Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.5, No.7, 2015
www.iiste.org

Sedimentation and Vegetation Colonization in Shah Tours Gully after Rehabilitation, Kilimanjaro, Tanzania

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Abstract
The Shah Tours gully, rehabilitated under the auspices of the project on Reducing Land Degradation in the Highlands of Kilimanjaro Region, is showing signs of recovery, only one year after rehabilitation. Check dams of stone and wire gabions, and sandbags, measuring 1.0 m high filled up with sediments at a rate of approximately 10.9 t ha^{-1} yr^{-1}. Considering that the average depth of gully is 3.0 m, it is projected that it will take 2 more years for sediments to fill up the gully, if more layers of check dams are added to the existing ones. With respect to colonization by vegetation, there is 100% cover mainly by herbaceous layer (grasses and herbs), but also some shrubs and trees in the gully bed, which was rocky and devoid of plants before rehabilitation. These results will be crucial in planning for other gully-rehabilitation works in the Kilimanjaro region.
Keywords Kilimanjaro ecosystem, land degradation, soil loss, rehabilitation, sediment deposition, vegetation colonization

1. Introduction

This paper seeks to provide an understanding of the recovery of a rehabilitated gully in the Kilimanjaro ecosystem. Such information is important when planning for rehabilitation and post-rehabilitation maintenance and management. Yitbarek *et al*., (2012) observed that rehabilitated gullies suffer from improper maintenance and management. From this observation, we postulate that gullies suffer from improper maintenance and management because governments or land-users do not plan and budget for such activities because of lack of appropriate information.

Gully rehabilitation is expensive, costs range from TZS 2.09[1] million to TZS 333.3 million per hectare depending on the costs of materials and labour employed (Mkanda *et al.*, this issue). Given the high cost of gully rehabilitation, maintenance costs, estimated to be 15% of the initial capital (Atampugre, 2014), are equally high. Therefore, for such works to be done within government budgets, proper information is needed for planning and budgeting purposes.

The significance of the Kilimanjaro ecosystem, the extensive degradation and deforestation it is experiencing, and the response to the land degradation by the Government of Tanzania, with technical and financial support from the Global Environment Facility (GEF) and United Nations Development Programme (UNDP) is described by numerous authors, for example UNDP (2010), Sangeda *et al*., (2014), Magigi and Sathiel (2014), Kangalawe *et al*., (2014). Therefore, suffice it to say that although there is soil erosion by wind in the region (Sangeda *et al*., 2014), part of the government's and cooperating partners' response is focussing on soil erosion by water because the fact that this type of erosion has received more attention by other investigators (Kaihura *et al*., 1997, Lal and Singh, 1998, and Lal *et al*., 2003) implies that it is considered more significant than other causes of soil loss. To contribute to the provision of the necessary information, this study assesses the period it will take the Shah Tours gully to recover after rehabilitation.

2. Description of the Study Site

The Kilimanjaro Region (13,209 km^2) is located in the north-eastern part of Tanzania, lying between 2^0 25' and 4^0 15' S, and 36^0 25' 30'' and 38^0 10' 45'' East (Fig.1). The region is bordered by Kenya in the north, and administrative regions of Arusha, Manyara, and Tanga in the north-west, west, and south-east respectively (United Republic of Tanzania (URT), 2014). It is administratively divided into 6 district councils, namely Siha, Mwanga, Rombo, Hai, Moshi, and Same, besides the Municipal Council of Moshi.

[1] US$1.00 was approximately TZS 1,800.00 in March 2015

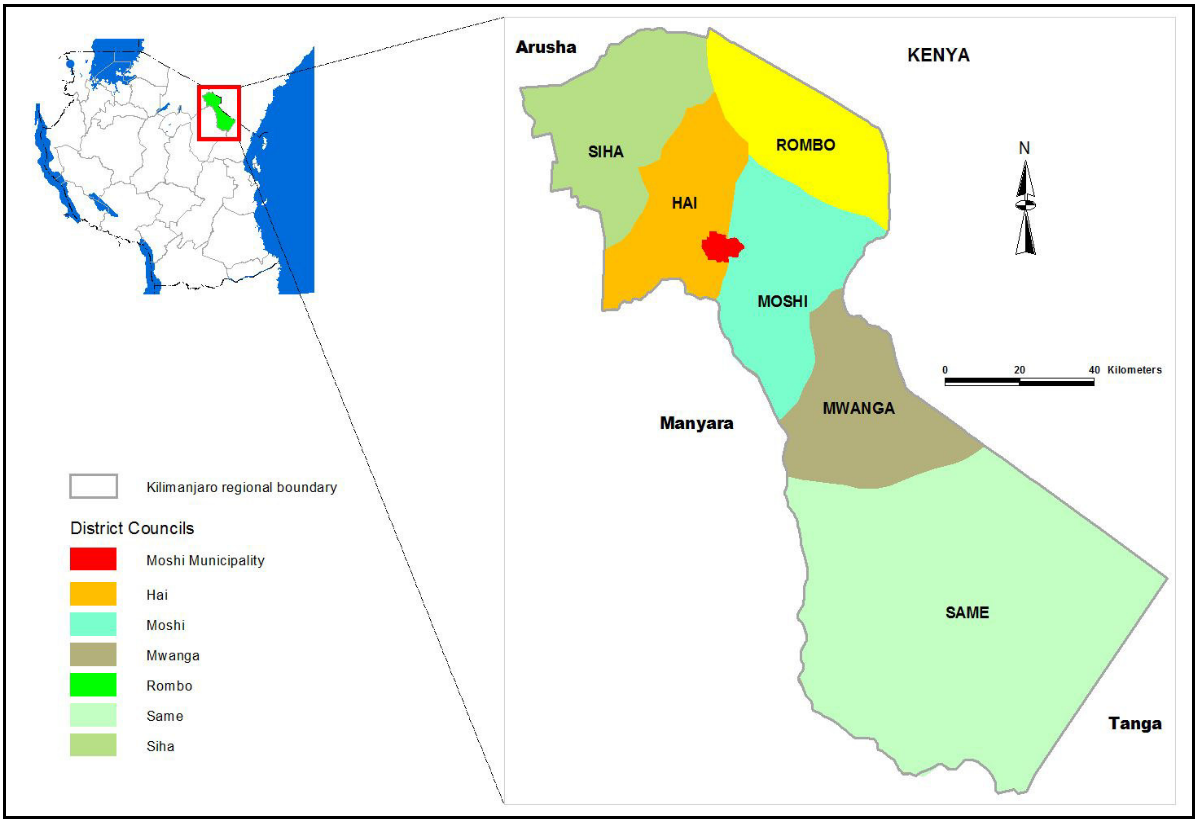

Figure 1: Location of Moshi Municipality, Kilimanjaro Region, Tanzania

The region is prone to soil erosion by water on account of its physical features and anthropogenic activities. A detailed description of the region's vulnerability to water erosion is given by Makundi (2009), Anon. (undated), and Mkanda *et al*., (this issue).

3. Methods

To assess recovery, we monitored soil deposition and colonization by vegetation in the Shah Tours gully in Moshi Municipality, the first council to rehabilitate a gully under the project. While there are several gullies within the Municipality, this one was chosen as a priority by a Ward Development Committee because of its size (Table 1), and threat it posed to property, especially houses and cultivated land.

Table 1: Characteristics of the Shah Tours gully, Moshi Municipality, Tanzania

Parameter	Measurement
Total gully area	18.48 (ha)
Mean top width	5.46 (m)
Mean bed width	2.01 (m)
Mean depth	3.01 (m)
Mean length	1083.3 (m)
Soil loss	432.46 (t ha^{-1})
Soil loss	17.3 (t ha^{-1} yr^{-1})

Before rehabilitation, topographic and corridor surveys were conducted to determine the layout and elevations of the gully so as to facilitate designing of intervention measures. Appropriate parameters needed to estimate soil loss, such as gully width, length, etc., were taken so as to estimate soil loss using the methods of Stocking and Murnaghan (2000), described in detail in the other study by Mkanda et al., (this issue).

Gully rehabilitation was done in January 2014. It involved use of physical structures, such as check dams of wire and stone gabions, interspersed with sand bags, and stems of Vetiver (*Vetiveria zizanioides*) grass planted on the banks because of its effectiveness in keeping soil-loss rates low (Hellin and Heigh, 2002; Truong and Loch, 2004). The key objective of the interventions is to slow water flow and cause sediment deposition, which may subsequently allow natural colonization by vegetation (Anon. 2003). Three check dams were made of wire and stone gabions, while 2 consisted of sand bags, which were used downstream of the gabions where the gully is narrow and the velocity of flow weaker than upstream. All the check dams were 1.0 m high above the gully base, and 0.5 deep into the ground. The ones made of sand bags were reinforced with concrete poles 1.0 m above the bed and driven 0.6 m deep into the ground.

We monitored sediment deposition and colonization by vegetation between the check dams of stone and wire gabions only because the latter are located where the gully is wide enough to allow for establishment of sampling plots. We established three plots, one behind each check dam; sizes varied with base width of the gully, two of them were 3 x 4 m and one was 5 x 5 m, giving a total area of 49 m^2. Sediment deposition was not monitored during the minor dry season because of unavailability of labour to collect data as result of other competitive tasks of the project. The unavailability of data, however, does not negatively affect the results because the deposition during the dry season is not as much as during the rains. Again, we followed the method of Stocking and Murnaghan (2000) to estimate sediment deposition behind each barrier (check dam) using the following calculations:

i) the average depth and of accumulation against each barrier;
ii) the average cross-sectional area (m^2) of the accumulation, using the formula for the area of a triangle (i.e., 0.5 depth x length);
iii) the volume (m^3) of soil accumulated behind each barrier, i.e., cross-sectional area multiply by barrier;
iv) the total volume accumulated to a volume per square meter (m^3/m^2) of the contributing area, i.e., volume accumulated ÷contributing area;
v) the volume per square metre to tonnes per hectare, i.e., soil loss (m^3/m^2) x bulk density; and
vi) the total soil loss as represented by the soil accumulated behind the barrier into an annual equivalent, i.e., soil loss (t ha^{-1}) ÷ time.

Total build-up in each barrier was summed up to determine the average for the area occupied by all the three barriers. Seasonal build up of sediments was monitored in relation to precipitation because rainfall expresses the energy transfer and splash from the action of raindrops, and the input to overland flow of water (Stocking *et al.,* 1988). The formula depicting the relationship between annual precipitation and rainfall energy was used to determine the latter per season based on precipitation data, obtained from the Tanzania Meteorological Authority in Moshi, which was categorized according to the four seasons of the region.

To monitor colonization by vegetation 1-metre strips were made using a metre-tape that was laid out on the ground at 1-metre interval across each plot. Plants were simply identified as life-form categories, i.e., herbaceous layer (herbs and grasses), shrubs, and trees. We followed the methods of Haugland *et al.,* (2005) of identifying the number of plants in each life-form category to determine percent cover within each plot. Percent cover was derived from the crown cover of each plant, which was obtained from the formula:

$$cc = \left(\frac{D_1 + D_2}{4}\right)^2 \pi$$

where D_1 is the first crown diameter measurement, D_2 is the second crown diameter measurement (Mueller-Dombois and Ellenberg, 1974).

Again, the totals for all plots were aggregated. Seasonal percent cover of life-form categories of colonizing vegetation was also monitored in relation to amount of annual precipitation because there is a common relationship between precipitation and grassland peak biomass for East and southern Africa (Deshmukh, 1984, Coe *et al.,* 1976).

4. Results and Discussion

Considering the size of the gully (Table 1), it is not surprising that the rate of soil loss exceeds 12.8 t ha^{-1} yr^{-1}, which is severe, according to Elwell and Stocking (1982). The amount of soil lost is higher than the maximum permissible limit of approximately 12.7 t ha^{-1} yr^{-1}, which is balanced by the rate of soil formation from below (Shaxson, 1970). Soil is, therefore, being eroded at a faster rate than it is being formed, thereby undermining the long-term sustainability of agriculture because soil erosion adversely affects soil quality and productivity by reducing infiltration rates, water-holding capacity, nutrients, organic matter, soil biota, and soil depth (Pimentel *et. al*., 1995; Troeh *et al.,* 1991). Research on soil erosion-soil productivity relationships indicates that, generally, crop yields on severely eroded soils are lower than on protected soils. In the Kilimanjaro, Tanga, and Morogoro regions of Tanzania, a study by Kaihura *et al.*, (1997) revealed that maize grain yield declined at the rate of 38.5, 55.0 and 87.7 kg respectively per centimetre decrease in topsoil thickness. A study by Lal and Singh (1998)also showed that reduction in maize grain yield on moderately and severely eroded soils compared with uneroded soils in Tanzania was 14 to 39%.

The soil loss also undermines sustainability of the environment because dislodged soil particles are transported into water bodies where the suspended sediments have a negative effect on the feeding and breeding behaviour of fish. They cause turbidity thereby limiting the penetration of light, which is essential for primary production (Bootsma and Hecky, 1999). Additionally, sediments seal holes where most of the rock-dwelling cichlids breed (Reinthal, 1993; Munthali, 1997). Gullies, therefore, require some form of intervention to promote a favourable environment for the establishment of plants, which increase soil protection, and allow for sediment deposition (Anon., 2003).

With such high rates of soil loss, it is not surprising that large quantities of sediments (10.9 t ha^{-1} yr^{-1}) are building up behind the check dams (Fig. 2). Seasonally, the deposition is highest during the major wet season obviously because of the high amount of energy (Fig. 2) transfer and splash from the action of raindrops, and the input to overland flow of water. The lowest was during the major dry season, which uncharacteristically had more rainfall energy than the minor rainy season.

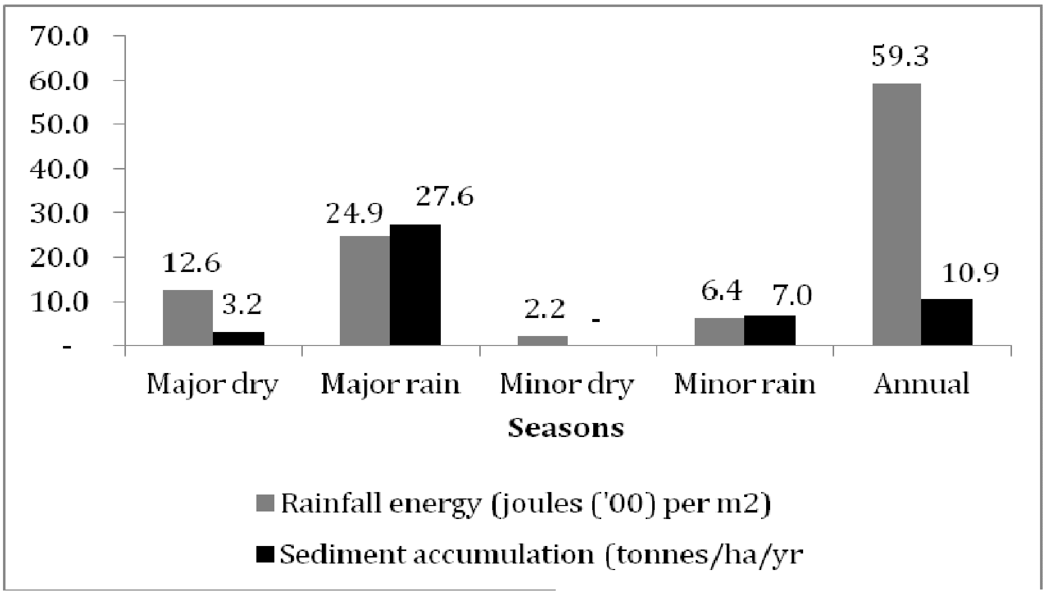

Figure 2 Seasonal trend in build up behind barriers in Shah Tours gully, Moshi Municipality, Tanzania

Within one year, all the three barriers were full of deposited sediments. Considering that the average height of the gully is 3.0 m, one would be tempted to project that all factors being equal, the gully would fill up with sediments within 3 years approximately, if additional layers of check dams are constructed. In the case of Kilimanjaro, inclusion of expenses for post-rehabilitation maintenance and management should commence in 2015 considering that funding by cooperating partners for the current interventions ceases at the end of that year.

With regard to vegetation colonization, the percent cover was 100% after rehabilitation of the gully (Fig. 3), the bed of which was devoid of any plant prior to implementing the intervention measures. The percent cover of the herbaceous layer is the higher than that of shrubs and trees because herbs and grasses have short lifespan (one growing season), rapid maturity, and produce numerous small easily dispersed seeds (Anon., undated). In terms of seasonal percent cover (Fig. 4), it is highest during the minor dry season, and lowest in the main dry because during the latter the bed was rocky, devoid of moisture and substrate on which plants could grow. During the main rainy season, there is not much cover either because of too much water flowing in the gully for plants to colonize, even though the accumulating sediments provide the right substrate. As soon as seeds germinate, they are easily washed away by storm water. However, the plants are able to establish themselves during the dry season when there is either less water or none in the gully; they grow on residual moisture.

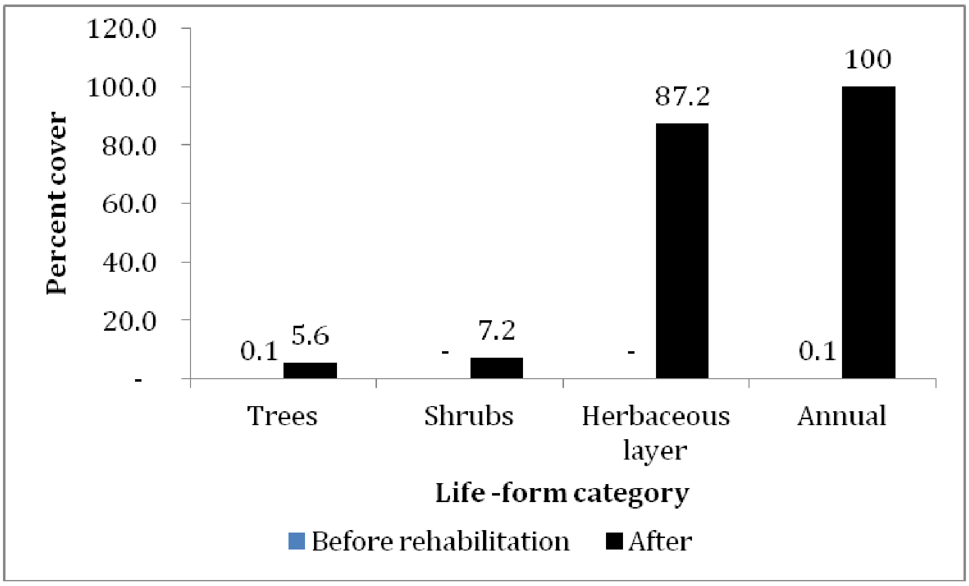

Figure 3: Percent cover of naturally colonizing plants, Shah Tours gully, Moshi Municipality, Tanzania

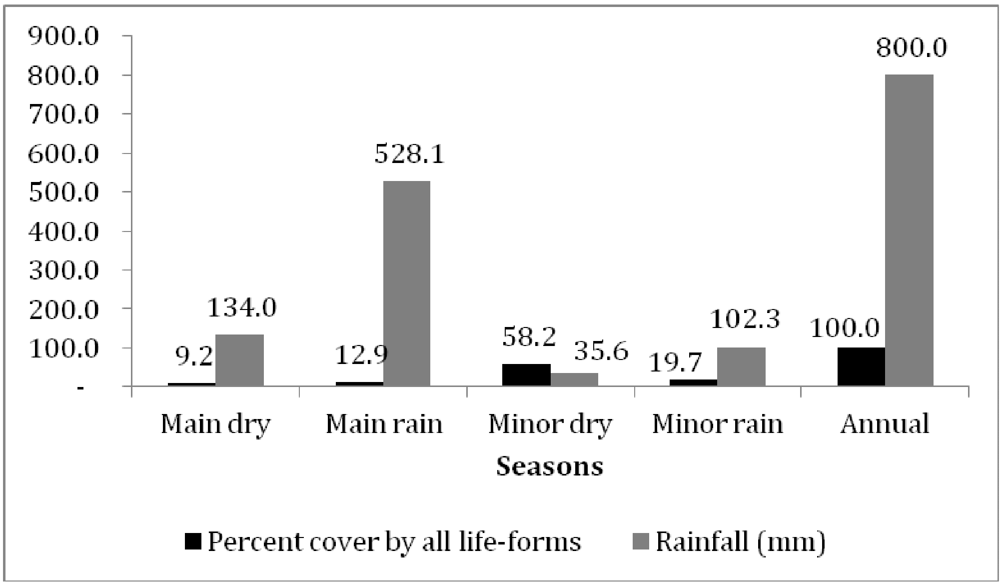

Figure 4: Seasonal trend in plant density, Shah Tours gully, Moshi Municipality, Tanzania

These being results for only one season, it may be contended by some critics that not any meaningful interpretation of gully recovery can be made yet. Notwithstanding the shortcoming, the results suggest than any rehabilitation of large gullies such as the Shah Tours should be done in the first year of a project where the latter have a short lifespan. All surveys, designs, and rehabilitation which consume a considerable amount of time, should be done as early as possible in a project's lifetime. Subsequent years should be devoted to maintenance of the barriers to avoid any failures in the structures. Considering that maintenance will inevitably cost less than installation of the intervention measures, it would be appropriate that inclusion of such activities in government work plans and budgets should be effective from the time rehabilitation is completed.

Conclusion

This study set out to provide an understanding of the recovery of the Shah Tours gully. Results from one year of monitoring sedimentation and vegetation colonization show that after 1 year, the barriers that are 1.0 m high have filled up with 10.9 t of soil ha^{-1} yr^{-1}. This quantity of sediment deposition suggests that the Shah Tours gully could fill up within the three years. There is also natural colonization of the gully bed by vegetation, percent cover by life-forms within the plots is 100%. Although based on one year of monitoring, the study provides the required information, hence considered as indispensable planning for other gully-rehabilitation works in the Kilimanjaro ecosystem.

Acknowledgements
The authors are extremely grateful to the Government of Tanzania, UNDP, and GEF, who are jointly funding the Project on Reducing Land Degradation in the Highland of Kilimanjaro, and this study by implication. They are also thankful to different individuals for their various roles at various stages of the study. Special thanks go to Polycarp Marunda, and Rajab Killaghai for surveying the gully, Martin F. Mgangaluma for designing the intervention measures, Nuru Mkwizu for supervising implementation of the intervention measures.

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