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Development of Gully Morphological Features and Soil Loss under Land Covers (LC) of Upper Imo River Basin (UIRB), South Eastern Nigeria

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ABSTRACT

In UIRB and globally, gully erosion is one of the most visible environmental and geomorphic hazards, which limits the maximum function of soils and landscape. Gully initiation and development increases runoff, soil loss, flooding and aids sedimentation. This research investigated and examined the gully morphological features and soil loss under various land covers of UIRB. It examined land cover change between 2008 and 2023; assessed the gullies under various land covers of the study area, analyzed the morphological features of the sampled gullies under land cover of the study area, and quantified the amount of soil loss resulting from gully erosion in various land covers. Landsat 8 and topographical maps was processed to identify the extent of the UIRB boundary. Eighteen gully sites were systematically selected considering the land cover of UIRB. Both primary and secondary data were was utilized in the research. Primary data are gully length, width, depth area, volume and slope gradient. The data was generated by field measurement and Digital Image Analysis (DIA) of the Landsat image of 2008 and 2023. The morphological properties obtained through measurement are the gully length, width and depth, while the gully areas, and soil loss were derived. The research identified five land covers in the study area between 2008 and 2023. All the identified land covers showed a well-observed change (gain/loss) within the time of study. The built-up area with 6.99% gain e showed the greatest gain in LC, while farmland with 12.79% loss indicated the highest loss in LC. Assessment done on the gullies in various LCs showed that none of the gullies in UIRB originated from water bodies. Built up areas and farmland has the greatest number of gullies found in them, containing 77.8% (39.8% each) of all the gullies in the study area. Built up areas and farmland are the two land covers that experience greatest attack of gully erosion with 22.55km^2 and 24.17km^2 respectively. Wetland has the least land (0.8km^2) attacked by gully erosion in the study area. The greatest gully spread was observed in farmland with 28.1% spread while the least spread was observed in wetland and water bodies (12.3% each). Soil loss computed in various land covers showed that the greatest soil loss was observed in forest cover (39%), built-up area (35%) loss, and the least soil loss was observed in wetland cover

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(4%). Gully morphological parameters were observed to vary across land covers of the study area, with built-up area and farmland being mostly under gully attack and forest cover and built-up areas being the covers with greatest soil loss in UIRB.

Keywords: Upper Imo River Basin, Morphological, Soil Loss, Land Cover

1. INTRODUCTION

Gully erosion is observed almost everywhere in Nigeria, and has been reported in almost all states of the country (Oparaku et al., 2014). It is an erosive process that contribute with other processes contribute to shape the earth's surface (Chibo and Fashae, 2023). All the countries of the globe annually, about 6 million hectares of land are lost to land degradation related to soil erosion. By implication, it is suggestive that gully erosion and its methods of control is everyone's business, be it an environmentalists, individuals, communities, and governments (Iorkua, 1999), because it is one of the most visible forms of accelerated erosion which occurs under widely different climates, geologic and land use conditions (Bocco et al., 1990, Udosen, 1991, Osadebe et al., 2014). The incidence of soil erosion especially gully erosion is not new, as it has formed a subject for serious consideration since the beginning of the 20th century (Ofomata, 2007). Various aspects of the phenomenon have been studied, and attempts made to identify the factors and processes, as well as describe their morphology (Ologe, 1988, Ofomata, 1991, Faniran and Areola, 1974, Jeje, 1988, Igwe et al., 2012). Most of the reports in the literature on gully erosion in Nigeria came from Eastern states, and researches show that population density, high relief, steep slopes, deforestation, infrastructure development, humid tropical climate and deeply weathered friable sandstones and shale, combine to predispose the soil to rapid process of gulling.

Gullying is one of the important processes, which largely contribute in shaping the earth's landscape. The development of gully is associated with many negative impacts, and in some cases, it involves loss of soil, and the deposition of a great amount of soil in other cases (Billi and Dramis, 2001). For many parts of South-Eastern Nigeria, the loss of soil due to gully, often resulted in the depletion of natural resources. Moreover, the formation of gullies implies an alteration of overland flow, the shortening of runoff lag time, and an increase in runoff volume. Once a gully is initiated, it continues to develop, and this process is seldom inverted or halted naturally. The outcome a substantial damage in the economy, and may represent a relevant constraint to the development of poor countries.

For gully to develop, a very significant role is played by man, through the disturbance of the forest (Okereke et al., 2013). Vegetation removal through logging, and expansion of crop land, in the humid tropics, or overgrazing in semi-arid areas, favors gully erosion development. Generally, a sparse vegetation cover results to a diminishing boundary roughness, and this opposes a reduced overland flow. The erosive capability of runoff therefore increased, while a deficit of organic matter in the soil, decreases its aggregate stability. Unless the causes of gully formation and development is identified, any effort at designing countermeasures to gully control may be frustrated. Probably, gullies are initiated, and developed through different concurrent factors, though we can agree with Fashae et al., (2022), that in all cases, runoff response, and sediment transport, on slopes plays an important role in gully formation.

Gully as the erosive process, whereby runoff water concentrates in a narrow channel, and removes a sizeable amount of soil from the narrow channel over a short period of time. Moreover, gully as a linear, deep erosion feature with active head cut, unstable side walls, subject to mass movement, with a non graded longitudinal profile, containing a temporal water flow. Gully as a continuous depression, created from concentration of surface runoff, under the influence of gravity, and this encourages the removal of earth material. Gully erosion as a channel with steep sides, often with steeply sloping and actively eroding head scarp, caused by erosion due to intermittent flow of water, observed during, and immediately after heavy rains. From all these definitions, it is clear that gully represents depressions which are larger, and more pronounced than rills. Once gully develops, it is difficult to be controlled by natural means, or by normal tillage operations.

Apper (2007), defines river basin, or drainage basin, as topographic region through which streams receives runoff, thorough flow, and ground water. According to Maria (2007), drainage basin is a region of the land, where water from rain, drain downhill into a body of water, such as lakes, dams, estuary, sea or ocean. It is an area of land drained by a river, and its tributaries, whose boundary is separated by a ridge, or highland, called a watershed, or basin divide. It is an area of the land that drains water, sediments and dissolved materials to a common outlet (Obeta, 2017). The number, shape and size of drainage basin found on the earth, vary widely (Obeta, 2010). The river basin consists of streams, and land, on which stream flows. A major river basin is made up of smaller river basins, which also consist of even smaller basins, each divided into specific watershed (Goldstein et al., 2007).

Naturally, erosion occurs primarily on geologic time scale, but man's activities on the landscape alters it, thereby greatly accelerating erosion processes (Chibo & Fashae, 2026). Most of the visible landscape observed on the Earth's surface today, has been the result of erosion by the action of water. Erosion, by the action of water has produced some of the most spectacular landscapes we know. The type of erosion that inspires fear among the people in the southeastern part of Nigeria, is gully erosion. Gully erosion can simply be seen as the erosion process, whereby runoff water accumulates in narrow channels, and removes considerable amount of soil from this narrow channel over a short time period. According to Iro (2020a), gully erosion is 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, while gully as a steep-sided channel, often with steeply sloping, and actively eroding head scarp, caused by erosion due to the intermittent flow of water, usually during and immediately following heavy rains.

While gully erosion is not a new phenomenon by any means, its importance has, however, gained more attention lately. Recent studies indicate that gully erosion represents an important sediment source in different environments, and are effective links for transferring runoff, and sediments from upland to valley bottoms, and permanent channel, where they aggravate off-site effects of water erosion. Unfortunately, the impacts of gully erosion are largely limited to developing countries than in industrialized countries, and it is often as a result of the lack of financial, technical, and institutional capacity. For example in the southeast of Nigeria, gully erosion is largely responsible for the destruction of transportation and communication systems, degradation of arable land, contamination of water supply, isolation of settlements and migration of communities (Egboka & Nwankwo, 1984; Iro, 2020b; Chibo and Fashae, 2025).

Recently, channels in some parts of the Upper Imo River Basin, were observed to have developed into valleys, resulting to loss of soil in the affected places. These channels eroded into red earth and unconsolidated materials, subjecting the area to gullies with near vertical slopes. Increased erosion activities around the early gullies have continued to expand these gullies into a complex system. Most of the gullies, especially those with high water discharge values are now of canyon proportion, and constitutes the most threatening environmental hazard within the basin. This environmental is experienced in many urban and rural settlements, like Owerri, Okigwe, Umuahia, Nekede, Ihitte Uboma, etc. (Acholonu, 2008).

The destructive effects of gully erosion in UIRB, is not only an annual washing away of the soil, and nutrients. It decreases the productivity of the soil and yield from food crops, and also causes to lives and properties of the people around the gully sites (Chibo, 2022). Gully erosion problems needs to be critically studied, and appropriate control measures, and structures sited at the right places, for various stages of gully development. There is a general consensus among gully erosion scholars, concluding that land use and land cover of an area, is an important factor to gully erosion development. There are land covers that promote the development of gully erosion faster than the other. For instance, land cover that encourages the growth of vegetation will discourages the growth and expansion of gully, while those that promotes the removal of vegetation, will encourages the growth and development of gully erosion. At this stage, the research will examine the land cover of the study area, with the view of establishing the relationship between the land cover and gully erosion development.

Gully development varies according to land use and land cover of an area. Gully erosion has been observed in various places. There is scarcity of research work, that have attempted to identify the location of gullies in various land covers of the UIRB. This research identified the locations of gully erosions in various types of land cover of the Upper Imo River Basin. This result identified the land cover types, that encouraged gully erosion most in the study area.

The aim of the research is access the development of gully morphological features, and soil loss under various land covers, to determine how different land covers are affected by gully erosion. The study examines the land cover of UIRB; investigates changes in the land cover of the study area between 2008 and 2023; assesses the gullies under various land covers; analyzes the morphological features of the sampled gullies under land covers; and, examines the amount of Soil Loss in various land covers which resulted from gully erosion.

2. THE STUDY AREA AND RESEARCH METHODS

This study was conducted in the upper Imo River Basin, South-Eastern Nigeria (see figure 1). The study focused on sampled gullied basins of the study area. The Imo River basin is found within a latitude of 4^0 38N − 6^0 01N and a longitude of 6^0 40E – 8^0 00E of the Greenwich meridian and covers an area of about 8100km^2.

The Imo River is the principal (major) river that drains the basin. The river rises from the cretaceous formation, flows though Imo clay, before it flows on coastal plain sand. It moves from North to South of Imo state, and has total a length of about 240km (Figure 1). The source of Imo River is from Nneochi, in Umunneochi Local government area of Abia state, Nigeria. The estuary of the river is around 240 kilometers wide, and the river has an annual discharge of 4 cubic kilometers with 26,000 hectares of wetland. The basin consists of about 529 stream channels of five different stream orders (figure 1). There are 369 first-order streams, 112 second-order streams, 37 third-order streams, 10 fourh order-streams, and 1 fifth order-streams

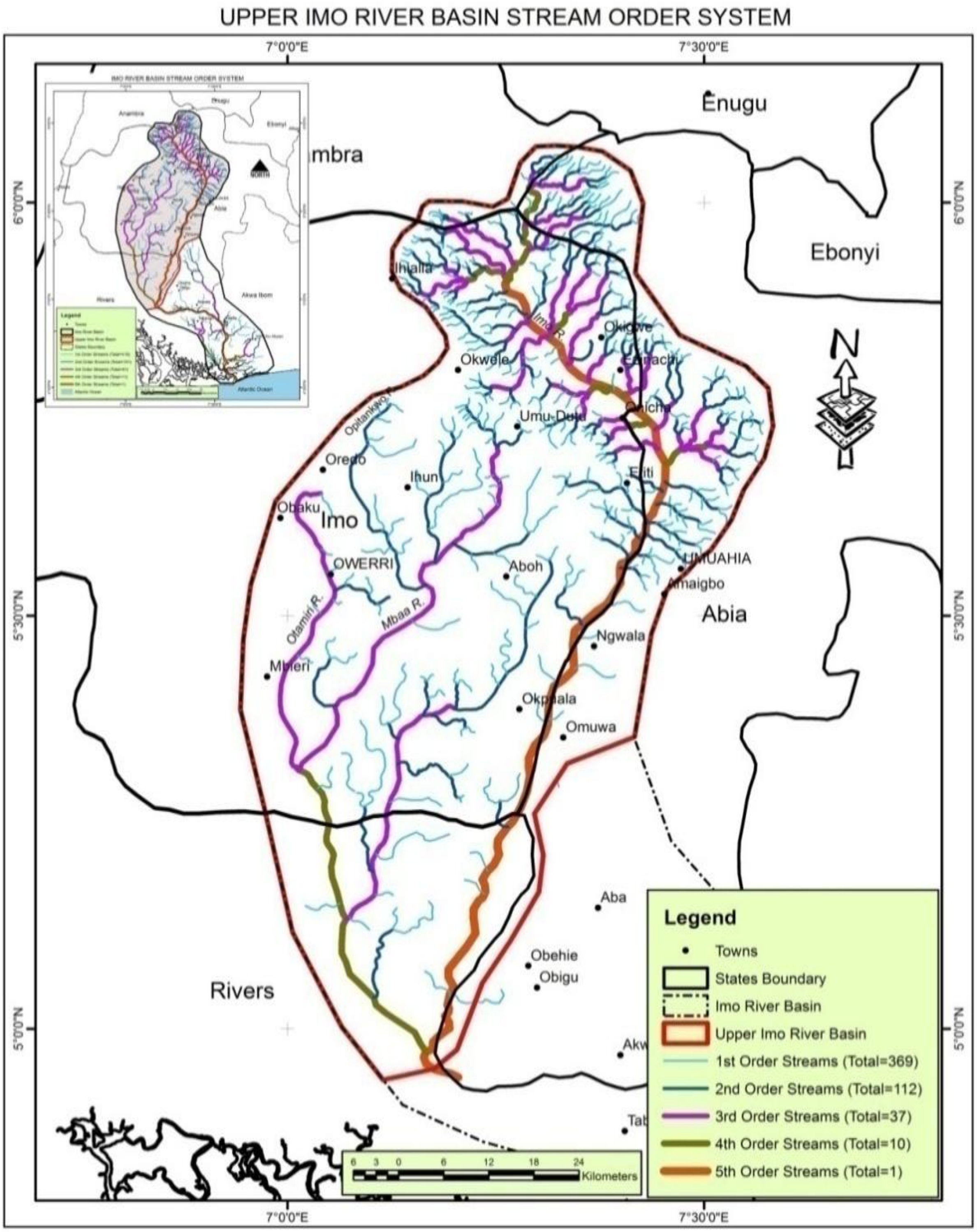

Figure 1. Stream order Map of Upper Imo River Basin

The Imo River Basin is covered by a bedrock of a sequence of sedimentary rocks of about 5480m thick, and with ages ranging from upper cretaceous to recent. Generally, there are two geological formations that underlie the Basin. The Coastal Plain Sands, which consist about 80 percent of the basin, is made UP of non-indurated sediments. The second formation, which constitutes the remaining

20 percent, is underlain by a series of sedimentary rocks. Generally, the geology of the upper Imo river basin is clasified into four formations, namely – lignite, Imo Clay-shale/Bende Ameki formation, False bedded sandstone and Coastal plain sand. The stratigraphic sequence of the geology of the study area is seen in Table 1.

Table 1. stratigraphic Sequence of the Study Area

Age	Formation	Lithology
Miocene – Recent	False Bedded Sandstone	Medium coarse drained poorly consolidated sand with clay lenses and strings
Oligocene	Bende – Ameki	Clay sandstone sandy clay stone. Sandstone intercalated with Shale and coal beds.
Miocene	Imo Clay Shale	Laminated, clayey shale
Eocene	Lignite	Consolidated sands with lignite seams at various layers.
Paleocene	Coastal Plain sand	Clayey sandstone, and sandy clay stones

The area lies within the tropical monsoon (AM) climate, based on Koppen's classification. In nearly all counts, the area is endowed with water resources from rainfall. The mean annual rainfall ranges from 2250mm to 2500mm, in areas lying between 5°40'N to 5°49'N. This decreases to mean annual value of 2000mm to 2250mm for areas between 5°49'N to 5°55'N, and further inland i.e. areas lying between 5°55'N to 6°03'N, the mean annual value decreased to 1750mm – 2000mm. An important feature of the rainfall, is its seasonal distribution. This is closely associated with movement of inter-tropical convergence zone (ITCZ), and precipitation resulting from conventional storm. The information in Table 2 shows the rainfall data of the study area from 2015 to 2024.

Table 2. Rainfall Data in mm of the Study Area from 2015 to 2025

	2015	2016	2017	2023	2019	2020	2021	2022	2023	2024
Jan.	0.0	0.0	33.0	0.0	0.0	59.3	2.5	20.7	0.0	36.0
Feb.	23.2	51.1	36.0	131.9	90.9	56.5	0.0	208.9	0.0	0.2
Mar.	86.6	94.7	36.2	75.0	55.3	83.2	157.0	26.1	266.6	152.2
Apr.	240.3	138.9	125.5	99.2	187.4	198.7	102.7	108.9	129.3	91.6
May.	309.6	239.0	282.0	413.3	306.1	330.7	308.2	252.9	277.8	167.5
Jun.	280.9	142.1	207.7	196.8	518.5	185.8	142.3	369.8	324.9	313.5
Jul.	580.4	291.7	86.1	289.5	516.0	263.1	288.7	184.7	265.1	201.2
Aug.	377.2	274.0	318.4	465.8	367.7	243.6	173.8	440.7	308.3	367.7
Sept	300.7	527.9	328.2	283.8	493.9	254.2	432.7	544.1	312.8	550.6
Oct.	244.9	214.9	398.8	257.9	211.8	159.9	236.2	345.6	273.4	164.9
Nov	26.4	88.3	108.6	69.8	86.2	56.5	163.1	37.2	4.5	8.7
Dec.	0.0	30.2	0.0	130.0	0.0	84.1	17.7	0.0	4.1	3.4
Tot.	2189.3	2146.8	1960.5	2413	2833.8	1975.6	2024.9	2539.6	2166.8	2057.5
Min.	23.2	30.2	33.0	69.8	55.3	56.5	2.5	20.7	4.1	0.2
Max.	580.4	527.9	398.8	465.8	518.5	330.7	432.7	544.1	324.9	550.6
mean	182.4	178.1	163.4	201.8	236.2	164.6	168.7	211.6	180.6	171.5

Source: Anambra Imo River Basin Development Authority, 2024

Methodology

A reconnaissance survey was first carried out, to acquaint the researchers with the existing physical features of the study area. This helps for an efficient classification process before proper data collection. The reconnaissance survey was carried out in 2021, and a detailed field survey, on the sampled locations and gully sites was done from 2022 till early 2024. Both primary and secondary data was used in the research. The primary data are gully length, width, depth, area, volume and slope gradient. These data were generated from field measurement, and Digital Image Analysis (DIA) of Landsat imagery obtained for 2008 and 2023. Field measurement were used to assess the morphological parameters of smaller gullies, at the early and initial stages of development. The procedure involves, the measurement of the morphological parameters of the sampled gullies in the various Land covers. Field equipments used are, the measuring tapes, and ranging poles. Due to visibility problems, the gully morphological parameters were measured at a 10 cm interval. The morphological properties measured are, the gully length, width and depth, while the gully areas were derived. Secondary data sources used are classified into two. They are Maps, and aerial photographs (satellite imagery). The maps were obtained from federal Ministry of Lands Abuja, and the satellite imagery (Landsat 8) was obtained from United States Geological Survey (USGS) Department. Maps and satellite imagery were processed to generate morphological data, for larger gullies.

The satellite imageries, and topographic map were analyzed, and the various land covers, and the gully morphological properties were determined and extracted. The Landsat 8 imagery was obtained at two different periods (2008 and 2023). These two periods was considered, because they are the years the Landsat 8, was able to identify the gully developments. The attributes of the satellite imageries obtained from the *ESRI Landsat unlock – earths - secrets Platform* is presented in Table 3.

Table 3. Attributes of acquired satellite imageries

	Data Type	Year of Acquisition	Resolution	Source	Month of Acquisition
1.	Landsat image	2008	30m ETM+	*USSG*	December
2.	Landsat Image	2023	76m ETM+	*USSG*	December

The imageries acquired, are classified into different land covers. To classify the imageries into several land covers, for the land cover analysis, geo-referencing was done. Geo-referencing was done, because the internal coordinate of the imageries compared to real ground coordinate, are not the same. 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 2008 and 2023. The classification of the images was carried out, using ERDAS Imagine pixel-based classification. An unsupervised classification was done. The two (2) images were classified into different land cover types. This method of classification, involves the procedure of identifying pixels possessing the same spectral features automatically (Wakirwa, 2015). The classified raster output was converted to vector (polygons), to allow for measurements to be done. The areas coverage of each of the LC (Land Cover) classes, were measured (in Square Kilometers [sqkm], for each of the years under consideration, using the export geometry tool in QGIS platform. A comparison of the land cover statistics assists in identifying the change in percentage, trend, and rate of change in UIRB over the periods of 2008 and 2023.

3. RESULTS & DISCUSSION

Land Covers in Imo River Basin

The result of the analysis carried out on the satellite imagery of Imo river basin, showed that the area consists of five different land covers (LC). The identified five have changed over the period under study, leading to increase in area of some of the land covers, and decrease in area of others. These changes in land cover have helped to trigger a major environmental hazard (gully) in the study area. The various land cover (LC) types identified are generalized into five classes, as presented in Table 4. The result of the sizes of the identified land covers is seen in Table 5.

Table 4. Land Cover classification scheme adopted in the study Area

S/N	Land Use Category	Description
1	Built Up Area	These areas consist of man modified environments, such as buildings, dams, roads, and other structures modified by man.
2	Wetlands	These areas consist of marshlands, swamps, or saturated land.

3	Farm Land	These areas consist of lands that are used for agrarian activities, consisting mostly of secondary vegetation.
4	Water bodies	These areas consist of rivers, streams, and lakes.
5	Forest	Pristine and untouched vegetation, which is mostly primary growth

Source: Authors Digital Image Analysis 2024

Table 5. Area of Land Cover in the Study Area in 2008 and 2023

Land Cover	Area (km²)			
	2008	Percentage	2023	Percentage
Water bodies	710	8.77	874	10.79
Wetlands	1048.3	12.94	1576.3	19.46
Forests	2105.5	25.99	1883.75	23.26
Farm lands	2736	33.78	1700	20.99
Built-up area	1500.2	18.52	2066	25.51
Total	8100	100	8100	100

Source: Author's Digital Image Analysis 2024

The information in Table 5, shows that the total area of Imo River Basin was 8100 square kilometers. In 2008, farmland covered the largest part of the basin, with a 2736 of square kilometers, representing 33.78% of the total land area. Next in terms of the area covered, is forest cover. Forest covered 2105.5 km^2, representing 25.99 percent of the total area. Built-up areas covered 1500.2 km^2 of LC, representing 18.52 percent of the total land area of the basin. The remaining 1858.3 square kilometers of the land cover of the Imo River basin, is covered with wetlands and water bodies, each representing 1048.3 km^2, and 710 km^2 respectively.

In 2023, there is a noticeable change in the area covered by the various land covers in the study area. Built-up areas constituted the largest area of land cover in UIRB. Built up area covered 2066 km^2 (25.51%), of the total area of Imo River Basin. There is a decrease in area covered by forest between 2008 and 2023. Forest covered an area of 1883.75km^2 or 23.26 percent of the land area of Imo River Basin, and farmland in 2023, covered 1700km2 or 20.99 percent of the study area. Other values of areas covered are 1573.3 km^2 (19.46%) for wetlands, and 874km^2 (10.79%) for water bodies.

Changes in Land Cover of Imo River Basin between 2008 and 2023

The land cover of an area determines the rate, and extent to which various types of erosion develop and expand. The information in Table 6 indicates the extent of change in the land covers of the study area from 2008 to 2023.

Table 6. Extent of Change in Land Cover of the Study Area

Land Cover	Area (km²)		Area (km²) difference	Percentage (%)		% difference	Mean Annual Loss/Gain
	2008	2023		2008	2023		
Water bodies	710	874	164	8.77	10.79	2.02	10.9
Wetland	1048.3	1576.3	528	12.94	19.46	6.52	35.2
Forest	2105.5	1883.75	-221.75	25.99	23.26	-2.74	- 14.8
Farmland	2736	1700	-1036	33.78	20.99	-12.79	- 69.1
Built up area	1500.2	2066	565.8	18.52	25.51	6.99	37.7
Total	8100	8100		100	100		

Source: Author's Fieldwork, 2024

As evident in Table 6, there is a substantial change in Land Cover of the study area between 2008 and 2023. Two land cover of the study area, experienced loss in the land area covered, they are forest cover and farmland. Three of the land covers experienced a gain in the land area covered, and they are water bodies, wetland areas, and built-up areas. The extent of change varies from one cover to another. For water bodies there is a gain from 710 km^2 in 2008 to 874 km^2 in 2023. This represents a gain of 164 km^2, or about 2.02% increase, translating to an annual gain of 10.9 km^2/year. In summary, it shows water bodies gained about 2.02 percent of the total Land Cover of the study area, from 2008 to 2023. For wetlands, there was also a substantial gain from 1048.3 km^2, in 2008 to1574 km^2 in 2023, representing an increase of 528 km^2 or 6.52 percentage increases. The result showed that wetland has a yearly gain of 35.2 m^2, within the periods under study. The result also showed that, wetlands gained about 6.52% of the LC change in UIRB between 2008, and 2023. There is a reduction in the areas covered by forest in the Imo River Basin between 2008, and 2023. In 2008, the area covered by forest was 2105.5km^2, and the area reduce to 1883.78km^2 in 2023. The result revealed, that there is a 221.75km^2 of forest cover lost to other LC in the study area. On annual basis, 14.8 km2 of was lost between 2008, and 2023 in the UIRB. The loss represents a 2.24% loss in forest cover of the Imo River Basin between 2008, and 2023. Another LC that experiences serious loss in the study area is farmland areas. There is a reduction of 1036 km^2 of the farmland, or about 12.79% reduction from 2008 to 2023. The built-up areas in Imo River basin in 2008 was 1500km^2, out of the total area of 8100km^2. This value increased in 2023, to 2066km^2, representing a gain of 565.8km^2 of the land cover, or a percentage gain of about 6.99%. By implication, the reduction in forest cover, and increase in built-up areas, is that large area of the land is exposed to various agents of erosion, since the vegetation cover of the area have been removed, and this, makes the area vulnerable to gully erosion attack.

Gully Assessment Under different Land Covers in Upper Imo River Basin in 2023

Gully assessment in various land cover, helps to provide the required information on the status of gullies in various land covers. To assess various gullies under various land cover, the land cover that contains the largest part of the gully area, is taken as the land cover where the gully is situated. Information on the gully assessment is seen in Table 7.

Table 7. Gully Assessments under Various Land Cover in UIRB in 2023

Land cover	Area (km^2)	No. of gully	Av. Gully Length (m^2)	Av. Gully Width (m^2)	Av. Gully Depth (m^2)	Av. Gully Area (m^2)	Gully Density	Soil Loss (m^2)
Water bodies	874	0	0	0	0	0	0	0
Wetland	1576.3	2	283.5	17.27	116.95	800.2	0.13	537,198.4
Forest	1883.75	2	336.4	195.1	79.7	821.9	0.12	5,230,841.7
Farmland	1700	7	344.9	83.1	102.3	24,165.1	0.41	2,932,039.7
Built up area	2066	7	360.31	118.4	110.3	22,549.9	0.34	4,705,475.7
Total	8100	18	1355.11	413.87	424.6	48,337.1	1.00	13,405,553.5

Source: Author's Fieldwork, 2024

Analysis of the information in Table 7, shows that none of the gullies originated from water bodies. The gullies that were found in the water bodies, were a result of encroachment from other land covers. This means that none of the sampled gullies has its head located in the water bodies. As revealed, the water bodies covered an area of 874 square kilometers, the calculated average length, width, depth, area, and the densities of gullies, were all zero. Built-up area, and farm lands, are the land covers with the greatest gully locations, and both contain 14 (7 each), of the 18 gullies sampled for this study. This imply that these land covers, contain 77.8 percent of the gullies in the study area. In terms of density, both land uses has the highest gully density as the density of gullies in farmland was 0.41, while gully density in the built up areas was 0.34. By implication, this mean that gullies in the farmlands are closely spaced together, than gullies in the built-up areas, and other land uses UIRB. The result also showed that farmland, is the most vulnerable to gully, followed by built up areas. The land cover with the least gully density in the study area is forested areas. This land use has a gully density of 0.12, implying that forested areas are not easily vulnerable to gully attack.

Farmlands and built-up areas are the land covers, mostly attacked by gully erosion, as can be observed in the gully area, length, width, and depth. For the gully area, farmlands has the highest area (24,165.1m^2), followed closely by built-up area (22,549.9m^2), then forest (821.9m^2), and the least land cover affected by the gully, is wetland (800.2m^2). It is only in the depth, where the vulnerability of gully is highest in the wetlands. It exposed the power of water, as a factor of soil erosion. From Table 7, the average depth of gullies in the study area, is highest in the wetland. The reason might not be unconnected with the fact that, water always available in this area have made the soil vulnerable to erosion. Every other gully morphological values in the study area was the least in the wetland, except the gully depth. This can lead to the conclusion, that wetlands are not easily prone to gully erosion, and it can be attributed to a very little human activities observed in the land cover.

A total of 13,405,553.5 m^2 of soil was lost to gully erosion in UIRB, between 2008 and 2023. 5,230,841.7 m^2 of soil, was lost in forest cover. This showed that about 39% of the soil loss in UIRB, was in forest cover. 35% of the total soil loss was observed in built-up area, translating to 4,705,475.7 m^2 of soil loss, between 2008 and 2023. Water bodies in the area do not experience any soil loss, because, no gully site was found to develop in the land cover, and wetland has the least quantity (4%) of soil loss in the area.

Analysis of the Sizes of Gully Morphological Features under Land Cover in the Study Area

The information in Table 8, shows the summary of descriptive statistics of gully morphological properties under land cover in UIRB. From the Table 8, the length of the gullies across land cover ranges between 60.2 m and 980 m. The figure proved, that all the land covers in UIRB had gullies of massive length. The highest (maximum) gully length (980m) was observed to occur in built-up area. The revelation is that in the UIRB, the gullies expands fastest in the built-up area. It can be as a result of the massive human activities taking place in the built-up areas of the study area. The least gully length (60.2m), was found in the wetland LC. Built-up area also has the highest mean gully length (374.7 m), while the least mean gully length (285.15), was identified in the wetland area. The least gully width identified across the land covers was 4.30m, was found in the forest cover, while the highest gully width in the land covers of UIRB was 441.20m, and was found in the built- up area. The highest mean gully width across the land covers was 195.06 m. The value was found in the forest LC, and the least mean gully width was 95.67 m, and this was found in the farmland. The maximum gully depth seen in table 8, was 420 m, and the depth was found the in the farmland, while the least (minimum) gully depth across the land covers was 56 m, and was found in the built-up area. It was revealed that the least mean gully depth (85.5 m), was identified in the forest land cover, while the highest mean gully depth (155.30 m), was identified in the farmland land cover. For land area affected by the gullies across the land covers of UIRB, two land covers was identified with largest area affected. They are the farmland and he built-up area. The highest gully area identified in the land covers of the UIRB was 100,000 m^2 (100 km^2). The least gully area in the UIRB was 15.8 m^2, and this was seen in forest cover. The least mean gully area across the land cover was 800.2 m^2, and this was seen in the wetland, while the highest mean gully area (27,922.91 m^2) was found in the farmland.

In conclusion, the greatest intensity and magnitude of gully erosion in UIRB, was seen in the built-up area, followed by farmland, wetland, and the least was observed in the forest areas.

Table 8. Summary of Descriptive Statistics of Gully Morphological Properties under Land Cover in UIRB

Land Cover	Gully Morphological Properties																			
	Length					Width					Depth					Area				
	M_1	M_2	M_3	Std.er	Std dev	M_1	M_2	M_3	Std.er	Std dev	M_1	M_2	M_3	Std. er	Std dev	M_1	M_2	M_3	Std.er	Std dev
Farmland	63.70	601.70	308.70	82.27	201.53	19.30	233.96	95.67	41.71	102.16	63.30	420.00	155.30	54.13	132.60	160.80	100000.00	27922.91	17822.93	43657.08
Built-up area	99.90	980.00	374.70	105.84	280.03	23.60	441.20	131.75	54.89	145.23	56.00	144.50	99.15	12.32	32.61	582.40	100000.00	22557.57	13829.02	36588.14
Wetland	60.20	506.10	283.15	222.95	315.30	15.90	18.58	17.24	1.34	1.90	92.50	141.00	116.75	24.25	34.29	62.01	1538.39	800.20	738.19	1043.96

Total	Forest
60.20	65.80
980.00	609.98
336.30	337.89
58.84	272.09
242.59	384.79
4.30	4.30
441.20	385.81
112.99	195.06
32.52	190.76
164.07	269.77
56.00	76.00
420.00	95.00
119.43	85.50
19.98	9.50
82.37	13.44
15.80	15.80
100000.00	1628.70
19334.43	822.25
8456.63	806.45
34867.58	1140.49

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

Source: Author's Fieldwork, 2024

4. CONCLUSION

Gully erosion development has a relationship with land cover of an area. The various types of land covers in UIRB, were identified and investigated, and findings reveals that the severity gully erosion, varies from one type of land cover to another. The morphological features (length, width, depth and area), of gullies also showed that these features varied from one land cover to the other. The result obtained showed that the gully length identified across the various land covers ranges from 60.2 meters to 980 meters, with the highest length identified in the built-up area, and the least gully length obtained in the wetland area. The analysis of other morphological features, showed that the severity of these features were highest, under the land covers that removes vegetation cover, and with heavy human activities going on in them. Theses land covers are built-up area, and farmland. Investigation on the gully assessment under land cover also indicated that farmland, and built-up areas has their land areas mostly attacked by gully erosion. For the gully density, farmland and built-up areas were the land covers with the highest gully density in UIRB. The conclusion is that these two land covers, are the most vulnerable to gully erosion. From the foregoing, it is recommended that the extent to which the land in the study area is being built-up is reduced. Farming activities in the area should be minimized, and more of the land should be allowed to have vegetations cover on them.

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Author Contributions

Dr. Chibo, designed the manuscript and the research, data collection and analysis and reading of the manuscript. Dr. Areola in responsible for GIS analysis as well as data processing, while Dr. Okoro designed the research and also helped in data analysis. Arc Ewulum sees to the correction of the manuscript, conducts literature as well as referencing and bibliographic works.

Informed consent

Not applicable.

Conflicts of interests

The authors declare that they have no conflicts of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Ethical approval & declaration

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Every data that supports the findings of this research are embedded in the manuscript.

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