Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com

Soil Vulnerability and Degradation Assessment of Mountainous Area in Ekoli-Edda, South-East Nigeria

[1*]Ekpe, I.I, [1]Oludare C. G, [1]Oti, N.N, [1]Ishiusah O. W, [1]Egboka, N.T, [1]Orji A. and [1]Nwankwo V.C.

[1]*Department of Soil Science and Technology, School of Agriculture & Agricultural Technology, Federal University of Technology, PMB 1526, Owerri, Imo State*

ARTICLE INFO

Article history:
Received November 2020
Received in revised form December 10, 2020
Accepted February 18, 2021
Available online May 24, 2021

Keywords:
Assessment
Degradation
Ekoli
Mountainous
Vulnerability

Corresponding Author's E-mail Address:

Ibiamik@yahoo.com

https://doi.org/10.36265 njss.2020.310204

ISSN– Online **2736-1411**

Print **2736-142X**

ABSTRACT

Soil vulnerability and degradation assessment of the mountainous area in Ekoli-Edda, South-East Nigeria was carried out on four experimental sites namely Egu, Ugwuelu 1, Ugwuelu 2, and Ocha. The slope of each study site was divided into three namely summit, mid-slope, and foot slope, and slope attributes were measured. Two profile pits were sunk equidistance apart at each of the slope positions and soil samples were collected from the pits according to visualized horizonation from the bottom layer to the top. Soil geotechnical properties were determined and the slope length and slope angles of all experimental sites recorded. Other physical properties determined included Atterberg limit, bulk density, moisture content, textural properties, shear strength, and plasticity index. The raw data generated were analyzed for means and percentages following standard procedures. The results showed that the slope length of Egu, Ugwuelu 1, Ugwuelu 2, and Ocha were 52, 105, 115, and 66 meters respectively while the slope angle for all the sites ranged from 14 – 52 degrees at the summit, mid-slope, and foot slope. The soils of Ocha and Egu were non-plastic while the soils of Ugwuelu 1 and Ugwuelu 2 recorded moderately high values of liquid limit, plastic limit, and plasticity index. For all the experimental sites, the safety factor recorded was lower than 1. This was an indication that the areas studied were prone to landslide occurrence. It was recommended that building and other agricultural activities should only be embarked upon with the advice of professionals.

1.0 Introduction

Land degradation is defined as the long-term loss of ecosystem function and productivity caused by disturbance from which the land cannot recover unaided (*Bia et al., 2008*). It can also be seen as all processes that cause a reduction in the capacity of the land to produce goods and services for the needs and benefit of current and future generations. Land degradation occurs slowly and cumulatively and has long-lasting impacts on rural people who become increasingly vulnerable (*Muchena, 2008*).

Human activities contributing to land degradation include unsustainable practices, deforestation, and removal of natural vegetation, frequent use of heavy machinery, overgrazing, improper rotation, and poor irrigation practices. Natural disasters that lead to degradation include drought, floods, and land landside. The term landslide includes all varieties of mass movements of hills slopes and can be defined as the downward and outward movement of slope forming materials composed of rocks, soils, artificial fills, or a combination of all these materials along surfaces of separation by falling, sliding, flowing either slowly or quickly from one place to another. Although landslides are primarily associated with mountainous terrains, these can also occur in areas where an activity such as surface excavations for highways, buildings, and open-pit mines takes place. Landslides are a major hazard in Africa where resources worth several millions of dollars are lost annually during seasons of heavy and also light rains. The mechanisms of rainfall-induced landslide have been extensively studied and some of the conclusion asserts that the amount of rain, nature of slope material, and weathering are the major factors predisposing a slope to failure (Iverson 2000; Mislimba and Holmes 2010; Wang *et al*., 2002; Sassa *et al*., 2004; Guzzetti *et al*., 2008).

Landslide induced by high intensity or prolonged rainfalls constitutes a major risk factor in Nigeria especially because they have generally been poorly defined in the past. The landslide has the potential to damage human settlements, industrial development, cattle ranch, forestry, and agricultural activities.

The spatial probability of the landslide event itself can be identified through landslide susceptibility mapping. Landslide susceptibility basically can be defined as quantitative and qualitative assessment including classification, volume, and spatial distribution of landslide which exist or potentially occur (Fell *et al*, 2008).

Landslide susceptibility mapping is one of the required activities in landslide-prone areas. This is intended to recognize the spatial probability of landslides as an action to minimize the upcoming impact. Landslide susceptibility map can be used as supporting information in the spatial planning process as well, particularly in restricting landslide-prone areas free of the development zone. The main objective of the study was to carry out a landslide susceptibility assessment of the mountainous area of Ekoli-Edda, south-east Nigeria to identify areas in Ekoli prone to landslide occurrence.

2.0. Materials and methods

2.1. Study area

The experiment was carried out at the mountainous area of Ekoli-Edda in the Edda Local Government area of Ebonyi State. It is located at latitude (05^0,47'N) and longitude (07^0,50'E) in Southeast of the high rainfall zone of Nigeria. The mean annual rainfall is about 2000mm-2500mm spread between March - December, the bedrock geology is shale residuum. The soil is shallow with unconsolidated parent materials within 1m of the soil surface classified as dystric leptisol. The mean annual minimum and maximum air temperature are 27^0c and 31^0c respectively with an average relative humidity range of 35-60% from dry season to the rainy season. The climatic zone is high rainfall dominated by tall trees and shrubs. The major occupation of the people is small-scale farming. Land preparation is by slash and burns while soil fertility regeneration is mainly by 9 year bush fallowing. Other socio-economic activities include palm oil processing, stone quarry, and small/ medium enterprises. Approximately 85% of the population depends on agriculture for their livelihood. The agricultural productions include crops, oil palm, and livestock produced at both subsistence and export levels. The location coordinates of studied sites are presented in Table 1

2.2. Field studies

Table 1: Determined location coordinates and elevations of the sampled sites

Location	Latitude	Longitude	Elevation above Sea level
Egu	$5^0 44.447^{11}$N	$7^0 50.556^{11}$E	177. 9m
Ugwuelu 1	1 $5^0 44.542^{11}$ N	$7^0 51.334^{11}$E	179m
Ugwuelu 2	2 $5^0 44.512^{11}$N	$7^0 5.403^{11}$ E	104m
Ocha	5^0 45'' N	$7^0 50^{11}$ E	188m

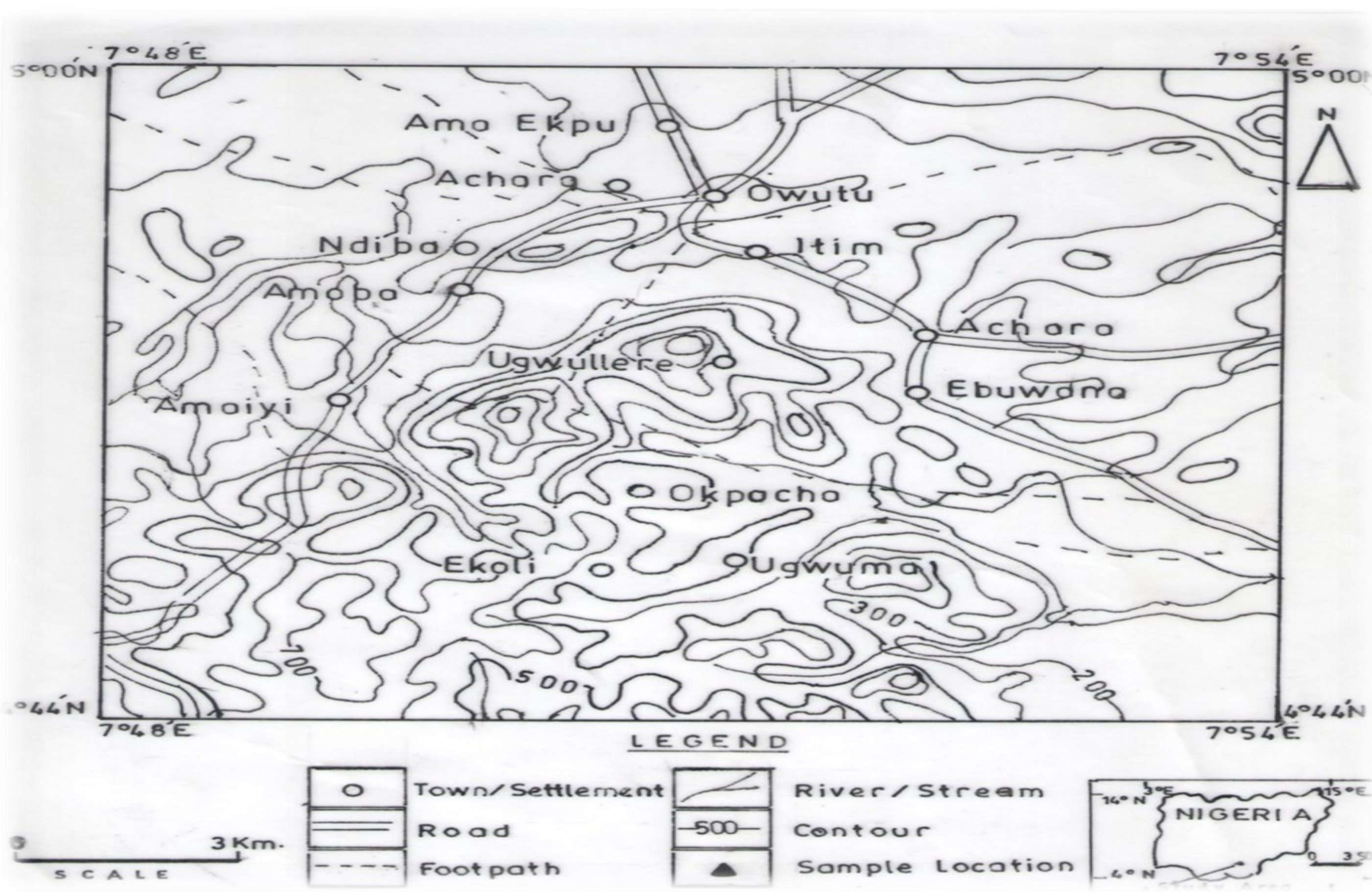

Fig. 1: Elevation Map of Study Area

A reconnaissance visit was carried out before field operations. The field survey was conducted to obtain several primary data related to soil properties (depth, texture, and permeability), land use, and location of landslide events. A total of four slope points was identified and used as study locations. Two profile pits were dug at each sample location at a distance of 15m apart and soil samples were collected from each pit according to the visualized horizon from the bottom layer to the top. Samples collected were bagged and labeled properly for easy identification and the samples were transported to the laboratory for analysis. In addition, surface samples from 0 – 30cm soil depth were collected with the aid of a core sampler to determine the physical and chemical properties of soils in the study locations.

2.3. Laboratory analysis

The soil samples were air-dried, crushed, and sieved before subjecting them to various analyses, evaluations, and classifications.

2.4 Physical properties

Particle size distribution was determined by the hydrometer method in water and Calgon; where sodium hexametaphosphate solution was used as dispersing agent (Gee and Or, 2002).

Bulk density was determined using the core method (Gross and Reinch, 2002). It was calculated thus;

$$Bulk\ density = \frac{mass\ of\ oven\ dried\ soil}{volume\ of\ core\ sampler}$$

It is expressed in g/cm^3 (Brady and Weil, 2010).

Total porosity was calculated from the result of bulk density and particle density.

Porosity,
$$Tp = \left(1 - \frac{pb}{ps}\right) X\ \frac{100}{1}$$

Where; Tp = porosity

Pb = bulk density (g/cm^3)

Ps = particle density (assumed to be $2.65g/cm^3$ for tropical soils)

Moisture content was determined by the gravimetric method. It was calculated thus;

$$\%\ MC = \frac{w_2 - w_3}{w_3 - w_1}\ X\ \frac{100}{1}$$

Where;

% Mc = Percentage moisture content

W_1 = Weight of moisture can

W_2 = Weight of air-dried soil + moisture can

W_3 = Weight of oven-dry soil + moisture can

2.5. Particle size distribution:

The soil sample was passed through the sieve of various sizes and the grain of soil retained in each sieve was measured. Atterberg limit was determined using Casagrande method and plasticity index (PI) was calculated following clause 4.5 and 5.3 part 2 of BS 1377 and BS 1990, respectively. Shear strength was determined as in ASTM D2487-11 (2000) specifications.

2.6. Statistical Analysis

The data collected from the field experiments and various laboratory analyses were presented in tables. The data was generated from this study was subjected to analysis of variance (ANOVA) based on a completely randomized design. Means that were significantly different were separated using Fisher's least significant difference (F-LSD) according to Gomez and Gomez (1984).

3.0 Results and Discussion

3.1 Slope angle

The result (Table 2) shows that the slope angles at the top, mid, and foot of the sampled sites record a range of 23^0 – 52^0, $14^0 – 44^0$, $17 – 41^{0,}$ and $26^0 – 39^0$ for Egu, Ugwuelu 1, Ugwuelu 2, and Ocha respectively. Using critical slope angle of 35^0 (Hock and Boyd, 1973), the results of the sampled sites shows the possibility of a landslide event in all the area because of their maximum slope angles greater than the critical slope angle of 35^0. This might explain the landslide event that occurred at Ugwuelu 1. However, the final conclusion cannot be drawn as there have been records of landslide events on slopes less than 35^o, (Fernandez et al., 2006). Fernandez et al. (2006) further found out that the frequency distribution of landslide (landslide potential index- LPI) depends on other factors. The study revealed that slope angles between 18.6^0 and 37^0 were the most frequent to fail, followed by 37.1^0 to 55.5^0 ranges. Beyond 55.5^0, LPI decreased. All things being equal, the steeper the slope, the greater the shearing stress and therefore the greater the likelihood of slope failure.

3.2 Physical properties

Table 2: Slope length and slope angle sites

Area	Slope length (Meters)	Slope locations		
		Summit	shoulder	Foot
Egu	52	23^0	39^0	52^0
Ugwuelu 1	105	14^0	36^0	44^0
Ugwuelu 2	115	17^0	29^0	41^0
Ocha	66	26^0	27^0	39^0

The results of the laboratory analysis of the physical properties of the soils are shown in Table 3.

3.2.1 Bulk density

The bulk density result shows that there was a statistically significant difference when the soil of Egu was compared with the soils of Ugwuelu 1, Ugwuelu 2 but not significant when compared with the soil of Ocha. A significant difference was obtained when the soil of Ugwuelu 1 was compared with the soils of Ugwuelu 2 and Ocha. Also, the soil of Ugwuelu 2 differed significantly when compared with the soil of Ocha. The mean value revealed that Egu soil had 0.27, 0.36, and 0.02 than Ugwuelu 1, Ugwuelu 2, and Ocha soil. Ugwuelu 1 recorded 0.09 more than Ugwuelu 2 and -0.34 less than the soil of Ocha.

3.2.2. Total porosity

The result of the total porosity of the sampled sites showed that there was a statistically significant difference when Egu soil was compared with the soils of Ugwuelu 1, Ugwuelu 2, and Ocha. A significant difference was recorded when the soil of Ugwuelu 1 was compared with the soils of Ugwuelu 2 and Ocha. But no significant difference was observed when the soil of Ugwuelu 2 was compared with that of Ocha. The mean value of the sampled sites shows that Egu recorded -10.19, -13.34, and -0.76 less than Ugwuelu 1, Ugwuelu 2, and Ocha soils respectively. The soil of Ugwuelu 1 recorded -3.15 less than Ugwuelu 2 soil and 9.43 more than Ocha while Ugwuelu 2 had 12.58 more than Ocha soil.

3.2.3 Sand

The result shows that there was a statistically significant difference when the soil of Egu was compared with the soils of Ugwuelu 1, Ugwuelu 2, and Ocha. A significant difference also was observed when the soil of Ugwuelu 1 was compared with the soils of Ugwuelu 2 and Ocha. The soils of Ugwuelu 2 and Ocha differed significantly when compared. The mean values of the four different sites revealed that Egu had 10.33, 20.33, and 11.00 more than Ugwuelu 1, Ugwuelu 2, and Ocha soils respectively. The soil of Ugwuelu 1 recorded 10.00 and 0.67 more than Ugwuelu 2 and Ocha soils respectively. The soil of Ugwuelu 2 recorded -9.33 less than Ocha soil.

3.2..4 . Silt

The result showed that there was a statistically significant difference in Egu soil was compared with Ugwuelu 1 but no difference, when compared with Ugwuelu 1, was compared with Ugwuelu 2 and Ocha, there was a significant difference but no significant difference was observed when the soil of Ugwuelu 2 was compared with Ocha. The mean values of the sites showed that Egu recorded – 12.00, - 0.33, and 0.00 less than Ugwuelu 1, Ugwuelu 2, and Ocha soils respectively. Ugwuelu 1 soil recorded a difference of 11.67 and 12.00 when compared with Ugwuelu and Ocha soils respectively. Also, the soil of Ugwuelu 2 had 0.33 more than Ocha soil.

3.2.5 Clay

The result showed that there was a statistically significant difference in their clay content when the soil of Egu was compared with the soils of Ugwuelu 1, Ugwuelu 2, and Ocha. There was also a significant difference when the soil of Ugwuelu 1 was compared with Ugwuelu 2 and Ocha differed significantly when compared. The mean values of the sampled sites revealed that the soils of Egu recorded 1.67 more clay than the soils of Ugwuelu 1, - 20.00 and 11.07 less than the soils of Ugwuelu 2 and Ocha respectively. The soil of Ugwuelu 1 revealed – 21.67 and – 12.74 less than Ugwuelu 2 and Ocha soils respectively while the soil of Ugwuelu 2 had 8.93 more than that of Ocha.

3.3. Atterberg Limits

Table3: Selected physical properties of soils in the sampled sites.

Area	MC (%)	BD (g/cm^3)	TP (%)	HC (g/cm^3)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Textural Class
Egu	17. 33[a]	1. 63[a]	38. 61[a]	0.82[a]	862. 9[a]	23.9[a]	113.2[a]	Loamy sand
Ugwuelu 1	46. 87[b]	1. 36[b]	48. 80[b]	0. 55[b]	697.43[b]	39.30[b]	263.20[b]	Sandy clay loam
Ugwuelu II	52. 63[c]	1. 27[c]	51. 95[c]	0. 13[c]	659. 6[c]	27.2[c]	313.2[c]	Sandy clay loam
Ocha	44. 10[d]	1. 61[a]	39. 37[d]	0.23[d]	837.50[d]	66.00[d]	96.50[d]	Sandy loam
F-LSD (P= 0.05)	4. 08	0. 06	2. 38	0. 085	12.19	11. 33	14. 29	

MC = Moisture content, BD = Bulk density, TP = Total porosity, HC = Hydraulic conductivity

The Atterberg limit test result is presented in Table 4. The Atterberg limit result of the sampled sites showed that the soils of Egu and Ocha are non-plastic (NP) while the soils of Ugwuelu 1 and Ugwuelu 2 recorded liquid limits of 37.8% and 37% respectively. The non-plasticity of soils of Egu and Ocha confirms the high percentage of sand in the textural class of the two sites. Also, non plastic nature of this resulted from the low clay contents recorded in the particle size analysis which was below the 10% threshold indicator for soils to possess" expansion potentials (Vander Merwe 1964; Baynes 2008). This non-expansive nature of soils in this area impacts very low susceptibility to landslide, all other things being equal. Furthermore, the soils of Ocha and Egu recorded high water permeability levels as revealed by the results of the coefficient of permeability (Table 8). Therefore, water retention within the soil pores is low as well as the shear stress which could increase with the increase in water content in the soil body. (Wati *et al*., 2010).

The high liquid limits recorded at the experimental sites of

Table 4: Atterberg limits of the locations

Area	Depth (cm)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Ocha	10 - 15	NP	NP	0
	15 – 60	NP	NP	0
Ugwuelu 1	0 – 15	37. 8	17. 9	19. 9
	15 – 60	41. 5	23. 2	18. 3
Ugwuelu 2	0 – 15	37. 0	19. 1	17. 9
	15 – 60	42. 8	19. 4	23. 4
Egu	0 – 15	NP	NP	0
	15 – 60	NP	NP	0

NP = Non-plastic

Ugwuelu 1 and Ugwuelu 2 qualifies the soils here as problem soils that are susceptible to landslide (Vander Merwe 1964; Baynes 2008). The Atterberg limits determine the behavior of soils before deformation occurs (Alexander, 1993). The Atterberg limits were determined to establish the structural strength of the soils in all the study areas. Liquid limit tests were carried out to determine the water content of the soils required before the soils split or crumble. The plasticity index was calculated from liquid and plastic limits to give the range over which the soils in this study area remain plastic before deformation.

Also, the clay fraction which is at the 10% threshold identified from the particle size analysis in the soils of Ugwuelu 1 and Ugwuelu 2 revealed the shrink-swell properties. Such soil exhibits expansion potentials concerning water contents and hence is susceptible to landslides. This is in line with the findings of Yang et al, (2007); *Jadda et al.* (2009); Wati *et al.* (2010) who showed that fine-textured clayey soils have small pores and liberate water gradually. The slow-release of soil water renders soil susceptible to landslide because of its high-water retention capacity. Furthermore, the low permeability values recorded from these sampled sites confirm the shear stress and thus the possibility of a landslide.

3.4. Particle size analysis:

The result of the particle size distribution is presented in Table 5. Particle size analyses were carried out to determine the percentages of gravel, sand, silt and which are prone to liquefaction under prolonged precipitation. Particle size also determines the physical soil properties which indicate stability (Alexander, 1993). In general, a high percentage of sand was recorded in all the sampled sites apart from the sample of Ugwuelu 1 which had a 26% sand value. This might be as a result of the agricultural and other human activities present here. The percentage silt was highest at Ugwuelu 1 at 52% and lowest at Ocha which recorded 30%. The clay content for all the sampled area range from 7 – 10%. Furthermore, the percentage of gravel content was highest in Ugwuelu 1 at 12% and lowest in Ugwuelu 2 at 0%. A 10% clay threshold has been used as an indicator of the expansion potential whilst > 32% clay content exhibits extreme expansion potential (Vander Merve 1964; Baynes 2008). This particle size analysis has aided the textural classifications of soils from Egu, Ugwuelu 1, Ugwuelu 2, and Ocha as sandy loam, silt loam, loam, and sandy loam respectively.

3.5. Shear strength:

Shear strength results are presented in Table 6. Plots of shear strength versus normal stress were used to compute the angle of internal friction and cohesion which were then used to calculate slope safety factor (Fs) for the sampled sites. Resistance and shear stress analysis can be expressed by the ratio of resistance to shear stress. This ratio provides a factor of safety which is assumed to yield a value of 1.0 (resistance equals shear stress). Higher values represent progressively more stable situations. This method of assessing stability is referred to as limiting equilibrium analysis (Crozier, 1989).

Table 5: Sieve Analysis and Classification

Area	**Depth**	**Sieve No 4 (4. 75mm)**	**Sieve No 10 (2.00mm)**	**Sieve No 40 (0.25mm)**	**Sieve No 200 (0.075mm)**	**Agg dry > (>0.075m)**	**Classification**
Ugwuelu Loc 1	0 – 15cm	100	88. 5	73. 3	62. 5	261. 8	F
Ugwuelu Loc 2		100	99. 8	84. 2	56. 5	284	F
Egu		100	95. 0	68. 0	38. 0	263	C
Ocha		100	93. 2	67. 8	40. 2	261	C
Ugwuelu Loc 1	15 – 60cm	100	89. 0	74. 7	53. 7	263. 7	F
Ugwuelu Loc 2		100	97. 3	69. 0	60. 0	266.3	F
Egu		100	95. 5	68. 5	39. 0	264	C
Ocha		100	94. 7	68. 7	41. 7	263. 4	C

C = Coarse (sand with fines)
F = Fines (inorganic silts and clay)

Table 6: Shear strength and safety factors of the experimental sites

Area	Depth (Cm)	C (KN/m^2)	$Ø^0$	r KN/M^2	Safety factor (Sf)
Ocha	0 - 15	4	20	68. 7	0. 386
	15 – 60	3	19	67. 7	0.380
Ugwuelu 1	0 – 15	8	16	58. 98	0. 332
	15 – 60	7	18	64. 8	0. 364
Ugwuelu 2	0 – 15	7	16	61. 4	0. 345
	15 – 60	7	17	61. 4	0. 345
Egu	0 – 15	4	20	68. 7	0. 386
	15 – 60	3	19	64. 2	0. 361

Where:

C = Cohesion

Ø = Angle of internal friction

r = Shear strength.

As depicted by the Fs in the table above, which is lower than the critical factor of 1, slopes at all the sampled sites are supposedly unstable. It is however noteworthy that even, slopes, where Fs is greater than 1, are conditionally stable. This stability is compromised once external and internal factors exert their influence on the slope. As noted by Sidle et al., (1985), Gupta and Foshi (1990), Inganga et al. (2001), Nyssen et al. (2002), Knapen et al. (2006), Claessens et al. (2007), NEAP (2007), and Kitutu et al. (2009), high rainfall coupled with human activities through deforestation, cultivation, and excavation are external factors that induce slope instability even on hitherto Stable slopes. Furthermore, other factors such as slope angle, water content, and liquefaction of the soil particles, *etc* need to be considered before any possible conclusion can be reached.

4.0 Conclusion

After careful examination of the results from these experimental sites, the calculated safety factor revealed results lower than the critical factor of 1. Therefore, there is the possibility of landslide occurrence. It is however noteworthy that even, slopes, where Fs is greater than 1, are conditionally stable. Other factors such as slope angle, water content, liquefaction of the soil particles and human activities, *etc* need to be considered before any possible conclusion can be reached on the susceptibility of a slope to landslide.

References

Alexander, D.: 1993, Natural Disaster, London, University College Library Press.

Brady N.C. and Weil R.R. 2002. The Nature and Properties of Soils. 13th Edition. Pearson prentice hall, New Delhi, India. 89pp

Bai, Z.G., Dent, D.L., Olsson, L., and Schaepman, M.E. (2008) "Global assessment of land degradation and improvement 1: Identification by remote sensing"

Baynes F J (2008) Anticipating problem soil on linear projects. In: Conference proceedings on problem soils in South Africa, 3-4 November 2008. Pp 9-21.

Claessens L, Knapen A, Kitutu MG, Poesen J, Deckers JA (2007) Modelling landslide hazard, soil redistribution and sediment yield of landslide on the Ugandan foot slopes of Mount Elgon. Geomorphology 90(1-2):2335. Doi: 10.1016/j.geomorph. 2007.01.007.

Crozier, M.: 1989, Prediction of Rainfall-Triggered Landslides: A test of the Antecedent Water Status Model, Earth Surface Processes and landforms 24, 825 - 833.

Fell ,R., J. Corominas, C. Bonnard, L. Cascini, E. Leroi and W.Z. Savage, 2008. Guidelines for landslide susceptibility, hazard, and risk zoning for land-use planning. Eng. Geol., 102:85-98.

Fernandes, F. Guimaraes, R. Vieira, B. Montgomery, D. and Greenberg, H.: 2006, Topographic Controls of Landslides in Rio de Janeiro: Field Evidence and Modeling. Catena 55, 163 - 181.

Gee, G.W and Or D. 2002. Particle Size Distribution. In: Dane J.H. and Topps, G.C. (eds). Methods of Soil Analysis, part 4, Physical methods. Soil Science Society of America, Book sales, No.5. SSSA, Madison, WI. PP225 -293.

Gomez, A.K, and A.A Gomez, 1984 *Statistical Procedures for Agriculture Research*. Second Edition. John Wiley and Sons Inc. NEW York, USA, 462pp.

Gupta RP and Foshi BC(1990) Landslide hazard zoning using the GIS approach. A case study from the Ramganga catchment, Himalayas. Eng Geol 28:119-131.

Guzzetti, F. Cardilla, M. Reichenbach, P. Cipolla, F. Sebastian, C. Galli, M. and Salvati, P.:2004, Landslides Triggered by the 23rd November 2000 Rainfall event in Imperial Province Western Liguria, Italy. Engineering Geology 73, 229 - 245.

Hock, E.: and Boyd, J.M.: 1973, *Stability of Slopes in Jointed Rocks*. *Journal of the Institution of Highway Engineers 4.*

Inganga, S. and Ucakuwun, E.: 2001, Rate of Swelling of Expansive Soils: A critical Factor in the Triggering of Landslides and Damage to Structure, Documenta Naturae 136, 93 –98.

Iverson R.M. Reid, M.E. Iverson, N. Lahusen, R. Logan, M., and Mann, J.E.: 2000, Acute Sensitivity of Landslide Rate to Initial Soil Porosity. Science 290, 513 - 516.

Jadda M, Shafri HZ, Mansor S, Sharifikia M (2009) Landslide susceptibility mapping (sebinkarahisar, Turkey). Bull Eng Geol Environ 68:459-471.

Kitutu MG, Muwanga A, Poesen J, Deckers JA (2009) Influence of soil properties on landslide occurrence in Bududa district, eastern Uganda. Afr J Agr Res 4(7): 611-620.

Knapen, J. Kitutu, M. Poesen, J. Brengelmans, W. Deckers, J. and Muwanga, A.: 2006, Landslides in Densely Populated County at the Foot Slopes of Mount Elgon (Uganda): Characteristics and Causal Factors, Geomorphology 73, 149–165.

Msilimba, G. Holmes, P(2010) Landslide in the rumphi district of northern Malawi: Characteristics and mechanisms of generation. Nat Hazards 54(3): 657677.

Muchena, F.N. (2008). "Indicators for sustainable land management in Kenya"s context". GEF land degradation focal area indicators, ETC- East Africa. Nairobi,

National Environmental Action Plan (NEAP).: 2007, Lilongwe, Department of Environmental affairs.

Nyssen, J.; moeyersons, J. Poesen, J., Deckers J and Mitiku, H (2002) The Environmental Significance of the Remobilization of Ancient Mass Movement in Atbara-Tekeze Headwaters near Hagere Selam, Tigray, northern Ethiopia, Geomorphology 49:303322

Sassa, K., Wang, G., Fukuoka, H. Wang, F. W. Ochiai, T., and Sugiyama S. T. (2004) Landslide risk evaluation and hazard mapping for rapid and long-travel landslides in urban development areas. Landslide 1(3):221235

Sidle, R.C, Pearce, A.J and O‟Loughlin, C.L.: 1985, Hill Slope Stability and Land Use.American geophysical union, Washington DC, P 125.

Van der Merwe DH (1964) The prediction of heave from the plasticity index and the percentage clay fractions of soils. Trans south Afr Inst Civil Eng 6(6): 103107.

Wang, FW, Sassa, K and Wang G (2000) Mechanism of a long-runout landslide triggered by the August 1998 heavy rainfall in Fukushima prefecture, Japan. Eng Geol 63(1-2); 169-185. Ward, R: 1967, Principles of Hydrology, London, McGraw - Hill

Wati SE, Hastuti T, Wijojo S, Pinem F (2010) Landslide susceptibility mapping with the heuristic approach in a mountainous area. A case study in Tawangmangu subdistrict, central Java, Indonesia. *Int Arch photo Rs Spat Inf Sci* 38(8):248-253.

Yang H, Adler R, Huffman G(2007) Use of satellite remote sensing in the mapping of global landslide susceptibility. Nat Hazards 43(2): 245-256. doi : 10.1007/s 11069-006-9104-z.