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Original Research Article

Relationships between average gully depths and widths on geological sediments underlying the Idah-Ankpa Plateau of the North Central Nigeria

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ABSTRACT

This study investigated the relationships between the average gully depth and the average width on two of the three geological sediments underlying the Ida-Ankpa Plateau of the North Central Nigeria. Gully length (L), average depth (D), and average width (W) were measured on 37 and 5 gully samples formed respectively on the Ajalli Sandstones' (AS) and the Upper Coal Measures' (UCM) geological sediments. From these, the average volume (V), average cross sectional area (A), and average form factor (W/D) were computed. These sets of variables (L, D, W, V, A, and W/D), a total of six for each gully, were analysed using correlation analysis and the sample bivariate regression to examine the relationships between D and W on the two geological units. Results show that D correlates poorly, positively, and significantly with W on the highly erodible AS ($R = 0.565$, $P < 0.01$), whereas the relationship is stronger, positive, and significant on the more resistant UCM ($R = 0.997$, $P < 0.01$). On the AS, D is a poor predictor of W with the relationship: $W_1 = 3.670 + 0.355D_1$ ($R^2 = 0.319$), whereas it is a near-perfect predictor on the UCM ($W_2 = 1.667 + 0.689D_2$, $R_2 = 0.994$). The results of the study suggest that for gullies cut on deep, homogeneous formations, the correlation of D with W diminishes with increasing vulnerability to erosion of the sediments, whereas the effectiveness of D as a predictive tool of W increases with the resistance of the sediments to erosion.

1. Introduction

Worldwide, gully erosion is a widespread environmental problem and it is the principal cause of land degradation. Pimentel (1993) reported that in the developing tropical lands, severe erosion-induced land degradation occurs on both Urban and agricultural lands, and the problem increases as the human population grows and more marginal lands are brought under cultivation. He estimated that, globally, and on an annual basis, about six million hectares of land were lost to erosion-related land degradation. Lal reported that the United Nations Food and Agricultural Organization (FAO) had estimated that more than 85% of Africa north of the Equator was experiencing rapid accelerated erosion in the form of gullies.

Gully erosion control projects are capital-intensive, thus the choice of which gully to control must be based on some rational criteria, namely: the value of the land on which the gully occurs and the volume of sediments produced by the gully. In Nigeria, control of gullies on rural lands seldom attracts the attention of governments at the federal and state levels, as well as the international donor agencies. This is because rural lands experiencing gullying are often considered of such marginal value that the cost/benefit indices derived from expenditure on such lands are usually adjudged unjustifiable.

The percentage contribution of gully erosion to the total volume of sediments produced in a catchment is unknown. Though usually occupying less than five percent of the total catchment area, it is estimated that gullies contribute between 10% to 95% of the overall sediments from a catchment (Poesen, Nachtergaele, Verstraeten, & Valentin, 2003). In addition, many published works have suggested that gully erosion occurring in catchments account for the production of the largest volume of sediments that damage Urban and Rural infrastructure (De Vente, Poesen, & Verstraeten, 2005; Poesen, 2011; Valentin, Poesen, & Li, 2005).

The average volume (V) of sediment yield from a gully is estimated by finding the product of the length (L), the average depth (D), and the average width (W) (V = L x D x W). While it is easy to

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measure the length in the field, from air photographs, and from satellite images, measurement of the average depth and average width are difficult and imprecise tasks. Most researchers in the field do not specify the criteria usually considered in their measurements and, therefore, do not attach any certainty to the results obtained. Casali, Gimenez, and Campo-Bescos (2015) have extensively discussed the difficulties encountered in the measurement of depth and width of gully cross sections because of their intricate shapes, and have, therefore, suggested the need for researchers in this area to clearly express and define the criteria considered in their measurements.

However, it is feasible to determine a fairly reliable estimate of D from only one side of a gully. Oparaku (1999) carried out rapid field measurements from one side of a gully to estimate the depths at cross sections and thus the average depth of the gully: A meter staff was placed vertically at 10 m intervals along one end and the same side of a gully floor from the head to the mouth. Then at each cross section on the ground surface coinciding with each interval point on the floor, a flat, rigid bar was placed horizontally perpendicular to the gully channel and extended into the channel until it made contact with the vertical staff. The reading on the staff at the point of contact was read off in metres and taken as an estimate of the depth of the gully at that cross section. The procedure was repeated at the successive interval points and the average depth (D) computed as $\sum$ d/Number of interval points, where d = estimated depth at each of the interval points.

The average width (W) is easier and more accurate to estimate for gullies of shallow and narrow cross sections. Nevertheless, for deep and wide cross sections, not only is it difficult to clamber from one side slope through the gully floor to the other to take measurements, the irregularities at the cross sections and the sag at the center of the measuring tape introduce cumulative errors that diminish the reliability of the estimated W. Therefore, models relating D and W on thick, homogeneous formations are required to predict W knowing an estimate of D, which is required to estimate the average volume of sediments produced from a gully.

Many researchers worldwide have attempted to investigate the interrelationships among gully dimensions. Cheng et al. (2007) found a strong correlation between gully length and gully sediment volume, and suggested that gully length could be a significant parameter for the estimation of the volume of gully erosion. The results of a study in the southeastern Spain revealed that gully volume (V) had a positive correlation with the form factor (W/D) (R = 0.436) and a negative correlation with the W/L ratio (R = –0.536) (Vandekerekhove et al., 2000). The results showed that gully widening was a more dominant phenomenon in this area than gully deepening.

Radoane, Ichim, Radoane, and Surdeanu (1990) reported a linear relationship between the form factor (W/D) and gully length given in Eq. (1) as:

$$W/D = 1.287 + 0.00199L \quad R^2 = 00.39 \tag{1}$$

From the descriptive statistics of field measurements of gully dimensions, the US-SCS (1966) found that the width of gullies formed on cohesive soils are three times their depth, while on non-cohesive soils, the ratio is 1.75. The relationships are given in Eqs. 2 and 3:

$$D = 0.34W\text{–cohesive soil} \tag{2}$$

$$D = 0.57\ W\text{–non–cohesive soil} \tag{3}$$

No previous work had considered the effects of varying vulnerability to erosion of homogeneous geological sediments on which gullies are formed on the interrelationships among gully dimensions. This study was, therefore, carried out to examine the relationships between the average gully depth and average width on two of the three geological sediments underlying the Idah-Ankpa plateau (IAP) of the North Central Nigeria. These two geological sediments with varying degrees of resistance to soil erosion are the Ajalli Sandstones (AS) and the Upper Coal Measures (UCM).

2. The study area

The study area comprises the Western Ankpa High Plateau and the Idah Flood Plains. It is situated in the Middle Belt of Nigeria, and lies between Latitudes 7° 17′ 00″ N and 7° 23′ 30″ N and Longitudes 8° 20′ 20″ E and 9⁰ 00′ 00″ E (Fig. 1). The total land area is estimated at about 5675 km^2 with a perimeter of 793,531.76 km (Oparaku, 2015). About 96% of the area lies in Kogi State, while the remaining 4% lies in Benue State.

The area is located in the tropical hot climate. The mean annual rainfall is 1260 mm with a range varying from 714 to 1890 mm. There are two major seasons in a year: the rainy season and the dry season. The rainy season responds to the prevalence of the moisture-laden southwesterly maritime winds that originate from the Atlantic Ocean, whereas the dry season responds to the dry continental northeasterly winds that blow from the Sahara Desert. The rainy season lasts from the middle of April to the end of October, while the dry season lasts from November until the middle of April. Temperatures are high throughout the year, and the mean varies from 31.40 °C in December to 34.50 °C in March, with an average of 32.60 °C. The average relative humidity may be as high as 98.70% in October and as low as 75.20% in January. The evapotranspiration ranges from 73.40 to 166.90 mm. September has the highest number of rainy days (8.00) and March has the least (1.2).

The geology of the area has been described as follows (Preez & Barber, 1965): The underlying geology (Fig. 2) consists of cretaceous sediments made up of three major formations which underly 100% of the plateau landscape. These formations comprise the Upper Coal Measures (UCM) (36%), The Ajalli Sandstones (AS) (44%), and the Lower Coal Measures (LCM) (20%). The geological successions of these sediments are as follows: UCM-AS-LCM, i.e., the UCM is the overlying formation, the LCM the underlying formation, while the AS is sandwitched in between the two. The UCM and LCM are each homogeneous up to a depth of 70 m, whereas the AS is homogeneous up to a depth of 170 m. The AS is exposed to the erosive processes of the elements at locations where the UCM, which provides a protective overburden, has been denuded away. And the LCM is exposed and subject to erosive processes where both the UCM and AS are denuded away. (Fig. 3)

Oparaku (2015) estimated that the total number of gullies in occurrence on the UCM was 100; the AS, 740; and the LCM, one (Fig. 4). Their study showed that the mean %sand + %silt on the UCM was 80%; AS, 95%; and LCM, 61%. Thus the vulnerability to erosion (erodibility) of the three sediments can be ranked as AS > UCM > LCM.

The three geological units control the hydrology of the area. The AS and the sandy units of the UCM form copious aquifers, whereas the argillaceous units of the UCM and LCM form aquitards. The geomorphology of the area consists of the Ankpa Plateau and the Ankpa Piedmont which lie over sandstones, but differentiated in the deep valleys. The Anambra River, which empties into the River Niger, is the main drainage basin in the area. The soils are predominantly cretaceous sandstones. They are deep, well drained, and frequently red or reddish brown in colour with sandy surface horizons occurring on the interfluves and the upper and middle slopes. Subsistent agriculture is practised in the area.