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GENERATION OF DIGITAL ELEVATION MODELS (DEMS) FOR GULLIES IN ONDO-STATE, NIGERIA

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Gully development is a significant problem at Ode-Irele, Lipanu, Akotogbo and Ajagba town in the Irele Local Government Area (LGA) of Ondo-State, Nigeria. To better understand gully development and features, digital elevation models (DEMs) are derived to establish gully morphometric attributes such as surface slope, catchment area, average depth and width, as well as cross-sectional area and volume of material/soil eroded. The DEM for each of the study gully catchments was derived from the values of the spot heights and coordinates of each point obtained through the use of GPS and processed using Surfer software. The values of slopes in the study gully catchments ranged from approximately $0^0$58'27" at Lipanu to $4^0$51'31" at Ajagba. The DEMs of gullies at Idogun, Ajagba and Ado quarter showed slopes that appeared steeper than the gully at Lipanu. The slope shapes are dominantly convex which implies that overland flow will be generated from all sides of the slope. The convexity of most of the gully catchments coupled with the termination of drainage channels, as well as poor roads and drains maintenance by the community and government, have led to the development of large deep gullies at Ode-Irele, Akotogbo and Ajagba. The development of gullies could be minimized by encouraging planting of cover grasses in adjacent areas rather than paving of the surface, which makes the ground impervious.

INTRODUCTION

The mechanisms involved in soil erosion by water vary over space and time. Some of these mechanisms are rain drop splash, unconcentrated downslope wash (sheet erosion), concentrated downslope wash (rill and gully erosion), and a mixed process in which entrainment is by rain drop splash and downslope transport is by surface wash. It has also been observed that man can also influence the dynamics of each of these mechanisms and thus improper human land management can accelerate the rates of erosion which may result in the development of rills and gullies.

Gullying resulting from accelerated soil erosion has been an issue of growing concern not only in the humid tropics but in many parts of the world. For instance, many published studies exist on the occurrence, assessment and monitoring of this phenomenon in an urban environment (e.g. Beths and DeRose, 1998 in Northeastern Island New Zealand; Bocco et al.; 1990 in Mexico; Ofomata, 1989 and 2000 in southeastern Nigeria; and Jeje, 1973, 1977, 1987 and 2005 in southwestern Nigeria). This issue is so important because the initiation of gullies, as well as the headward and lateral progression, releases large amounts of sediments and can enhance rates of overall landscape lowering and evolution (Hancock and Willgoose, 2001, 2002; Alonso et al., 2000). Also, this may result in increased sedimentation and water quality problems in many drainage basins. In addition, there has been considerable research into understanding of gully development and channelization, but much of this effort has been on evaluation of ephemeral gullies in disturbed or agricultural/urban settings, (Jeje, 1973, 2005; Patton and Schumm, 1975; Hancock and Evans, 2006).

The development of Geographic Information System (GIS) recently has led to increasing use of Digital Elevation Models (DEMs) to model gully positions, features and development as well as its use in the studies of landscape change, particularly in the area of studying gullies and terrain analysis (Prosser and Aberneathy, 1996; DeRose et al., 1998; Hancock et al., 2000; Torri and Borselli, 2003) in both small and large catchments. There are no known studies on the application of GIS to the study of gully position and development in urban setting of southwestern Nigeria, if not in the whole of Nigeria. In this regard, the present study attempts to generate DEMs for gullies in the Irele Local Government Area (LGA) of Ondo-State, Nigeria.

STUDY AREA

Gullies at Ode-Irele, Lipanu, Akotogbo and Ajagba in the Irele LGA constitute the study area. The Irele LGA is part of the lowland area of the southeastern part of Ondo-State. It is located between Latitudes $06^0$17'57"N and $06^0$43'21"N and Longitudes $04^0$49'47"E and $05^0$10'26"E (see Figure 1).

The area falls within the Bitumen Belt of Ondo-State and is predominantly populated by the Ikales of Yoruba extraction. According to the 2006 Population Census, the population of the Local Government Area was put at 145,166 (NPC, 2001). This population settled in agglomerations or clusters either in towns or villages. Also, as observed by Jeje (1988), the development of most of these settlements (towns and villages) occurred without any systematic planning. Buildings sprang up without any recourse to physical planning particularly during evolution of traditional urbanization which took place in many of the Yoruba settlements in the late 18^{th} century. This development has given rise to haphazard arrangements of buildings in the settlements (Ode-Irele, Lipanu, Ajagba and Akotogbo) where the gully studies are located.

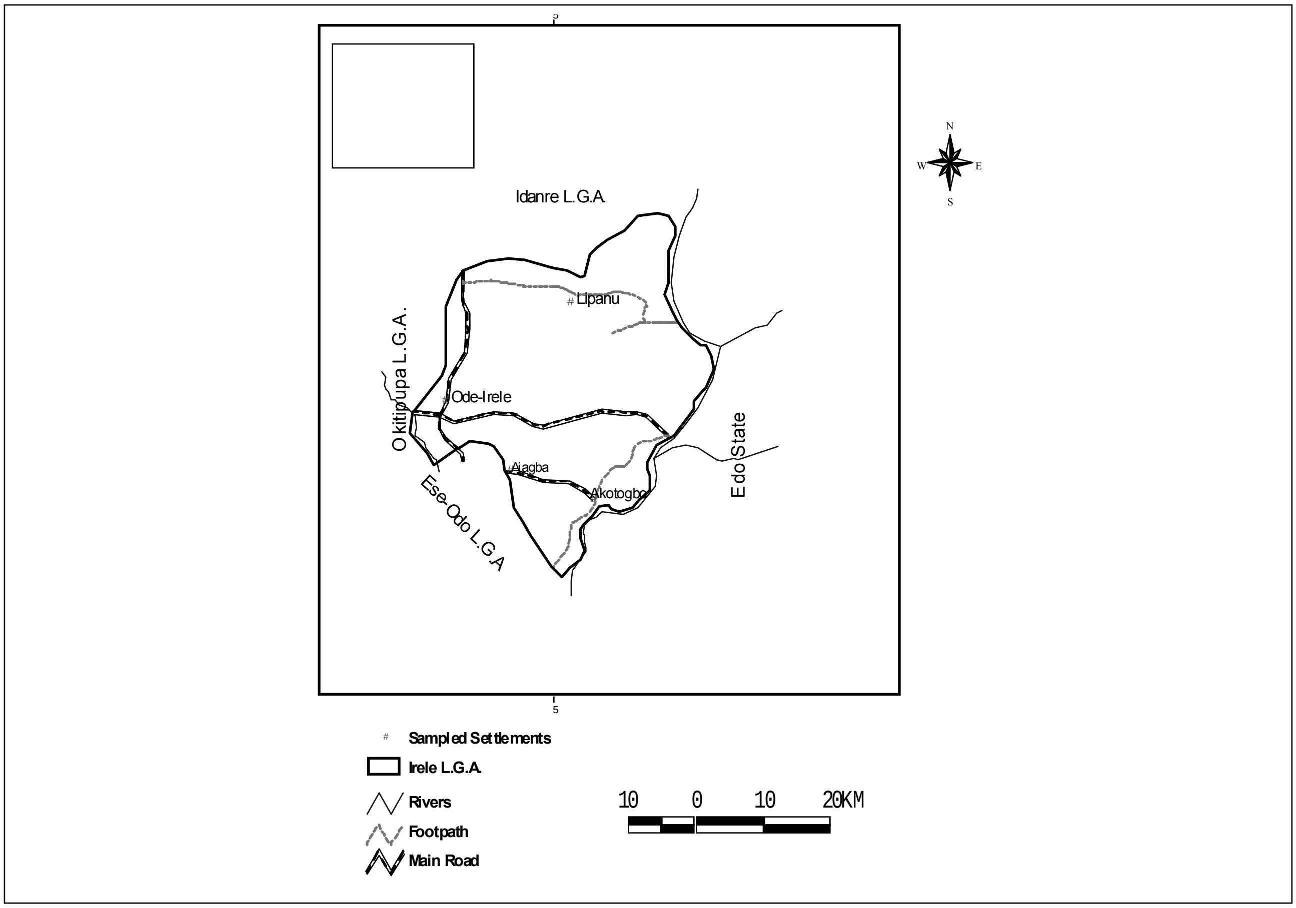

Figure 1. Map of Irele Local Government Area showing the study settlements.

The area falls within the tropical rainforest region and as such the climate is characterized by two main seasons; the rainy season (April-October) and the dry season (November-March). The available meteorological data for Ode-Irele indicated that annual rainfall varies from 1,900mm to 2,700mm (see Agro-Climatological and Ecological Monitoring Unit, Akure). The annual average temperatures range between 21.4^{o}C and 31.1^{o}C and mean annual relative humidity is about 77.1% (Iloeje, 1978).

The area has a general elevation of 45m above mean sea level, but the ground slopes imperceptibly in a north-south direction as evidenced by the flow direction of drainage systems such as the rivers Oluwa, Ufon, Mene and Salawa (see Geological Consultancy Unit, University of Ife, 1980). Most of these rivers meander freely and are actively engaged in lateral erosion at meander bends thereby widening their channels.

According to Areola (1983), the area is underlain by terrasols that consist mainly of loams, sandy loam and in some places clay loams which are easy to cultivate but however suffer from excessive internal drainage and intensive leaching. Also, the original vegetation of the zone which is tropical rainforest has been replaced by arable crop cultivation, rubber and palm plantations and exotic tree plantations established by forestry divisions and secondary forest regrowth (Areola, 1983).

STUDY METHOD

Four settlements in the Irele LGA were selected for the study of gully morphology and derivation of DEMs for the gully catchments. These settlements are Ode-Irele (the LGA headquarters), Akotogbo, Ajagba and Lipanu. Apart from Ode-Irele which was purposely selected due to its position as the administrative headquarters of the LGA, others were sampled using the table of random numbers of the list of prominent settlements in the Local Government. The erosion channels and gullies were identified in all the selected settlements, out of which five gullies were selected for study: two gullies at Ode-Irele, and one gully each at Akotogbo, Ajagba and Lipanu.

The catchments of each gully was visually delineated based on the slope gradient and gully pattern and points were selected along the catchment perimeter. The Global Positioning System (GPS) receivers (Garmin GPS 12) was used for determining the coordinates (Northing and Easting) of all turning points until the area enclosed by the gully catchment was covered. The area covered by each catchment was determined using values of coordinates of turning points (see Ibitoye, 2006).

Also, for the generation of DEMs, the areas of the study gully catchments were later divided into grids at regular intervals of 50m. Along each traverse/gridline, at intervals of 50m, spot heights and their Cartesian coordinates were determined using GPS. On the whole, a total number of 126, 73, 69, 334 and 34 spot heights were determined for gully catchments at Ode-Irele, Ajagba, L.A. Primary School Area and Lipanu, respectively.

The data obtained from the field measurements were processed and used for the generation of contour maps and DEMs (Digital Elevation Models) of the selected gully catchments. In this regard, the values of spot heights obtained from the gully sites were plotted against the coordinates of each point using Surfer 8.0 software.

Gully morphometric attributes such as gully width, depth and cross-sectional area were measured using tape and leveling staff. The cross-sectional area of each of the selected gullies was determined using a formula adopted by Ofomata (2000) in southeastern Nigeria. The formula is given as:

$$A = wd \tag{1}$$

where A = cross-sectional area (m^2), w = mean width of the gully, and d = mean depth of the gully.

The values of the cross-sectional area were used to estimate the volume of soil removed by gully erosion from each of the gully catchments. A prismoidal formula was used in this study (see Bannister and Raymond, 1983). The amount of sediment loss from the gully site was estimated by multiplying volume by the soil bulk density (see Jeje, 2005). The bulk density was determined from the core samples taken from the floor of each of the study gullies using a McCauley corer (core sampler) of approximately 5.5cm diameter and 4m height. In all, 30 core samples were taken from the study gullies and analyzed in the laboratory for the determination of the bulk density by following the procedures outlined by Singh (1989).

RESULTS AND DISCUSSION

Morphometry of the Study Gullies

From the results obtained by physical assessment of the study gully catchments, two types of gully shapes were identified. These are "V" shaped gully system (see Holy, 1980 and Jeje, 2005). The gullies at the L.A. Primary School Area, Ajagba and Lipanu exhibited V-shapes for most of their lengths while those at Idogun, Ode-Irele and in Akotogbo displayed remarkable U-shapes for most of their lengths.

With respect to the slope gradient as shown in Table 1, the value of slopes in the study gully catchments ranged from approximately $0^0$58'27" at Lipanu to $4^0$51'31" at Ajagba. The slopes at Lipanu and L.A. Primary School Area are almost flat while those at Idogun, Ajagba and Ado Quarters, Akotogbo are steeper.

As shown by the Digital Elevation Models (DEMs) of the study gullies coupled with field observation, the slopes at Idogun, Ajagba and Ado Quarters in Akotogbo appeared steeper than the others. Ordinarily under vegetal cover, these slope gradients should not enhance erosional processes but due to exposure to direct raindrop impact and human activities coupled with the poor soil aggregation, accelerated erosion has become pronounced particularly at Idogun Quarters in Ode-Irele, Ajagba and Akotogbo.

Further, the slope shapes as revealed by the Digital Elevation Models (DEMs) of the study gullies are dominantly convex (see Figures 2a, 2b, 2c, 2d and 2e). This implies that overland flow will be generated from all sides of the slope which invariably increases runoff into the gully channels. The DEM for the Lipanu gully catchment exhibits relatively uniform flat terrains (see Figure 2e) which ordinarily should enhance deposition and flooding but gullying occurred here due to human activities.

Soil Characteristics and Accelerated Erosion

Soil physical characteristics and the estimated sediment loss from study gully sites are shown in Table 2. The soil textural properties of the gully catchments show a high proportion of sand with a mean value of 59%, while the mean values of clay and silt are 34% and 7% respectively (see Table 2). As observed from the field, the soil especially at the upper horizon is predominantly sandy clay and changes to sandy clay loam with depth. Also, most of the gully floors are characterized by sandy clayey regolith. With a high proportion of sand at the upper layer, one would have expected these soils to be highly permeable and thus not susceptible to soil erosion. Because of compaction of the ground in the built-up (urban) environment, as in the case of the study gully catchments, the soils are relatively permeable and therefore susceptible to the action of sheetwash and gullying.

The values of soil loss from the study gully systems shown in Table 2 compared favorably with the total sediment loss obtained from Effon-Alaaye Gully Systems by Jeje (2005) in southwestern Nigeria and Ofomata's (2000) findings in southeastern Nigeria. In fact, the volume of soil loss from the study gully catchments as shown in Table 2 further confirmed the findings of Harley et al. (2003) in the North Island East Coast Region of New Zealand. For instance, 13,213m^3 of soil

Table 1. Morphometry of the study gullies.

Gullies	Gully order	Mean gully length (m)	Mean gully depth (m)	Mean gully width (m)	Mean cross sectional area (m^2)	Gully catchment area (Ha)	Surface slope of the gully catchment
Lipanu	1st	61	0.97	2.31	2.27	5.049	$0^0$58'27"
L.A. Pry Schl. Area (Ode-Irele)	1st	750	3.07	5.14	21.95	86.895	$01^0$06'06"
Idogun Qtr. (Ode-Irele)	3rd	340	5.51	7.83	37.89	25.889	$02^0$06'06"
Ajagba	1st	214	1.54	3.32	5.57	11.887	$04^0$51'31"
Ado Qtr; Akotogbo	2nd	130	2.66	4.79	12.48	13.269	$03^0$02'41"

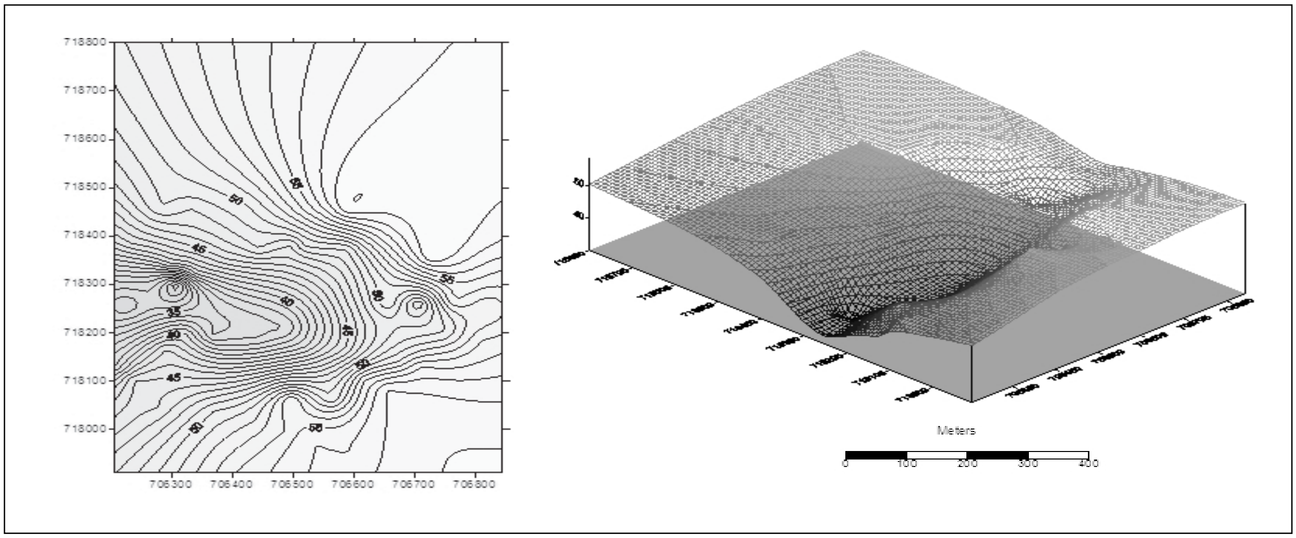

Figure 2a. Contour map and DEM of gully at Idogun Quarter, Ode-Irele

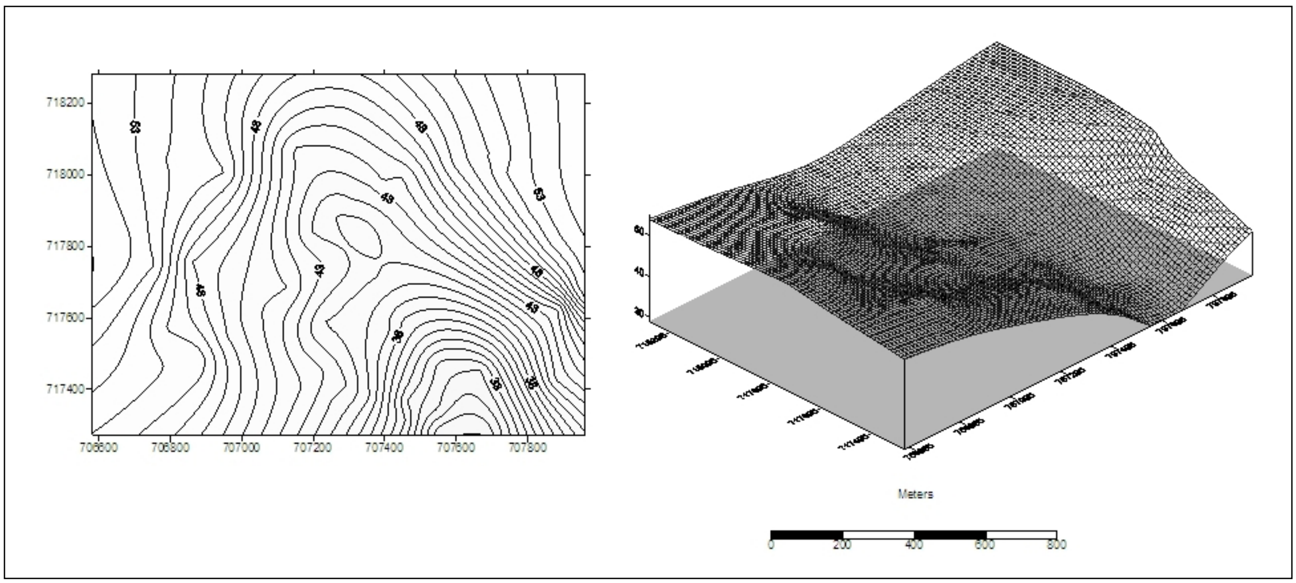

Figure 2b. Contour map and DEM of gully catchment at LA primary school area, Ode-Irele.

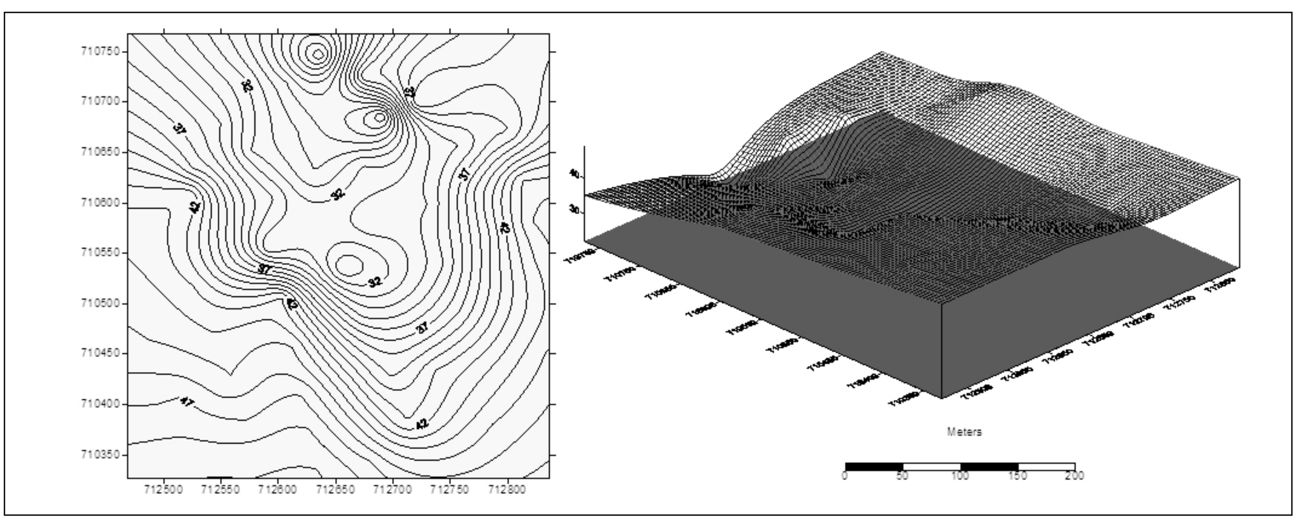

Figure 2c. Contour map and DEM of gully catchment at town hall/market area, Ajagba.

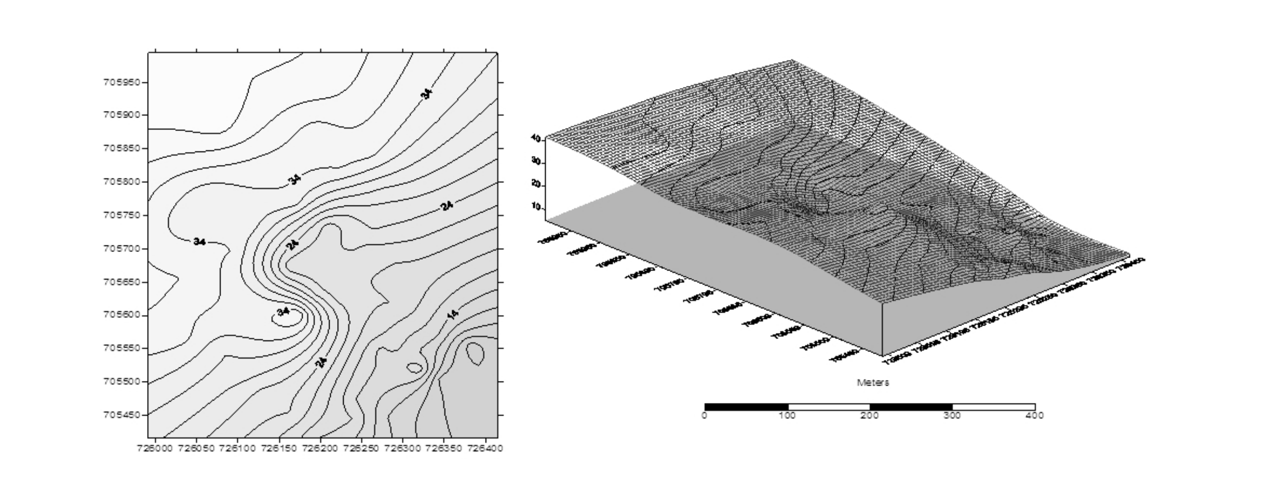

Figure 2d. Contour map and DEM of gully catchment Ado quarter, Akotogbo.

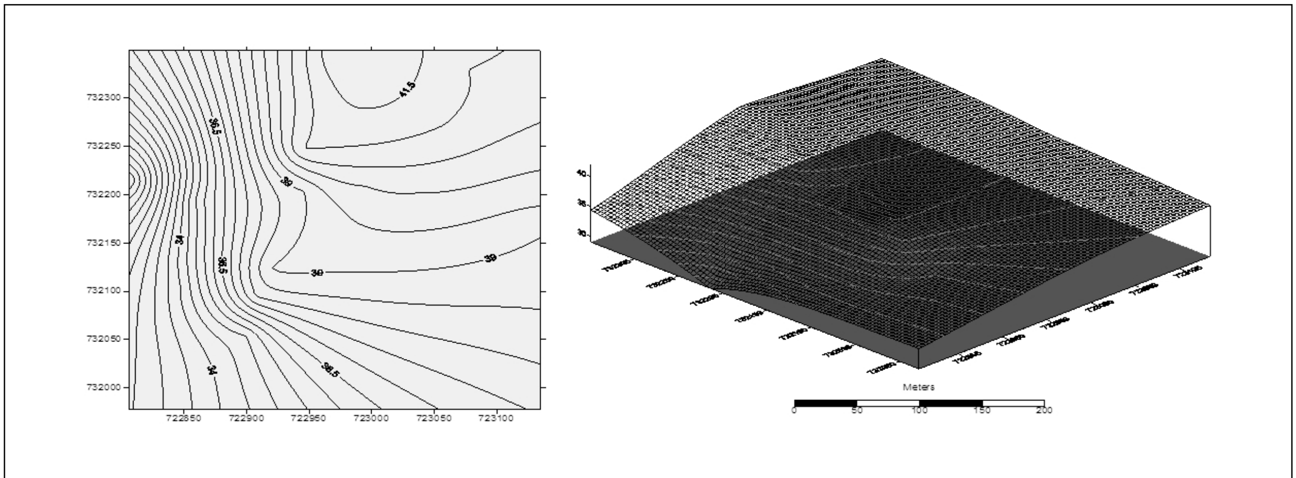

Figure 2e. Contour map and DEM of gully catchment at Lipanu.

Table 2. Sediment loss from the study gullies.

Gullies	Mean bulk density (g/cm^3)	Soil texture			Volume of soil loss (m^3)	Sediment loss (tonnes)
		% sand	%silt	% clay		
Lipanu	1.45	54	14	32	132.47	192.08
L.A. Pry Schl.(Area (Ode-Irele)	1.61	63	07	30	16,147.10	25,996.83
Idogun Qtr (Ode-Irele)	1.88	59	04	37	16,861.77	31,700.16
Ajagba	1.65	63	07	30	1,167.54	1,926.44
Ado Qtr. (Akotogbo)	1.89	56	03	41	13,213.25	24,973.04

has been removed from the 2nd order gully system at Ado Quarters, Akotogbo with a gully catchment area of 13.27ha (see Table 2) though higher but compared favorably with 6,900m^3 of material eroded from the 7-8ha of gully system in the North Island East Region, New Zealand by Harley et al. (2003).

As evident from Tables 1 and 2, the severity of gully erosion is not attributable to slope gradient. For instance, field observation showed that in the L.A. Primary School Area Gully system, the bulk of surface runoff that created gully erosion in the area was generated about 500-600m away from the gully site. In fact, the runoff originated from the main road, near the police station and was routed through the built-up area via the comprehensive Grammar School at Araromi/Gbonye Street, down to Kanye Quarters where it developed into a pond-like feature before exiting into the Erioko Stream.

However, it is important to discuss how some human activities within the study area, specifically the study catchments, normally promote the generation of surface runoff loaded with sediments. For instance, the construction of drainage channels along urban streets normally encourages the concentration of urban runoff but an improper handling of the project may enhance accelerated erosion. In this regard, as observed in the area, the termination half way of the construction work on erosion channels being constructed some years back by the Ondo-State Government in most of the study settlements triggers accelerated erosion (gully erosion). Runoff in the form of falls from the concretized portion of the channels onto the bare earth below gave rise to a gully from the points where the concrete gutters terminated (Ibitoye, 2006). In fact, during the field survey, a gully head of 3.4m deep and 3.3m wide was measured where the concrete channel terminated at Idogun Quarters. However, the runoff that brought about the gully at Idogun Quarters was generated from the network of concrete drains that covers just about 8.3ha (32%) of the total gully catchment area.

Also, virtually all the study settlements were poorly provided with drainage systems. In fact, Akotogbo and Lipanu were hardly provided with any of these facilities. Thus, most of the surface runoff flows along the untarred roads and the unpaved drains. Even, the few drains and culverts provided were inadequate to accommodate the volume of surface runoff generated during heavy rainstorms.

Another important factor responsible for the development of gullies in the area is roofing materials. Buildings in the area are roofed with the galvanized iron sheets which has severely increased the volume of runoff produced from any given rainfall. In fact, only few houses in the area have their compounds paved with concrete, the surroundings of most of the houses are subjected to severe compaction and subsequent sheet erosion (see Plate 1 (a) and (b)). This phenomenon was earlier observed by Okoye (1988) and Jeje (1988, 2005) in their studies on accelerated erosion in Aba and Effon-Alaaye in Nigeria, respectively. Also, it was observed that after a gully has been initiated, the process of soil removal both vertically and laterally will continue at every rainy season. In most cases, lateral expansion is by basal undermining of gully sides by runoff thus resulting to mass wasting of poorly consolidated sands and eventual collapse of mass into the gully floor (see Plate 1 (c)).

CONCLUSION

The gullies at Ode-Irele, Lipanu, Akotogbo and Ajagba in Irele LGA of Ondo-State, Nigeria were studied with a view to derive the DEM for each of the study gullies. The values of slopes in the study gully catchments ranged from approximately 0^{0}58’27” at Lipanu to 4^{0}51’31” at Ajagba which are generally low and gentle. However, the DEMs of the study gullies coupled with the field observation at Idogun, Ajagba and Ado Quarters displayed slopes that appeared steeper than others. Ordinarily under vegetal cover, these slope gradients cannot cause accelerated erosion but due to exposure to direct rain drop impact resulting from human activities coupled with the poor soil aggregation, gullying has become pronounced in Idogun Quarters in Ode-Irele, Ajagba and Akotogbo.

The slope shapes displayed by the DEMs of the study gullies are dominantly convex which implies that overland flow will be generated from all sides of slopes. This invariably increases

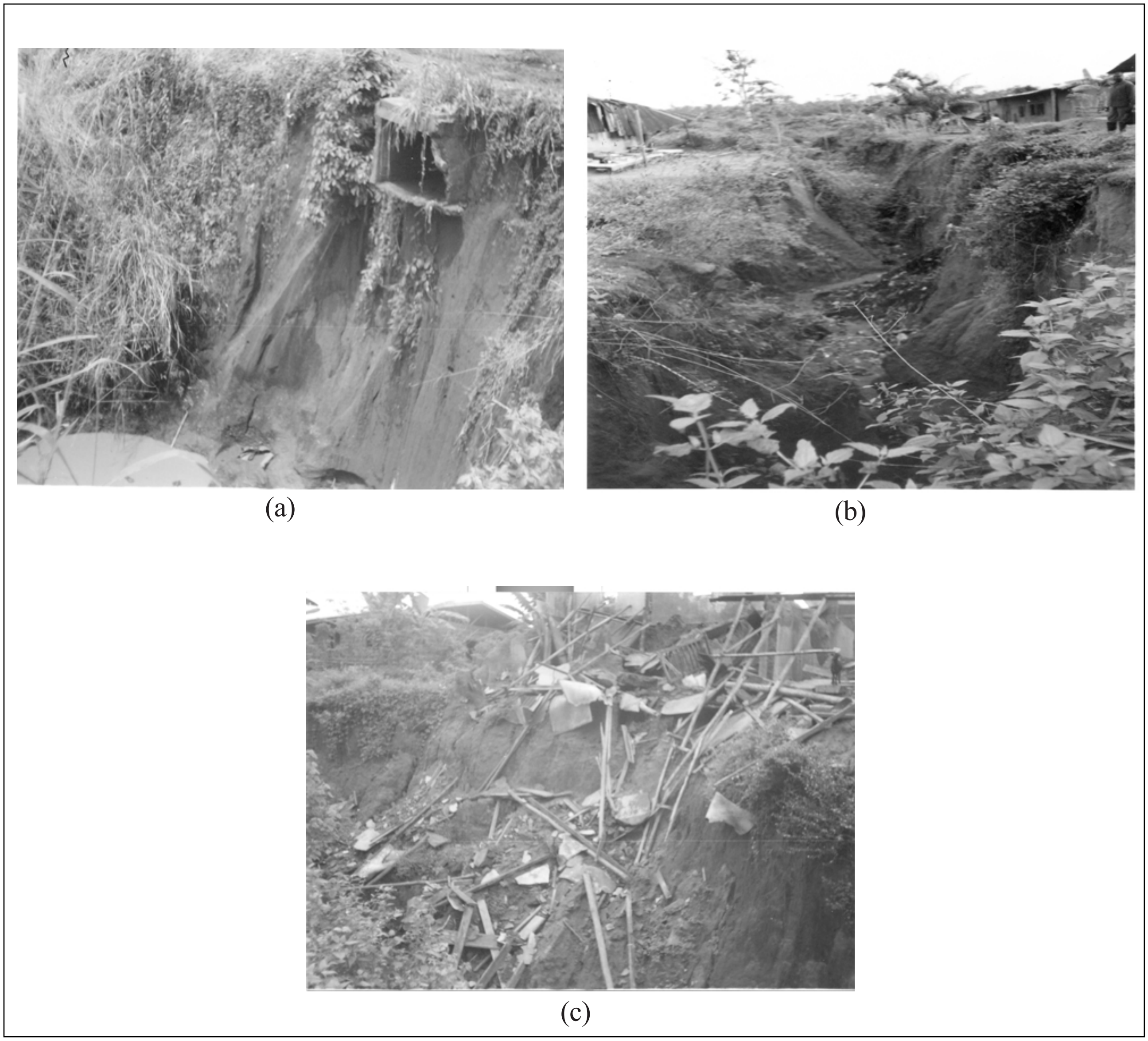

Plate 1. (a) Gully at Ado quarter, Akotogbo. (b) Gully at LA primary school area, Ode-Irele. (c) A one story building collapsed into the gully floor at Akotogbo.

runoff into the gully channels. In other words, the convexity of most of the gully catchments allows runoff from all sides of slopes and the termination of drainage channels half way coupled with the poor roads and drains maintenance by the community and government have led to the development of large deep gullies at Ode-Irele, Akotogbo and Ajagba.

In the light of the above, since gullies result from the intensive scouring action of concentrated runoff, an effective mitigating measure is to reduce the velocity of the runoff and encourage infiltration. This can be achieved by encouraging the planting of cover grasses in the adjacent areas and in the spaces between buildings rather than cement paving which makes the ground more impervious.

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