African Journal of Agricultural Research Vol. 4 (7), pp. 611-620, July 2009
Available online at http://www.academicjournals.org/AJAR
ISSN 1991-637X © 2009 Academic Journals

Full Length Research Paper

Influence of soil properties on landslide occurrences in Bududa district, Eastern Uganda

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Accepted 22 June, 2009

The aim of this study was to carry out a detailed soil survey to determine soil types and their influence on landslide occurrence in Bududa District in eastern Uganda. Four transects were chosen following zones with and without landsides. Soil profile description and classification was done using FAO methods. Infiltration rates were measured as described by Landon in 1991. Results show that the soil types are those conditioned by topography and tropical climate namely Nitisols, Cambisols, Lixisols, Ferralsols, Leptosols, Gleysols, and Acrisols. Soil type was not significant in landslide occurrences. However soil texture in the horizons was significant in some of the landslides especially in the western zone. One factor that was common to all soils sampled in the western side was the same soil texture of clay down the profile and the subsequent absence of landslides in the surroundings of the profiles. In the eastern zone soil profile horizon is significant in some of the landslides but in the shallow landslides the slope and the shallow depth which creates a discontinuity between the saprolite and the rock causing water stagnation is the main influence. The clay minerals present are high plasticity clays; Kaolinite and Illite. The infiltration rate of the top soils is generally rapid in the top soils, allowing fast flow of water into the deeper horizons.

Key words: Soil types, soil horizon, infiltration, landslides, Bududa district.

INTRODUCTION

Although considerable research has been done on landslides in the world, little is known about their causes in the mountainous areas of Uganda. Bududa District which lies on the steep slopes of Mt. Elgon in eastern Uganda has increasingly experienced catastrophic landslides over the years and according to one of the elders, in the past communities believed in myths and superstitions as the causes of these landslides. Chenery (1960), in ‘An introduction to the soils of the Uganda Protectorate’, mentions soil slips in this area of Bududa. During the El Niño rains of 1997 landslides killed forty eight people and displaced ten thousand in this area (Kitutu et al., 2004). By 2004 about fifteen thousand people were displaced and landless, giving a rate of 700 internally displaced persons per year. In addition, damage to roads and bridges further constrains the district in development initiatives.

There is probably no such a thing as a single cause of landslides, because a number of conditions usually interact to make a rock or soil susceptible to landsliding. According to Knapen et al. (2006), the factors that influence landslides in the east African highlands are high rainfall, steep slopes, slope shape and high clay content in the soils. Sidle (1985), observed that soil properties such as particle size and pore distribution of the soil matrix can influence slope stability. These properties influence the rate of water movement and the capacity of the soil to hold water. In addition finer soils tend to hold higher volumes of water under unsaturated conditions than do coarse textured soils (Sidle, 1985). Other parameters that play a part in triggering landslides are swelling properties of clay and the rate at which water infiltrates into the clay at depth (Inganga and Ucakuwun, 2001). Zung AB (2008) shows that certain soil characteristics may be useful tools for assessing landslide frequency. He further supports the hypothesis that landslide occurrence in the Bridger-Teton National Forest is

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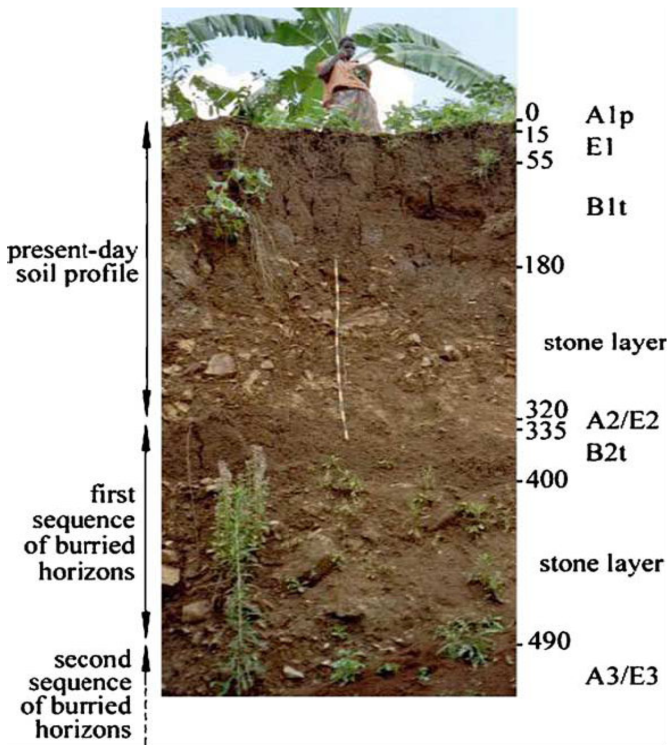

Figure 1. General sequence of the layers on the landslide scars in the western zone. The B2t layer becomes saturated during rain seasons causing landslides Knapen et al., 2006.

Forest is related to geology, and to the weathering of slope material, which effects clay mineralogy. Knapen et al. (2006) studied soil profiles of seven of the fifteen landslides that occurred in the western zone of this area in 1997. Results show that the scarps of these landslides showed the same sequence of soil layers, but their thickness was not always equal. The general sequence of the soil layers on the landslides scarps is given in Figure 1 below and the B2t horizon which had black manganese mottles on the ped surfaces indicating reduced drainage was the failure plane in all the landslides studied. The explanation was that the texture of B2t is a silty clay to clay and A3/E3 has a sandy silt loam to sandy loam texture. So a fine textured layer overlays a coarse textured layer, which implies a discontinuity of pores resulting in a reduced drainage. It has also been observed in the field that water flows out of the B2t during rain seasons.

Therefore, this study was undertaken to try to understand the nature and characteristics of soils in this area and how these soil properties influence landslide occurrence there.

MATERIALS AND METHODS

Study area

The study area is in Bududa district which lies at the foot of the south-western slopes of the Mount Elgon volcano. It is geographically bound by latitude 2° 49’ N and 2° 55’ N, longitude 34° 15’ E and 34° 34’ E. The geomorphology of the area is greatly controlled by the volcanism and doming of the country rock. The main geology is fenitised basement rocks and in the central part known as Bukigai, a pre-Elgon alkaline volcanic structure, the Butiriku carbonatite Complex stands out. This carbonatite intrusion of Oligocene-Miocene age (King et al., 1972) is one of the sub-volcanic complexes that occur along a 65km stretch in south-eastern Uganda. Soil surveys done by Isabirye et al., (2004), show that soils in this area have a sequence where the central carbonatite dome is covered by Rhodi andic Nitisols and the surrounding areas by Rhodi andic Luvisols, Haplic lixic Ferralsol, and Humic andic Nitisols, respectively, as you move away towards the edge of the study area. The concentric drainage pattern from the weak slopes surrounding the carbonatite meet in River Manafwa that finally drains in the Lake Kyoga swamps in the central region of the country. The average precipitation in the area is above 1500mm of rainfall per year and this is controlled by the high altitude of 1250-2850m. Two distinct wet seasons can be distinguished, separated by dry periods during December to February and July.

Soil Sampling and analysis

Soil sampling points were selected on four transects namely Bududa, Bushika, Nusu, and Bukalasi, with spacing intervals of 1 Km (Figure 2). The Bushika, Nusu and Bukalasi transects cut through zones with landslide occurrences while the Bududa transect cuts through a zone without landslides and this was meant to give a good comparison of areas with and without landslides. Soil profiles were described according to the FAO Guidelines for soil profile description (FAO, 1990) and soils were classified according to the FAO World Reference Base for Soil Resources (FAO-ISRIC-ISSS, 1998). The data collected on the characteristics of the profile site was location, soil classification, topography, slope, micro-topography, landuse, parent material, effective soil depth, erosion, soil water relationships, flooding, drainage, groundwater depth, moisture conditions and soil horizon description. Soil color was described using the Munsell Colour Chart, (2000). Soil samples were analysed at the Soil and Plant Analytical Laboratories at the National Agricultural Research Laboratories, (NARL), formerly Kawanda Agricultural Research Institute, using methods described by Okalebo et al. (1993).

Laboratory analyses done included cation exchange capacity (CEC), exchangeable bases, acidity and organic carbon.

Soil physics

Water infiltration was done as described by Landon (1991) and tests were carried out near the soil profile pits. Atterberg limit tests were carried out on soils in Bududa and Nusu zones. Soil samples were obtained from one of the landslide sites at different depths. The Plastic Limit (PL) and Liquid Limit (LL) for each sample were determined using the drop cone penetrometer method at the Soil Mechanics Laboratory at Makerere University. The Liquid Limit is the moisture content when the standard cone penetrates 20 mm into the soil. The plastic Limit is the moisture content when the cone penetrates 2 mm. The Plasticity Index (PI) = LL – PL.

Radiometric analyses of soil samples

The scarps of most of the landslides in the western zone of Bududa district show the same sequence of layers (Brugelmans, 2003). These landslide scarps are indicated in Figure 1 and the sequence shows buried soil profiles. Radiometric analyses were done using ^{210}Pb dating techniques to interpret the buried soil profiles. Dried sediment samples from a soil core from a landslide scar at Busayi

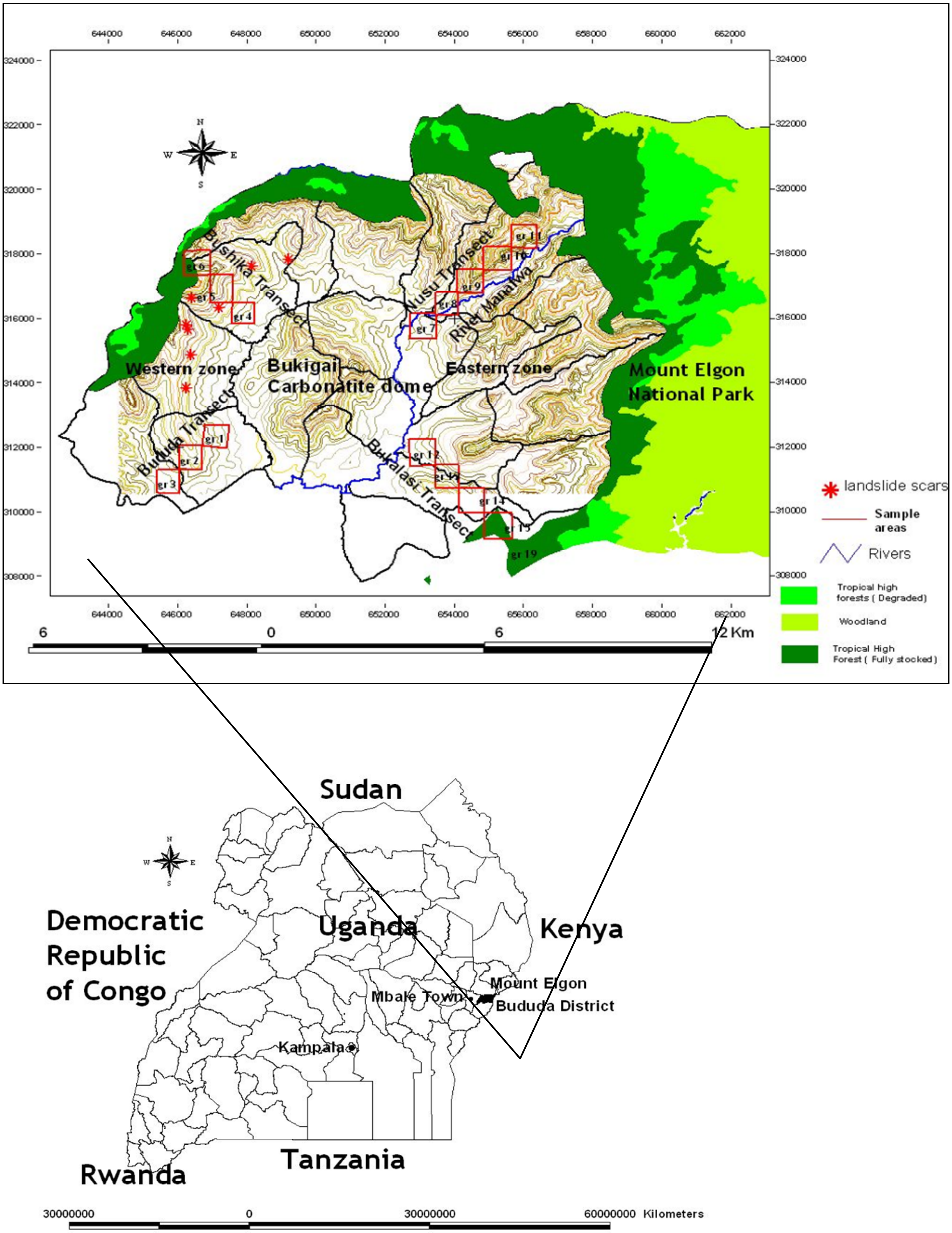

Figure 2. Sampling points and location of the study area.

Table 1. Horizon properties for the soil profile on the carbonatite dome (Soil type*: Rhodic Nitisol*).

Soil Horizon	Depth (cm)	Clay %	Silt (%)	Sand (%)	Texture class
A	0 - 40	49.6	21.3	29.1	Clay
B	40 - 140	63.6	13.3	23.1	Clay
B continues	140 beyond				Clay

in Bududa zone were analysed for ^{210}Pb, ^{226}Ra, and ^{137}Cs by direct gamma assay in the Liverpool University Environmental Radioactivity Laboratory, using Ortec HPGe GWL series well-type coaxial low background intrinsic germanium detectors (Appleby et al. 1986). ^{210}Pb was determined via its gamma emissions at 46.5 keV, and ^{226}Ra by the 295 keV and 352 keV γ-rays emitted by its daughter isotope ^{214}Pb following 3 weeks storage in sealed containers to allow radioactive equilibration. ^{137}Cs was measured by its emissions at 662 keV. The absolute efficiencies of the detectors were determined using calibrated sources and sediment samples of known activity. Corrections were made for the effect of self-absorption of low energy γ-rays within the sample (Appleby et al. 1992).

RESULTS AND DISCUSSION

Soil variability

Most of the upland soils on steep slopes and pediments in the surveyed area are deep and very porous in the top 100cm of clay loams or clays. They have very little or no laterite and they show very little horizon differentiation below the top 20 - 25 cm apart from slight changes in firmness. However, along the streams which radiate almost from all directions, especially from the mountain slopes, soil material has been brought down and packed with stiff clay, forming an impervious layer within 100 cm from the soil surface. Stratification above this layer is not a common feature due mainly to the speed of the water which tended to carry away all fresh sediments to the lower areas.

Soils on the carbonatite dome

Soils on the carbonatite dome in Bukigai are clay-rich with more than 30% clay, uniform color down the profile and less than 20% change in clay content over at least 12 cm in the top 2 m of the profile (Table 1). Sand and silt contents reduce down the profile. The soil has a redder hue in the top horizons and the B horizon has shiny ped faces. The structure and consistence are also uniform and there is no translocation of clay in the top 200 cm of the profile. The soils are permeable to water and plant roots in the top 200 cm and there is little run-off erosion except on unprotected slopes exceeding 15%. The soils are Rhodic Nitisols. These are very stable and do not suffer from landslides. Drilling disclosed that these soils are weathered to depths of about 40 meters and are derived from minerals such as magnetite and hematite which are rich in iron hence the distinct red color in the soils (Reedman, 1973). The stability of these soils may be due to the high cohesion as a result of cementing minerals such as calcium carbonate. A similar phenomenon was also observed by Pearce et al. (1981) in New Zealand, that the degree of calcium carbonate cementing was directly related to some of the stable rocks and soils.

Soils in the western zone

The Bududa and Bushika transects are situated in the zone west of the carbonatite dome. The soil types identified are Cambisols, Nitisols, Acrisols and Lixisols.

The described soil profiles at sample areas gr1, gr2, gr3, gr4, gr5 and gr6 show a similar sequence of high clay content throughout the horizon (Table 2) and this sequence differs from the one observed by Knapen et al., 2006 at the landslide scars. The sample area gr3 being downslope is not susceptible to landslide occurrences (Table 2). Four landslides were observed around gr5 but the soil profile does not show any horizon stratification neither the properties of water stagnation which seem to be common to the soils on the landslide scars. The sequence of buried soil profiles appears to be localised at places were the landslides occur and this may be due to past landslide activity. Past landslide activity was confirmed by the local people in this western zone and they estimated a recurrence of approximately 100 years.

Soils in the eastern zone

The eastern zone had the highest number of landslide occurrences in 1997 and the main areas affected were Nusu and Bukalasi. These landslides are shallow as compared to those in the western zone (Figures 3 and 4). The soil profiles at gr7, gr12, gr14 and gr15 had the same sequence of clay in the Ap and down the B horizons (Table 2) and landslides were only observed in the surroundings of gr14. Sample areas gr7 and gr12 being at the lower slope are not susceptible to landslides however the high number of landslides at gr14 could be due to a combination of other factors such as terraces, cultivation and concavity which had been reported by Knapen et al., 2006 to have a significance in landslide occurrence.

The soil profiles at gr9, gr10 and gr11 have sandy clay loams in the upper soils which are underlain by the sandy clay soils. The surroundings of gr11 had no landslide

Table 2. Texture analysis and infiltration for soils around the Carbonatite dome in Bududa District.

Soil Horizon	Depth (cm)	Clay %	Silt (%)	Sand (%)	Texture class	Cumulative Intake (cm).	Basic Infiltration rates (cm/hr)	Infiltration category (BA1,1979)	Number of landslides
Bududa transect									
Soil profile gr1: *Fluvic Cambisol* (Lower slope) landuse : banana and coffee									
Ap	0-20	43.6	11.3	45.1	Sandy clay				
AB	20-32	-	-	-	-	96.1	12.4	Rapid	0
B	32-90	45.6	13.3	41.1	Clay				
BC	90-120	47.6	11.3	41.1	Clay				
C	120+	57.6	13.3	33.1	Clay				
Soil profile gr2: *Rhodic Nitisol* (Lower slope) landuse : banana and coffee									
Ap	0-15	55.6	15.3	29.1	Clay				
B1	15-45	55.6	7.3	29.1	Clay	212.4	25.2	Rapid	0
B2	45-80	53.6	19.3	39.1	Clay				
BC	80-150	45.6	17.3	35.1	Clay				
Soil profile gr3: *Rhodic Acrisol* (Upper slope) landuse : banana and coffee									
Ap	0-15	53.6	17.3	29.1	Clay				
Bt1	15-50	81.6	11.3	7.1	Clay	227.1	38.0	Very rapid	0
Bt2	50-160	83.6	7.3	9.1	Clay				
BC	160-200	77.6	5.3	17.1	Clay				
Bushika transect									
Soil profile gr6: *Endo-skeletic Cambisol* (Upper slope) Landuse : cultivated garden									
Ap	0-30	49.6	9.3	41.1	Clay				
B1	30-50	55.6	5.3	39.1	Clay	176.7	29.6	Very rapid	0
B	50+	-	-	-	-				
Soil profile gr5: *Rhodic Nitisol* (Upper slope) Landuse : cultivated garden									
Ap	0-30	57.6	15.3	27.1	Clay				
B	30-80	43.6	11.3	45.1	Sandy clay	216.7	36.8	Very rapid	4
Bt	80-120	53.6	9.3	37.1	Clay				
B	120 +	-	-	-	-				
Soil profile gr4: *Haplic Lixisol* (upper slope) land use : banana coffee									
Ap	0-30	57.6	11.3	31.1	Clay				
Bt	30-90	69.6	11.3	19.1	Clay	275.8	3.1	Moderately slow	0
Bc	90-160	67.6	7.3	25.1	Clay				
Nusu transect									
Soil profile gr7: *Haplic Ferralsol* (lower slope) landuse: sugarcane and Eucalyptus									
Ap	0-20	39.6	13.3	47.1	Sandy clay				

Table 2. Contd.

AB	20-40	45.6	17.3	37.1	Clay	47.2	1.5	Moderately slow	0
B	40-80	41.6	17.3	41.1	Clay				
BC	80-120	35.6	7.3	57.1	Clay				
Soil profile gr9: *Endo-leptic Lixisol* (Upper slope), Landuse: grazing land									
Ap	0-20	25.6	21.3	53.1	Sandy clay loam	43.0	11.2	Moderately rapid	2
Bt1	20-70	33.6	15.3	51.1	Sandy clay loam				
BC	70+	37.6	13.3	49.1	Sandy clay				
Soil profile gr10: *Haplic Gleysol* (upper slope), Landuse: banana and coffee									
Ap	0-30	25.6	11.3	63.1	Sandy clay loam	94.7	14.8	Rapid	7
Bt	30-70	31.6	7.3	61.1	Sandy clay loam				
Bg1	70-110	37.6	9.3	53.1	Sandy clay				
Bg2	110-130	38.6	7.3	55.1	Sandy clay				
Soil profile gr11: *Gleyic Lixisol* (Lower slope), Landuse: banana coffee									
Ap	0-30	19.6	19.3	61.1	Sandy loam	104.2	18.8	Rapid	0
Bt	30-70	39.6	15.3	45.1	Sandy loam				
Bg	70-110	29.6	17.3	53.1	Sandy clay loam				
Bukalasi Transect									
Soil profile gr12: *Haplic Ferralsol* (lower slope) Landuse: bananas and coffee									
Ap	0-28	39.6	15.3	45.1	Sandy clay	108.8	17.2	Rapid	0
B1	28-50	45.6	21.3	33.1	Clay				
B2	50-100	53.6	11.3	35.1	Clay				
BC	100+	55.6	9.3	35.1	Clay				
Soil profile gr14: *Haplic Acrisol* (Upper slope) landuse: cultivated garden									
Ap	0-20	39.6	11.3	49.1	Sandy clay	230.5	45.6	Very rapid	13
Bt1	20-50	59.6	15.3	25.1	Clay				
Bt2	50-80	59.6	13.3	27.1	Clay				
Bt3	80-130	55.6	3.3	41.1	Clay				
Soil profile gr15: *Rhodic Lixisol* (Upper slope) landuse : grazing field)									
A	0-20	55.6	15.3	29.1	Clay	112.9	20.8	Rapid	0
Bt1	20-50	67.6	11.3	21.1	Clay				
Bt2	50-150	67.6	5.3	27.1	Clay				

Figure 3. Shallow landslides on the Nusu transect 2007.

Figure 4. Surficial landslide on cultivated land in Bukalasi transects 1997.

occurrences and this can be explained by its position in the lower slope. However, the gr9 and gr10 had two and seven landslides respectively. The explanation of land-slide occurrences could be due to the sandy clay loams which are lighter and promote faster flow of water into the lower horizons richer in clay which stagnates water flow through the soil thereby causing water to accumulate in the potential failure planes increasing hydrostatic pres-sure in the soils. Another observation made is that the parent rock is nearer to the surface and the porous saprolite forms an abrupt discontinuity with the coherent basement complex granite (Figure 3 and 4). In here the conditioning factors are soil horizon differ-rentiation and the saprolite forming a discontinuity with the parent rock-granite. During rains, drainage of water through the soil profile is stopped at the point of discon-tinuity thereby causing water to accumulate. These phenomena results in a semi-solid sub soil material that will easily flow or slump under pressure from the top soil accerated by the accelerated by the slope gradient. This can be confirmed by the gleyic properties in the gr10 profile. The soil profile at gr11 and gr12 are not susceptible to landslides because of their position lower in the slope.

The soils on average have a high infiltration rate which creates a fast flow of water into the soils down the profiles and where there is higher clay content water flow stagnates causing landslides.

Atterberg limits

Soils in the survey area contain clays of high plasticity (CH) according to the Unified Soil Classification System (Figure 5). Depending on the water content soil may behave as a solid, semi-solid, plastic or liquid. The amount of water needed to change the behaviour depends on the species of clay mineral present (Selby, 1993). According to the CEC values, the clay minerals in these soils are Kaolinite and illite, which are known for causing slumps in the Himalayas (Dhruba, 2000).

Radiometric analyses of samples from a landslide scar using ^{210}Pb method.

The results of the radiometric analyses are given in Table 3 and shown graphically in Figure 6. In all samples analysed, total ^{210}Pb activity appeared to be equal to or significantly lower than that of the supporting ^{226}Ra (Figure 6). Reasons for this deficit could be underesti-mation of the total ^{210}Pb activity due to higher than expected losses of 46.5 keV photons by self-absorption within the sample caused by an unusual mineral content of the sediments with a high attenuation coefficient, or in situ losses of ^{222}Rn from the soil by exhalation to the atmosphere. Regardless of the explanation, it is clear that concentrations of fallout ^{210}Pb in the samples analysed, measured by the extent to which total ^{210}Pb activity exceeds that of the ^{210}Pb produced in situ decay of the supporting ^{226}Ra, are negligible, and that these samples cannot therefore be dated by ^{210}Pb.

Artificial fallout radionuclides

Caesium-137, (^{137}Cs), activity was below levels of detec-tion in all samples analysed. The absence of fallout radio-nuclides indicates that none of the soil samples analysed have been exposed to the atmosphere for several decades at least. Such fallout that has occurred has pre-sumably been retained in the top 20 cm.

Conclusion

The soil types present are mainly those conditioned by topography and wet tropical climate namely Cambisols,

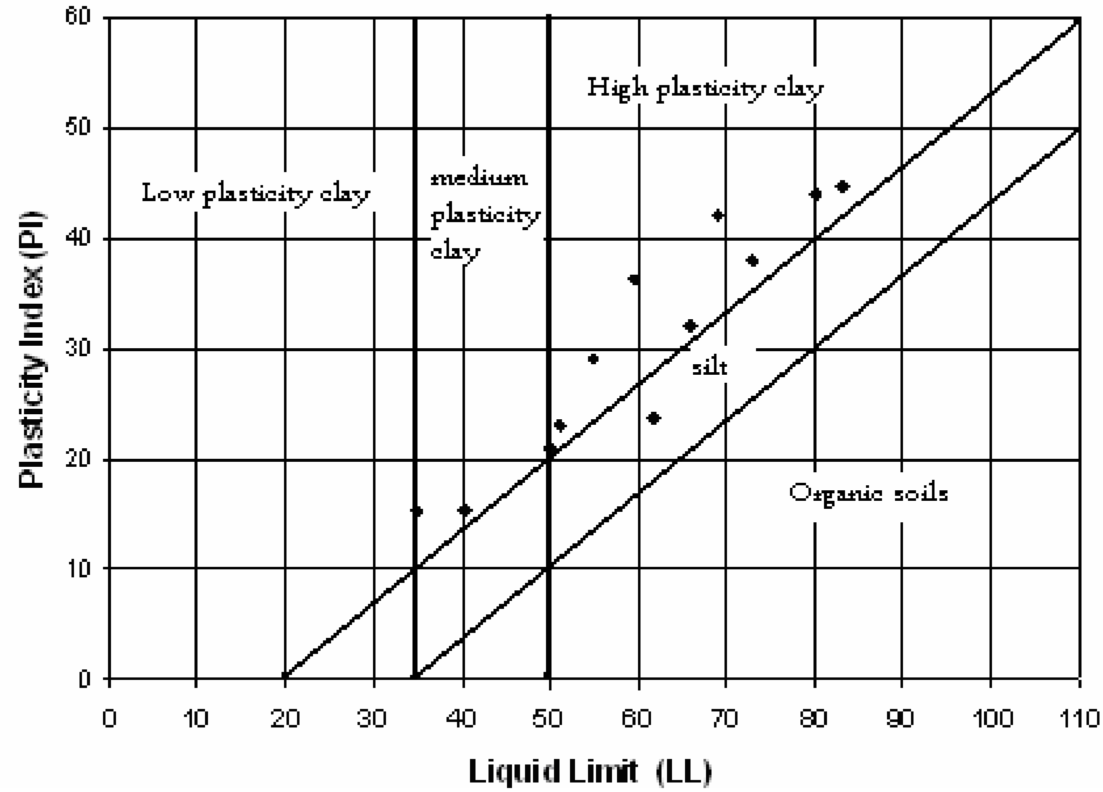

Figure 5. Plasticity Properties of Nitisols in Bududa District using AASHTO Classification.

Table 3. Fallout radionuclide concentrations in the Bududa soil core.

		^{210}Pb							
Depth		**Total**		**Unsupported**		**Supported**		^{137}Cs	
cm	g cm^{-2}	Bq kg^{-1}	±	Bq kg^{-1}	±	Bq kg^{-1}	±	Bq kg^{-1}	±
50	63	39.3	3.8	-28.9	3.9	68.2	0.8	0.0	0.0
100	137	48.9	4.8	-10.4	4.9	59.4	1.0	0.0	0.0
150	215	33.2	3.0	-12.0	3.1	45.3	0.6	0.0	0.0
200	288	25.0	3.2	-7.8	3.2	32.9	0.6	0.0	0.0
250	351	34.1	3.2	-7.3	3.3	41.3	0.6	0.0	0.0
300	415	53.7	3.0	3.7	3.1	50.0	0.6	0.0	0.0

Lixisols, Ferralsols, Leptosols, Gleysols, Nitisols and Acrisols. The soil type has no influence on landslides but soil texture seems to be of significance. Landslides in western zone are due to soil horizon stratification that favours water stagnation in the lower horizons and they are only confined to places where there is water stagnation in the lower soil horizons. The landslides in the eastern zone are dependent on several factors which include soil texture, depth to the bedrock, landuse and slope shape. The clay minerals present are Kaolinite and illite. The buried soil profiles in the western side could be due to different landslide events but the high deposition rates do not allow the soils be exposed to the atmosphere for more than a decade and hence cannot be dated using ^{210}Pb method.

ACKNOWLEDGEMENTS

Appreciation goes to Mr. Clement Ssali a soil scientist at Namalere Agricultural Station for the technical support during the soil surveys. More appreciation goes to Dr. Moses Isabirye and Mr. Sendiwanyo of Kawanda Agricultural Research Institute and Dr. Mwanjalulu Mwajaliwa of Makerere University for the technical assistance during the laboratory soil analysis and general discussions.

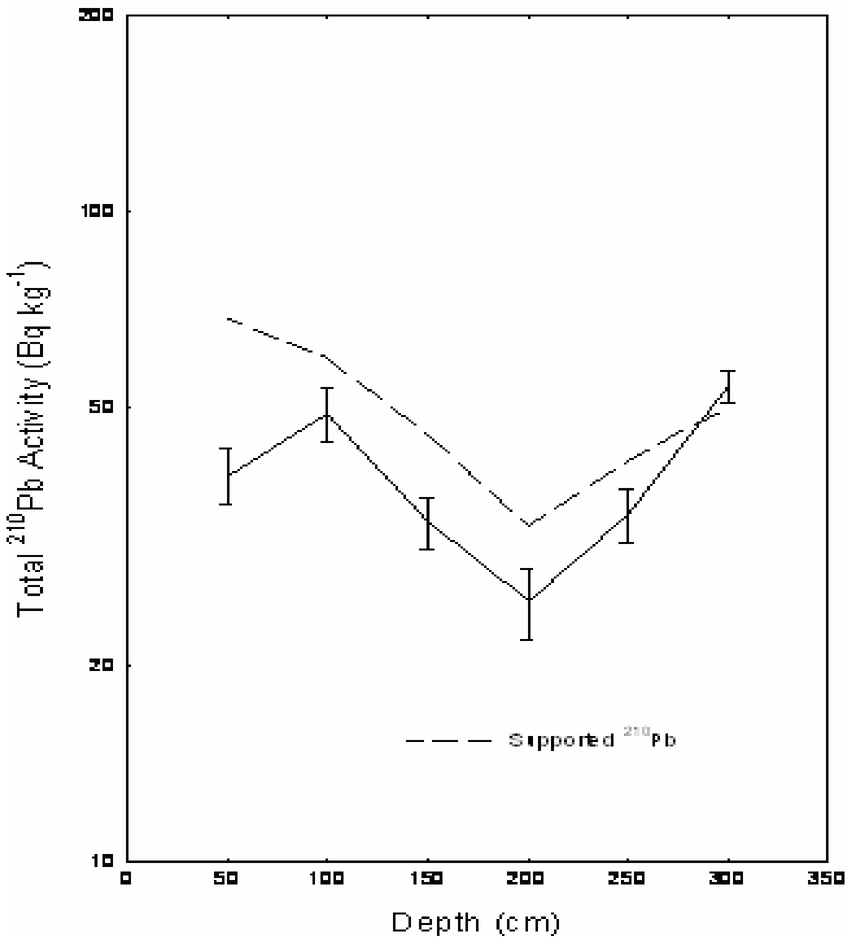

Figure 6. Total and supported ^{210}Pb concentrations versus depth in the Bududa soil core.

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