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FORMATION AND DISTRIBUTION OF THE VALLEY SIDE GULLIES IN CENTRAL UGANDA

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Abstract: The dry subhumid area of Central Uganda forms part of the 'cattle dry corridor' characterized by relatively low but unpredictable rains, poor resource development, high livestock population and increasing human population densities leading to environmental degradation problems including gully erosion. This paper examines the characteristics of gullies and the main intrinsic and extrinsic variables affecting their spatial distribution in the central drylands of Uganda. A field survey was used. Preliminary studies were done covering two sub counties in the district of Nakasongola, and then more detailed studies narrowed to 2 sub catchments close to Migera town. Ten gullies were sampled for detailed measurements. The spatial distribution of all gully scars were identified in the field and their positions recorded using a Global Position System. This data was imported in Geographical Information System in ILWIS 3.2 environment. Field measurement of gully dimensions (lengths, width and depth) was done and the data used for computing the volume of soil loss from gully erosion. Results revealed that in general land degradation by gullies in this dry sub humid area is an increasing problem, which is mainly attributed to human activities of livestock grazing and movement. The extent and magnitude of erosion by gullies, however, is controlled by soil characteristics and topographic variations. The gullies were largely discontinuous, dominantly of linear pattern and rarely exceeded 2 m depth. There is urgent need to address the problem of degradation by gullies, while taking into consideration the controlling factors, in order to ensure sustainable rangeland management.

Keywords: Dry sub-humid, gully erosion, land degradation, Nakasongola, Uganda

I. INTRODUCTION

Degradation resulting from gully erosion is a serious problem in many fragile environments such as dry lands (Dregne, 2002; Boardman et al. 2002). Gully erosion is a conspicuous phenomenon that merits special attention when considering land degradation, as well as in terms of conservation. Recent studies and observations (Nyssen et al. 2007; Poesen et al. 2002; Morgan, 1995; Singh and Agnihotri, 1987; Lal, 1985) indicate that soil losses by gully erosion are far from negligible in a range of environments and that gullies are important and effective links for transferring water and sediment from uplands to valley bottoms and permanent channels. Consequently, there is a particular need for monitoring of gullies, and experimental and modeling studies of gully erosion, as a basis for predicting the effects of global changes (land use and climate changes) on gully erosion rates as well as on the contribution of this soil degradation process to overall land degradation (Poesen et al., 2002). Once gullies develop, they increase the connectivity in the landscape and the problem of degradation intensifies.

Gullies are a major source of land degradation and their presence is a strong indicator that erosion is out of control and that the land is entering a critical phase that threatens its productivity (Laflen and Roose, 1997). Gullies are almost always associated with accelerated erosion and therefore with landscape instability (Morgan, 1995). The removal of plant cover and compaction by large numbers of livestock usually leads to high runoff generation, which on sloping lands may concentrate into gullies (Boardman, et al. 2002; Allsopp et al. 2007; Strunk, 2000). Achten et al, (2008) also indicated that land degradation by gully erosion is common in South Eastern Tanzania.

The initiation and development of gullies, however, is very complex (Leopold et al., cited by Morgan, 1995) and varies from one area to another. In some areas piping or tunnel erosion due to sub surface flow processes (Nordström, 1989; Whitlow, 1989; Singh and Agnihotri, 1987) is the main cause. Zhang et al. (2007) observed that gully development in north eastern China was promoted by freeze-thawing cycles in summer processes and was affected by type of agricultural operations and crop in summer. Land use change can induce the development of gullies as observed in many environments; e.g. Mose and Holden (2009) in Ethiopia. Studies in Tanzania by Achten et al. (2008) found that gully erosion was positively associated with rough terrain and negatively with population density. They further observed that on the Makonde plateau occurrence of gully erosion was associated with the presence of roads, while on the inland plains it was predominantly found in fields. In Lesotho, the primary cause of gully formation was found to be roads and paths (Showers, 1996). The areas of occurrence of linear landslides are also potential points for gully erosion. In Uganda, gully erosion was reported during the 1930s but the problem has increased particularly in grazing dry lands of Nakasongola, Karamoja and Mbarara (Nakileza, 2006; Olson and Berry, 2003; NEMA, 2002) due to continued poor land practices. There are, however, limited studies on the evolution and development of gullies in Uganda. The objectives of this paper were (i) to characterize the gullies and (ii) examine the factors accounting for their formation and spatial distribution in the dry sub-humid lands of Nakasongola district, in central Uganda.

II. STUDY AREA AND METHODOLOGY

2.1 Study area

The central dryland area is located approximately between 1^{o} 10' N and 1^{o} 40' N longitude and 32^{o} 5' E and 32^{o}50' E latitude (Fig. 1). It mainly covers the districts of Nakasongola, Kiboga, part of Luwero and Mubende.

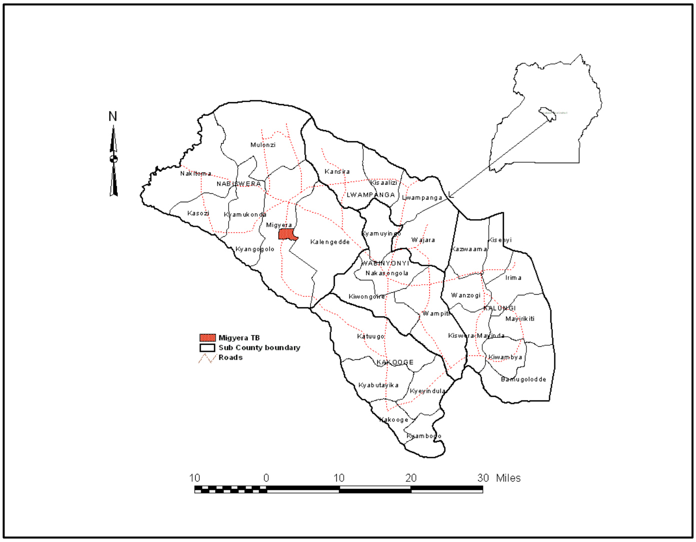


Fig. 1 Location of Nakasongola dryland area in central Uganda

The geology of the area though not studied in details generally consists of mobilised and intrusive granites derived from the 'basement complex' rocks. The geomorphology of the area is less complex; the landform is highly subdued. Tanganyika and Acholi surfaces underlie the area. McConnel cited in Pallister (1960) described and termed the Acholi surface as valley-floor peneplain, a surface of accumulation generally attributed to the lower Pleistocene. The most dominant, however, is the Tanganyika surface, which belongs to the end-tertiary and covering much of the hills and hill slopes. It is a peneplain consisting of pediments, which have undergone a varying amount of degradation and slopes of $<5^{o}$ are a rule (Pallister, 1960). Thus, much of the land is gently to moderately undulating with broad bottom valleys. Some massive granitic rock outcrops occupy areas around the town of Nakasongola.

Lateritic ironstone is frequently found on this Tanganyika surface but is not prominent as on the remnants of the Buganda peneplain. The laterite is frequently overlain by soils and is encountered in pits on the crests and sides of hills. But on the lower slopes of the pediments the lateritic crust frequently emerges from under the soils and may increase the sensitivity of these areas to heavy runoff and soil loss.

In the north, along the shores of Lake Kyoga and the valley of the River Kafu, there are extensive areas of alluvium and a series of terraces.

In terms of climatic conditions the area can be described as relatively moist, warm and dry (dry sub humid). The mean monthly rainfall is about 100 mm but the mean annual rainfall ranges from 800 to 1000 mm (Fig. 3). Droughts are observed to be frequent thus affecting soil cover and agricultural productivity. Rainfall erosivity is moderate (Wortmann and Eledu, 1999). The rainfall erosivity computed using the modified Fournier-Index ranges from 100 to 200 (UNEP, 1987; Yost and Eswaran, 1990), and is thus similar to other dry land areas in the country. Occasionally, the area receives erratic torrential rains that contribute to heavy runoff and soil erosion including gullying. The mean annual maximum temperature is about 30^{o}C but the mean minimum temperature falls to about 17.5 ^{o}C.

Under limited soil and vegetation cover, wind can be a very effective medium for the transport of sediment (Wiggs, 1997 cited by Holmes, 1998). Strong winds occur during the dry season mainly in February to March causing wind erosion particularly on patchy works and cultivated crop fields. The area is mainly drained by small rivers and streams, some of which are seasonal. Most of these rivers/streams empty into seasonal swamps that eventually drain into Lake Kyoga.

The vegetation, which is greatly modified by human activities, is a function of drainage, soils and geomorphology. Vegetation serves as a control on surface processes and as an indicator of prevailing climatic conditions (Holmes, 1998, p.49). Changes in vegetation covers can be used as an important indicator in estimating the rates of soil degradation in general. The dominant vegetation types occupying the hillsides and hilltops include the dry acacia, moist combretum savannahs and moist thickets. The grassland savannahs are also common in open but relatively flat areas. Dominating the broad valley bottoms are the seasonal swamps, which are covered by various grass species. Papyrus swamps are limited to the few permanent swamps occurring on the out skirts of the district but mostly around Lake Kyoga. Very few remnants of woodland forests exist in the area.

The soils of the study area belong to the ancient lake sediments overlying the Tanganyika surface and its dissected remnants. A large part of the area is dominated by red ferrallitic soils or plinthic feralsols (FAO system) of sandy loam and sandy clay loam type. The ferrallitic soils have little reserve of weatherable minerals, deep horizons not clearly differentiated and Kaolinite (1:1) as the main clay mineral associated with Fe, and Al oxides. Langlands (1974) categorised them as fair productivity soils, which occupies much of the area described as the cattle corridor. The hydromorphic soils, rich in sodium minerals and belonging to the ancient lake sediments, occur in areas close to Lake Kyoga and River Lugogo low-lying swampy areas. Their texture varies from sandy to loamy type while the pH ranges from acidic to neutral. Soil erodibility is low, and the soils especially in the north-west part of the area are observed to harden on drying. Soil productivity is generally high as computed by UNEP (1987) basing on texture, depth, pH, fertility, drainage, organic matter, workability and water holding. However, nutrients and water are known to constrain crop productivity (Wortmann and Eledu, 1999).

2.2. Materials and methods

The study adopted a field survey approach using field measurements, supported by interviews of key informers. In order to understand the spatial distribution gullies in the study area (Fig.1), a field survey and mapping was undertaken. The positions of all observed gullies were recorded using a Global Position System (GPS) and data was captured in a GIS environment (ILWIS ver 3.2, Netherlands). Determining the distribution pattern of gullies is not only important in analysing the problem of degradation but also in drawing up strategies for improved soil and land management. The main parameters related to gullies, notably slope form, land cover, land use intensity and soil type were also recorded. Gullies were classified based on Imeson and Kwaad as cited in Nordström, (1989). Aerial photos and images are reported (e.g. Laflen and Roose, 1997) to be useful in mapping gully erosion. However, these were not very helpful in mapping gully erosion in this area except for interpretation of general land cover. The aerial photos available date back to 1960s but were very unclear and probably because channel erosion had not yet formed in the area.

Field measurements of gully width, depth and length were undertaken using a tape measure in order to characterize the gully profiles, to estimate the sediment loss and area of land affected. Laflen and Roose (1997) argue that channel erosion (gullies and rills) is best measured volumetrically, provided rates are such that sufficient precision can be gained. The pressing need for more reliable data, relevant for determining priority problems at national or international level, has been stressed by Dregne (2002).

Erosion pins, installed in April 2001, were used to monitor the rate of head-ward erosion for one of the main gullies in the Bizibitukula sub catchment (Fig. 2). The annual rate of gully advancement was computed based on the age, as determined from the local interviews, and the present length of the respective gullies. The local community, including pastoralists and cultivators in the area, was interviewed in order to gain further insight on possible gully formation and corroborate this data with field observations.

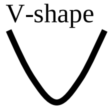
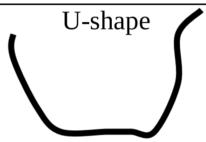
III. RESULTS AND DISCUSSION

3.1. Characteristics of gullies

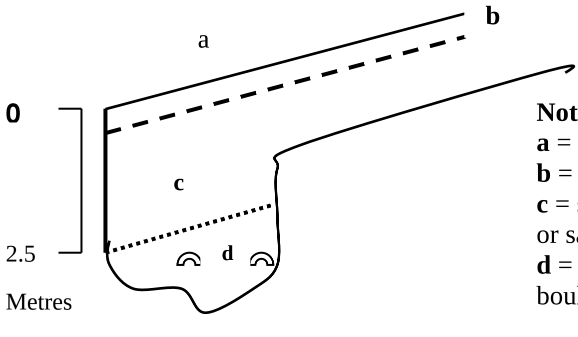
Gullies in the area were characterized in terms of their morphological features, namely: profiles or sections, dimensions (depth, width and length) and spatial distribution.

The type of gully erosion identified in this area was discontinuous valley side gullies (Table 1).

Table 1. Generalised morphological sections of prominent gullies in Nakasongola, Uganda

Landscape position	Form	Remarks
Upper and mid slope	V-shape 	Common where the soils are sandy or clay loam and compacted
Lower slope	U-shape 	Clearly developed where soils are sandy or sandy loam e.g. Kyamukama

A sketch of a discontinuous gully section on the lower pediment



Note:
a = ground surface
b = shallow top soil
c = sub-soil (sandy clay loam or sandy loam)
d = deposited sand or exposed boulders at gully bottom

The gullies were observed at any point along the slope as a headcut. The headcuts included cattle tracks, terrace or anything including weathered rock exposures that provided a break in the soil surface or concentrated the runoff. At each point a small headscarp forms and as this retreats headwards a trench is left down-valley with a debris fan spreading out from its toe to form an alluvial fan. Elsewhere, in many dry valleys discontinuous gully erosion were also noted to begin at several points where vegetation cover was broken (Selby, 1982).

As illustrated in Table 1, the valley side gullies were categorised as ranging from V-shaped to U-shaped under overland flow, and occurring anywhere in the landscape except valley bottoms and hilltops. In some of these areas, complex gullies have formed due to variations in the slope, soils and more secondary deepening caused by scouring action of the runoff as explained below. The gullies have developed more or less perpendicular to the main valley line following local surface runoff concentrations cutting into the hillside. Based on the level of their development, the gullies in this area are described as incipient gullies.

The results of gully dimensions (width, length and depth) measured in the study area are summarised in Table 2.

Table 2. Average measurements of prominent valley side gullies in Nakasongola district

Gully no.	Location	Age (years)	Length (m)	Width (m)	Depth (m)	Soil loss (m^3)	Mean retreat ($m\ yr^{-1}$)	General pattern
1	Bizibitukula	10 – 15	150	1.5	0.5 - 1	86.8	10 - 15	Dendritic
2	Bizibitulula	10	80	2	0.45		8	Linear
3	Kabojja	>15	80	2	1.5	80.5	5	Linear/ dendritic
4	Kyamukama	>10	140	3	2.5	306.6	14	Linear
5	Bujumbura	5 – 10	80	1	0.5 - 0.8		8 - 16	Linear
6	Sebwato	<5	65	0.7	1	16.3	10	Linear
7	Uweso Road	20	900	3	0.9	687.3	45	Linear

Field observations revealed that 70% of the gullies are of linear pattern closely linked to the roads and tracks. Very few of the gullies were of dendritic pattern. In general, gully depth rarely exceeded 1 m whereas the width ranged from 0.5 m up to 3 m. Gully density is generally low approximating to 1 gully per km^2. The spatial distribution of gullies in the study area is illustrated in Fig. 2. Gullies were observed in almost all the villages studied in Nalukonge, Sija, Kaboja, Kyamukama, Bujumbura and Kyalapande. The gullies were unevenly distributed, and about 68% of the gullies occur within relatively short distances of a few metres particularly around Migera township in Nalukonge village. This is probably explained by reduced vegetation cover among other factors as discussed below.

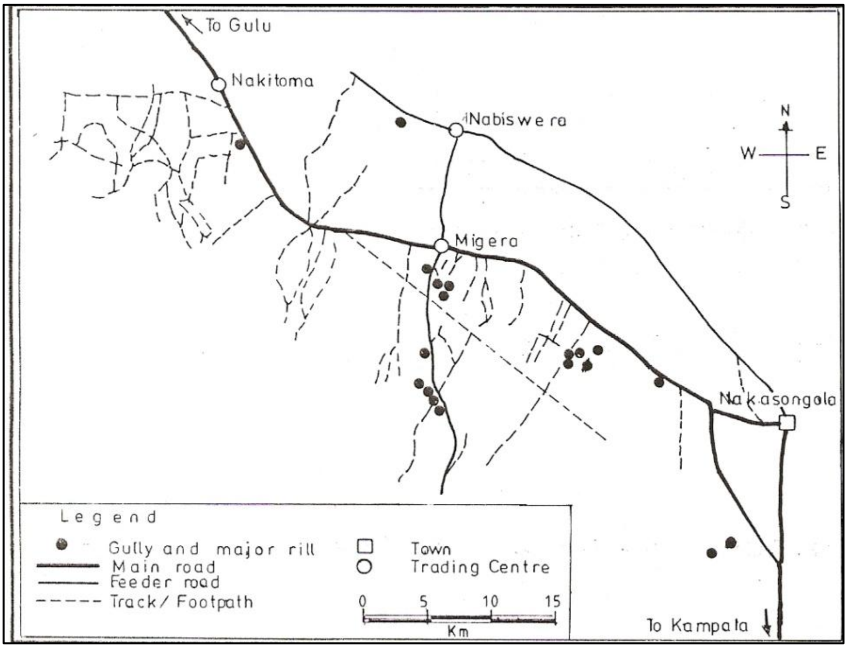


Fig.2 Spatial distribution of the gullies in Nakasongola district, Uganda

3.2. Factors influencing gully formation and distribution

The main factors influencing the formation and therefore distribution of gullies include bio-physical (e.g. slope form and angle, geology, vegetation cover) and socio-economic (e.g. footpaths and livestock tracks). These factors operate interactively as also pointed out by Whitlow (1989). Reduced plant cover or absence of it was widely observed in a number of patchy spots in the area. The reduction in cover or its absence was mainly attributed to overgrazing and frequent droughts, which have consequently induced increased runoff generation (Author 2006). Related observations in Zimbabwe by Whitlow (1989) and in Lesotho by Nordström (1989) demonstrate that a decrease in rainfall causing drought conditions would lead to deterioration in vegetation cover. However, decrease in vegetation cover hence bare land in some places in Nakasongola, was largely due to coupled termite activity, livestock grazing and trampling. Bare lands are commonly associated with generation of high rate of runoff flow and volume. This is supported by field measurement of runoff (Nakileza, 2006), which was observed to be greater from the bare lands compared to the vegetated areas (Fig. 3). In general, the pattern of runoff losses indicated relatively higher losses of surface runoff from the severely degraded plots (321 mm yr^{-1}) compared to the moderately degraded ones (261 mm yr^{-1}) as reported by (Nakileza, 2006).

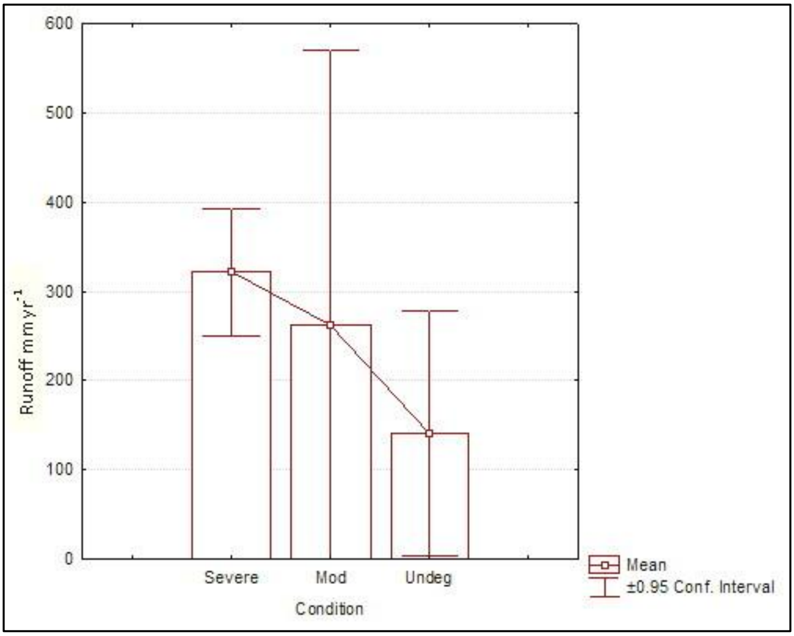


Fig. 3 Runoff off losses from different vegetated surfaces (severe - unvegetated or bareland, Mod - approximately 20% vegetated, Undeg - above 60% vegetated by both ground and canopy cover) over the period (Nakileza, 2006)

The non-degraded plots recorded ~ 2 times less runoff compared to the severely degraded plots. The high runoff losses from severely degraded plots can be accounted for by low infiltration rates caused by surface crusting and compaction of soils due to livestock trampling. Increased runoff concentrated along compacted and depressed lines (livestock tracks and paths) often running downslope to the watering points. Strunk (2000) made a similar observation that on degraded soils, rainfall of an average thunderstorm may cause overland flow and erosion resulting in gully erosion. As explained by Morgan (1995) gullying will occur if tractive force exceeds a critical or threshold value. Once the gully channel is established (USDA in FAO, 1986), the resulting concentration of flow is sufficient to sustain gully erosion. The scouring action of the runoff causes gully deepening whereas the head-ward erosion contributes to its extension upslope. Subsequent head-ward erosion and widening will continue until the gully is adjusted to a new set of equilibrium conditions and becomes relatively stable (USDA in FAO, 1986).

The dynamics of gullies are influenced by other numerous factors. Factors such as the characteristics of the geologic layers, topography, land use and volume of runoff control the rate of gully head advance. A change in these conditions above an advancing gully head in Bizibitukula catchment was observed to have altered its rate of advancement. Respondents interviewed reported that over the last 10 years there had been significant reductions in vegetation cover and changes in soil properties due to frequent droughts and increased grazing pressure. This is likely to have resulted in the development of gullies in the area as evidenced by many gully heads in the severely degraded areas compared to the non-degraded ones (Fig. 4).

Fig. 4. Gully erosion in Nakasongola district, Uganda

The majority of the gullies were observed to be active with the main erosion processes being sidewall collapse, failure of gully walls due to reduced soil cohesion, side erosion, downward and headward erosion and deposition. Desiccation cracking on the main gully walls, which are more exposed to drying and wetting compared to areas further away, leads to development of tributary gullying. Tributary gullying usually leads to development of dendritic gully pattern.

Approximately 30% of the gullies were observed to have reached a local base level (underlying hard lateritic rock) and the erosion processes confined to head ward and width expansion. The lateritic rock, which acts as a local base level, greatly controlled the deepening of gullies. However, whenever the bedrock surface is eroded the base level is lowered and this sets in motion new head cutting along the gully bottom. The average head ward gully retreat for one gully was estimated at 0.36 m per annum. This rate of retreat is small when compared to similar environments (e.g. Singh and Agnihotri, 1987) but it implies that gully development on the rangeland can become a serious threat and more costly if no action is taken in the short term.

The morphology of the catchment(s) also plays an important role in the development of the gullies. In the study area the gullies were observed on landscapes with slope angles ranging from as low as 3 %. Nordstrom (1989) based on studies in Lesotho states that gullying does not require steep slopes. He observed gullies and gully heads on very low slopes of < 2%. Slope length is another important factor affecting gullying mainly by causing a build up of runoff hence increased erosivity (Morgan, 1995). The effect of slope length in the study catchments was, however, difficult to assess. Slope length varied greatly but frequently ranged from 300 m to 800 m. Deeper sections of gullies were observed on the midslopes and lower pediments in the study area. Long slopes lead to generation and concentration of surface runoff, which increases the scouring action downslope (Morgan, 1995).

The local bedrock topography also affected gullying in the catchment more directly since gullies were noted to be discontinuous due to bedrock outcrops. The local bedrock diverts and accelerates runoff flow causing greater turbulence and erosion.

Human influence on gully development manifested itself in many ways. Gullies initiated by human activities had a characteristic pattern e.g. they were typically located along cattle tracks, road ditches or human tracks/paths running down and upslope and thus had a linear pattern. Fig. 2 has already shown the distribution of gullies in association with the main cattle tracks and paths. Erosion features such as rills and gullies have developed in close association with the tracks and paths due to concentration of runoff along these heavily trampled and compacted surfaces.

Increase in human population has led to increased infrastructural developments such as roads and tracks (locally called *ebihandagazi*), which are compacted surfaces. Increase in runoff yield and flow from the compacted surfaces constitutes a significant potential for gully development especially along the poorly maintained road diversion channels. As already alluded to above, increase in human and livestock population, directly causes general reduction in vegetation cover and development of tracks hence accelerated soil degradation including gullies. In a related environment in Tanzania, Kangalawe et al. (1999) observed extensive gullies on the hillslopes formed along the former cattle tacks and aligned down slope. However, the existing major rills and continued interplay of the above factors may result into growth of more gullies. It is therefore likely that gully expansion will cause heavy soil loss and siltation hence environmental rangeland deterioration particularly in terms of quality and quantity of the water sources located in the valleys.

Observations of soils in the area reveal general dominance by sandy loams (Table 3). An increase of sand (60%) in the upper soil horizon was observed from upper to lower slope position. Sandy soils are less coherent and more permeable. This combined with the convex slopes and changes in slope gradient contributed to deepening of the gullies toward lower slope position. The influence of slope on gully erosion has been widely noted (e.g. Gabris et al., 2002).

Table 3. Soil textural properties of a few selected soil profiles in Bizibitukula sub-catchment

Texture (%)	Upper slope		Mid slope			Lower slope	
	Topsoil (0-20cm)	Subsoil (20-40cm)	Topsoil (0-20cm)	Subsoil (20-40cm)	Subsoil >40cm	Topsoil (0-20cm)	Subsoil (>20cm)
Sand	27.5	29.5	37.5	19.5	23.5	45.5	37.5
Silt	64.9	64.9	56.9	68,9	68.9	44.9	52.9
Clay	7.6	5.6	5.6	11.6	7.6	9.6	9.6

IV CONCLUSION AND RECOMMENDATIONS

Valley side gullies are increasingly becoming a dominant phenomenon of land degradation in the dry sub humid rangelands of central Uganda. Most of the gullies identified were of linear pattern and discontinuous with V-shape and rarely exceeding 2 m in depth. The initiation and development of gullies is strongly linked to bare lands or areas of degraded plant cover due to livestock concentration and trampling, and human tracks aligned up- and down-slopes. Continued change in land use/cover due to intensive grazing, human tracks and roads, and vegetation degradation under changing climate conditions will lead to surface flow concentration and more gullying in future. This will further undermine the rangeland productivity. Therefore, strategies to address environmental degradation in such areas should not ignore gullies and particularly the interacting factors controlling their development. Long term monitoring of the rangeland use dynamics with respect to gullies is necessary in order to provide greater understanding and design of the necessary interventions.

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