sediment yield of 11987 m^3) for Filiglig and Grashito reservoirs, respectively. The economic life times considered during the design phase were 30 and 20.6 years for Filiglig and Grashito reservoirs, respectively. Based on this study, however, the life time of Filiglig Grashito are 5.7 and that of is 4.4 years, respectively. Hence, the economic life time of the two schemes is almost 5 times shorter than that of the values considered during the design phase.

Key words: Reservoir siltation, Water harvesting, Tigray, northern Ethiopia

1. Introduction

The study is conducted in Tigray, Northern Ethiopia. Out of the estimated 60 million ha of agriculturally productive land in Ethiopia, about 27 million ha is significantly eroded, 14 million ha seriously eroded and 2 million ha reached the point of no return; with an estimated total loss of 2 million m3 of top soil per year and an average annual loss from cultivated lands of 100 tons/ha (FAO, 1986). The Northern part of Ethiopia and particularly the study area is well known for sever land degradation and food insecurity (Hagos et al., 1999; Nyssen et al., 2005). To address food insecurity and land degradation in the region, Tigray Water Resources Development Commission had been established. The commission has focused on water harvesting for small scale irrigation and about 12 dams have been constructed with in Adigudom watershed. During the construction of the dams, the local communities had a good participation and were optimistic about the positive change that these projects would bring.

Like the case in many places, early siltation of dams was also assumed to be one of the major treat for the projects. And hence, the estimations were made on the basis of some theories and practices while the reservoirs were designed and set their economic life time. Despite all these efforts, the level of sedimentation observed during the first two water harvesting season was more than expected Among the various reasons for such extra sedimentation rate than the estimated values during designing is lack of adequate past studies, for a sound estimation. In order to plan appropriate measurement interventions, knowledge of the existing sedimentation rate of reservoirs is necessary. Thus, this study was initiated with the major objective of assessing the rate of sedimentation in two selected reservoirs, *Filiglig* and *Grashito.*

2. Materials and Methods

The study sites

The two project sites are located in Tigray, North Ethiopia. More specifically, they are found closer to Adigugom town which is located some 40 kms from the capital town of the region, Mekelle (Figure 1). Filiglig is located between 545365 N and 1464317 E and Grashito between 554713 N and 1460219 E.

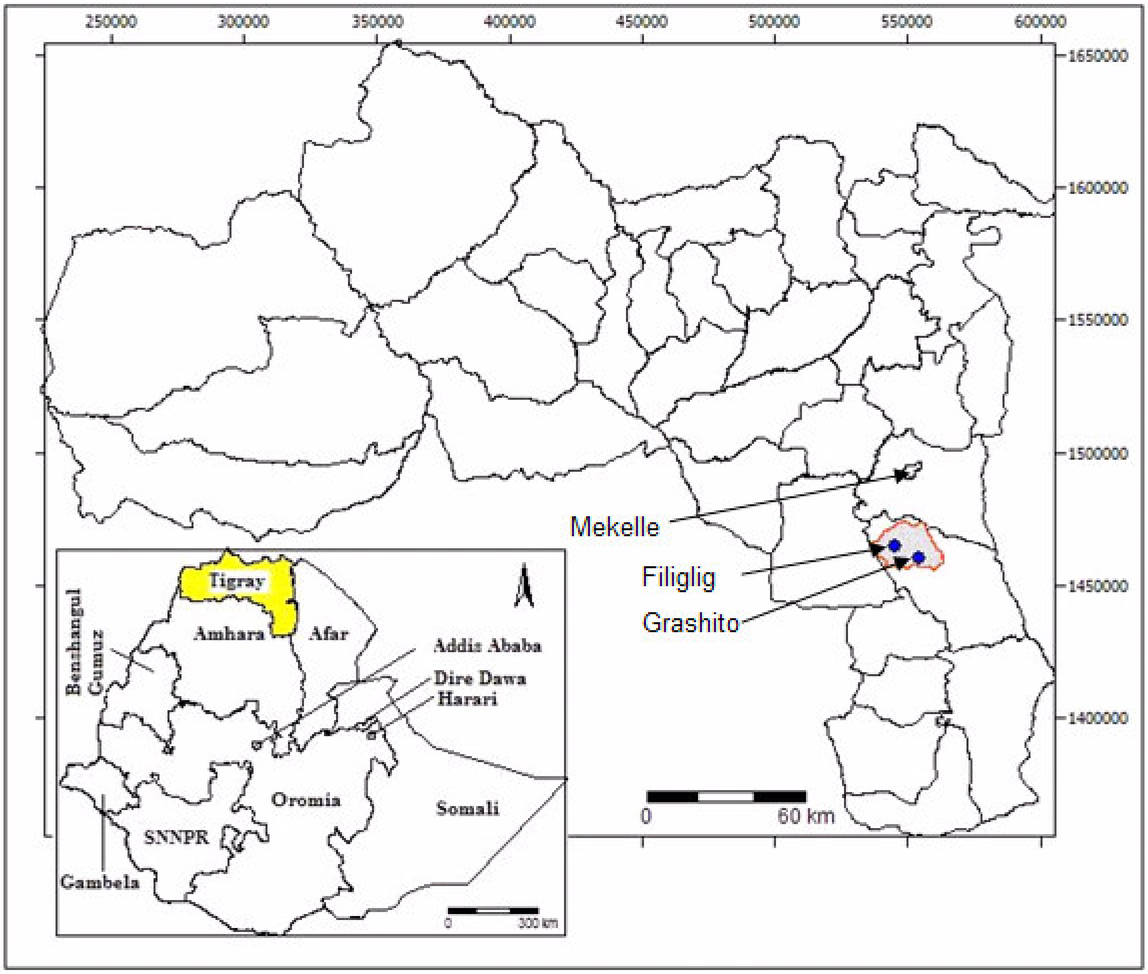

Figure 1: Location map of the study sites

The study area is one of the regions where the rainfall is small (about 460 mm) and show erratic nature. Rainfall pattern, hence, is considered as one of the limiting factors for crop production and as a result large part of the rural community in the study area is food insufficient. Tigray is one of the rugged parts of the Northern Ethiopia that makes agricultural practices difficult and more prone to erosion process (Tamene, in press). However, large part of the study area has gentle slope (<10%) with few steep slopes found in the watershed peripheries that contribute for a higher runoff velocity that contributes to deeper gully incisions at the lower slopes.

Large part of the natural forest in the watersheds have been removed and few scattered trees, dominantly *Olea europea sub spp. africana* are found within church compounds and escarpments which are less accessible (Aynekulu, 1997). To rehabilitate degraded lands and enhance soil and water conservation, some areas were enclosed from livestock and human interference. In addition, some trees were planted and physical soil and water conservation such as hillside terraces were constructed along sloppy areas. Compared to Grashito, the vegetation cover, both trees and grasses in Filiglig watershed is in a better condition. Particularly the grazing land, which roughly covers about 12% of the total Filiglig watershed, significantly controls the further expansion of gullies and hence reduces the amount of sediment load coming to the reservoir.

Figure 2: Selected characteristics of reservoirs/watersheds:(a)-silt deposit overtopping the inlet box at Grashito, (b)- difference in soil colour and level of consolidation to identify the sediment depth (at the periphery of Grashito reservoir, (c)- deep gully incision with in Filiglig watershed which extends up to the grazing land (see Figure 3), (d)- part of the Filiglig watershed peripheries which are bare with few scattered trees

Major characteristics of Filiglig and Grashito reservoirs are summarised in table 1

Table 1: Major characteristics of Filiglig and Grashito reservoirs

Variables	***Unit***	***Filiglig***	***Grashito***
Location	***Projection***: UTM ***Zone***: 37 N ***Datum***: Adindan	545365 N 1464317 E	554713 N 1460219 E
Altitude	masl	2112	2098
Catchment area	km^2	6.12	5.11**
Drainage length	km	10.4	9.3
Drainage density	km/km^2	1.7	1.8
Reservoir storage capacity*	m^3	39697	53201
Age	year	2	2
Economic Lifetime *	Years	30	20.6

* Gebrehawaritat and Haile, 1999
** Haregeweyn et al., 2005

Methods

The silt boundary was first surveyed and then sample pits were opened with a uniform spacing (grid form) and the silt depth was measured using measuring tape. The depth of the sediment was identified using one or the combination of the following major points:

- the difference in colour and texture between the instiu soil and that of transported from the catchment,
- level of soil consolidation and surface hardness,
- level of stoniness,
- Grass and other vegetation remnants which are partly decomposed or un decomposed, and
- Farmers knowledge

Each pit was surveyed using theodolite and contour maps (contour interval = 10cm) were produced using silt depth with 1:500 scale and area is measured using digital coordinator (planimeter). Later the sediment volume (m^3) was computed taking the depth (m) and area (m^2) (Equation 1). Dry bulk density was estimated by taking six samples from the different parts of Grashito reservoir and the mean value was used for both reservoirs. Rate of sedimentation was calculated by dividing the sediment volume to the age of the reservoir (Equation 2). The economic life time (life expectancy) was then derived by dividing the reservoir dead storage capacity (Gebrehawariat and Haile, 1999) to rate of sedimentation (Equation 3). The volume of the silt was then converted to sediment yield (mass) by multiplying silt volume and dry bulk density (Equation 4). Finally, the specific sediment yield (SSY) was calculated by dividing sediment yield to catchment area (trap efficiency is not considered) (Equation 5).

$$SV = area * depth \quad \text{(Equation 1)}$$

$$SR = \frac{SV}{y} \quad \text{(Equation 2)}$$

$$LE = \frac{RSC}{SR} \quad \text{(Equation 3)}$$

$$SY = SV * dBD \quad \text{(Equation 4)}$$

$$SSY = \frac{SY}{A} \quad \text{(Equation 5)}$$

Where,

SV is sediment volume (m^3); **area** is the area of contour of sediment thickness (m^2), **thickness** is the thickness of the sediment measured from the pits (m); **SR** is rate of sedimentation (m^3 y^{-1}) **y** is age of reservoir (year); **LE** is the life expectancy of the reservoir (year); **RSC** is the reservoir storage capacity (dead) (M^3); **SY** is sediment yield (t y^{-1}); **dBD** is dry bulk density (t m^{-3}); **SSY** is specific Sediment Yield (t km^{-2} y^{-1}) and **A** is catchment area (km^2).

3. Results and discussion

Sediment thickness

Comparatively, the sediment thickness of Filiglig was easier to distinguish than that of Grashito which makes the measurement more accurate. This is due to the reason that the original soil of the reservoir has a reddish colour while the sediment is largely darker making a good contrast.

The sediment thickness commonly ranges from 5cm usually around the reservoir peripheries, up to 165cm close to the inlets. The spatial distribution of sediment thickness in the reservoir depends on the original reservoir topography (Haregeweyn et al., 2005).

Sediment yield

As indicated in table 2, the sediment volume (SV) of Filiglig and Grashito reservoirs are 13856 and 23974 m^3 respectively. Taking the two years age of the reservoirs, the rate of sedimentation (RS) of Filiglig and Grashito reservoirs are 6928 and 11987 m^3y^{-1}, respectively. These values are with in the range that Haregeweyn et al. (2005) found. However, the value of Grashito is a bit higher than the value that Haregeweyn et al. (2005) had estimated (7268 m^3 y^{-1}) while the reservoir was at the age of 5 years. This might be due to the variation in sediment yield during relatively longer years (five) than in the first two years.

To compute the sediment yield (SY), the average dry bulk density of Grashito was estimated to be 1.3 t m^{-3}. Since the type of sediment in Filiglig looks quite similar to that of Grashito, the same dry bulk density value (1.3 t m^3) was used. Since many of the reservoirs in study area have got a trap efficiency of closer to 100%, (Haregeweyn et al., 2005; Tamene et al., in press), it was assumed to have less influence in the values of SSY and was excluded from the computation.

The SY of Filiglig and Grashito are 9006 and 15583t y^{-1}respectively. Both values are with in the range 1427 to 76320 t y^{-1} that Tamene et al. (in press) have estimated in the highlands of northern Ethiopia. More specifically, the value of Grashito is quite close to the one that Tamene et al. (in press) have found, 16909 t y^{-1} The SSY of Filiglig and Grashito reservoirs, taking a dry bulk density of 1.4 t m^{-1} and assuming a 100 % sediment trap efficiency, are 1472 and 3049 t km^2 y^{-1} respectively. Still the SSY value are with in the range that Tamene et al. (in press) have found, between 345 and 4935 t km^2 y^{-1},while Haregeweyn (2005) have found vales within the range of 237 to 1817 t km^2 y^{-1}. Regarding Grashito reservoir, the SSY values according to Tamene et al. (in press) and Haregeweyn (2005) were 3019 and 1817 t km^2 y^{-1}, respectively. Hence, the result of this study is very close to that of Tamene et al. (in press).

Table 2: Silt deposit in Filiglig and Grashito reservoirs

Variables	Filiglig	Grashito
Sediment volume (SV) (m^3)	13856	23974
Age (y)	2	2
Annual Sedimentation rate (SR) (m^3 y^{-1})	6928	11987
Reservoir storage capacity (m^3)	39697	53201
Lifetime, estimated (LE) (y)	5.7	4.4
Lifetime, designed (y)	30	20.6
Catchment area (A) (km^2)	6.12	5.11
Dry bulk density (dBD)(t m^{-3})	1.3	1.3
Sediment yield (SY) (t y^{-1})	9006	15583
SSY (t km^{-2} y^{-1})	1472	3049

Economic life time of reservoirs

In the case of the Filiglig site, the life time of the reservoir might decrease from 30 years to 5.7 years considering the current rate of sedimentation while it will be 20.6 to 4.4 in the case of Grashito. Thus, the economic life time of both reservoirs is almost five times lower than the life expectancy considered while designing the projects. This result indicates that, the assumptions or data used during designing the projects have significant shortcomings that might already brought negative socio-economic impact in the area. Although the rate of sedimentation is under estimated during the design phase, it is truly estimated that the level of sedimentation in the Grashito is higher than that of Filiglig. As indicated in table 2, the annual sedimentation rate in case of Filiglig is much less than (by about 40%) than that of Grashito while their economic life time will reduce equally (5 times). This could due to the small reservoir capacity of Filiglig.

Why high level of sediment yield?

The major causes of higher sedimentation in the study area are largely attributed to the bio-physical characteristics of the watersheds and anthropogenic reasons.

Larger proportions of both watersheds (>75%) is under plain to gentle slope ranges (slope<10%) and as a result it has less contribution to sediment yield. Moreover, higher/steep slopes are found along the boundaries of the watersheds far from the reservoir peripheries that still might reduce the impact. Tamene (in Press) has also found less correlation between mean slope and sediment yield.

Another major reason, for a higher sedimentation yield, could be land use in which large parts of both watersheds are under cultivation and being often disturbed and can be easy detached by runoff. Moreover, farmers were observed ploughing very close to the reservoir peripheries that might contribute much loos soil, erodible soil that has been transported over a shorter distance to reach at the reservoir. In case of Filiglig watershed, the contribution of the grazing land in reducing sediment load seems significant. As indicated in Figure 3, the two deep gullies running down the watershed are checked within short distances after they reached at the grazing land and large part of the sediment is settled near the grazing land which otherwise might end up in the reservoir.

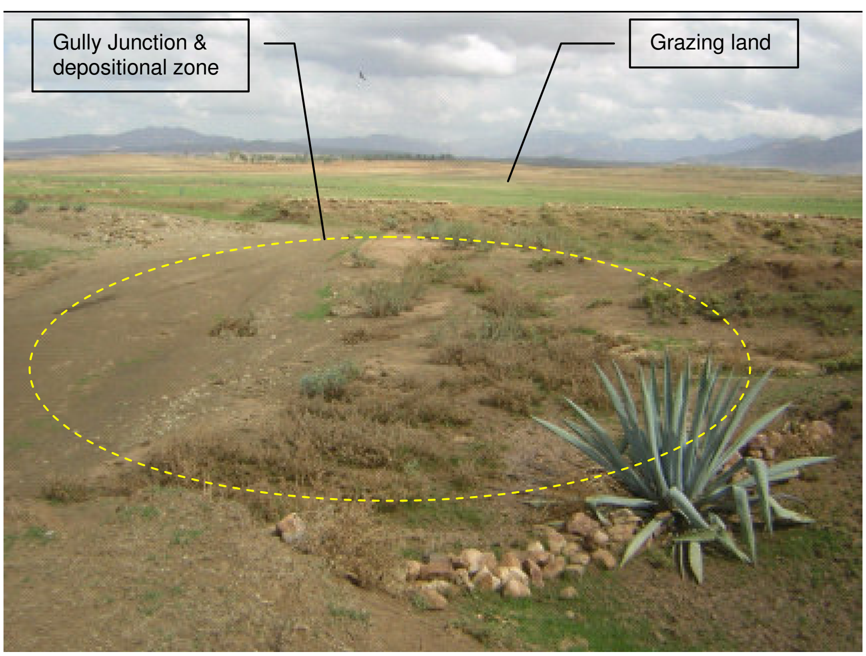

Figure 3: the lower middle part of Filiglig watershed where the grazing land checked the further expansion of gullies

The other possible factor that positively contribute for the sediment load could be the size of the watersheds. Since both schemes have smaller watershed size, the suspended sediment being carried by the flood, might reach the reservoir in a relatively shorter distance with out settling somewhere in the watershed. Lack of proper implementation of watershed development plans to treat major sediment sources by soil and water conservation mechanisms might also accelerate erosion and consequently increased the sediment yield.

5. Conclusion and Recommendation

This study indicates that sedimentation is a serious problem that undermines the economic life time of reservoirs. Lack of proper study or adequate data on reservoir sedimentation in the region was a problem in estimating the economic life time of the reservoirs. This study attempts to provide quantitative information related to the rate of sedimentation and its impact on the economic life of example reservoirs. Although the study was conducted only in two reservoirs, it was possible to observe similar situations in many other reservoirs as well (Haregeweyn et al., 2006; Tamene et al., in press).

The irrigation projects in the study area were built with the intention of bringing significant socio-economic impact. However, if their economic life time is so short like the case in the study area, it will difficult to meet the objectives. Hence, it is recommendable to give attention for sedimentation and related studies before implementing many projects at a time. The author had observed in the field that many of the farmers who were the beneficiaries of the irrigation project have positive attitude on the projects but were highly disappointed with their economic life time.

Since the erosion process occurred in the watershed is believed to be the major source of sediment load, it is important to give due attention for appropriate watershed development or soil and water conservation at least for those places which are major causes for higher sediment yield.

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