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Urban development and informal drainage patterns: Gully dynamics in Southwestern Nigeria

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ABSTRACT

This study evaluated the attributes of gullies in selected urban towns in part of Southwestern Nigeria. It identified the gully type and characterized them in terms of dimension and volume of eroded material. It also determined the relationship among their morphometric attributes and the factors of gully development in the study area. This was done with a view to modeling their development process. Twenty (20) towns were randomly selected for this study from where thirty (30) gully systems comprising forty (40) 1st order and five (5) 2nd order gullies were measured using Total Station (TS) and Global Positioning System (GPS) receivers for the transfer of coordinates (*xyz* values) to gully catchment. Google Earth images (2.5 m spatial resolution) were used to extract catchment characteristics such as area, drainage lengths, number of houses in the catchment and the impervious surface area. Soil samples taken from gully shoulders (soil tops) and floor were analyzed for textural characteristics and bulk density. Data collected was analyzed using descriptive statistics, analysis of variance, multiple regression (stepwise) and geospatial techniques. The result showed that impervious surface (X_1) and bulk density (X_2) contributed 89.8% ($R^2 = 0.898$; $\beta = 0.557$; $P < 0.05$) to the soil loss variance in the study area. The study showed that urban gully development was largely caused by large volume of runoff on mainly steep earth roads and unpaved drains coupled with poor engineering work and drains maintenance.

Introduction

Soil erosion especially accelerated gully erosion is a serious environmental problem around the world. The formation of gully systems is a sign of severe accelerated soil erosion and gullies are an important sediment source in both dry lands and humid regions (Herzing, Dymond, & Marden, 2011; Poesen, Nachtergaele, Verstraeten, & Valetin, 2003; Reuben et al., 2009; Rijsdijk, Bruijnzeel, & Prins, 2007; Sidorchuk, 2006; Yangqiu et al., 2008). Specifically, it was observed by Herzig et al. (2011) in the North Island East Coast region of New Zealand that erosion gullies, once begin, usually at channel heads can grow to large size and reach up to 90 ha as in the case of Walapa Catchment in New Zealand. It has also been observed that the dominating process of sediment production is gully erosion (Keay-Bright & Boardman, 2007; Marden, Bettis, Arnold, & Hambling, 2008; Rajesh, Norman, & Victor, 2011).

Accelerated soil erosion could even become more severe in an urban areas of high population growth and high rainfall intensity (Bouchnak, Sfar Pelfoul, Boussema, & Snare, 2009; Frankl et al., 2011; Marker & Sidorchuk, 2003; Nazari, Wasson, & Malekian, 2011). The phenomenon has assumed destructive dimensions in many parts of the world especially in the urban environment.

Generally, several published studies exist on gully processes, retreat, initiation and development as well as modeling in many parts of the world (e.g. Archibold, Levesque, deBoer, Aitken, & Delanoy, 2003; Frankl, Presen, Deckers, Haile, & Nyssen, 2012; Gardner & Gerrad, 2003; Kakembo, Xanga, & Rowntree, 2009; Marden, Herzig, & Arnold, 2011; Martinez-Casanovas, 2003; Marzoff, Ries, & Poesen, 2011; Parkner, Page, Marutani, & Trustrom, 2006a, 2006b; Poesen et al., 2003; Sidorchuk, Marker, Moretti, & Rodolfi, 2003; Wu & Cheng, 2005; Zhang, Wu, Liu, Zhang, & Yin, 2007; Zhu, 2012). For instance, Poesen et al. (2003) examined gully processes. Martinex-Casanovas (2003) and Sidorchuk et al. (2003) assessed gully initiation and development. However, Marden, Arnold, Gomez, and Rowan (2005) and Parkner et al. (2006a, 2006b) described the spasmodic development of gullies in space and time. Also, Kakembo et al. (2009) examined the relationship between spatial distribution of gully erosion and topographic thresholds as well as land use change in the form of abandoned lands in several affected catchments of the Eastern Cape Province, South Africa using Digital Elevation Models (DEMs). Some studies also exist on urban gully phenomenon in Nigeria (e.g. Adediji, Ekanade, & Ibitoye, 2009; Ebisemiju, 1989a, 1989b; Jeje,

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2005). For instance, Jeje (2005) observed that accelerated erosion in form of gullying was to a large extent an urban phenomenon in Southwestern Nigeria. Adediji et al. (2009) generated DEMs for gullies in Irele Local Government Area of Ondo State, Southwestern Nigeria: Much as these studies contributed to the body of knowledge on accelerated erosion, however they are based on very few gullies in very few urban centres. Also, urban gully is becoming a topical issue at the global level and specifically, the outcry for prompt and proper management of this phenomenon requires in depth understanding of gully dynamics as well as the interaction between specific gully catchment characteristics and other related attributes or factors such as rainfall, geology, soil and land use especially urban land surface characteristics (e.g. housing density, drainage networks/density and impervious surface area). In this regard, there is little or few existing studies on quantitative assessment of gully occurrence in Nigeria (e.g. Adediji et al., 2009; Jeje, 2005). Therefore, this study attempts to relate urban land surface characteristics and environmental factors to gully development in some towns of Ekiti and Ondo State in Southwestern Nigeria. Also the study aims at developing model for monitoring the dynamic of urban gully in this part of the humid tropics.

Study area

This study is restricted to urban areas in two States of Southwestern Nigeria (Ondo which is partially on Sedimentary formations and Ekiti mainly on Basement Complex rocks). The choice of the two states was as a result of their true representation of Southwest Nigeria (excluding Lagos State) in terms of geology and physiographical characteristics.

The study area which is part of the eastern section of Southwest Nigeria, lies between latitude 5° 57′ N and 9° 12′ N and longitude 2° 40′ E and 6° 03′ E (Fig. 1). It has a population of about 5,825,236 people predominantly Yorubas comprising sub groups such as, Akures, Ekitis, Ondos, Ikales and Ilajes; that settled in various sized villages and urban centres. As observed by Jeje (1988), the development of most of these towns and villages occurred without any systematic planning. Buildings sprang up without recourse to physical planning particularly during the evolution of traditional urbanization which took place after the Yoruba civil wars at the end of the 19th and early 20th centuries. Some of these towns had a modicum of planning during the colonial period, with the result that high density residential areas adjoined low density fairly laid out residential areas which was joined to the traditional areas and they are high density urban cores. With the introduction of planning policies, residential plots for low and medium density in form of grid pattern became prominent particularly in the newly open up areas/towns. The poor execution of the policy (residential layout design and implementation), often result in accelerated soil erosion in the study area and thus making the problem an urban phenomenon in contrast to gullying in Southeastern Nigeria which is both rural and urban.

The study area is mainly on the Coastal Plain Sands, Tertiary and Cretaceous Sandstone formations to the south and Basement Complex to the north. The terrain rises gradually from an elevation of less than 30 m above sea level from the southern part to the northern part of the region, reaching general elevations of about 415 m in Ekiti State on the Basement Complex with some prominent isolated elevations of more than 600 m such as Idanre Hills, Efon Alaaye and Oke Imesi ridges (Udo, 1981, pp. 17–18). The terrain slopes imperceptibly in a north–south direction as evidenced by the flow direction of the main rivers such as Ogbese, Oluwa, Owena, Ose and Ominla. Some of the rivers are perennial but with remarkable seasonal variations especially during the dry season. Most of these rivers traverse some of the towns and villages where urbanization processes have altered the hydrology and geomorphology of the rivers within the urban catchments. The study area is underlain by the Ferruginous Tropical soils at the northern part, Ferralitic soils at the central and hydromorphic soils formed on fluvial and lacustrine alluvium in the southern part (Smyth and Montgomery, 1962, pp. 15–17).

The study area is characterized by humid tropical climate (Am and Aw of Koppen's climatic classification) with mean annual temperature of 27 °C and a mean annual rainfall ranging between 1250 mm and 1400 mm and distributed between the months of March and October with peaks in July and September, and short dry spells in August, whose occurrence however varies from year to year (Adejuwon and Jeje, 1975, pp. 12–16). The rainfall effectiveness is between 6 and 9 months in the year (Udo, 1978, pp. 21–23) but in recent years the rains started much earlier in February in some parts of the study area (Odekunle, 1997). From November through February, the area experiences the dry season due to the prevalence of the dust laden north-east trade winds (cT air masses) that blow across the region, loaded with fine dust from the Sahara with short periods of haze weather, locally referred to as harmattan. The onset and withdrawal of the rains are marked by thunderstorms accompanied by high rainfall intensity (Odekunle, 1997). This at times may be so intense that unconsolidated soils are removed during thunderstorms.

Material and methods

Both primary and secondary data were used for this study. In order to measure the gullies using Total Station, the values of existing Ground Control Points (GCPs) were collected from Survey Sections of the States Ministry of Lands and Housing in Akure and Ado Ekiti, respectively. Where the points were found to be insufficient or too far from the gully sites, a single frequency geodetic Global Positioning System (GPS, South H66 and H68) was used to provide more control points. The positional coordinates (Easting and Northing and Elevations) obtained through this method were later used for correction and geo-referencing of the Google Earth imageries (2.5 m spatial resolution) used in the study area. Population data of selected settlements in the study area were collected from the Federal Office of Statistics while rainfall data were collected from the Agro-climatological and Ecological Project Office, Ministry of Agriculture, Forest Resources, Akure and Ado Ekiti, respectively.

Twenty (20) towns were randomly selected from a list of 25 towns with cases of serious gully erosion problem. Thirty (30) gully systems comprising forty (40) 1st order and five (5) 2nd order gullies were selected for the study. The gully catchments were delineated on the ground and from Google Earth imageries. The dimensions (i.e. length, width, depth and gully surface area) of each of the selected gullies was measured using Total Station (TS) with angular and linear accuracy of 2″ and ±2 mm + 2 ppm, while spot height (terrain configuration) of the catchment was determined using GPS receivers in a 'track-and-go' method. While using the Total Station, it was ensured that the coordinates used were on the same framework with the coordinates used for geo-referencing the imageries. This is to ensure common origin. Measurement was done at a centimeter resolution. Gully channel dimensions were measured at every 10 m interval due to variations in depths and widths while spot heights (*XYZ*) of gully catchments were measured at approximate distance of 50 m grid interval due to variations in the terrain. In the case of U-shaped and large V-shaped, gully floors and depths were measured across the widths of channel at interval of 1 m. The dimensions of ten (10) out of the gullies were manually (analog) measured with tape and the values were used to validate the accuracy of data obtained using TS. For