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Landslide Investigation of Ikwette, Obudu Local Government Area of Cross River State, Nigeria

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Abstract: *This study investigates the causes of a slope failure at Ikwette, Obudu local Government Area of Cross River State, Nigeria in 2013. It also involves a slope stability analysis of the failed slope, which was OB1. To understand instability in the study area, a combination of field, geotechnical and statistical analysis were undertaken. Some obtained parameters were then applied in a slope/W Geostudio 2012 software program which uses the conventional limit equilibrium methods to simulate the dominant factors inducing instability. Results of the geotechnical investigations of the samples taken from Ikwette, showed an average maximum dry density value of 1.63kg/m^3, which was a low to moderate value and average optimum moisture content value of 18%. Analysis from the particle size distribution, showed that the particle sizes where silty sand, with a Coefficient of uniformity (Cu) value of 1.8 and Coefficient of curvature (Cc) value of 0.968, indicating that the soil is uniformly or poorly graded. Triaxial compression test showed an angle of internal friction and cohesion values averaging around 12.65° and 43kPa respectively, which indicates that the shear strength of the soil was reduced, due to the activities of high precipitation intensity which increased to a monthly value of 375.3mm before the landslide event. Also, the factor of safety value for the slope in OB1, where the landslide occurred was 1.114, which is close to the value for an incipient failure. Hence the results of the aforementioned methods and simulation shown can be used in predicting areas of possible landslides, as well as the causes of such soil deformations, and as such, safety measures could be taken against the reoccurrence of landslides in such areas.*
Keywords: *Slope Failure, Ikwette, Slope/W Geostudio, Simulation.*

I. Introduction

In natural hill slopes one of the most frequent triggering factors is represented by rainfall (De Vita and Reichenbach 1998) that can directly infiltrate the slope surface or can indirectly provide subsurface water supplies from the bedrock. Due to the usual large extension of the rainfall events, these landslides can be triggered over large areas (up to tens of square kilometres) and they generally involve shallow soil deposit of different grading and origin. Significant examples are frequently recorded in pyroclastic deposits in Central America (Capra et al. 2003) and New Zealand (Ekanayake and Philipps 2002), in situ weathered soils in Hong Kong (Take et al. 2004) and Japan (Wang et al. 2002), colluvial weathered deposits in Brazil (Lacerda 2004) and Hong Kong (Fuchu et al. 1999). The autumn and early winter of 2004 were particularly wet in the Umbria Region of central Italy. Repeated rainfall episodes and high intensity storms resulted in a cumulative rainfall in the period from October to December exceeding 600mm. On 4–6 December and on 25–27 December 2004, two severe storms hit the Umbria Region. The rainfall events produced numerous landslides, which were particularly abundant along the Tiber River valley, E and SE of Todi, and in the Orvieto area (Cardinali et al 2006). (Fan-Chieh et al 2006), documented and analyzed sixty-three landslide data including rainfall, initiation time, and magnitude of landslides to identify the landslides and rainfall characteristic in Taipei City during Typhoon Nari. The study focused on the types and magnitude of landslides relating to the peak intensity rainfall and the cumulative rainfall. The landslide characteristic analyses revealed that landslides induced by high intensity rainfall are mainly in smaller magnitude of erosion, debris slide, block slide or circular failure. It is also concluded that the occurrence of massive landslides are associated with higher cumulative rainfall.

Internal slides are usually caused by an increase of pore water pressures within the slope material, which causes a reduction in the effective shear strength. Indeed, it is generally agreed that in most landslides, groundwater constitutes the most important single contributory cause. Hence, landslides can be triggered by rainfall if some threshold intensity is exceeded so that pore water pressures are increased by a required amount (Olivier et al., 1994). Rises in the levels of water tables because of short-duration intense rainfall or prolonged rainfall of lower intensity are a major cause of landslides (Bell, 1994a). An increase in moisture content also means an increase in the weight of the slope material or its bulk density, which can induce slope failure. Significant volume changes may occur in some materials, notably clays, on wetting and drying out. Not only does this weaken the clay by developing desiccation cracks within it, but the enclosing strata also may be adversely affected. Seepage forces within granular soil can produce a reduction in strength by reducing the number of contacts between grains. Weathering can effect a reduction in the strength of slope material, leading to sliding. The necessary breakdown of equilibrium to initiate sliding may take decades. (Meisina, 2004).

Landslides in Nigeria are more profound in the southern part of the country than in the northern part. In South-eastern Nigeria, the major cause of landslide is gully erosion. There is a widespread occurrence of large and deep gullies in the area and the annual impact of rainfall induced floods weaken the ground around the gully sites and slopes, resulting in landslides in many locations (Igbokwe et al. 2003, 2008). In 1988 a major landslide which required the evacuation of more than 50 families, occurred in the little town of Nanka in Anambra State, Nigeria. Investigation revealed that the landslides were caused by an over-consolidated, very highly plastic mudstone layer (PI=67) which probably contained quantities of montmorillonite clay (Okagbue. 1992).

Analysing the stability of earth structures is the oldest type of numerical analysis in geotechnical engineering. The idea of discretizing a potential sliding mass into slices was introduced early in the 20th century. In 1916, Petterson (1955) presented the stability analysis of the Stigberg Quay in Gothenberg, Sweden where the slip surface was taken to be circular and the sliding mass was divided into slices. Fellenius (1936), in the following decade, introduced the ordinary or Swedish method of slices. In the mid 1950s, Janbu (1954) and Bishop (1960) developed advances in the method. The advent of electronic computers in the 1960s made it possible to more readily handle the iterative procedures inherent in the method which led to mathematically more rigorous formulations such as those developed by Morgenstern Price (1965) and by Spencer (1967). Krahn (2004), stated that Slope/W is one component in a complex suite of geotechnical products called Geostudio. One of the powerful features of this integrated approach is that it opens the door to types of analysis of a much wider and more complex spectrum of problems including the use of finite element computed pore water pressures and stresses in a stability analysis. Not only does an integrated approach widen the analysis possibilities, it can help overcome some limitations of the purely limit equilibrium formulations. Also, according to Ming-Chien Chung et al. (2010), for an active landslide analysis, a two-dimensional numerical program, GeoStudio, and a three-dimensional numerical program, FLAC 3D, were employed and modeling practice was performed. The reliability of the resulting numerical results was validated with field data from one case study at Song-Mao landslide site. Results showed that the landslide initiation, enlargement and reactivation could be more confidently predicted through the use of aforementioned physics-based models. These researchers have validated the reliability of the Geostudio software in the stability of slopes in different conditions, and have been able to generate a factor of safety value in these conditions. Although Udosen and Bassey (2013), applied Geographic Information System (GIS) and Digital Elevation Models in predicting landslide susceptibility, but however, attention was paid only to the slope angles, hence, information on the geotechnical properties of slope materials, the rainfall statistical data and the factor of safety, which are important in slope failures where neglected. In this study the slope/W limit equilibrium method was adopted so readily, since solutions could be obtained by hand-calculation. Also, the morgentern-Price method was used for this analysis because it considers both shear and inter-slice forces, it satisfies both shear and force equilibrium, and it allows for a variety of user-selection inter-slice force function.

Pradeep et al (2012), used twenty three soil samples collected from the landslide sits in Nilgiris district and made analysis for their geotechnical properties like cohesion, angle of friction, density, etc., then used these sample properties in slope stability analysis using numerical modelling software package GeoStudio-Slope/W 2007. In the study, Bishop's simplified method of the conventional limit equilibrium method was used to analyze the stability of slopes and the Factor of Safety values were estimated for the identification of risk. It was observed that when resultant factor of safety was less than 1 under wet and dry conditions, those locations seemed to be unstable and were at a very high risk. Hence the study showed that the model has a better reliability in investigation and prediction of slope instabilities.

This study analyses a rainfall-triggered natural slope failure that occurred on the 17th of October 2013 at Ikwette, Obudu Local Government area of Cross River State, Nigeria. After a period of torrential rainfall, the landslide occurred, when a loud noise of high intensity was heard. According to reports from the media and eye witnesses, there were no casualties, but however, high tension electrical power poles were destroyed, as well as farm lands, and over 20 persons were stranded at the top of the mountain resort as the road access to the popular Obudu Mountain Resort was blocked. The damages were incurred as a result of land shift that resulted in the dislodging of rock boulders. In this study, a combination of Site investigations, Geotechnical analysis of soil samples, rainfall data analysis, and slope stability calculations using the Slope/W, Geostudio software, where used to investigate the landslide at Ikwette, Obudu L.G.A. The purpose of this study was to: (i) Document the type, and the possible causes of a landslide occurrence at Ikwette, Obudu L.G.A (ii) Study the rainfall conditions that triggered the landslide, (iii) Determine the geotechnical properties of the failed and unfailed soil materials, (iv) To carry out a slope stability analysis on the slope at OB1, so as to unravel its factor of safety.

1.1 Geological and Geomorphologic Settings

The area is a part of the Obudu Plateau and represents a terminal portion of the western Bamenda Massif of the Cameroons that wedges into eastern Nigeria (Orajaka, 1964; Umeji, 1988). Fig. 1 shows the general geology of Cross River State.

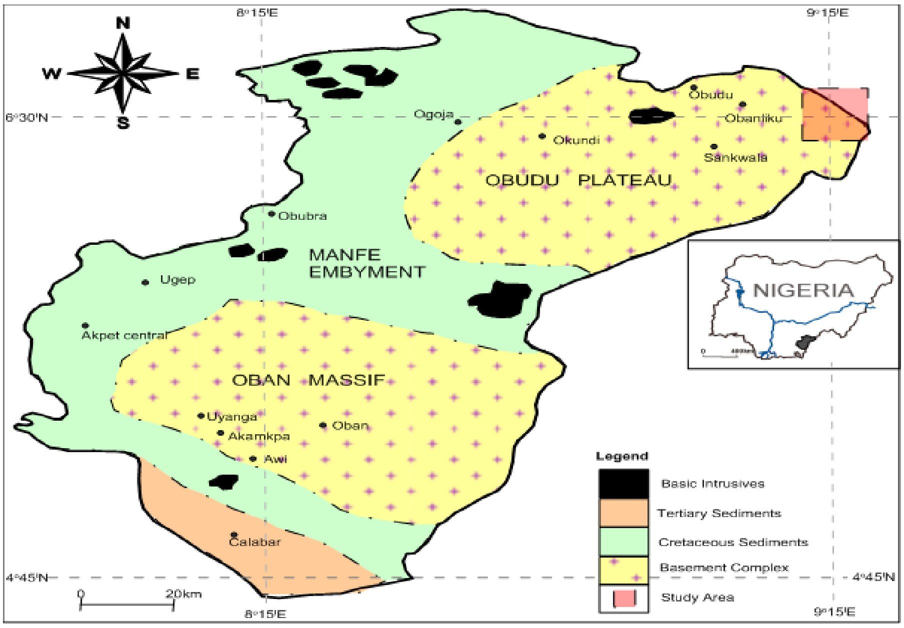

Fig. 1 Geologic map of Cross River State showing the study area. (After Ekwueme et al. 1995).

It lies within the reactivated Precambrian Basement of Nigeria, which forms a portion of the pan-African Tectonothermal belt located between the West African Craton, to the west and the Gabon-Congo Craton, to the east. The dominant rock unit in the Plateau is the migmatite-gneiss complex, while schist, quartzite, dioritic and peridotitic rocks are comparatively less in abundance (Ekwueme, 1990a, 1994a, 1994b, 1998). Igneous bodies like granites, dolerites, charnockites and diorites intrude into this dominantly gneissic and schistose complex [Umeji, 1988, Ekwueme, 1990a, 1994a, 1994b]. Fig. 2 shows the local geology of Ikwette, Obudu L.G.A.

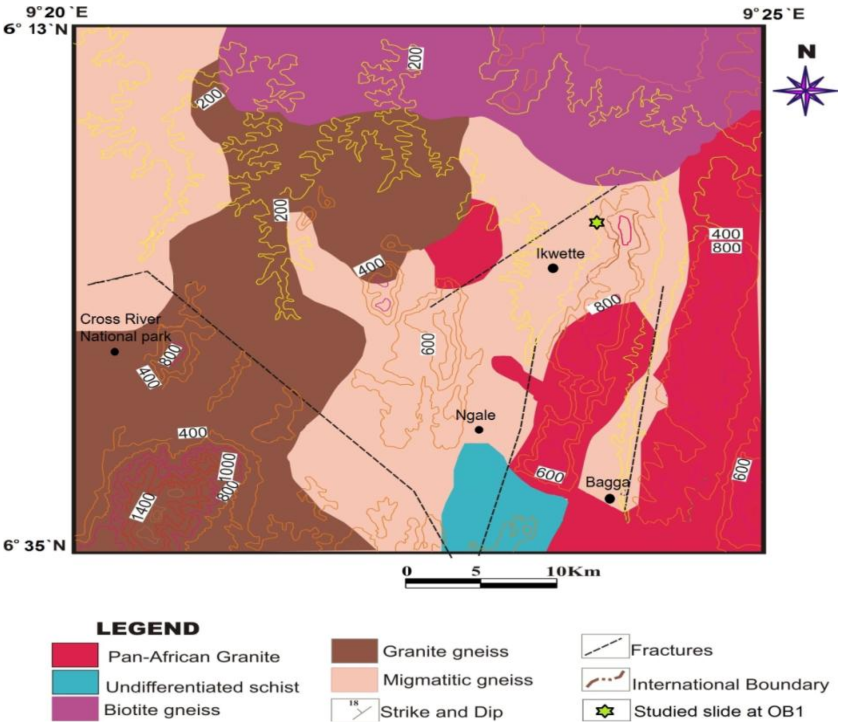

Fig. 2 showing the local geology of Ikwette, Obudu L.G.A.

The study area has a rugged topography comprising north-easterly trending ridges separated by lowlands, which form valleys and passes. Generally, the Obudu Plateau constitutes the highest elevated part of South-eastern Nigeria, with a maximum height of 1576m above sea level at the Obudu Cattle Ranch Udo, (1978). Fig. 3 below is the SRTM image showing the general relief.

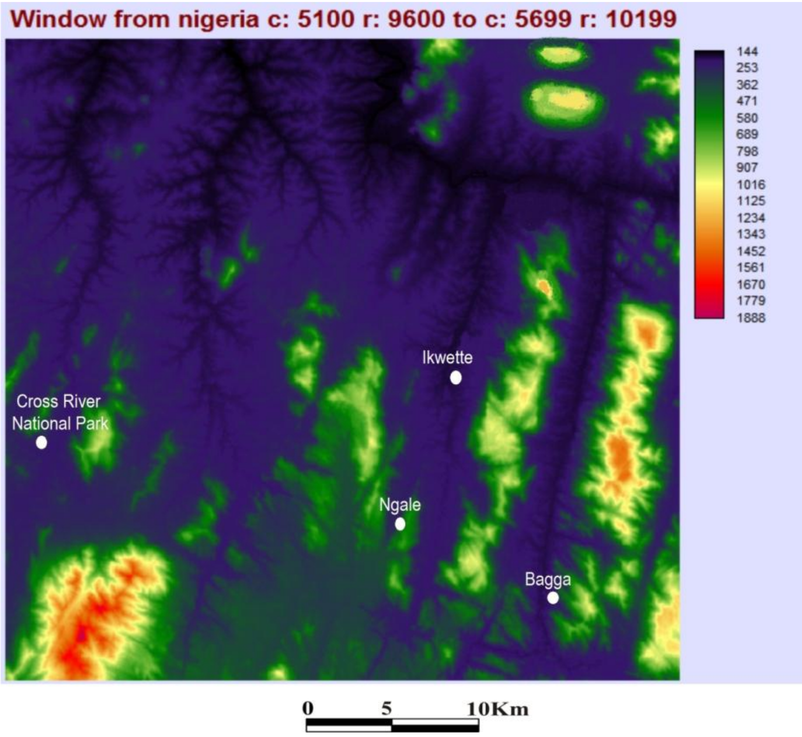

Fig. 3 SRTM image showing the general relief.

1.2 Structures

The pan-African events is believed to have produced structures trending N-S to NE-SW, whereas structures produced by earlier events are thought to trend E-W and NW - SE, and are generally preserved as inclusions. Older Granites are pockets of generally coarse-grained or porphyritic granites in Obudu Plateau. The varieties include biotite granites, muscovite-biotite granites and tonalites (Ekwueme, 1990a). The biotite granites may be hornblende bearing, while the muscovite-biotite granites are coarse-grained with simple mineralogy. Also, the area has a rugged topography with a series of elevated ridges separated by lowlands. Structural data (Oden et al., 2012), show that the most prominent fracture set in Obudu basement area is the NW-SE which trends 140º - 150º from north. Minor sets occur in the NNE-SSW, E-W and ESE WNW directions. Fig. 4 below is a rose diagram showing the orientation of joints in the area.

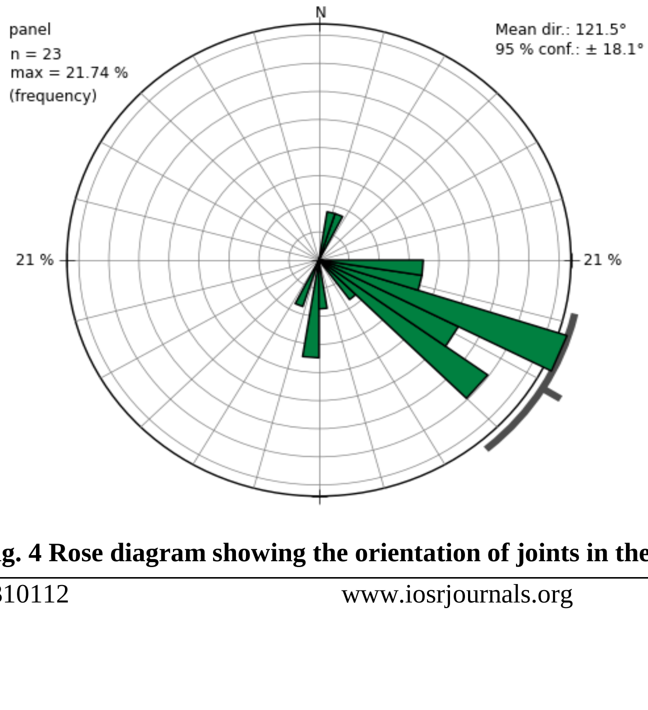

Fig. 4 Rose diagram showing the orientation of joints in the area.

1.3 Tropical Weathering

The study area covers the Obudu plateau, South-eastern Nigeria with a humid tropical environment which experiences alternation of wet and dry seasons. Hence, there has been intense and deep weathering of the basement rock in the area for a long time resulting in thick piles of laterites. Integrated geophysical investigation has revealed that the thickness of this weathered material ranges from 2.0m to as high as 19.3m. Mean maturity index (M.I) value of 82.04 also corroborates the fact that the weathering is deep and severe (Ushie 2010). The formation of laterites in Obudu is favoured by the high temperature and precipitation, leaching, capillary rise, stable upland topography, weathering of the parent rocks and the long period of weathering since the Cretaceous and Tertiary time. Also, apart from being rich in solid minerals like limestone, gypsum, salt, silica and kaolin, they also form the weathered crust in which the landslide occurred.

II. Materials And Methods

Data used for the study includes, a Google earth satellite image maps, a geologic map prepared from information gathered during field work, Monthly, Cumulative monthly and Annual rainfall data monitored from 2005 to 2010, and the Slope/W Geostudio 2012 software. The methodology employed for this research were carried out systematically in four phases, which includes: (i) Site investigations carried out in the field, (ii) Geotechnical analysis carried out in the laboratory, (iii) Analysis of rainfall Statistical data gathered from agencies, and also from previous literatures. (iv) Application of the results from some geotechnical parameters to a Slope/ W Geostudio 2012 software program, to simulate the two-dimensional morphology of the landslide on one hand, and to generate a factor of safety value on the other hand.

2.1 Field Investigation

The following data were recorded, after field investigations were carried out between the 20th and the 24th of October 2013 and the following activities were carried out:

a. The hydrogeology of the area, which included ground water levels, as observed in nearby wells, stream courses, gullies, and the discharge of ground water at the slope.
b. Determination of the landslide properties, which included the studies of the slope angles, depth of sliding surface, run-out distance (length of landslide), thickness of the sliding mass, as well as the date the landslide occurred as reported by local residents.
c. The geographical location of all the sampling points was established, using a GPS.
d. Geologic descriptions were recorded in geologic field note books, and the descriptions included; the lithologic compositions, the bedding surfaces, faults and joint systems, dip amounts, as well as dip and strike directions with the help of a compass clinometer.
e. Disturbed and undisturbed samples of residual soils were collected for further analysis, using a hand auger.
f. The vegetation type was also determined, and it included studies of the tree types, the density of coverage, as well as the cultivation practices.
g. Photographs of important geologic and geographical features were taken, as well as photographs of the landslide for reference purposes.

2.2 Laboratory Testing

The samples from the different locations were air dried, and analysed in the laboratory to define their geotechnical properties. The tests were performed according to the specifications of ASTM (American Society for Testing and materials). The tests include; Direct shear test (carried out to determine the shear strength parameters such as cohesion and internal frictional angle) and particle size distribution analysis (targeted at unravelling the particle size distribution, coefficient of uniformity (Cu) and the coefficient of curvature (Cc)). Also, the Compaction test was done to determine the maximum dry density (MDD) and the optimum moisture content (OMC), Triaxial compression test, Permeability test and Density test of soils were also carried out.

III. Results And Discussion

3.1 Results from Site Investigation

Results from the site investigation revealed: Google earth Satelite images of the landslide, the morphology of the land slide, and the sample location points.

3.1.1 Satelite Images of the Landslide at OB1.

Fig. 5 and 6 below shows Google Earth Satelite images of the landslide at OB1.

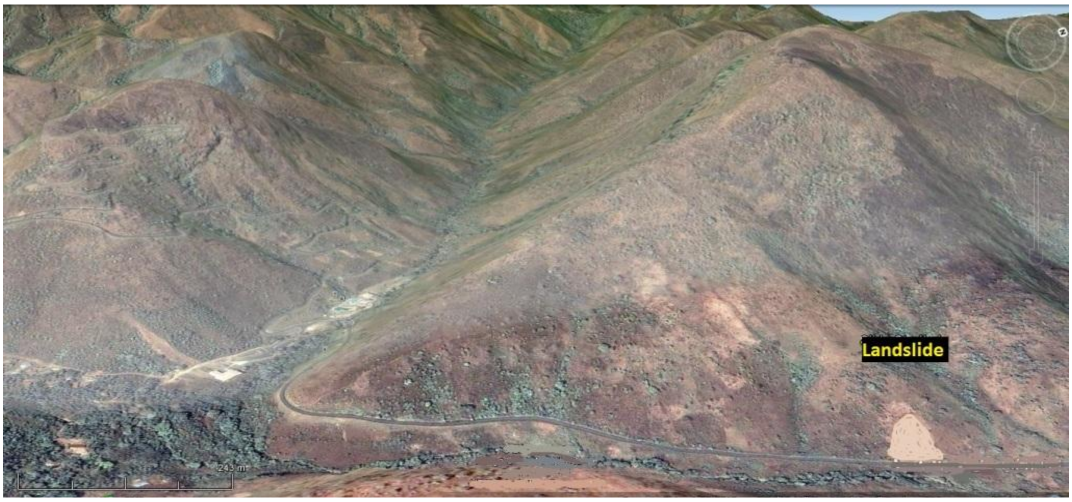

Fig. 5 Front view of the google earth satellite image of the landslide.

Fig. 6 Side view (from the right) of the google earth satellite image of the landslide.

3.1.2 Landslide Morphology

The rain-fall induced rock-fall debris avalanche at slope OB1 occurred at latitude 06° 24’ 16.5” N and longitude 09° 24’ 31.2” E. An estimated 50 tonnes of rock and debris was moved for up to 60metres from the scarp of the slide at 800 metres above sea level, to the toe below. The slide also had a run-out distance of 60 meters, with depth of sliding about 8 meters, while the width had a lateral extent of about 104 meters. The slip surface was rotational, having a slope angle of 60°, and according to Singh (2004), the critical angle of slope (angle of repose) value for unconsolidated sediments is 35°, and for jointed/ fracture crystalline rock ranges from 60° to 90°. Hence the slope angle of 60° indicates that the slope was at a critical value, and was already susceptible to sliding. Fig.7 and 8 below show the morphology and danger posed by the slope failure respectively.

Fig. 7 Picture of slope OB1 showing the scarp of the slide, as well as the rocks and debris moved.

Fig. 8 Picture of slope OB1, showing the threat posed by this slope instability on road users.

Failed Materials

These materials included loose, unconsolidated sediments which formed the debris, and the crystalline rocks. The crystalline rocks, mostly of metamorphic character failed because of the presence of schistosity, foliation and cleavage structures. According to Singh (2004), these structures all behave as surfaces of weakness and promote failure. Bell (2007) also stated that some of the earliest effects of weathering are seen along discontinuity surfaces. This is because, in most cases weathering (Deterioration) in these rocks will take place along those planes, making the contacts quite vulnerable. Also, because of the stress history in the area, most of the crystalline rocks were highly fractured with joints to reasonable depths on macro and micro scales, (shown in fig 9a and 9b below) and these joint sets reduced the shear strength of the mass considerably.

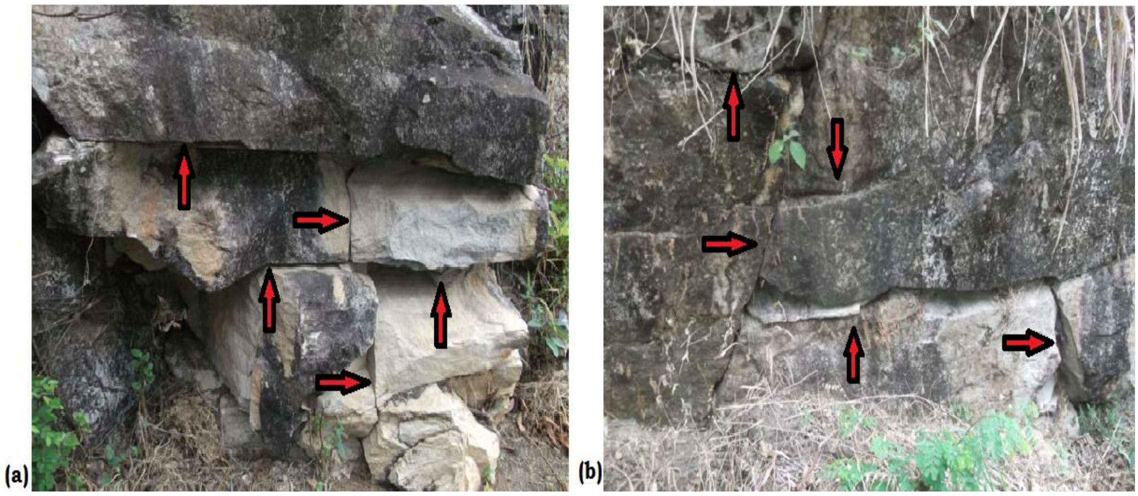

Fig. 9 Picture showing joint structures in the basement rocks.

In some areas, these joints were further expanded, widened and lubricated by the activities of plant roots, and seepage of water through these joints, and this generally reduced the stability of the rock mass in such slopes. Fig. 10a and 10b shows these activities.

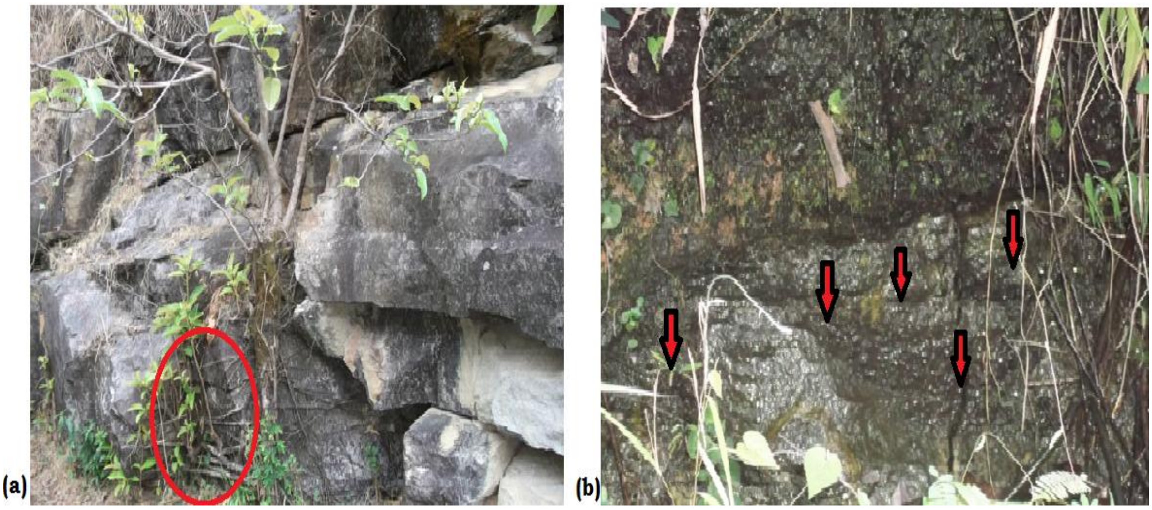

Fig. 10 Picture showing the activites of plant roots, and water on the joints.

3.2 Results from Geotechnical analysis

Table 1 below, summarises the results of the Geotechnical analysis carried out on the soils.

Table 1. Summary of the Soil Geotechnical Properties.

Soil type Property	Average values of Soil geotechnical properties
Grain Sizes (%)	
2.0 – 4.76 (mm)	11
0.42 – 2.0 (mm)	81
0.074 – 0.42 (mm)	5.5
0.002 - 0.074 (mm)	2.5
Coefficient of Uniformity (C_u)	1.8
Coefficient of curvature (C_c)	0.968
Optimum Moisture Content (%)	18
Maximum Dry Density (Kg/m^3)	1.63
Wet Density (Kg/m^3)	1.92
Angle of Internal Friction ($^\circ$)	12.65
Cohesion (kPa)	43
Permeability (cm/s)	3.48×10^{-3}

From results of laboratory analysis, the grain size distribution plots gave values for coefficient of uniformity (C_u) as 1.8 and coefficient of curvature as 0.968. According to the unified soil classification system, for sands, a well graded soil will have a Cu value greater than 6.0, and a uniformly or poorly graded soil will have Cu values less than 2.0, also a well graded soil will have its coefficient of curvature (Cc) more than 1.0, but less than 3.0, and a uniformly or poorly graded soil will have Cc values of less than 1.0. Hence, the Cu and Cc value of 1.8 and 0.968 respectively for OB1 indicates that the soil is uniformly or poorly graded. These well sorted samples are predominantly medium grained, and the absence of fines indicates a poorly cemented soil with a reduced shear strength which will always make the soil susceptible to sliding.

Results from the triaxial compression test produced plots of the shear strength against the values of the shear stress as shown in fig. 11 below.

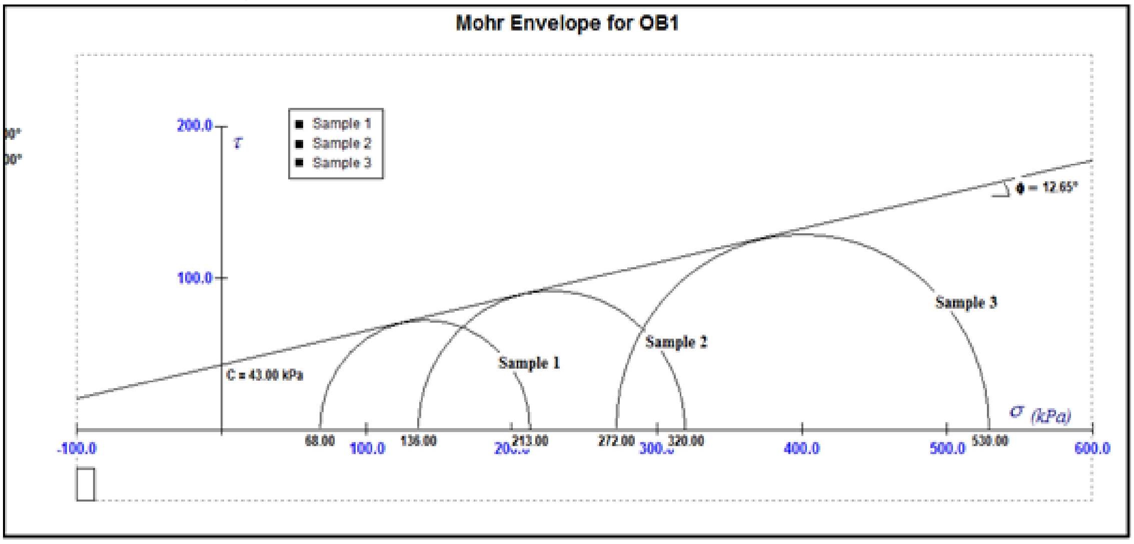

Fig. 11 Triaxial test plot showing the mohr envelope, cohesion and friction angle.

Taking clue from this figure, the angle of internal friction, and the cohesion was determined to be 12.65° and 43kpa respectively. According to Arora (2008), the forces that try to resist a slide depend on the cohesion and its frictional force. Silty sands, and sands with uniform grains have angle of internal friction (ϕ) values ranging from 27° to 35°. Bell (2007) also stated that, the angle of internal friction for sands should be in the range of 32° to 42°. Hence the value of 12.65° shows a low value for angle of internal friction, indicating that the soil will offer little resistance to shear forces that may cause failure.

From results of the compaction test, the maximum dry density value averaged around 1.63kg/m^3. Bell (2007) stated that the maximum dry density values for sands ranged from a minima of 1.35Kg/m^3 to a maxima of 1.9Kg/m^3, hence the value of 1.63Kg/m^3 indicates a low to moderate dry density. This low value indicates a soil with reduced shear strength that can easily disperse. Also, moisture content values averaged around 18% and the presence of water in this relatively high amount will increase the pore pressure, and hence reduce the shear strength of the soil.

The permeability test gave an average value of 3.48×10^{-3}cm/s, and this fair permeability value indicates that the soil was draining water away at a rate lower than the rate of recharge during the precipitation event that triggered the slope failure.

3.3 Results from Rainfall Statistical Data

To investigate the rainfall-triggered landslide that took place on the 17th of October 2013 in Obudu L.G.A, records of the Annual Rainfall in the area from year 2009 till 2013, the Monthly Rainfall data in year 2013, and the Cummulative Monthly Rainfall data in year 2013 were analysed. The charts in figure 12a shows the amount of annual rainfall from 2009 to 2013, figure 12b shows the monthly rainfall values in year 2013 when the slope failure occurred, while figure 12c shows the cumulative monthly rainfall values in 2013.

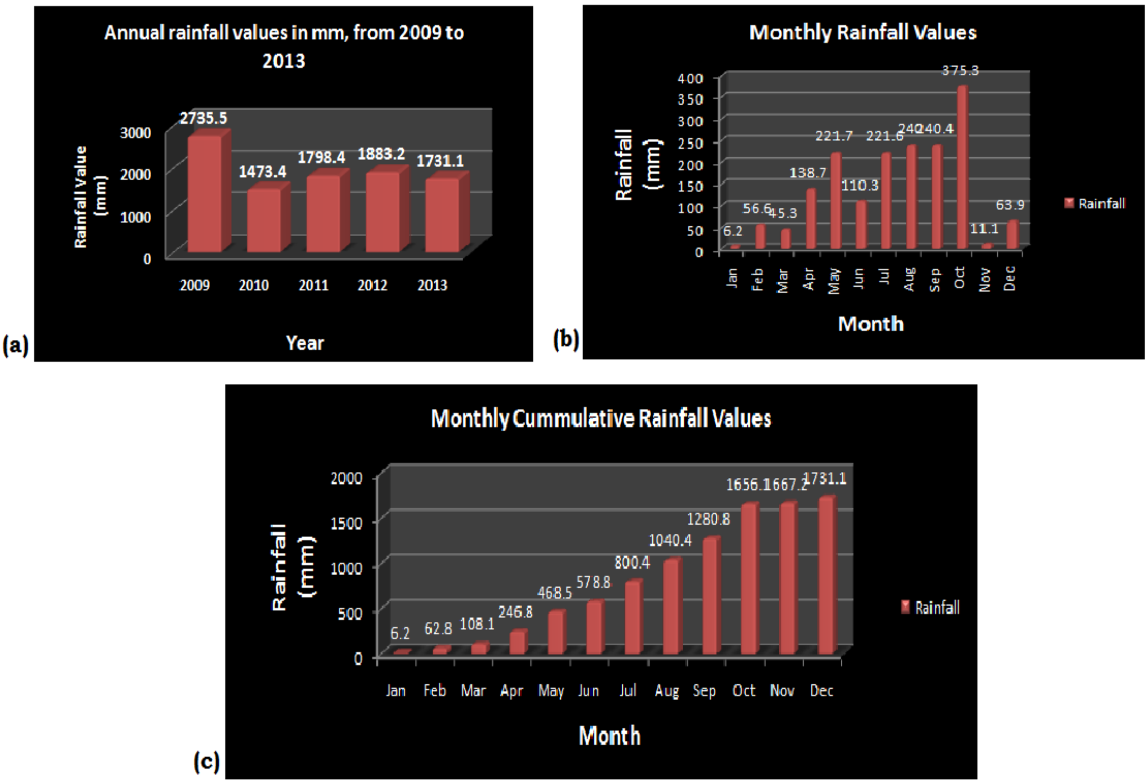

Fig. 12 Charts showing rainfall statistical data. (Source NIMET).

From fig. 12a, the annual rainfall value of Obudu in year 2013 was very high, though not as high as the value in the previous year. The monthly rainfall values in year 2013 were plotted and represented on a chart as shown in figure 12b. Analysis showed that the monthly rainfall values in year 2013 increased gradually until it got to a peak value of 375.3mm in the month of October, before it reduced drastically in the following month. This high precipitation intensity in the month of October was high enough to trigger the landslide that occurred in the area, as the accumulation of water in the soil increased the pore pressure, which also reduced the shear strength of the soil. This is further buttressed by the large value of the Cummulative monthly rainfall values in 2013 (fig. 12c) which measured up to 1280.8mm before the month of October, when the landslide occurred, indicating that the activities of precipitation had already begun its impact on the soil, and thereby reducing its shear strength, before the heavy rainfall that caused the landslide occurred.

3.4 Result from Slope/W Geostudio Model analysis

A model diagram of the morphology of the landslide was produced and the factor of safety value was computed for, using the Slope/W Geostudio 2012 software. The method adopted was the Morgentern-Price limit equilibrium method, and the parameters keyed into the software included; the cohesion, the unit weight and the angle of internal friction, gotten from the geotechnical tests, as well as the slope geometry which includes the slope angle and height.

Model 1 (OB1) ; c = 43kPa, ϕ = 12.65°, U. Wt = 15.89kN/m^3

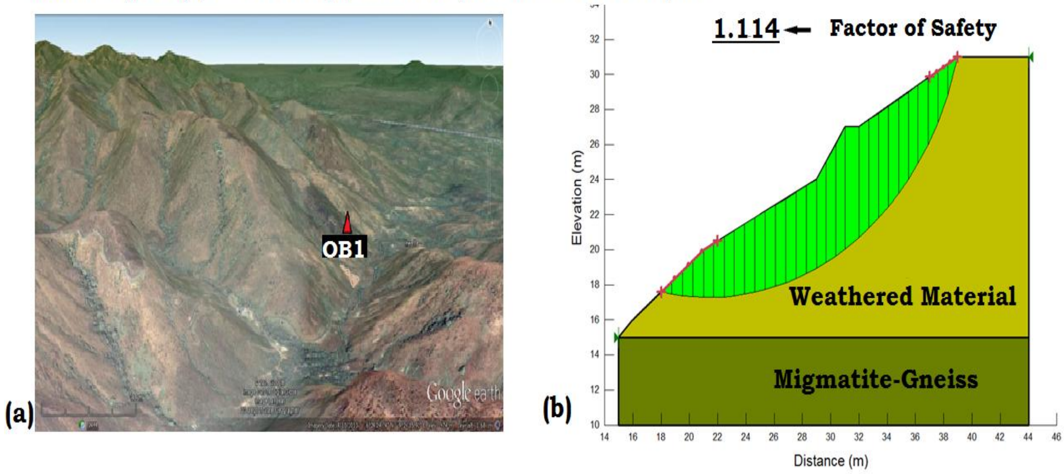

Fig. 13 Geostudio Model diagram of the slide at OB1.

The Slope/W Geostudio Model representation of the morphology and the factor of safety calculated for the slope at OB1 is shown in Fig. 13a above, at given geotechnical parameters. Hence, at given geometrical parameters of; slope angle-40°, height-60m, rise-40m, and geotechnical parameters of; Unit weight 15.89kN/m^3, Cohesion 43kPa, and angle of internal friction 12.65°, the model showed a rotational slip surface, having a depth of about 8 meters. The factor of safety was computed to be 1.114. According to Coduto (2007), a factor of safety value of 1 indicates incipient failure, hence any slope with factor of safety greater than 1 will supposedly be stable, but because of uncertainties in our analyses we need to account for, and the presence of triggers in the field, larger values should be considered safe. Hence most common design criterion requires a factor of safety of at least 1.5 for stability, and the extent of stability and instability is expressed in this paper as the closeness to factor of safety values of 1.5 and 1 respectively. Hence the factor of safety value of 1.114 for the slope at OB1 indicates that the slope was stable but not at safe levels required, since the values was still very close to 1, which is the value required for an incipient failure. Hence the triggers in the field were able to cause the landslide.

IV. Summary And Conclusion

The study has shown that the use of the combination of geotechnical investigations, rainfall statistical data, and the slope/W Geostudio software has been successful in landslide investigation.

The study has also helped us to identify the fact that landslide occurrences are widespread in some parts of Nigeria, amongst which Ikwette, Obudu L.G.A is a part of, and the dangers and threats posed by these events cannot be over emphasised.

While rainfall events have been the major triggering factors of landslides in these areas, Geologic features and processes also play a part in compounding on the intensity of these events and the possibility of landslides with similar magnitudes reoccurring in these areas is high. This is because; the landslide causing factors and triggers are still present in the area.

The slopes should be improved on by methods like; drainage control, and slope flattening. The latter reduces the weight of the mass tending to slide, providing a support below the toe and this support also increases the resistance to sliding and hence increases the stability. Also, grouting and injection of cementing materials into weak zones also help in stability. This highlights the need for more rigorous analysis of the soil and subsequent adoption of appropriate prevention techniques.

References

[1]. Bell, F.G. (1994a). Floods and landslides in Natal and notably the greater Durban region, September 1987: a retrospective view. Bulletin Association Engineering Geologists, 31: 59 -74.
[2]. Bell, F.G, (2007). Engineering Geology (2nd Edition). Elsevier Linacre House, Jordan Hill, Oxford OX2 8DP, UK. PP 92.
[3]. Bishop, A.W. and Morgentern, N., (1960). Stability Coefficient for Earth Slopes. Geotechniques, 10(4): 164-167.
[4]. Capra L, Lugo-Hubp J, and Borselli L (2003). Mass movements in tropical volcanic terrains: the case of Teziùtlan (Mexico). Eng. Geol. (Amsterdam), 69: 359–379.
[5]. Cardinali, M., Galli, M., Guzzetti, F., Ardizzone, F., Reichenbach, P and Bartoccini, P. (2006). Rainfall induced landslides in December 2004 in south-western Umbria, central Italy: types, extent, damage and risk assessment. Nat. Hazards Earth Syst. Sci., 6, 237–260.
[6]. Coduto DP (2007). Geotechnical Engineering; Principles and practices. Prentic Hall of India private Limited pp 528-529.
[7]. De Vita, P., and Reichenbach, P. (1998). Rainfall-triggered landslides: A reference list. Environ. Geol., 35(2–3): 219–233.

[8]. Ekanayake, J. C., and Philipps, C. J. (2002). Slope stability thresholds for vegetated hillslopes: a composite model. Can. Geotech. J., 39: 849–862.

[9]. Ekwueme, B.N. (1990a). Petrology of Southern Obudu Plateau, Bamenda Massif, South Eastern Nigeria. In, Rocci G. and Deschamps n. (eds). Recent data in African Earth sciences. 22: 155-158.

[10]. Ekwueme, B. N. (1994a), Basaltic Magmatism Related to the Early Stages of Riftiing Along the Benue Trough: the Obudu Dolerites of South-east Nigeria: Geologic Journal: 29 (4): 269-276.

[11]. Ekwueme, B. N. (1994b). Structural Features of Southern Obudu Plateau, Bamenda Massif, S.E Nigeria. Preliminary Interpretations. Jour. Min. Geol; 30: 45-47.

[12]. Ekwueme, B. N., Eyo E. Nyong., Sunday W. Petters (1995). Geological Excursion Guidebook to Oban Massif, Calabar Flank and Mamfe Embayment, Southeastern Nigeria. Dec. Ford.

[13]. Ekwueme, B. N. (1998). Geochemistry of Precambrian Gneisses of the Obudu Plateau, Southeastern Nigeria. Global Journal of Pure and Applied Science, 4 (3): 81-93.

[14]. Fan-Chieh, Y., Tien-Chien, C., Meei-Ling, L., Chien-Yuan, C., and Wen-Hai, Y. (2006). Landslides and rainfall characteristics. Analysis in Taipei City during the typhoon Nari event. Natural Hazards 37:153-167.

[15]. Fellenius, W., (1936). Calculation of the Stability of Earth dams. Preceedings of the Second Congress of Large Dams, pp. 445-463.

[16]. Fuchu, D., Lee, C. F., and Sijing, W. (1999). Analysis of rain storm induced slide-debris flows on natural terrain of Lantau Island, Hong Kong. Eng. Geol. (Amsterdam), 51: 279–290.

[17]. Igbokwe J.I, Akinyede J.O, Dang B, Alaga T, Ono M.N, Nnodu V.C, and Anike L.O (2008). Mapping and monitoring of the impact of gully erosion in south eastern Nigeria with satellite remote sensing and geographic information system. International Archives of Photogrammetry, remote sensing and spatial information sciences. 36(8): 865-871.

[18]. Igbokwe J.I, Ojiako J.C, and Nnodu V.C (2003). Monitoring, characterisation and controlling of floodwater erosions using remote sensing techniques. Proceedings of the technical session of 38th annual conference of Nigerian institution of surveyors. Lokoja, Nigeria. pp 73-79.

[19]. Janbu, N, (1954). Applications of Composite Slip Surfaces for Stability Analysis. in Proceedings of the European Conference on the Stability of Earth Slopes, Stockholm, 3: 39-43.

[20]. Krahn J, (2004). Stability Modelling with Slope/W. An Engineering Methodology. GEO-SLOPE/W International Ltd. (First Edition). Revision 1: 1-3.

[21]. Lacerda, W. A. (2004). The behaviour of colluvial slopes in a tropical environment. Landslides: Evaluation and Stabilization, W. A. Lacerda, M. Ehrlich, S. A. B. Fontoura, and A. S. F. J. Sayao, eds., Taylor and Francis, London, 2: 1315–1342.

[22]. Meisina, C. (2004). Swelling-shrinking properties of weathered clayey soils associated with shallow landslides. Quarterly Journal Engineering Geology and Hydrogeology, 37: 77–94.

[23]. Ming-Chien Chung, Chih-Hao Tan, Shu-Yeong Chi, Cheng-Yu Ku, Tai-Wei Su, Jiin-Fa Lee, Li-Yuan Fei (2010). Monitoring and modeling of rainfall-induced landslides–a case study of song-mao landslide in central Taiwan. Conference on geology and slope hazards.

[24]. Morgenstern, N.R., and Price, V.E (1965). The Analysis of the Stability of General Slip Surfaces. Geotechnique, 15: 79-93.

[25]. Oden, M. I., Okpamu, T. A., & Amah, E. A. (2012). Comparative analysis of fracture lineaments in Oban and Obudu areas, SE Nigeria. Journal of Geography and Geology, 4(2), 36-47.

[26]. Okagbue, C.O (1992). The 1988 Nanka landslide, Anambra State,Nigeria. Bulletin of the International Association of Engineering Geology. 46(1): 79-87.

[27]. Olivier, M., Bell, F.G. and Jermy, C.A. (1994). The effect of rainfall on slope failures with examples from the greater Durban area. Proceedings Seventh Congress International Association Engineering Geology, Lisbon, Balkema, Rotterdam, 3, 1629–1636.

[28]. Orajaka, S.O. (1964). Geology of the Obudu area, Ogoja Province, Eastern Nigeria. Le Naturaliste Canadien, XCL vol 3, pp 73-78.

[29]. Petterson, K.E. (1955). The Early History of Circular Sliding Surface. Geotechnique, 5: 275-296.

[30]. Pradeep, K.V., Lakshumanan, C., Viveganandan, S., Karikalvalavan, S. (2012). Evaluation of

[31]. Limit equilibrium method for Landslide Susceptibility Analysis (LSA) – A case study on Nilgiris district. Int. Journal of Advances in Remote Sensing and GIS, Vol. 1, No. 2.

[32]. Singh, P. (2004). Engineering and General Geology. S.K. Kataria & sons, New Delhi. (7th ed.), pp 465-481.

[33]. Spencer, (1967). A Method of Analysis of Embankments assuming Parallel Inter-slice Forces. Geotechnique, 17(1): 11-26.

[34]. Take, W. A., Bolton, M. D., Wong, P. C. P., and Yeung, F. J. (2004). "Evaluation of landslide triggering mechanisms in model fill slopes." Landslides, 1: 173–184.

[35]. Udosen, C., andBassey, E., (2013). Predictive Analysis of Landslide Susceptibility in a fast Developing City, Uyo Nigeria Using GIS-DEM. Proceedings of the Global Geospatial Conference 2013. Addis Ababa, Ethiopia.

[36]. Umeji, A. C. (1988). The Precambrian of South eastern Nigeria, a magmatic and Tectonic study. In: Oluyide, P. O. Mbonu W.C and Ogezi, A.E.O (eds). Precambrian Geology of Nigeria. Geol. Surv. Nig. Pub. pp.69-75.

[37]. Ushie, F. A., (2010) The Economic Evaluation of Lateritic Rocks from Obudu Area, South Eastern Nigeria. (Unpub.) PhD Thesis, Nnamdi Azikiwe University, Nigeria. pp 277.

[38]. Wang, F. W., Sassa, K., and Wang, G. (2002). Mechanism of a long run-out landslide triggered by the August 1998 heavy rainfall in Fukushima Prefecture, Japan. Eng. Geol. (Amsterdam), 63: 169–185.