

## Erosion Scars Caused by Earth Flows - A Case Study from Central Kenya

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**Abstract:** Earth-flow features are described on a small-holder farm in Nyandarua District (Central Kenya), where over 900 earth flows occurred with most of the farms (>50 %) in the region being affected. Individual flows affected areas from a few square metres to two hectares. In the area, the earth-flow features occurred exclusively on grazing land and on convex slopes, and are the result of extremely slow processes. The first visible signs are usually shallow scars along the contour, breaking the grass vegetation. Subsequent mass movement is very slow and gradual. According to old area residents, some of these earth-flow features have been observed as long as 60 years ago. Because of the extremely slow development, it was not possible for the local residents to date the earthflows; these earth flows “had always been there”. Therefore, these features could not be attributed to recent (<30 years) land-use changes. One earth flow studied in more detail revealed that soil stratification, impeded drainage leading to oversaturation of the top soil layers, and seasonal sub-surface flow seemed to be mainly responsible for soil movement. No obvious triggering effect could be identified.

**Keywords:** earth flows, mass-movement erosion, Kenya

### 1 Introduction

In the densely populated and intensively cultivated highlands of Central Kenya, mass-movement erosion is a common phenomenon (Larsson, 1989; Rowntree, 1989). Most of these soil movements are small, but the areas affected by mass movements are usually completely destroyed and rendered useless for further agricultural use. Such areas need considerable efforts and investments for reclamation. Considering the scarcity of fertile land in the region and the small size of the individual land holdings (Muchoki, 1985), the loss of fertile land -even if the area is very small- is always a serious drawback for the farmers.

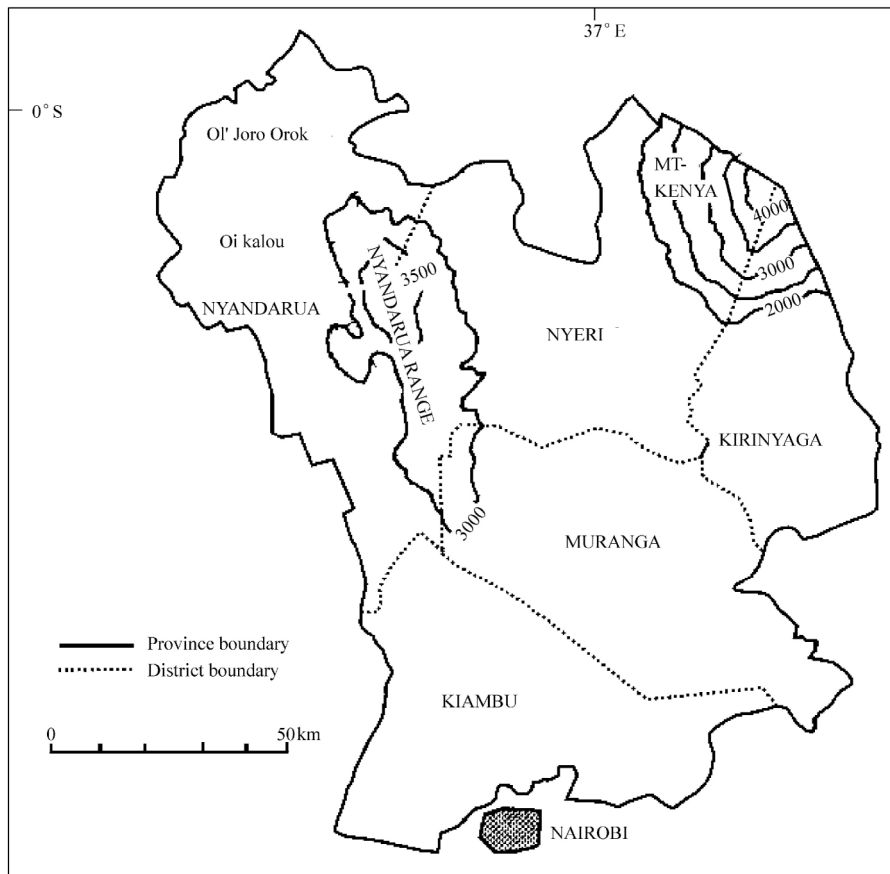
As there is no easy ‘cure’ for mass soil movements, only preventive measures will help to save valuable land. For this, the causes and triggering effects have to be understood. Although the general underlying principles and causes of mass movements are well known (Schuster and Krizek, 1978; Gasser and Zöbisch, 1988), the spatial variability of the environmental and land-use conditions make it impossible to develop universally applicable preventive strategies and recommendations. Therefore, the study of earth movements typical for particular environments is a prerequisite for the development of appropriate preventive countermeasures.

In Central Kenya, an area seriously affected by earth movements is the Nyandarua District. In a survey in 1989, more than 900 erosion scars caused by earth flows were counted there (Ministry of Agriculture, 1992). Most of these scars were found in two particular areas of the District, Ol’Joro Orok and Ol’Kalou. In Ol’Joro Orok, 50 % of the farms were affected. The total area affected of around 120 ha was comparatively small, but the disturbance caused by the dissection of the land was, however, significant. Larsson (1989) also reported several hundred “land slides” in Nyandarua District, dissecting the slopes, but did not classify the type of mass movement causing the erosion scars.

The present case study is an investigation into some major characteristics of the land affected by mass-movement erosion in the area. The study also attempts to classify the type of mass-movement erosion, which produces the scars. A typical medium-sized erosion scar on a small farm in Nyairoko (Ol’Joro Orok area) was selected for the case study.

## 2 The study area

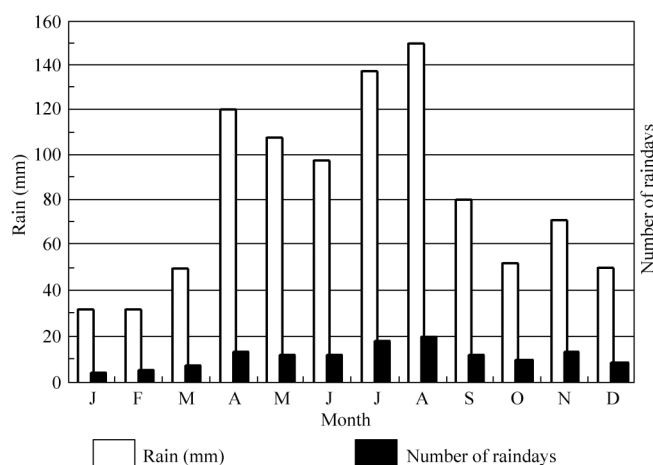
The Ol'Joro Orok area (Fig.1) has a hilly topography with altitudes around 2,400 meters above sea level. According to Jaetzold and Schmidt (1983), the area is classified as *Upper Highland Wheat Pyrethrum Zone*. Its geology is characterized by volcanic rocks, i.e., basalts and tuffs and other superficial deposits of volcanic origin, and diatomites (McCall, 1967). Two major soil types are found in the area; moderately well drained, dark reddish-brown Luvisols ranging from 0.80 to 1.80 m depth, and extremely deep (> 1.80 m), well drained, red to reddish-brown nitisols (Kenya Soil Survey, 1982). The soils of the area have a moderate to low fertility. Water-holding capacity is moderate with moderate to good soil work-ability (Jaetzold and Schmidt, 1983).



**Fig.1** Location of the Ol'Joro Orok study area

The subtropical highland climate of the area is influenced by its proximity to the equator and its altitude (Ojany and Ogendo, 1973). Mean annual rainfall is around 980 mm, with rain falling throughout the year and peaks in April and July/August (Fig.2).

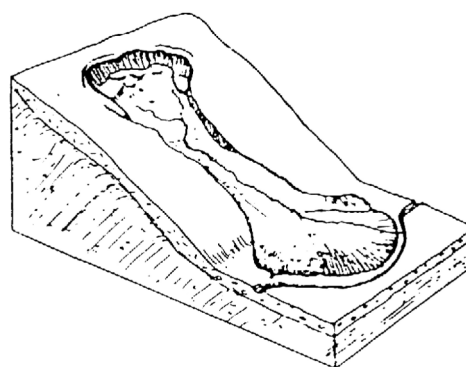
In comparison to other high-production potential areas of Kenya, the Ol'Joro Orok area has a relatively low population density of 99 persons per km<sup>2</sup>. The land use has not changed significantly over the past 20 years (Min. Agric., 1978, 1992). Forest (plantations and indigenous forest) covers 19 % of the area. The land is used by small-scale farmers, with average farm sizes between 3.9 and 6.0 ha. Approximately half of the area is grazing land, with most of the farmers' income coming from dairy cows. Each farmer keeps between 10 and 15 cattle and a few sheep. Arable farming is based on maize and potatoes. The production of wheat, barley and pyrethrum, which were previously the main crops, has decreased.



**Fig.2** Mean monthly rainfall and number of rain days per month at the Kenya Agricultural Research Institute Meteorological station, Ol'Joro Orok, 1947—1990 (Min. Agric. 1992)

## 2.1 Type of mass-movement erosion

Occasionally, the erosion features in the area are referred to as “solifluctions” (Min. Agric., 1980, 1992). Solifluctions, however, are usually limited to the movement of top soil layers with high root density. They are also linked to freezing and thawing cycles. Solifluctions also feature smaller swelling-like deformations of the vegetated surface over larger areas and do not show pronounced scars. A field-reconnaissance study of the mass-movement erosion features in the areas of O'Joro Orok and Ol'Kalau Divisions revealed that the erosion scars were the result of earth flows and not solifluctions. The scars surveyed showed typical features of earth flows (Fig.3). Mass-movement erosion is generally classified according to the material moved, the type of movement and the speed of the movement (Gasser and Zoebisch, 1988). In the case of the erosion scars studied, all features and conditions linked to earth flows were fulfilled. According to Záruba and Mencl (1982) and Rib and Liang (1985), wet earth flows are generally slow-to-very slow processes. They may involve viscous and plastic flow and they are complex in nature. The head commonly consists of a slump block which breaks into several pieces that clearly show flow structures. The material moved spread around the foot of the flow. Around the flow scar, surface cracks may be visible. The flanks are usually curved and have steep sides.



**Fig. 3** Characteristic features of earth flows (Rib and Liang, 1985)

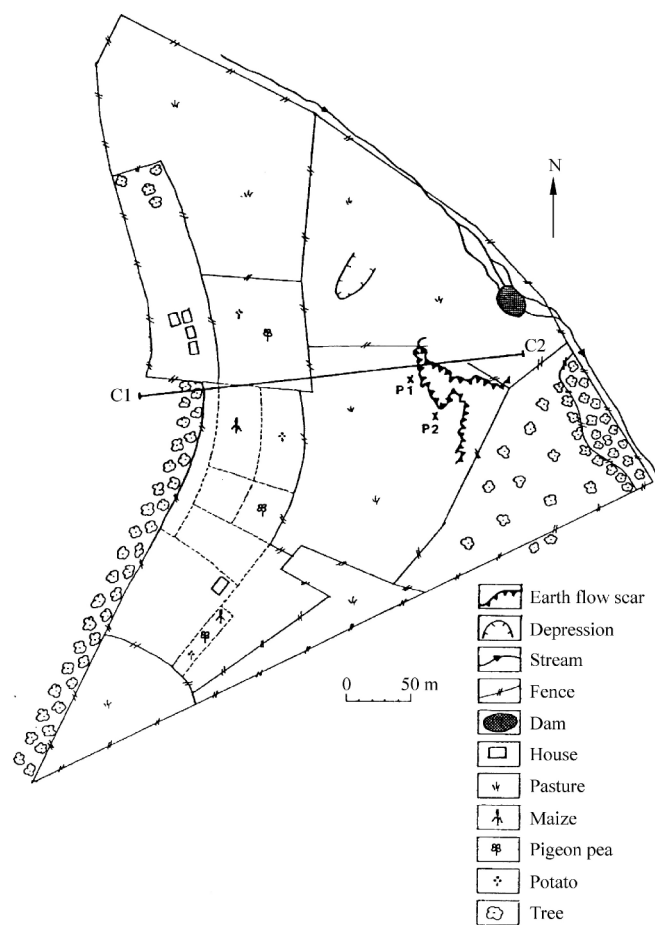
## 2.2 Local observations on erosion scars

It was observed that the earth flows in the area were not recent developments because no fresh initiated earth flow was found. Old farmers reported that these earth flows had been noticed in the area for a long time. Of 27 old persons interviewed, 11 settled in the area after 1963. The 16 other persons lived in the area for the previous 30 to 63 years. All persons interviewed also confirmed that the land use had changed over time. According to their observations, the cultivated area had increased. Also, more trees are now grown on individual farms than before. Only on common land had the number of trees decreased.

They also believed that the total number of cattle kept in the area has not changed since European settlement, only their distribution amongst farmers. It could not be established clearly through the interviews when the scars first developed. All interviewed persons remembered that the scars “have always been there”. It could not be clearly established whether the number of erosion scars in the area had increased. The answers were somewhat conflicting and imprecise. However, it was obvious from the answers that the scars continued to grow over time. These statements could not be verified independently, but they indicate clearly that the erosion scars are an old phenomenon in the area and that not a lot of attention was paid to them.

### 3 Methods

One typical medium-sized earth-flow scar was selected to study in more detail the topographic and soil conditions. The scar is located in Nyairoko on Mr. and Mrs. Githinji’s farm (Fig.4).



**Fig. 4** Githinji farm in Nyairoko, Ol’Joro Orok area. The soil catena is marked C1-C2, soil-profile pits are marked P1 and P2

The farm has a total area of approximately 12 ha, is situated on a 10° slope facing Northeast, and ranges in altitude between 2,700 and 2,750 m. The lower end of the farm borders the valley bottom, where just within the lower farm boundary, a small dam was built to secure drinking-water supply from a seasonal stream. About 20 % of the farm is used for crops (maize, potatoes, green peas); the remaining area is grassland. A herd of 15 cattle are kept on the farm.

Rainfall characteristics were studied using rainfall records from the Kenya Agricultural Research Institute's meteorological station at Ol'Joro Orok. A topographic survey of the erosion scar was carried out, and the soil catena of the main farm slope was studied. For the soil investigation of the site, seven auger holes were drilled along the main slope of the farm. For profile characterization and more detailed soil investigations around the erosion scar, two soil-profile pits were dug above and below the erosion scar. Soil samples from each layer were taken and examined in the laboratory for physical characteristics. The soil profiles were described according to recommendations of the International Soil Science Society (Landon, 1996). Seepage velocity estimations were made along the catena using the method described by Hills (1970).

## **4 Results**

### **4.1 Rainfall characteristics**

Ol'Joro Orok Division receives an annual average rainfall of 978 mm. The 80 % probability value (i.e., amount of rainfall that is likely to be exceeded in 4 out of 5 years) is 782 mm. The total range of rainfall recorded since 1947 was between 46 % and 153 % of the average rainfall. Between 1947 and 1990, there were 22 years with rainfall below average and 20 years with rainfall above average. Monthly variations in rainfall are considerable (Fig.2). Each month, including those with the lowest means, may receive heavy rainfall. Likewise each month, with the exception of June, July and August, may be very dry. Rain days of less than 10 mm rainfall account for over 75 % of the total number of rain days, but only for about 35 % of the total rainfall, while 55% of the rain days receive less than 5 mm of rain. Only 12 % of the total rainfall occurs with amounts of more than 35 mm. This suggests that intensive and erosive rainstorms are not common in the area.

### **4.2 Erosion scar description**

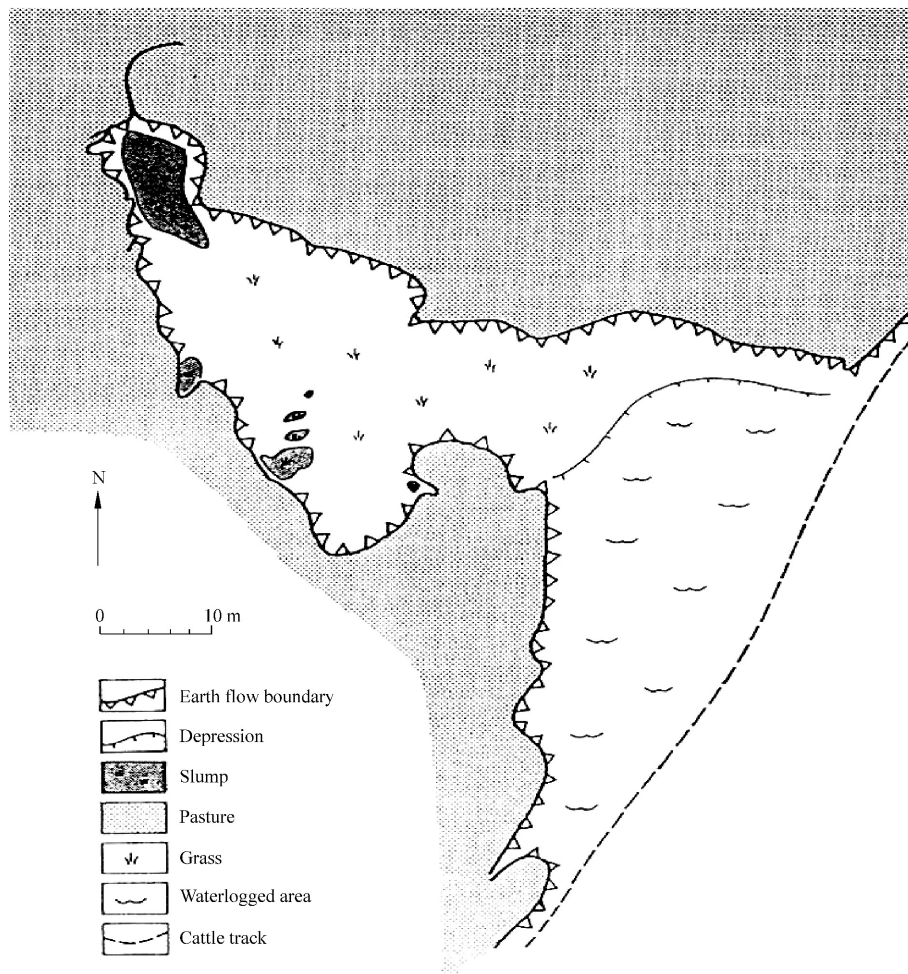
The erosion scar is situated at the lower part of the farm, facing 60° east (Fig.5). The slope section containing the scar was convex with an average steepness of 13°. The erosion scar had a total surface area of 1984 m<sup>2</sup> (approx. 0.2 ha) and a horseshoe-like shape. Its maximum depth was 4.4 m. Just above the head of the scar were several parallel just-recognizable furrows which drain water into the scar during rainfall. The northern part of the scar extended by a gully-type form of head-wall collapse. A section of the northwestern vertical escarpment had collapsed. During high-rainfall periods, water emerges at various points along the escarpment, some of it from small soil pipes. During these periods, this part of the earth-flow scar is permanently waterlogged.

Inside the scar, patches of grass were growing. Some of the grass was established by the farmer, who also planted a few eucalyptus trees. The land around the scar is pasture. No particular measures to protect and heal the scar were being taken. The total volume of soil estimated to be lost by the earth flow is 3,380 m<sup>3</sup>. However, no signs of soil deposition were observed in the natural drainage way.

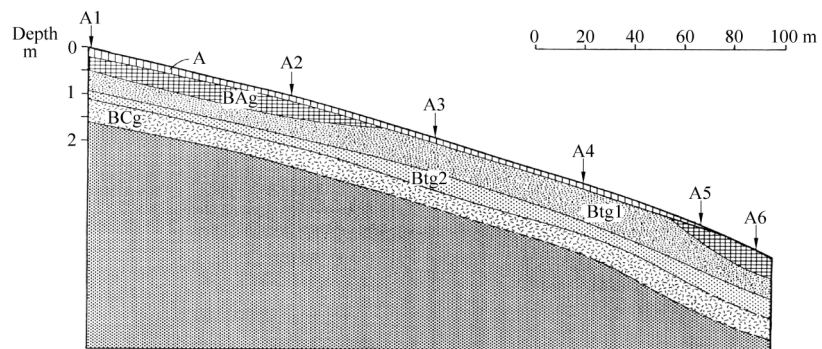
### **4.3 Soil characteristics**

Table 1 summarizes the main characteristics of the two soil profiles. Boundaries between the horizons were generally diffuse. Seepage water was present in both pits, beginning at a depth of about 0.6 m at the boundary between horizons Btg1 and Btg2.

The seepage layer was approximately 0.2 m wide and intersected by four to five silt layers of 2—3 mm thickness. Faunal activities were sparse. After horizon identification, a soil catena was drawn from auger information (Fig.6).



**Fig. 5** Map of the earth-flow scar



**Fig. 6** Catenary horizon diagram for slope C1-C2 (refer also to Fig. 4)

**Table 1 Main soil characteristics of the two investigated soil profiles**

Pit	Soil depth (cm)	Clay (%)	Silt (%)	Sand	Texture USDA	Clay Ratio	Silt/Clay Ratio	Bulk Density (g/cm <sup>3</sup> )	Organic Matter (%)	Water retention		Avail. H <sub>2</sub> O (% vol)	Base Sat. (%)	PH (H <sub>2</sub> O)	CEC (me/100g)
										pF 0 (% vol)	pF 4.2 (% vol)				
1	0—10	26	29	45	loam	2.8	1.1	0.9	9.0	58	34	24	34	4.9	22
	10—35	13	23	64	sandy loam	6.7	1.8	1.2	2.4	42	20	22	20	5.6	14
	35—65	19	23	58	sandy loam	4.3	1.2	1.3	1.5	39	19	20	23	5.6	13
	65—85	47	24	29	clay	1.1	0.5	1.3	0.5	37	18	19	25	5.6	31
	85—160	45	16	39	clay	1.2	0.4	1.3	0.4	37	25	12	17	5.6	34
2	0—15	31	29	40	clay loam	2.2	0.9	0.9	8.5	56	32	24	35	5.0	22
	15—35	26	30	44	loam	2.8	1.1	1.0	4.3	41	20	21	29	5.2	15
	35—55	28	30	42	clay loam	2.6	1.1	1.1	2.4	41	24	17	20	5.4	17
	55—85	18	32	50	loam	4.5	1.8	1.3	0.9	40	20	20	19	5.4	18
	85—160	35	24	41	clay loam	1.9	0.7	1.2	0.3	41	22	19	25	5.5	19

#### 4.4 Soil texture

The grain-size distribution, silt/clay ratio and clay ratio showed little differences between the two profiles (Table 1). More erodible layers, i.e., higher silt/clay ratios occurred at depths between 0.1 and 0.6 m. At the lower part of the slope, at around auger holes 5 and 6 (Table 2, Fig. 6), texture tended to be finer than on the upper part, possibly due to slow surface erosion and deposition processes. The change in texture along the slope, however, also influences bulk density, and therefore reduces infiltration and hydraulic conductivity. Hence, layers of finer texture will create relative water barriers to guide seepage-water flow. The overlying layers of higher erodibility (i.e., higher silt/clay ratio) would then easily attain their liquid limits and begin to flow.

**Table 2 Soil characteristics for auger holes A1—A6**

Auger hole	Soil depth (cm)	Color Munsell	pH (H <sub>2</sub> O)	Organic Matter (%)	Texture USDA
A1	0—20	7.5YR3/4	5.0	9.1	sandy clay loam
	20—50	5YR3/4	5.2	6.5	loam
	50—90	7.5YR3/3	5.1	5.6	loam
	90—110	5YR3/3	5.3	3.3	loam
	110—160	5YR3/6	5.6	1.2	clay loam
A2	0—10	7.5YR3/4	5.3	11.6	loam
	10—45	7.5YR3/4	5.3	6.1	clay loam
	45—80	7.5YR2/3	5.1	5.8	clay loam
	80—100	5YR4/6	5.1	3.3	sandy loam
	100—140	5YR3/6	5.1	1.7	sandy loam
A3	0—10	7.5YR3/4	5.0	12.4	sandy loam
	10—75	5YR3/4	5.1	5.1	loam
	75—110	5YR3/4	5.1	1.5	clay loam
A4	0—10	7.5YR3/4	4.9	9.4	loam
	10—70	5YR3/4	5.1	4.6	clay loam
	70—95	5YR3/4	5.0	1.8	sandy clay loam
	95—110	5YR3/6	5.2	1.0	sandy clay loam
A5	0—10	7.5YR2/3	5.2	9.8	clay loam
	10—40	5YR3/4	5.2	6.3	clay loam
	40—100	5YR2/3	5.3	2.6	clay loam
	100—140	5YR3/4	5.8	2.1	clay loam
A6	0—50	5YR3/4	5.2	3.1	clay loam
	50—70	5YR3/4	5.6	2.9	clay loam
	70—110	5YR3/6	5.7	0.9	clay loam

Except for the top layers, the bulk-density pattern clearly follows the textural composition of the soil (Table 1). Due to the relatively high organic matter contents in the top layer, high root density of the grass vegetation, and the well developed soil structure, bulk densities are low (i.e., around 0.95 g/m<sup>3</sup>). These conditions in the top layer indicate favourable moisture-uptake conditions.

#### 4.5 Water-retention

Water-retention characteristics for the two profile pits were uniform (Table 1) due to textural and bulk-density changes, generally decreasing with depth, again, because of favourable aggregation and high organic matter content, the top layer exhibited a higher water-holding capacity than underlying layers. The soil catena showed a relatively uniform distribution of water-holding capacity, decreasing slightly with depth.



## 5 Conclusions

Although no obvious triggering effects could be identified, it seems possible that initial surface cracks, which break up the shallow grass rooting-system, have led to a loss in the cohesion of the soil mass. Surface runoff entering into these cracks could then cause rapid over-saturation of the surface layers leading to wet earth flow and subsequent slumping of the up-slope part of the crack, thus forming an initial erosion scar.

Because of the evenly distributed rainfall, the soil remains saturated over long periods. Less permeable layers at 0.65 m—0.80 m depth restrain deep percolation, encourage lateral water movement and lead to temporary waterlogged conditions. These will cause plastic or even liquid-state conditions encouraging wet earth flow. This tendency will be greatest on steep slopes and may explain why all erosion scars observed in the area are located on convex slope sections.

However, initial triggering effects and conditions which encourage the development of the erosion scars still remain unclear. Further detailed studies are required to establish the processes leading to earth flows in the area.

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