INVESTIGATIONS ON SOIL CHARACTERISTICS AND GULLY DEVELOPMENT IN A SUBTROPICAL ENVIRONMENT

H.M. Mushala *

Abstract

Gully development processes in Swaziland are widespread. Increasing population and overstocking lead to overgrazing of the rangelands. The land use practices influence the soil characteristics and patterns of gully development. The paper describes soil characteristics associated with gully development on four sites in Swaziland. Aspects of infiltration, particle size distribution, organic carbon content and K-values are related to the parent material and the occurrence and rate of weathering of saprolite. It is concluded that land use practices influence the nature of soil properties and the character of gully development.

Introduction

Processes of gully development are widespread in Swaziland and it is estimated that gully erosion alone accounts for a loss of close to 3,000 hectares. annually (GOS 1991). Gully erosion contributes to the loss of agricultural land and reduced economical potential of the rural areas. Increased surface runoff which initiates most of the gully erosion processes reduces the water storage capacities of subsurface aquifers, and accelerates river and reservoir sedimentation. It is becoming apparent that increased population pressure and overstocking are exacerbating the problem mainly because of reducing the effectiveness of the protective vegetation cover. The problem is more pronounced in the Middleveld which supports the majority of the human and bovine populations in the country.

Previous studies on gully erosion in the country indicate that the physical and chemical properties of the surface materials determine the character of gully development (Price Williams and Watson 1982, Watson et.al 1987). It is further suggested that the most striking gully forms are developed exclusively in colluvial sediments (WMS Associates 1990). Other studies of erosion in the country do not deal with gully erosion as such but provide either qualitative or quantitative evidence or evaluate some soil conservation measures. Spaargaren (1977) used the Soil Loss Estimation Model for Southern Africa (SLEMSA) and estimated soil losses of between 2.5 - 5 .0 tonnes/hectares/year for selected soils. Pitman (1981) used river samples to estimate sediment yield as an indicator of the magnitude of soil erosion. The estimated sediment yield ranged between 4 - 10 tonnes/hectares/year.

* Dr. Hezekiel. M. Mushala is a Senior Lecturer in the Department of Geography, Environmental Science and Planning, University of Swaziland.

Sediment yield is not a good indicator of sediment source and can incorporate sediment from stream bank erosion thus exaggerating the magnitude of soil loss from arable and grazing areas. Engoru-Ebinu (1983) reviews some of the problems caused by gully erosion in Swaziland and suggests some measures to stabilise gullies thus controlling gully erosion. Mamba and Khumalo (1985) review the causes of soil erosion on rangelands and arable land. They also propose some preventive measures on arable land and conservation measures on rangeland. Nyanhongo (1982) investigates the relationship between gully density and other factors such as population density, overgrazing, slope and vegetative cover. His characterisation of soil properties does not provide adequate correlation to gully development. Van Baarsen and Ndlovu (1986) evaluate the causes of erosion in a specific area of Swaziland by examining aspects of land and crop management.

The above studies provide some background information on aspects of soil erosion but do not provide specific data on properties of host materials and how they influence gully development. This paper describes soil characteristics on four out of five study sites associated with gully development selected for intensive investigations. It is meant to give further insights on processes of gully erosion in Swaziland. It is anticipated that after the completion of the initiated study of the physical and chemical properties of the materials will be ascertained. A comparison of the results of the current study with those of previous studies will validate the extent to which characteristics of the surface materials influence gully erosion processes.

Methodology

Initially five sites were selected from the lower Highveld, (1) upper Middleveld (3) and lower Middleveld (1) based on the nature of gully erosion as observed on site, the accessibility of the site for regular monitoring and the nature of the slope. (fig. 1). The aim was to investigate the genesis and characterise the properties of eroded and non-eroded soils. For logistic reasons site 1, on the lower Highveld, was dropped and investigations were concentrated on four sites.

For each of these sites the general characteristics of the site including the geology, soils, land use and land cover were identified as shown in Table 1. On each of these sites the following characteristics were determined.

(i) Infiltration rates were determined for bare surfaces representing sheet erosion; overgrazed rangelands; grazed rangelands and cultivated land around study sites using the double cylinder infiltrometer.

(ii) Particle size distribution was determined using pipette method for the silt and clay fraction, and sieving for the sand fraction.

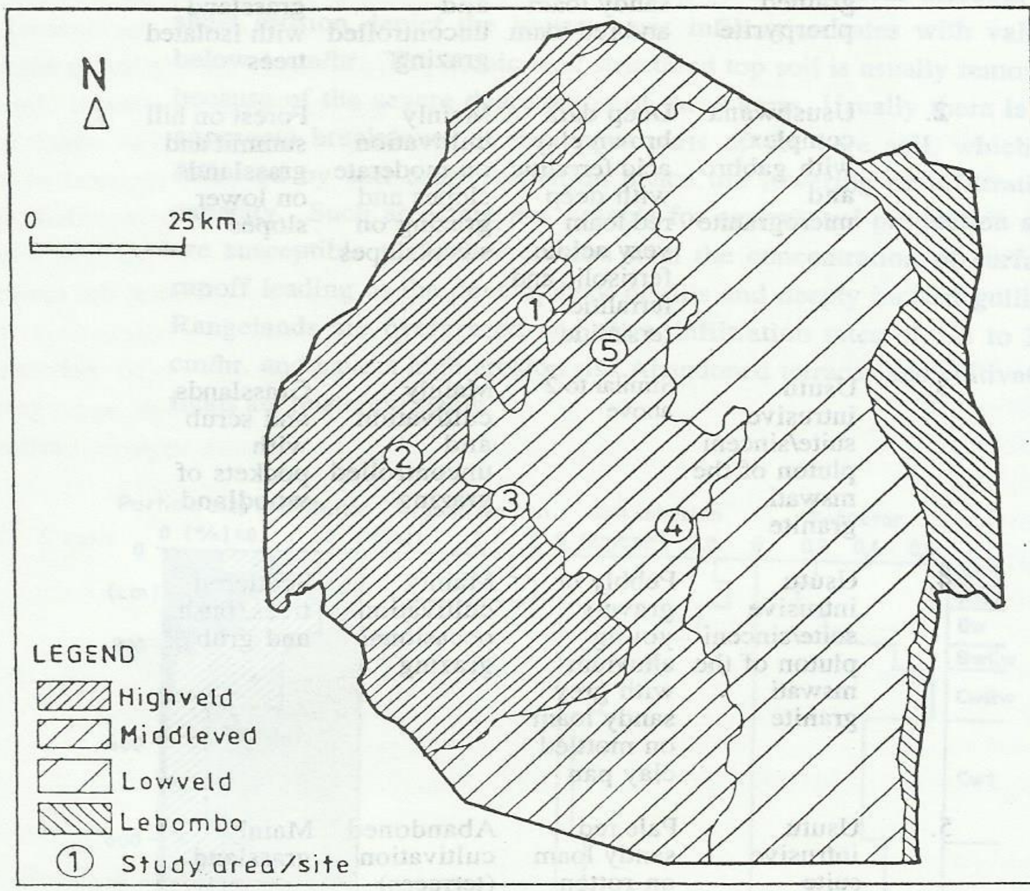

Figure 1 Location of study sites.

(iii) The organic carbon content was determined by the gas chromatographic method using an auto analyser, whereby the soil sample is burnt into gaseous form and carbon and nitrogen values determined simultaneously.

(iv) The K-factor was determined according to the Kirby and Morgan procedure.

Table 1 : Characteristics of Study Sites

Site No	Geology	Soils	Land Use	Land Cover
1.	Coarse grained phorpyrite	Pale red sandy loam and red loam	Cultivation and uncontrolled grazing	Mainly grassland with isolated trees
2.	Usushwana complex with gabbro and microgranite	Deep dark brown clay, acid ferralitic with deep red loam very acidic ferrisolic and ferralitic fersialitic	Mainly cultivation on moderate slopes and grazing on steep slopes	Forest on hill summit and grasslands on lower slopes
3.	Usutu intrusive suite/sinceni pluton of the mswati granite	Similar to 2 above	Mainly cultivation and uncontrolled grazing	Grasslands and scrub with pockets of woodland
4.	Usutu intrusive suite/sinceni pluton of the mswati granite	Pebbly or gravely young alluvium with grey sandy loam on mottled clay pan	Mainly cultivation occasional grazing	Scattered trees, bush and grub
5.	Usutu intrusive suite	Pale red sandy loam on rotten rock with grey loam on thick stoneline on red loam.	Abandoned cultivation (terraces)	Mainly grassland

Preliminary Results

The preliminary results were as follows:

a) Results of infiltration are shown in Figure 2. The areas affected by sheet erosion depict the lowest basic infiltration rates with values below 1 cm/hr. The humic well structured top soil is usually removed because of the severe degradation of these areas. Usually there is an aggregate breakdown of the upper parts of the bare soil, which is followed by soil crust formation hence the lowering of infiltration capacity. Such areas are not suitable for agricultural production and are susceptible to further erosion with the concentration of surface runoff leading to the development of rills and deeply incised gullies. Rangelands are overgrazed and show infiltration rates of 1.5 to 3.0 cm/hr. and have a high erosion risk.Abandoned terraces and cultivated fields are relatively stable.

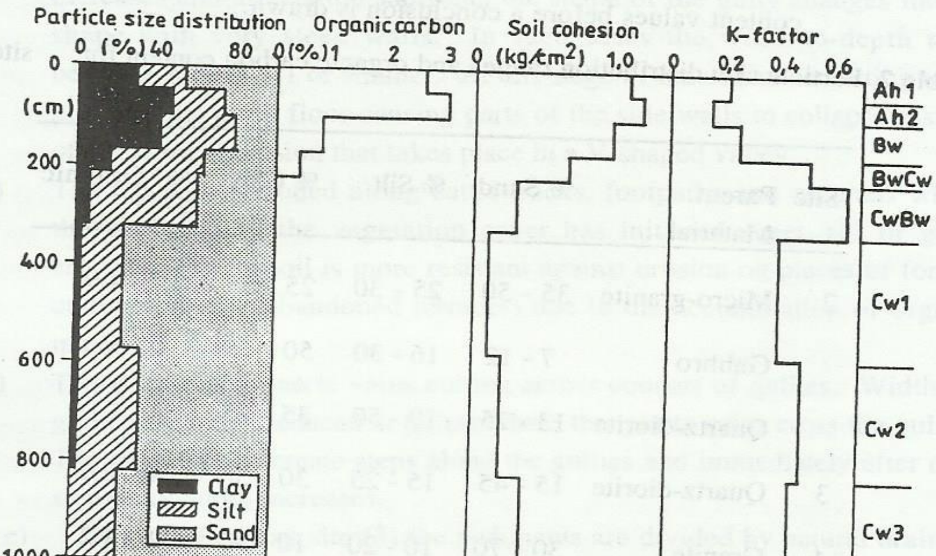

Figure 2 Soil characteristics.

b) Results of particle size distribution and organic carbon content of top soil (except for cultivated land) are shown in Table 2 The particle size distribution indicates some correlation with the nature of the bedrock on each site. Ranges in the different size classes are relatively high depending on different transportational lengths for sand, silt and clay. There is an increase in the clay content of material downslope, which is an indication of the downslope transportation of top soil material over the entire slope. The highest clay content, as expected, is recorded on gabbro, and the highest sand content is on granite. If particle size distribution is considered on its own, one can surmise that the lower slopes of site 2, which are on quartz-diorite are mot susceptible to erosion by virtue of having silt contents of up to 50 percent. Nevertheless this has to be evaluated against the high aggregate stability and the high infiltration rate together with organic carbon content values before a conclusion is drawn.

Table 2 Particle size distribution ranges and organic carbon content for sites 2 - 5

Site	Parent Material	% Sand	% Silt	% Clay	% Organic C
2	Micro-granite	35 - 50	25 - 30	25 - 35	2.7 - 4.9
	Gabbro	7 - 12	16 - 30	50 - 75	
	Quartz-diorite	13 - 25	19 - 50	35 - 75	
3	Quartz-diorite	15 - 45	15 - 25	30 - 50	1.0 - 2.0
4	Granite	30 - 70	10 - 20	10 - 50	0.8 - 1.2
5	Granodiorite	16 - 60	13 - 30	20 - 75	1.0 - 2.9

c) Results of organic carbon content are also shown in Table 2 above. Site 2 indicates the highest organic carbon content values of 2.7 - 4.9% for the A-horizon. The lowest values of 0.8 - 1.2% are recorded on site 4. The highest concentrations of organic carbon for all land sections within the study sites are found on uneroded abandoned terraces.

d) The results of the K-factors are shown in Figure 2. They show a distinct increase in erodibility between humic colluvium and the subsoil and sapolite. The transition zone between B-and C-horizon with K-values of 0.50 and 0.60 is the most susceptible area to erosion.

Characteristics of Gully Development

General observation on study sites indicate the following:

a) The study sites are located on areas having 1-2m thick ferralitic soils with a thick A horizon developed on top of at least 10-20m thick saprolite. On the Usutu site (2) the saprolite is developed from micro-granite and gabbro. On all sites erosion processes have incised up to 15m deep gullies into the saprolite. The Bulunga Port site (4) is mainly composed of Vertisols from basin sediments, rich in clay near the stream valley.

b) On sites where the saprolite is covered by a regular colluvial ferralitic soil (average thickness 1-1.5m), smaller gullies, which do not affect saprolite, appear v-shaped with a width-to depth ratio of 2:1. Wherever erosion increases and affects the saprolite, the shape of the gully changes into u-shape with very steep walls. In such cases the width-to-depth ratio becomes almost 1:1 or smaller. At this stage of erosion undercutting takes place on the gully floor causing parts of the side walls to collapse instead of the vertical erosion that takes place in a V-shaped valley.

c) The top soil is eroded along cattle tracks, footpaths and on areas where the depletion of the vegetation cover has initiated sheet, rill or gully erosion. The topsoil is more resistant against erosion on places of former cultivation (e.g. abandoned terraces) due to the accumulation of organic matter.

d) There are many quartz veins cutting across courses of gullies. Widths of gullies are much reduced at points where the quartz veins cross the gullies. The quartz veins create steps along the gullies and immediately after each step gully width increases.

e) On the Ntondozi site (3) the pediments are divided by natural drainage channels filled with up to 15m colluvial material. The majority of the deeply incised gullies follow closely along former stream valleys.

Discussion

The observations made above can lead to an understanding of the processes of gully erosion in a number of ways:

a) Saprolite is an intermediate stage in processes of soil formation in that it is a product of the weathering of the parent rock in situ. Over time and with the influence of other factors (e.g. climate, land use etc.) soil develops over the saprolite. From the above observations it is evident that the extent of gully erosion is influenced by the occurrence and intensity of weathering in the saprolite. Rapid gully development occurs on saprolite especially where moisture is introduced in the subsurface because saprolite disintegrates very easily when wet. Gully erosion processes are accelerated with cattle tracks and footpaths channelling the runoff and triggering off saprolite disintegration hence initiating gully formation. Once the runoff is channelled and drains into a gully the hydraulic dynamics of the runoff lead into potholing of the gully head resulting into undercutting and gully head extension. In other words land use practices that influence the channelling of surface runoff on weathered saprolite tend to accelerate processes of gully development.

b) The shape of the gully is a function of the volume and velocity of the surface runoff, the characteristics of the surface material and the occurrence of saprolite. As has been noted elsewhere (e.g. Mushala 1988, Morgan 1986), the physical characteristics of soil profile (e.g. texture, aggregate stability, organic matter content) influence the susceptibility of the soil to erode. The effectiveness of the vegetation cover can no longer be disputed because it has been observed that the top soil is eroded wherever the vegetation cover is depleted. V-shaped gullies occur during initial stages of gully formation and the main influencing factors are the volume of the runoff and the physical characteristics of the soil. The volume of the runoff initially determines the size and the shape of the channel on non-saprolite material. Once the saprolite is affected the dynamics of the erosion processes become more complex so that the shape and size of the gully cannot be estimated to any level of precision.

c) Land use practices play a significant role in influencing the nature and extent of gully erosion. First land use practices determine the extent of vegetation depletion. Apart from the general land use practices of crop production whereby land is cleared extensively, the problem of overstocking is exacerbating gully development. It has already been noted that the current stocking rate in Swaziland of one stock unit per 1.3 hectares of grazing land is one of the highest in Africa and results in severe overgrazing (WMS Associates 1990). Most of the lower and middle slopes are used mainly for crop production so that the only areas available for communal grazing are hill and escarpment crests. The cattle follow given routes and over time these tracks are void of vegetation. These cattle tracks eventually become channels for the surface runoff from the escarpment crests initially developing as rills but eventually develop into gullies as the volume of the runoff increases and subsequently affects the saprolite as observed above.

The depletion of vegetation cover on hill and escarpment crests increases surface runoff in this way. Livestock graze on the grasses and shrubs until the land is almost bare. Initial rains on these bare soils cause surface sealing due to the expansion of the clay to close the voids in between the soil particles. The subsequent rain, therefore, does not infiltrate into the subsurface, instead it escapes as surface runoff, which is channelled through the footpaths and cattle tracks to initiate rills and gullies eventually.

d) The occurrence of quartz veins along gully courses is an indication of the complexity of the geology of the country as a whole. The purpose of this paper is not to highlight into any level of detail the geology of Swaziland but suffice to mention that the sites are located on areas which have been subject to igneous processes including folding and faulting. The quartz veins therefore partly control the shape of the gullies as well as influence the form and areal extent of sheetwash erosion.

e) As noted already the colluvial materials often represent eluvium which has been eroded by hillslope processes, and subsequently deposited on lower pediment slopes, in topographic basins, and in river valleys. The occurrence of gullies along natural drainage channels has significant implications for soil erosion control, an aspect discussed in the following paragraphs.

Implications for soil and water conservation

Aspects of gully development as outlined in the foregoing paragraphs have significant implications on soils conservation in Swaziland and other countries where similar observations can be made. The implications are not identified in any order of significance.

First, the erosion of saprolite is an indication of a very serious problem especially considering that saprolite is an initial phase in the process of soil formation. The depletion of saprolite can be equated with the serial killing of infants en mass in a country because it affects the structure and compositions of the population in subsequent decades. It is not an over exaggeration to say that the depletion of saprolite at this rate would reduce Swaziland to a complete desert in less than 5 centuries. If no drastic steps are taken to alleviate the situation it is not surprising that in another 30 years Swaziland soils will not be capable of supporting the existing population for any considerable period.

Since it is already known that the introduction of moisture on saprolite accelerates its disintegration it is proper then to direct conservation efforts that curtail these processes. One such method is reforestation of the eroded hill and escarpment crests. Reforestation would increase the rate of infiltration and reduce surface runoff thus limiting the impact of surface flow. It will also increase the rate of organic matter build up to the top soil reducing its susceptibility to erosion. Over the long term more ground water will be available to sustain base flow in rivers so that the impact of drought is minimised.

Reforestation, however, is to be accompanied by a reduction in stocking rates and increasing the quality of the animals. Current practices of overgrazing especially on Swazi Nation Land can be reduced if effective use is made of the "sisa" ranches. Each household has to be limited to a number of livestock while other animals are taken to the ranches for fattening. Once the animals are rehabilitated they can be sold for cash to improve the living standards of the rural population.

As can be seen soil conservation efforts cannot be undertaken individually by the small scale farmers. In all earnest soil conservation has to be a community effort supported by proper legislation and enforcement. Reforestation, for example, has some implications on land tenure, an aspect of significance in soil conservation. The purpose of this paper is not to highlight on aspects of land tenure in the country except to point out that for soil conservation to be successful there are significant aspects of land tenure to be addressed. The idea is to arrive at land use practices that are compatible with the soil carrying capacities.

It has been observed that some of the gully erosion processes occur along natural drainage ways. In this case the most appropriate soil conservation strategy would be to control the triggering mechanisms. As it is clear the landscape scenery we observe today are a result of processes of geologic erosion whereby rivers carved out their own valleys and more resistant landscapes stand out as highlands. Thus the gully erosion taking place along natural drainage ways can represent "geologic" erosion on a micro scale. The strategy here would be as an example to increase the vegetation within the micro catchment so as to stabilise the catchment denudation processes. It would not be wise to construct structures such as check dams or gabions only along the gully course as this would merely trap the sediments but would not control the gully headward erosion.

Conclusion

Characteristics of gully development as observed above are influenced by the nature of the host materials, which in turn, is influenced by the land use practices. Soil infiltration is much reduced on overgrazed areas. These areas are depleted of the organic carbon content thus reducing the cohesion of the particles. The occurrence and extent of weathering of the saprolite influence the shape and the rate of gully development. The nature of the parent material influences particle size distribution thus determining the extent to which certain size materials can be eroded. Although particles size cannot determine the extent of erosion independently, it can be linked to aggregate stability and infiltration to estimate the susceptibility of the host materials to erosion

For the most part land use practices that deplete the vegetation cover has a strong influence on processes of gully erosion. Overgrazing and rapid population growth increase pressure on the use of available land resources. The characteristic development of gullies has strong implications on soil conservation strategies. The current observation indicate the need to re-establish depleted vegetation so as to make the necessary adjustments within the hydrologic cycle in order to limit exacerbating mechanisms such as the generation of surface runoff. The rehabilitation of gullies occurring along natural drainage ways has to be undertaken with care as it can prove to be an impossible task especially because it affects natural geomorphic processes that are inevitable.

References

Engoru-Ebinu. A 1983 Gully erosion hazards in the farming systems in Swaziland *Jour. Royal Sco. Scie. Tech.* 5 (1).

Government of Swaziland, 1991 Ensuring Our Future: National Report of the Kingdom of Swaziland on Environment and Development. Mbabane.

Mamba, S.L. and Khumalo, S. 1985 Causes of soil erosion on arable land and rangelands. Paper presented at the seminar on Soil erosion. Yen Saan : Mbabane.

Morgan, R.P.C. 1986 Soil Erosion and Conservation ,Longman.

Mushala, H.M. 1988 Soil Erosion in Swaziland: A review of research needs. *Swazi Journ. Scie. Technology* Vol. No. 2, 7 - 19.

Nyanhongo, S. 1982 A gully erosion assessment in the Ntondozi area of Swaziland. Student dissertation. University of Swaziland.

Pitman, W.V. 1981 Surface Water Resources of South Africa Vol. V1 Hydrological Research Unit Report.

Prince Williams, D. and A. Watson, 1982. New Observations on the prehistory and palaeoclimate of the late Pleistocene in Southern Africa *World Archaeology* 13: 372 - 381.

Spaargaren P. 1977 Soil Conservation Measures in the Rural Development Areas in relation to soil texture, soil depth, soil structure permeability and land slope. Ministry of Agriculture. Mbabane.

Van Baarsen, B. and Ndlovu, L. 1986 Erosion on Arable Land in Ntondozi Area *SSRU Research paper* 21 University of Swaziland.