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Spatial and Temporal Extent of Gully Erosion in the Mwisanga Catchment, Kondoa District, Central Tanzania

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Abstract

Soil erosion is an ongoing land degradation process in the Mwisanga Cathcment of the Kondoa District in Tanzania. Gully erosion is particularly significant in the area. Changes in gully size between 1960 and 1992 were mapped on aerial photographs. It was estimated that the rate of gully expansion is 1.1 percent per year. The expansion was found to be a combination of two processes. The first, is side-wall erosion that was estimated to contribute 80.3 percent. This is shown by the increase in the gully width. The second process, is gully head extension, and development of "shoots" leading to new gully systems. This type of gully erosion contributes 19.7 percent. The gullying process has generally converted the arable land to "badlands" by the merging of two or more gullies to form basin-like features. Such land is difficult or impossible to reclaim. Poor land husbandry enhances gully erosion in the area. For example, most of the new gully systems branch from the main gully systems and very often adjoin man-induced features such as footpaths, cattle tracks, and field trenches.

Introduction

The problem of land degradation in Semi-arid Tanzania can be traced back to at least the 1890s (Banyikwa *et al.*, 1979). At that time degradation was localised around settlements. The intensification of agriculture in close proximity to permanent settlements enhanced the degradation in the area (Christiansson, 1972). By the early 1930s such areas around settlements were already severely degraded (Mushala, 1986). The most conspicuous feature of degradation was soil erosion. There are various forms of soil erosion, such as sheet, rill and gully erosion (Berry and Townshend, 1972: p. 241; Christiansson, 1981: p. 152-159). The Kondoa Irangi Hills in Kondoa District, Central Tanzania, were reported to be among the most severely degraded parts of the country.

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Some studies have also been carried out in the Dodoma Region with the aim of establishing the magnitude of soil erosion (Christiansson, 1972; 1978; 1979; 1981; and 1988). The studies involved a wide range of aspects including a morphological study of the degraded landscape in the Kondoa Irangi Hills. However, the studies concentrated on quantifying the rates of soil erosion in different parts of the region by using reservoir in-fill surveys. Other studies include the research conducted at the Mpwapwa Agricultural Research Station, which was focused on estimating surface runoff and soil loss in experimental plots with different treatment. The findings of this study are reported in Staples (1936) and Van Rensburg (1955). Another extensive body of research is that reported in Rapp *et al.* (1973) and involved different studies in different parts of the country. These studies were aimed at obtaining reliable data on the types, extent and contemporary rate of soil erosion and sedimentation in Tanzania. Furthermore, Strömquist and Johansson (1978) carried out a study in the Mtera area that involved estimation of the rate of denudation using the tree mound technique. There have also been recent studies in the area with emphasis on the reconstruction of the land degradation history in Kondoa Irangi Hills (Payton *et al.*, 1992; Mung'ong'o and Yanda, 1993; Payton and Shishira, 1994; El-Daoushy and Eriksson, 1997; Eriksson and Christiansson, 1997).

Although other aspects of land degradation are addressed in the above studies, dynamics of the gullies prevailing in the study areas are not known. It was therefore, important to establish whether the gullies were still active, and the rate at which the gullies had been expanding in the Kondoa Eroded Area. This knowledge is important as gullies transform the productive land into badland. Furthermore, gullies make mechanization difficult as the land is cut into blocks, some of which are inaccessible. A need for establishing the rate of gully erosion in the Kondoa Eroded Area has therefore led to the initiation of this study in Mwisanga Catchment, Kondoa Irangi Hills, Kondoa District, Central Tanzania (Figure 1).

Case Study Area

The Mwisanga Catchment is located above the escarpment of the eastern arm of the E.A. rift valley, at an altitude ranging from 1,620 to 1,800m above sea level. Pre-Cambrian crystalline rocks underlie the catchment with a predominance of migmatitic quartzo-feldspathic gneiss with biotite. Others are; muscovite gneiss with biotite, and quartzite with mica (mainly with muscovite). Shallow soils are common on the hill slopes and hilltops. The pediment slopes are covered by reddish-brown loamy sand to sandy clay loam soils (*Haplic Lixisols*) on upper pediments and red clayey *Ferric Lixisols* on middle to lower pediments. *Lixisols* are referred as soils with marked accumulation of clay in the B horizon (argillic B horizon), has Base Saturation Percentage (BSP) equal to or more than 50, and cation exchange capacity (CEC) is less than 24 me/100 g clay (FAO, 1988).

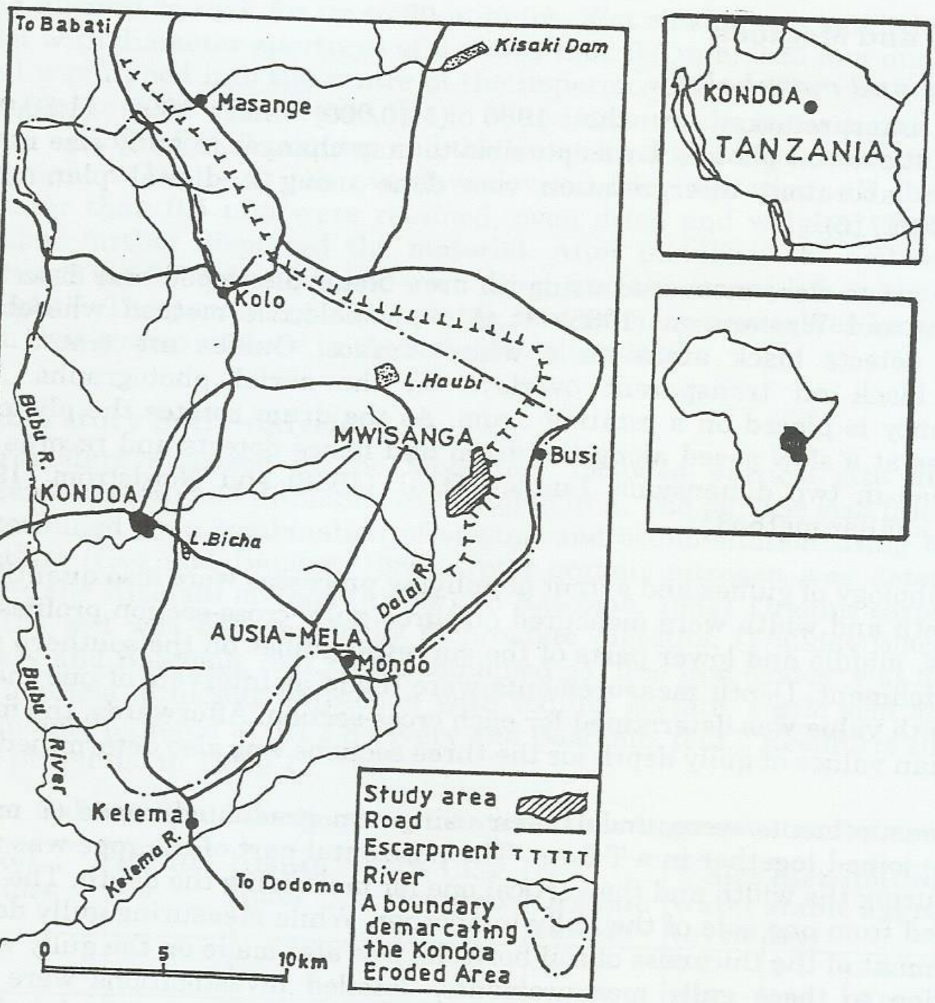

Figure 1: *Location of the Study Area*

The thickness of the soil on the pediment slope increases downslope. The colluvial footslopes have coarse textured soils (*Albic Arenosols* and *Haplic Gleysols*). The alluvial toeslopes are characterized by alluvial sand fans. These young sandy soils are either immature *Haplic Arenosols* or are still actively accumulating (Yanda, 1995).

The mean annual rainfall for Mwisanga catchment area is about 900 mm (based on rainfall data of the period 1958 to 1990 collected from Haubi Mission, about four kilometres from Mwisanga) and distributed between November and May as it is the case for the Kondoa town.

Materials and Methods

Gully size and morphology

Through interpretation of the 1960 (1:40,000) and 1992 (1:30,000) panchromatic aerial photos, it was possible to map changes in gully size in the area. The laboratory interpretation was done using a digital planimeter (Ottplan 700/710).

The gully areas were measured using an area-meter developed and described by Ekman and Wastensson (1968). It is a photoelectric method whereby a photocell detects black areas on a white surface. Gullies are traced and coloured black on transparent overlays on the aerial photographs. The transparency is placed on a rotating drum. As the drum rotates the photocell also moves at a slow speed along the drum and hence detects and records the black areas in two dimensions. Lunden et al. (1986) and Nordström (1989) applied a similar method.

The morphology of gullies and extent of gullying processes were also quantified. Gully depth and width were measured on three gully cross-section profiles, on the upper, middle and lower parts of the surveyed gullies on the southern part of the catchment. Depth measurements were made at intervals of one metre. Mean depth value was determined for each cross-section. Afterwards, the mean of the mean values of gully depth for the three sections was also determined.

Gully measurements were undertaken using two graduated ropes (1 metre intervals) joined together in a T form. The horizontal part of the rope was used for measuring the width and the vertical one for measuring the depth. The rope was pulled from one side of the gully to another. While measuring gully depth, measurement of the thickness of soil horizons was also made on the gully walls. In addition to these gully measurements, detailed investigations were also made along transects within the gullies. Here, records were made of the dominant gully morphologies and gullying processes. Photos were taken to illustrate these features.

Soil Aggregate Stability

The most common measure of aggregate stability is the determination of water-stable soil aggregates. This methodology has been applied in different parts of the world. A similar technique has been used in various studies (Van Bavel, 1952; Low, 1954; Bryan, 1968; Mochoge and Mwonga, 1992). In addition to the determination of aggregate stability, soil properties, which influence aggregate stability, such as organic carbon and iron associated with free iron oxides, were also determined.

The method of aggregate stability adopted in this study was wet sieving. Aggregates of 5-10 mm were separated from the air-dried samples by dry sieving. About 50 grams of the 5-10 mm sample were put into 100 ml of water and allowed to soak for up to 30 minutes. Wet sieving was carried out using a nest with diameter apertures of 2 mm, 1 mm, 0.5 mm, 0.25 mm and 0.100 mm. Soil was tipped into the centre of the uppermost sieve. The nest of sieves was lowered into the tube at an angle to eliminate air locks in the sieves. The sieves were agitated for 17 minutes and the water level was kept constant in the tube throughout by using the overflow device. After agitation, all the materials greater than 0.5 mm were retained, oven dried and weighed. Puddling in a beaker further dispersed the material. After puddling, the soil was washed through the 0.5 mm sieve and oven dried, and the stones left on the sieve were weighed. The percent of water-stable, non-primary aggregates larger than 0.5 mm that were contained in the soil was determined.

Laboratory Soil Analysis

Parameters analysed in the laboratory included particle size distribution, organic carbon, and dithionite extractable iron. The particle size fractions were determined by a combination of sieving and sedimentation using the pipette method (Gee and Bauder, 1986). Total organic nitrogen was determined by using the Kjeldahl method (Avery and Bascomb, 1982). Organic carbon content in the soil was determined by dichromate digestion (Walkley-Black method; Avery and Bascomb, *ibid.*). Iron combined as "free iron oxides" was determined by a single dithionite extraction with sodium acetate, acetic acid and sodium dithionite buffered at pH 3.8 (Avery and Bascomb, *ibid.*). Results of the analysis are presented in Table 1.

Table 1: Size Distribution of Water-stable Aggregates in Percentage

Soil Class	Profile No	Depth (cm)	% Clay content	% Organic carbon	% Size distribution of water stable aggregates (oven dry)			
					3-2 mm	2-1 mm	1-0.5 mm	0.5-3 mm
Haplic Lixisol		Ah(0-25)	26	1.4	54.7	8.3	6.0	69
	1	Bt2(27-76)	28	0.5	0.8	3,3	9,6	14
		Bt3(76-90)	37	0.3	0.6	2.6	7.0	10
Lixisol Ferric		Ap(0-26)	34	1.4	14.2	8.4	8.0	30
	2	Bt1(26-40)	40	0.6	0.7	2.8	14.3	18
		Bt2(40-120)	60	0.6	0.3	4.5	17.3	22
Eroded Lixisol	6	2Bt(40-70)	33	0.1	3.1	5.7	9.4	18
		BCt(70+90)	30	0.2	0.6	1.9	5.7	8
			34	1.4	14.2	8.4	8.0	30
Haplic Arenosol	8	2AC(14-36)	18	0.2	0.2	8.5	6.9	17
Haplic Lixisol	10	Bt(20-35)	41	0.2	1.5	3.9	11.2	1.7
Ferric Lixisol	11	B1(0-34)	41	0.1	1.0	1.6	4.2	7
		Bt2(34-140)	42	0.1	4.7	9.2	12.6	27

Notes: The profiles represents less degraded soil with A horizon (Profiles No. 1 and 2), and stripped soil with exposed B horizon (Profiles No. 6 and 11). Profiles 8 and 10 are not complete because the rest of the samples had only fine aggregates.

Temporal Changes in Gully Sizes

The 32 years (1960-1992) gully erosion was quantified by using aerial photographs in order to compare the size of the gulled areas in 1960 and 1992. However, this assessment only gives a generalised overview because of the large time interval.

The results show significant gully expansion between 1960 and 1992 (see Figure 2). For example, the surface area of mapped gullies was 56.6 ha in 1960 and 76.2 ha in 1992, thus an increase of 19.6 ha, which is about 34.6 percent for 32 years. The rate of gully expansion is thus calculated to be 1.1 percent per year, indicating significant ongoing gully erosion in the area. This area with gullies is larger than that reported in the Leribe (Mathokoane) and Maseru (Sofonia) catchments, but is smaller than that reported in the Mohales Hoek (Ha Khitsane) catchment, all three situated in Lesotho (Lunden *et al.*, 1986; Nordström, 1989: p. 67). The rate of gully expansion in this area is higher than that reported from the Saint Michael's Mission area (Mhondoro Communal area) in Zimbabwe (0.5 % per year) (Keech, 1992: p. 58).

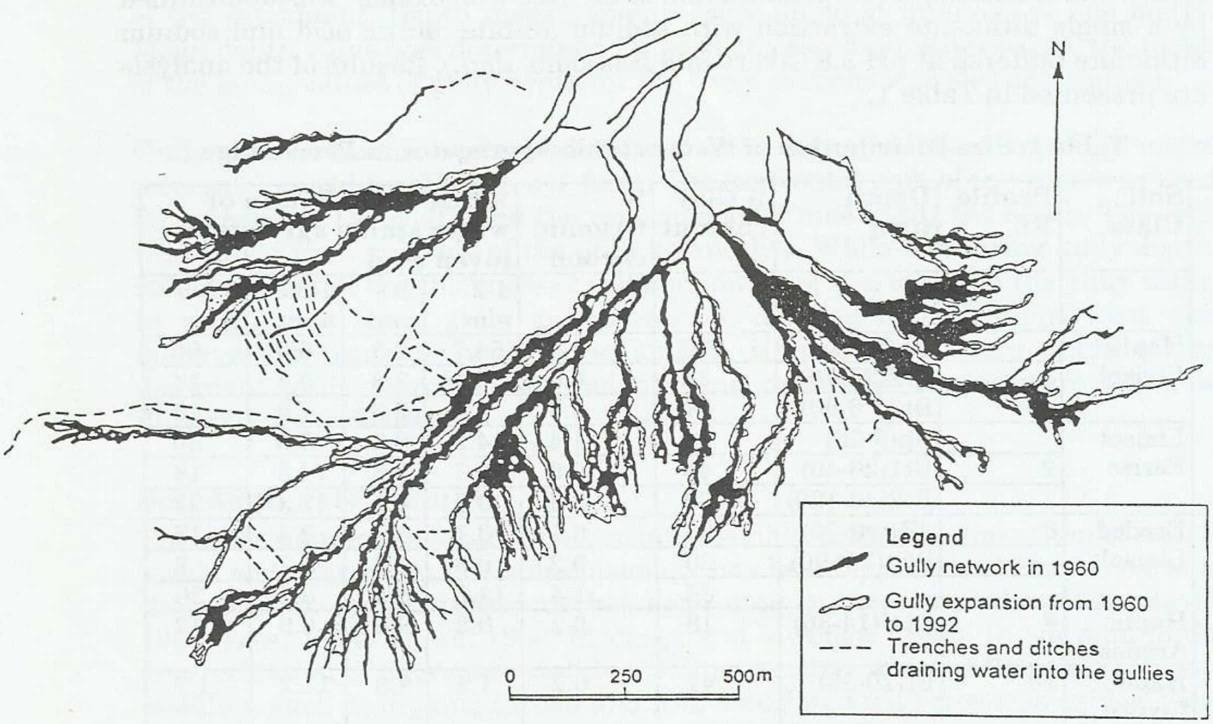

Figure 2: ***Gully Erosion – 1960 & 1992***

The estimation of the rate of gully expansion is based on two observations separated by a long period of time during which there may have been extreme events of gully expansion, as described by Stocking (1987). Hudson (1981) also suggests that major erosion events can take place in relatively short periods. For instance, it was observed in Zimbabwe that the major changes in the size of one of the prominent gully systems in the Saint Michael's Mission area occurred during the period between 1946 and 1956 (Keech, op. cit.).

The gully expansion in the area is found to be a combination of two components. The first and more pronounced involved side-wall erosion estimated to contribute 80.3 percent of the expansion. This is shown by the increase in the gully width. The second component, which is less pronounced, was the gully head extension and the development of "shoots" which are new gully systems. This type of gully erosion contributes 19.7 percent to gully expansion. Similar gully erosion processes are reported in other parts of the world such as New South Wales (Australia) (Blong *et al.*, 1982 and Blong, 1985) and Zimbabwe (Keech, op. cit.).

Figure 2 shows that most of the new gully systems that developed between 1960 and 1992 branch from the main gully systems and very often adjoin man-induced features like footpaths, cattle tracks, and field trenches. Such features act as drainage lines, draining water into the main gully systems. There are often differences in the base levels between the trench floor and the gully floor. This generates "waterfalls" that impose more erosive energy on the gully wall, and thus enhance the erosion that follows the alignment of these features. This illustrates the role of man in gully erosion in the area.

During the gully survey it was observed that the walls of the active parts of the gullies were vertical (70-80^0 slope). Such vertical gully walls are not stable and are thus subject to failure, as reported by Crouch and Blong (1989) in Eastern Australia. This kind of gully morphology facilitates slumping. Gully undercutting leading to gully wall collapse is also common and contributes to gully side-wall erosion (Figure 3).

The undercutting processes are facilitated by lithological differences in the deeply weathered saprolites, whereby the most resistant rock to weathering (quartzitic gneiss) forms fluted gully walls while the underlying, less resistant, more clayey saprolitic material (micaceous schist) is differentially eroded. This finally leads to the collapse of the fluted saprolite from the gneiss. The temporary damming of water by fallen blocks of saprolite/soil collapsed from the wall of the gully causes accelerated erosion. When the dam fails, high-energy flow is promoted that can erode and transport significant amounts of sediments (see Figure 3).

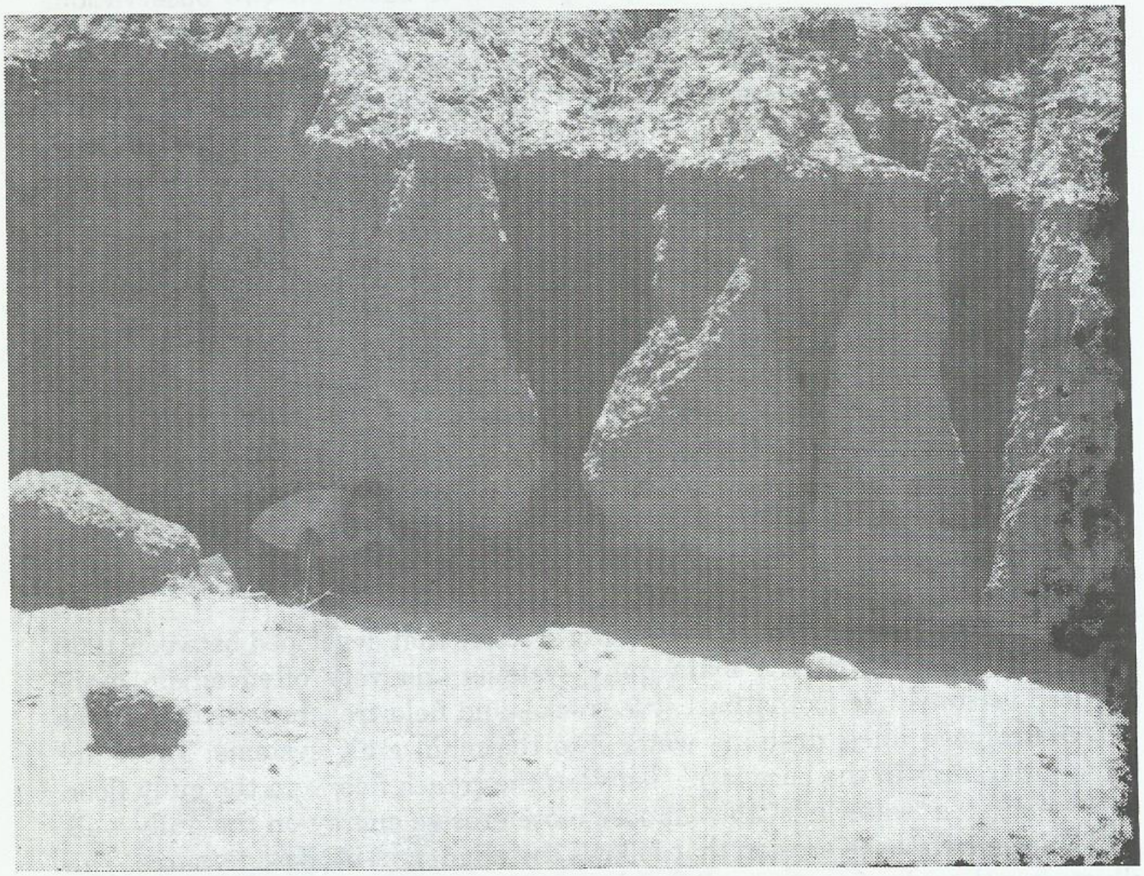

Figure 3: *Undercutting Process*

Some Physical Factors Influencing Gully Erosion

A number of factors have contributed to the gully erosion in the area. Land and crop management systems have enhanced soil degradation in the catchment. For example, deep, narrow trenches were dug on the upper slopes to protect crop fields from wild pigs. As a result, such trenches act as waterways draining water down-slope into the gullies. Consequently, such features have enhanced gully advancement. Similarly, ditches dug as boundaries between different agricultural fields, and also to drain water from the upper slopes into the adjacent gullies, have accelerated gully erosion. Cattle tracks and footpaths have had similar effects in the southern part of the catchment.

Soil erodibility has a profound effect on the gully formation. The A horizon of *Lixisols* has a higher percentage of stable soil aggregates than the B horizon (see Table 1). This implies that in the less degraded *Lixisols* the A horizon is more resistant to water detachment and removal than the argillic B horizon.

The differences in soil aggregate stability are influenced by differences in the organic carbon content, which is higher in the A horizon compared to the argillic B horizon. The organic matter content acts as soil structure stabilising agent. Well developed structure of the A horizon enhances water infiltration; thus, the less degraded soils have higher infiltration capacities, compared to the degraded ones (Yanda, 1999). This is particularly because of the textural and structural contrasts between the A and B horizons of *Lixisols*. The removal of the A horizon material leads to reduced infiltration capacity of the surface and increased surface runoff. Again, the underlying soil horizons are less stable, thus the gully formation processes seem to increase when rills are formed on the B horizon.

Conclusion

It is evident that there is continuing gully erosion in Mwisanga Catchment. Other erosion processes, including sheet and rill erosion, are common in the agricultural fields. It is, however, difficult to draw a definite conclusion on whether gully erosion is currently the most dominant type of soil erosion because it has not been possible to estimate the rate of sheet and rill erosion. However, gully erosion is the most destructive type of land degradation because the gullied part is considered a "badland" and thus cannot be put to any land use. Areas affected by sheet and rill erosion can still be productive under an ecologically sound land management system, an area that calls for further research.

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