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# Geophysical investigation of Obot Ekpo Landslide site, Cross River State, Nigeria

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ABSTRACT

Data from 2-D electrical resistivity tomography (ERT), vertical electrical sounding (VES) and seismic refraction were used to investigate the causes of the Obot Ekpo Landslide in the Odukpani Local Government Area (LGA), Nigeria. Results show that low resistivity shaly and/or clayey materials with bulk resistivity less than 10 Ω m dominate the shallow subsurface of the area. These argillaceous materials intercalate with marls (and/or mudstone/limestone) materials that are characterised by relatively higher resistivity values. Average P-wave velocities were observed to vary from 655 to 1381 and 1787 to 1820 m/s for the first and second layers respectively. The marls are laterally heterogeneous due to multiple fracturing at different locations caused by the probing action of tree roots in a sloping terrain and other mechanical stresses such as those set up by the expansion of clays in confined areas. Most of the downward percolating water gets into deeper layers through the fractures and at depths, are blocked by the underlying impermeable materials. As the blocked groundwater accumulates gradually at the interface of the marl and the underlying shale units, pore-pressure and uplift forces begin to increase while cohesive force is reduced, leading to instability. With increased rainfall, the ground becomes over-saturated and therefore the instability condition increases in the area. Transmission of mechanical forces of wind into the sloping ground through tree roots and to a lesser extent, mechanical vibrations from heavy-duty equipment working in the vicinity, caused the over-saturated materials to flow, leading to the landslide.



## 1. Introduction

Natural hazards are life threatening activities that have the capacity of causing serious harm and even damage to both the environment and the biodiversity, not only at the moment of their occurrence, but also thereafter. Whenever and wherever natural disasters strike, they usually leave behind economic losses and damage to vital infrastructure and property due to their destructive nature. Loss of life and property, health problems and disruption in community activities are some of the social problems that usually pervade any natural hazard-stricken area; although the severity of such effects usually depend largely on the magnitude of the event, developmental status, human vulnerability, spatial location and geomorphic setting (Alcántara-Ayala, 2002).

Natural disasters including those that originate from geophysical and geological (e.g., volcanic eruptions, landslides, earthquakes and tsunamis); atmospheric and meteorological (e.g., storms, tornadoes and cyclones); hydrological (e.g., floods, avalanches and famines); biological (outbreak of diseases, epidemics and animal plagues); climatological (droughts and wild fires) and anthropogenic (e.g., oil spills, industrial and transport accidents) can occur anywhere in the world. Yet, despite the fact that natural hazards are global problems, their impacts including destruction of lives, property and the environment are usually more in the developing countries like Pakistan, the Philippines, India and China (EM-DAT database).

Nigeria is relatively free from the highly destructive natural hazards. Rather, isolated communities in the country are usually challenged annually by recurring flood, erosion and storm-induced hazards (George et al., 2008a,b; Akpan et al., 2009; Ezezika and Adetona, 2011; Okoyeh et al., 2013), in addition to the occasional outbreaks of epidemics such as yellow fever (Ezezika and Adetona, 2011), cholera (Adagbada et al., 2012;

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Ogunniyi, 2014) and meningitis (Collard et al., 2013). Isolated low-magnitude earthquakes (tremors) have also occurred at different times (Akpan and Yakubu, 2010; Afegbua et al., 2011). However, losses due to geological hazards in Nigeria are usually far less than in other countries, for example Pakistan, the Philippines and China (EM-DAT database). This can be partly attributed to the location of Nigeria outside of the disaster endemic Circum-Pacific region where approximately 80% of the relatively more destructive natural hazards are concentrated (Anderson and Decker, 1992; Alcántara-Ayala, 2002). Also, the gradational nature of the onset of some natural hazards (e.g., floods, windstorms) and the presence of warning systems that can alert people about these impending disasters have helped reduced human casualties and economic losses. There are several reports of minor natural disasters such as low-magnitude earthquakes (Osagie, 2008; Akpan and Yakubu, 2010; Afegbua et al., 2011), floods, erosion and landslides (Egboka and Okpoko, 1984; Afahide et al., 2008; George et al., 2008a,b; Igbokwe et al., 2008; Akpan et al., 2009; Ezezika and Adetona, 2011; Okoro et al., 2011) in different parts of Nigeria.

Landslides are disasters of hydrometeorologic origin and a common geological hazard in areas where the slope angle of soils and regoliths over bedrock is greater than its frictional angle. Soils that have suffered continuous saturation with water are prone to changes in their long-term physical properties and such changes can lead to instability on slopes. Slope failures and mass movements are examples of such instabilities. Other factors that can also trigger landslides include earthquakes, volcanic activities, changes in groundwater level and anthropogenic activities such as slope excavation and increased surface runoff from channelled water in urban areas (Barnhardt and Kayen, 2000; Havenith et al., 2000; Lapenna et al., 2003; Konagai et al., 2005; Drahor et al., 2006; Friedel et al., 2006; Makino et al., 2007; Younger, 2007; Göktürkler et al., 2008; Grandjean et al., 2006; Heincke et al., 2010; Arango-Galván et al., 2011; Chambers et al., 2011). These widespread processes and activities have made landslides to be a common natural disaster in locations such as riverbanks, hilly and mountainous areas and other inclined terrain. Although documentation of severe and damaging landslide activities do not exist in Nigeria, records are replete with environmental problems resulting from recurrent small-scale mass-movements, particularly in the gully erosion-prone Nanka Formation in Anambra Basin (Egboka and Nwankwo, 1985; Okoro et al., 2011; Okoyeh et al., 2013) and along the banks of Cross and Calabar Rivers.

Geophysical techniques like electrical resistivity, seismic refraction, ground penetrating radar and electromagnetic surveys can be used to monitor, track and map the distribution of zones with anomalous physical properties in terrain beset by landslide problems (Makino et al., 2007; Akpan et al., 2009; Grandjean et al., 2006; Al-Saigh and Al-Dabbagh, 2010; Heincke et al., 2010; Arango-Galván et al., 2011; Chambers et al., 2011). The application of geophysical techniques to landslide investigation is fairly recent compared to the traditional geological and geotechnical testing methods. Their emergence as a disaster investigative tool follows the pioneering works of Brooke (1973) and Bogoslovsky and Ogilvy (1977).

Although results from unconstrained interpretation of geophysical data can be fraught with errors due to some inherent limitations in techniques, the application of geophysical methods in environmental investigation still has many advantages over conventional geological approaches. Such limitations include poor depth resolving powers, ambiguities inherent in the transformation of geophysical results to its equivalent geological model and the inability of geophysical techniques to generate direct information on geology. The main advantages of the geophysical approach include flexibility, economical and fast and surveys that can be performed even on steep slopes. Geophysical surveys are environmentally friendly because they are noninvasive and permit the generation of continuous subsurface imaging of large volumes of soils and rock masses (McCann and Forster, 1990; Jongmans and Garambois, 2007: Perrone et al., 2014). Consequently, joint analyses of data generated from multiple geophysical and/or other techniques (geological and geotechnical) have been found to be a better approach for resolving non-unique problems and therefore generating reliable subsurface models (Frasheri et al., 1998; Gallardo and Meju, 2003; Friedel et al., 2006; Linde et al., 2006; Göktürkler et al., 2008; Godio and Naldi, 2009). Inspired by the successful application of geophysical techniques in investigating landslide-ravaged sites, we applied three common geophysical techniques in the investigation of the Obot Ekpo Landslide site (Fig. 1A–C). Electrical resistivity (VES and ERT) and seismic refraction surveys aimed to assess the internal structure of the landslide area and infer the influence of groundwater flow in the initiation of the landslide activity were performed.

## 2. Site description

### 2.1. Physiography and climate

Obot Ekpo village is located ~33 km along the Calabar-Itu Road in the Odukpani LGA, Cross River State of Nigeria, between Longitudes 08°17′E and 8°21′E of the Greenwich Meridian and Latitudes 05°10′N and 05°13′N of the Equator (Fig. 1A and B). The community is moderately populated: peasant farmers, traders and civil servants dominating the inhabitants. Two major rivers, the Cross and Calabar, and their tributaries drain the area. The region is located in a tropical rain forest zone where tall trees and oil palms dominate the vegetation. Hot and humid conditions are typically experienced during two seasons: wet (March to October) and dry (November to April). Annual precipitation is usually around 2200 mm, (Fig. 3A), while ambient temperature varies between 23 °C and 32 °C annually. Average relative humidity of the area is ~88%. The beginning of the wet season usually marks the arrival of the moisture-laden, northward blowing, Trans-Atlantic air mass. The rains usually begin to recede diffusely in mid-September and ends obliquely in October. This period usually coincides with the arrival of the southwards blowing Trans-Sahara trade wind. Winds speeds are usually low in the months with high amount of rainfall. The distribution of rainfall and wind speed data for the period 2005 to 2009 is shown in Fig. 3A and B. The dry season is usually characterised by high aridity, heat, ambient temperatures and comparatively high wind speeds.

### 2.2. Geological setting and stratigraphy

The study area is located within the Calabar Flank Sedimentary Basin (CFSB) in southeastern Nigeria (Fig. 1A). The CFSB begins at the southern margin of the Precambrian Oban Massif in the north and extends to the Tertiary Niger Delta basin in the south (Fig. 1C). It is characterised by a system of NW–SE trending crustal block faults that led to the formation of the Ituk High (a horst) and the Ikang Trough (a graben). The horsts latter became the centres of carbonate sedimentation while clastic sedimentation occurred in the grabens (Ekwueme et al., 1985; Reijers and Petters, 1987).

The sedimentary materials in the area are predominantly of Cretaceous age (Table 1) and comprise the ancient river-borne Awi Formation that rests unconformably on the Precambrian basement (Adeleye and Fayose, 1978). The marine Albian Odukpani Group overlies the Awi Formation. The Odukpani Group consists of the Mfamosing Limestone, the Ekenkpon Shale and the New Netim Marl. These sediments are extensively exposed in many