Earth Sciences
2025, Vol. 14, No. 5, pp. 206-214
https://doi.org/10.11648/j.earth.20251405.14

Research Article

Spatial Assessment of Expansion of Gully Morphological Parameters Between 2013 and 2018 and Their Variations Across Land Covers of Upper Imo River Basin (UIRB) South Eastern Nigeria

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Abstract

The development of gully morphological parameters seems to vary with the land covers and lithology across the globe. This research analyzed the variations in morphological parameters of gullies across land covers and lithological units and investigated land cover change between 2003 and 2018. Eighteen gully locations were systematically selected based on land cover and lithology. Gully morphology parameters- length, Width, depth and Area were determined through standard field measurement and digital image analysis. Five major land covers identified in the study area between 2003 and 2018 shows substantial change in all of them. Greatest gain (6.99%) in land cover was observed in built up area, while the greatest loss (12.79%) was observed in farmland. Three out of the identified five lithological formations were affected by gully in UIRB. Coastal plain lithology was observed to be the most affected lithology as 71.83%, 78% and 79.29% of the gully length, width and area respectively are found in it. The mean gully length (0m, 28.9m, 337.89m, 345.88m and 269.00m), width (0m, 17.27m, 195.1m, 83.1m and 118.4m), depth (0m, 116.95m, 79.7m, 102.3m and110.3m) and area (0km^2, 0.80km^2, 0.82km^2, 24.17km^2 and 22.55km^2) respectively were distributed for water bodies, wetland, forest, farmland and built up areas. Gully morphological parameters were observed to vary across lithology and land covers of UIRB.

Keywords

Land Cover, Lithological Formation, Gully Morphological Parameter, Upper Imo River Basin

1. Introduction

Gully erosion is one of the most fatal geomorphic hazards in UIRB and globally that affects soils and land functions. The consequence of the interaction between human activities and the environment manifests in many ways. These manifestations can be seen in various environmental problems ravaging both the rural and urban environments especially in the developing countries. Among such environmental problems is gullying which is seen as one of the landscape processes which in no small measure contribute in shaping the earth's landscape [1]. This problem has identified in all

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Received: 10 July 2025; **Accepted:** 28 July 2025; **Published:** 28 October 2025

climatic zones where the resultant effect include the soil removal, production of sediments land deterioration and change in the morphology of the landscape [2, 3-7]. In gully development, a very significant role is played by man through the alteration of the vegetation cover [8]

Amangabara defined gully as the erosive process whereby runoff water concentrates in a narrow channel and cuts considerable amount of soil from the narrow channel over a short period of time [9]. Sidurchuk sees gully as a linear deep erosion feature with active head cut, unstable side walls, subject to mass movement, and non-graded longitudinal profile with temporal water flow [10]. Kaur et al sees gully as a continuous depression created from concentration of surface runoff under the influence of gravity which encourage the removal f earth material [11]. Possen and Govers defines gully as a steep sided channel, often with steeply sloping and actively eroding head scarp caused by erosion due to intermittent flow of water, usually during and immediately following heavy rain. From all these definitions, it is clear that gully represents depressions which are larger and more pronounced than rills, and once developed; it is difficult to be controlled by natural means or by normal tillage operations [12]. According to Egboka and Nwankwo, there are over 1,970 gully erosion sites in the humid tropics of Imo and Abia States of South eastern Nigeria [13]. Igbokwe et al reported 450, and Egboka estimated that there are over 2,500 active gully erosion sites in Imo state alone [14, 15]. Ofomata observed that over 1.6% of the entire land of Eastern Nigeria is occupied by gullies. Over the past forty decades, precisely about 1980, the notable gully locations in the region were the Agulu, Nanka, Oko in Aguata area of Anambra state, Isuikwuato and Ozuitem in Abia State and Orlu area in Imo state [16].

Strong relationship was found between geotechnical variables and land cover with gully development and formation in different parts of southeastern Nigeria. Wu and Cheng identified gully morphological features to include branching and length ratio, density, frequency, length, width, depth and cross sectional area, and these parameters have been found to vary across different land coves, climate, geology as well as human activities in various parts of the world [17]. Specifically, this study tends to document gully erosion within the Upper Imo River Basin by linking their appearance with local factors such as morphological and land-use characteristics. In the view of the above, this research aims at assessing the morphological parameters of gullies in UIRB with the view of investigating the spatial variation of gullies across land covers and lithological units. We identified and documented the land cover change in UIRB between 2003 and 2018.

2. Literature Review

There has been no systematic compilation as regards to the gully morphological features in a wide range environment, despite the fact that hydraulic geometry analysis of gully could contribute to explaining the process that acts on their development and also the mitigation measures and conservation practices [18]. Literature search reveals that the main morphological characteristics of gullies documented are length, width, depth and sometimes cross sectional areas.

Geochim et al in his research identified the following morphological features viz branching ratio and length ratio, gully density and gully frequency, and coefficient of main and attribute gullies [19]. Clear understanding of gully morphology is the first step in the evaluation of procedures and processes that initiate and develops gully [20]. It therefore follows that a systematic a systematic compilation of gully morphological features (example length, width, depth and area) and the controlling factors (example topography, land cover type, soil type, slope and hydrology) in a wide range of environment are necessary factors for gully erosion study [21].

Addis et al observed that classical statistics (minimum, maximum, range, standard deviation and coefficient of variation) can be used in the study and description in the variability in gully morphological characteristics [22]. The study results obtained on the morphological characteristics of gullies in North West Ethiopia is presented in Table 1

Table 1. *Summary of Descriptive Statistics of Selected Gully Morphological Parameters in North West Ethiopia*

Gully morphology	Min	Max	Range	Mean	S.D	SE (mean)	C.V
Length	25	2400	2375	373.78	412.01	51.91	1.10
Head cut depth	0.45	2.50	2.05	1.21	0.43	0.05	0.36
Depth (50% of gully length)	0.53	2.90	2.37	1.46	0.55	0.07	0.38
Lower depth	0.12	0.35	0.23	0.23	0.06	0.01	0.27
Head Cut width	0.80	3.00	2.20	1.33	0.41	0.05	0.31
Width (50% of gully length)	1.20	8.70	7.50	4.06	1.52	0.19	0.37

Gully morphology	Min	Max	Range	Mean	S.D	SE (mean)	C.V
Lower width	1.10	6.00	4.90	2.29	1.12	0.14	0.39

S.D: Standard Deviation; SE (mean): Standard Error of Mean; C.V: Coefficient of Variation
Source: [22]

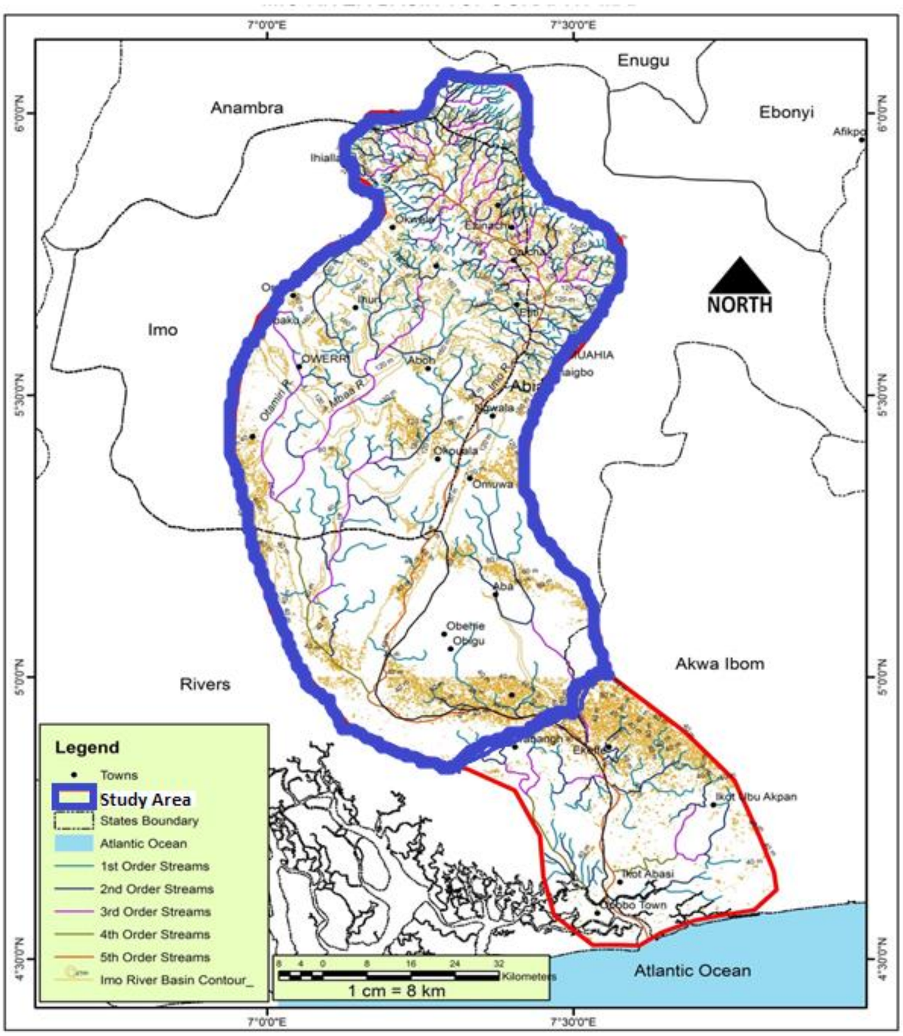


Figure 1. *Map of Imo River Basin showing Upper Imo River Basin.*

Cappa did a compilation of mean characteristics of gully morphological parameters in different parts of the globe and his findings identified gully length, width and depth [18]. From his findings, the mean cross sectional area of ephemeral gully system in Sicily was about $0.2m^2$; 90 percent of the sections measured showed an area below $0.5m^2$ [23, 24]. Some empirical studies that have been carried out on gully erosion includes the works of [25-29]. The works of Cappra et al was centred on 'Evaluating the Stability of Gully Walls in Agulu-Nanka- Oko gully erosion complex area of Anambra State, Nigeria' [26]. The result of their research indicated that for all the sites studied, the top stratum (laterite soil) possesses some cohesion, though little, whereas the substratum made of predominantly whitish grey sands possesses no cohesion. The studies of Avni and Nyesen et al reported that gully erosion has a greater impact on the faster depletion of soil moisture and ground water in arid and semi arid region [30, 31]. Possen et al reported that gully erosion causes severe damage to agricultural land and construction sites [32]. Savindra and Prakash estimated an alarming rate of gully erosion with an average soil loss of 2.35 million m^2 of agricultural soil per year at Jawa Block, Rewa district in Madhya Pradesh India. They also estimated that the affected area will increase by 50 percent in the next 50 years. Mansur and Muhammed results show that several parameters, including poor rangeland vegetation cover, overgrazing, human activities, intensive and short-period rainfall, improper land cover, improper irrigation design, improper discharge of water in the channels, and soil characteristics influence the gully erosion [34]. Gully erosion causes severe damage to agricultural lands, including soil loss, increase in surface runoff, lower soil water-holding capacity, lower quality and quantity of water, lower groundwater table, and lower agricultural production. Heimsat et al and NRW observed that gully erosion caused substantial damages to construction sites such as bridges, roads, and settlements as well as rivers and reservoirs and increased sediment concentration in rivers [35, 36].

3. Materials and Methods

3.1. The Study Area

Upper Imo River Basin (UIRB) is located in South Eastern Nigeria (see Figure 1). It cuts across three states – Imo, Abia and some parts of Rives. With an It is located within latitude $4^0$38N $-6^0$01N and longitude $6^0$40E – $8^0$00E of the Greenwich meridian and covers an area of about 8100km^2 (Figure 1).

3.2. Methodology

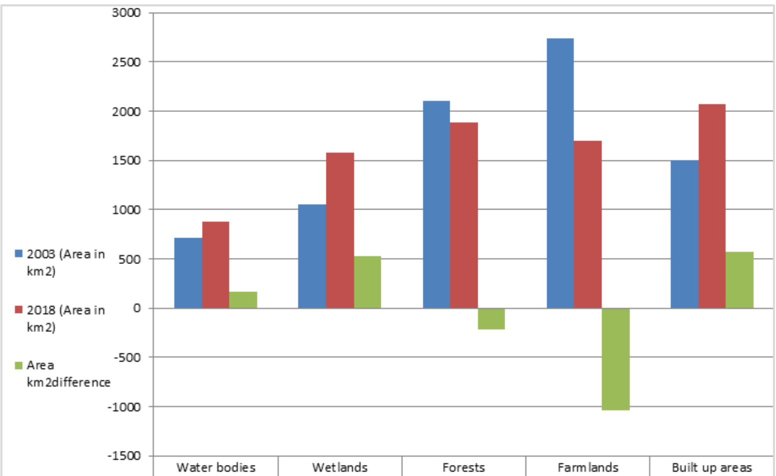
Field measurement was carried out to determine the morphological features of smaller gullies. The smaller gullies are OkohiaIsiama (OKI), UmudurugoObowo (UMO), AmuzuOkwuohia (AMZ), Umueze- Eziala – Obizi (UEO), AmakohiaOwerri (AMO), and Umueze 2 (UMZ). The morphological features were measured using measuring tapes with raging poles at 5m intervals following the procedures outlined by Ehiorobo and Audu (2012). Topographical map (Sheet 312) and satellite imagery (land sat ETM-30M resolution, obtained in 2003 and 2018 from USGS) were used to obtain the morphological features of larger gullies. The larger gullies are Aba 1 (AB1), Aba 2 (AB2), Umuduru (UMD), Okigwe (OKG), Emekuku (EME), Isiebu (ISB), New Owerri (NEO), AmainyiIhitteUboma (AMI), Nekede (NEK), Ibeku (IBE), Umuahia (UMU) and Isinweke (ISI). In general a total of eighteen gully locations were sampled for the study from the study area. The gully morphological features investigated are gully length, width depth and area and they were obtained through digital image analysis. These morphological variables were chosen because literature search reveals that the main morphological characteristics of gullies documented are length, width, depth and sometimes cross sectional areas (Cappa, 2013).

To classify the imageries into several land covers needed for the land cover analysis, the imageries were geo-referenced to WGS84 EPSG 4326. The outputs of the geo-referenced images were clipped according to the boundary of the study area, using the clip tool in the QGIS platform. A post classification comparison of the change detection techniques was utilized in order to detect the changes within 2003 and 2018. The classification of the images was carried out using ERDAS imagine pixel-based classification. The two (2) images were classified into different land cover types.

4. Results and Discussion of Research Findings

4.1. Land Cover Change Between 2003 and 2018

Five distinct land covers were identified in the study area in 2013 and 2018, and analysis showed a significant change in all the land covers between 2003 and 2018. The identified land covers are forest, built-up areas, farmland, wetland and water bodies.



	Water bodies	Wetlands	Forests	Farmlands	Built up areas
2003 (Area in km2)	710	1048.3	2105.5	2736	1500.2
2018 (Area in km2)	874	1576.3	1883.75	1700	2066
Area km2difference	164	528	-221.75	-1036	565.8

Figure 2. *Extent of Change in Land Cover between 2003 and 2018.*

The extent of change of the identified land cover in UIRB is presented in figure 2 Analysis of the information in figure 2 shows that five land covers were identified in the study area These identified land cover tallies with 3 out of the 5 identified land cover by Nwogu and Okeke (2018) in Nanka Gully location of Anambra State.

Analysis of the information in figure 2 showed that there were substantial changes in Land cover of the study area between 2003 and 2018. The land cover in the Upper Imo River Basin that experienced that highest gain was built up area. The built up areas in the basin in 2003 was 1500km^2 of the total area of 8100km^2. This value increases in 2018 to 2066km^2. This represents a gain of 565.8km^2 or a percentage gain of about 6.99%. The greatest loss in the land cover in the study area within the period was observed in farmland. There was a reduction of about 1036 km^2 of farmland or about 12.79% reduction from 2003 to 2018. These findings in some area agree with the findings in Nanka gully erosion where there is an increase in built-up area and reduction in vegetation cover but disagrees with the finding where vegetation cover has the highest area extent and there was a reduction in water bodies from 2003 to 2015 (Nwaogu and Okeke, 2018). The implication of the reduction in forest cover and increase in built up areas is that large area of the land has been exposed to various agents of erosion since the forest cover of the area has been removed. This makes the area more vulnerable to gully erosion. The implication of the reduction in forestland and increase in the built up area is that more vegetation cover in the study area will be removed thereby making the area more vulnerable to different degrees of erosion, since the protection which forest vegetation gives the soil of the area has been reduced (Ofomata, 2007, Okereke, et al 2013)

4.2. Variations Gully Morphological Parameters Across Land Covers

The information in Table 2 showed the descriptive statistics of the gully morphological and geotechnical variables under different land cover. From the table, the highest minimum gully length (99.9m) was observed to occur in built-up area while the least (60.2m) occur in the wetland land cover type. The gully width around the wetland regions was observed to be the least (18.58m) while gully width around forest regions has the highest mean value (that is, 195.06m). The least mean gully depth (85.5m) occur for the forest land cover while the largest mean gully depth (155.30m) occurs for the farmland. The high values of the gully morphological variables in the farmland and built-up area of the UIRB suggest that these two land cover types are seriously exposed to gully erosion.

Table 2. Summary of Descriptive Statistics of Gully Morphological Properties under Land Cover in UIRB.

Land Cover	Gully Morphological and Geotechnical Variables									
	Length (m)					Width (m)				
	M_1	M_2	M_3	Std.er	Stddev	M_1	M_2	M_3	Std.er	Stddev
Farmland	63.70	601.70	308.70	82.27	201.53	19.30	233.96	95.67	41.71	102.16
Built-up area	99.90	980.00	374.70	105.84	280.03	23.60	441.20	131.75	54.89	145.23
Wetland	60.20	506.10	283.15	222.95	315.30	15.90	18.58	17.24	1.34	1.90
Forest	65.80	609.98	337.89	272.09	384.79	4.30	385.81	195.06	190.76	269.77

Land Cover	Gully Morphological and Geotechnical Variables									
	Depth (m)					Area (km^2)				
	M_1	M_2	M_3	Std. Er	Stddev	M_1	M_2	M_3	Std.er	Stddev
Farmland	63.30	420.00	155.30	54.13	132.60	160.80	100000.00	27922.91	17822.93	43657.08
Built-up area	56.00	144.50	99.15	12.32	32.61	582.40	100000.00	22557.57	13829.02	36588.14
Wetland	92.50	141.00	116.75	24.25	34.29	62.01	1538.39	800.20	738.19	1043.96
Forest	76.00	95.00	85.50	9.50	13.44	15.80	1628.70	822.25	806.45	1140.49

M_1 = Minimum, M_2 = maximum, M_3 = mean, Std. er = standard Error, Stddev = Standard deviation

Variations in Gully Morphological Parameters across Lithological Units

Result of the examinations made on the analysis of the distribution of the cumulative sizes of the gully morphological features in various lithologies. Information obtained is presented in Table 3.

Table 3. *Cumulative Sizes of morphological Features in Various Lithologies.*

Lithological Formations	**Cumulative Sizes of Gully Morphological Properties**					
	Length (m)	**%**	**Width (m)**	**%**	**Area (km^2)**	**%**
False Bedded Sandstone	0.0	0.0	0.0	0.0	0.0	0.0
Lignite formation	1,157.27	18.93	447.98	21.5	67.07	20.31
Coastal plain Sand	4,390.18	71.83	1,625.26	78.00	261.91	79.29
Imo Clay Shale	0.0	0.0	0.0	0.0	0.0	0.0
BendeAmeki	565	9.24	10.5	0.5	1.32	0.40
Total	6,112.45	100	2083.74	100	330.30	100

Source: Author’s Fieldwork, 2018

A total length, width, and area of 6,112.45m, 2083.74m and 330.30 km^2 respectively were measured and calculated for all the sampled gully locations in the study area. Analysis of these values showed that out of the total length of 6,112.45m, 71.83 percent or 4,390.18m were found in only coastal plain sand leaving the remaining 28.17 percent found in lignite and Bende-Amekilithologies at the rate of 18.98 percent (1157.27m) and 9.24percent (565m) respectively. The same trend was also observed in the width and areas of these gullies in the various lithologies. For the width of the gullies, out of the total width of 2083.74m, 78 percent or 1,625.26m were located in the coastal plain sand lithological formation, while only 21.5 percent or 447.98m were found in lignite lithology and 0.5percent or 10.5m of the gully width found in the Bende-Ameki lithology. The total area covered by the sampled gullies was 330.30 km^2. Coastal plain sand lithology took 79.29 percent or 261.91 km^2 of the total area. Lignite lithology took 20.31percent or 67.07 km^2 of the total area while Bende-Ameki lithological formation contains only about 0.4 percent or only 1.32km^2 of the total areas covered by gully in UIRB. Given the above, it was concluded that the effect and intensity of gully erosion in UIRB is most severe in coastal plain sand, followed by Lignite lithological formation and least in Bende-Ameki lithological Formation of the study area.

Table 4 presents the summary of descriptive statistics of gully morphological parameters across lithological units. From the Table, the mean gully length, mean gully width, mean gully depth and mean gully area were observed to vary for coastal plain sand and lignite lithological formations. The mean gully length, width, depth, and area respectively for coastal plain lithology were 350.42m, 125.02m, 119.45m and 20.12 km^2, while their standard deviation respectively were 254.42m, 144.63m, 93.99m and 36.90 km^2 for the gully length, width, depth and area. For the lignite lithological formations, the mean gully length, width, depth and area were 290.44m, 73.90m, 119.38m, and 16.77 km^2, while their various standard deviations were 226.48m, 97.6m, 29.13m, and 3206 km^2 respectively. The mean gully length, width, depth and area values of 350.52, 125.02, 119.45m, and 20.12 km^2 respectively for coastal plain lithology was observed to be greater than the values from lignite lithology with respective mean values of 290.44m, 73.90m, 119.38m and 16.77 km^2 for gully length, width, depth and area. Information from the table also showed the standard deviation values for the variables of interest are also higher in coastal plain sand lithological formation than the lignite lithological formation.

A test of homogeneity for variance values for the variables to ascertain the level of disparities of gully morphological variables across land covers at 95% confidence interval shows no statistically significant difference in the variance values for the morphological variables. As such, the observations taken on gully length, gully width, gully depth and gully area for all the locations based on land cover types are assumed to be approximately the same across the gully locations. Further investigations on the disparity of the mean values for the variables were done using Analysis of Variance (Table 5). The values for these ANOVA were calculated at 95% confidence interval and the result also showed no significant variations for any of the variables (length, width, depth, and area).

Table 4. Summary of Descriptive Statistics of Gully Morphological Features across Lithological Formations in UIRB.

Variable	Lithological formation					
	Coastal plain sand			Lignite		
	Mean	Std. Error	Std. Deviation	Mean	Std. Error	Std. Deviation
Gully length (m)	350.42	70.56	254.42	290.44	113.24	226.48
Gully width (m)	125.02	40.11	144.63	73.90	48.80	97.60
Gully depth (m)	119.45	26.07	93.99	119.38	14.57	29.13
Gully area (km^2)	20123.79	10232.71	36894.56	16769.00	16028.74	32057.48

Table 5. Spatial variation of morphological and geotechnical variables across land covers of UIRB.

		Sum of Sq	Df	Mean Square	F	Sig.
Length (m)	Between Groups	20550.57	3.	6850.19	0.097	0.960
	Within Groups	921059.75	13	.70850.75		
	Total	941610.3	16			
Width (m)	Between Groups	36070.326	3	12023.442	0.621	0.614**
	Within Groups	251515.161	13	19347.320		
	Total	278585.487	16			
Depth (m)	Between Groups	12916.556	3	4305.519	0.585	0.635**
	Within Groups	95644.602	16	7357.277		
	Total	108451.158	16			
Area (km^2)	Between Groups	1887728688	3	62924896.1	0.466	.0.711**
	Within Groups	175600000	13	1351095724.0		
	Total	1945000000	16			

5. Conclusion

Specifically, the Upper Imo River basin in its entirety transverses some parts of two states in South Eastern Nigeria, namely Imo and Abia. The area consists of Basement Complex Rock of Precambrain age and is underlain by five lithological compositions – false bedded sandstone, lignite, Imo Clay Shale, lignite and Coastal Plain Sand. In the UIRB, five different land covers were identifiable, and analysis made on them showed changes in each of the land cover, with some experiencing gain and others experiencing loss in their area. Water bodies, wetland and built up areas experienced gain with the percentage gain of 6.99%, 6.52% and 2.02% respectively. Annual mean gain for these land covers were 37.7km^2, 35.2km^2 and 10.9km^2 respectively. Loss in land cover was experienced in forest and farmland with percentage loss of 2.99% and 2.74% respectively, and these values represents an annual loss of 69.1km^2 and 14.8km^2 respectively. Assessment of the gully morphological variables (length, width, depth and area), showed the average values for these variables to be as follows: built up area (361.3m, 18.4m, 110.3m and 22.6km^2), farmland (344.9m, 83.1m, 102.3m and 24.2km^2,); forest (336.4m, 195.1m, 79.7m and 0.82m^2); and wetland (283.5m, 17.27m, 116.95m, and 0.80km^2) respectively for gully length, width, depth and area. These values are large compared to gully morphological features obtained under land cover across some parts of the globe.

Gully morphological parameters in this research were observed to vary across the various lithological units of the study area. Three lithological compositions were identified to be affected by gullying in UIRB. Lithological field studies in South Eastern Nigeria revealed that gullying remained active over lithological landscape. Gully intensity in UIRB was revealed to be highest in the coastal plain sand lithological composition, and least in Bende-Ameki lithology. The data obtained showed that the length, width, depth and area together with their percentages are highest in the coastal plain sand lithology. The result obtained showed that of the total gully length of 6,112.45m in UIRB, 4,390.18 (71.83%) were in coastal plain sand lithology, 1,157.27m (18.93%) were in lignite lithology, while 565m (9.24%) were in Bende-Ameki lithology.

Author Contributions

Chibo Christian Nnamdi: Conceptualization, Data curation, Formal Analysis, Methodology, Resources, Writing – original draft

Olutoyin A. Fashae: Investigation, Supervision, Validation, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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