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Impact Of Urbanization On Gully Erosion In Benin City, Edo State Using Remote Sensing And GIS

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ABSTRACT
Urbanization is a global phenomenon with significant implications for environmental sustainability and land management. This study investigates the impact of urbanization on gully erosion processes in Benin City, Edo State, Nigeria. Through a combination of field surveys, remote sensing analysis, and statistical modeling, the study examines the relationships between urbanization factors and gully erosion dynamics within the urban landscape. Key findings reveal that proximity to gully sites, land use patterns, slope characteristics, and built-up density are important determinants of gully erosion severity in urban areas. The analysis demonstrates positive relationships between distance to gully sites and built-up density, as well as between distance to gully sites and slope gradient, highlighting the influence of human activities and topographic factors on erosion processes. These findings stress the urgent need for integrated approaches to urban planning and land management that prioritize erosion control measures, sustainable land use practices, and community engagement. By addressing the underlying drivers of gully erosion and implementing proactive strategies, policymakers and stakeholders can work towards creating resilient and environmentally sustainable urban environments in Benin City and beyond. This study contributes valuable insights to the understanding of urbanization impacts on land degradation and provides a basis for informed decision-making and action towards sustainable urban development.
Keywords: urbanization factors, urban landscape, gully erosion

1.0 INTRODUCTION

Benin City, situated in Edo State, Nigeria, stands as a historical and cultural hub, tracing its roots back to ancient kingdoms and civilizations. Nestled in the heart of the Niger Delta region, Benin City boasts a rich heritage alongside its modern urban landscape. However, alongside the urbanization surge, the city grapples with the increasingly prevalent issue of gully erosion, which poses significant threats to its infrastructure, environment, and inhabitants, which is a characteristic faced in urban cities (Wang et al., 2018). Gully erosion, characterized by the deepening and widening of channels due to rapid water flow, presents a pressing challenge in urban areas like Benin City. The significance of understanding gully erosion lies in its far-reaching consequences, including the degradation of land, loss of property, and disruption of livelihoods (Alaigba et al., 2021). As such, investigating the dynamics of gully erosion within the context of urbanization is crucial for effective management and sustainable development.

Over the decades, Benin City has experienced rapid urbanization driven by factors such as population growth, rural-to-urban migration, and economic activities. This urban sprawl has led to extensive changes in land use patterns, as agricultural lands give way to residential, commercial, and industrial developments (Ercoli et al., 2020). Consequently, the natural landscape undergoes significant alterations, exacerbating issues related to soil erosion and sediment transport. Against this framework, gully erosion emerges as a visible manifestation of environmental degradation, particularly in areas with inadequate drainage systems and improper land management practices (Kayode-Ojo et al., 2019). Understanding the underlying causes and spatial distribution of gully erosion within the urban context is imperative for devising effective mitigation strategies and promoting sustainable urban development.

The purpose of this study is to investigate the complex relationship between urbanization and gully erosion in Benin City, Edo State. By examining the spatial distribution of gully erosion sites, identifying contributing factors, and analyzing urbanization trends, the study aims to shed light on the complex dynamics driving erosion processes in urban environments. Through a combination of remote sensing techniques, and statistical analysis, this research seeks to uncover the underlying mechanisms linking urbanization to gully erosion severity. Additionally, the study endeavors to provide recommendations for urban planners and policy makers to mitigate the impacts of gully erosion and foster resilient urban landscapes.

2.0 Theoretical Framework

In order to properly understand the relationship between urbanization and gully erosion processes, the theoretical framework is used as a method to explain how urbanization processes can affect the formation of gullies overtime –

1. **Systems Theory**:

- This theory views urban ecosystems as complex systems composed of various interconnected components, including physical, biological, social, and economic elements. Gully erosion in urban areas can be understood as an emergent property of the interactions between these components within the urban system (Dalil et al., 2016; Ibrahim et al., 2021). For example, changes in land use (such as urban expansion or deforestation) can alter the hydrological cycle, leading to increased surface runoff and erosion processes.

2. **Human-Environment Interaction Theories**:

- These theories examine the reciprocal relationship between human activities and environmental processes, emphasizing the ways in which human actions shape and are shaped by the environment. In urban areas, human activities such as urbanization, land development, and infrastructure construction can directly impact erosion processes by altering land cover, soil composition, and hydrological pathways (Ercoli et al., 2020). Conversely, erosion phenomena can also influence human activities by affecting infrastructure integrity, property values, and community resilience.

3. **Landscape Ecology Perspectives**:

- This examines the spatial patterns and dynamics of landscapes, focusing on the interactions between ecological processes and human activities across different scales. In urbanized landscapes, gully erosion often occurs in specific spatial patterns influenced by factors such as land use, topography, and soil

properties (Adediji & Ibitoye, 2013; Bouramtane et al., 2022). Landscape ecology provides tools and methodologies for analyzing these spatial patterns and understanding the underlying drivers of erosion processes.

3.0 METHODOLOGY

3.1 Data Collection Method

Table 1: Data Description

Data Type	**Source Of Data**	**Specification/ Resolution/Scale**	**Purpose**
Field Coordinate	GPS	3m accuracy	For the identification of the gully sites
Field Question/Response	Questionnaire		To ascertain the effects of gully erosion and the scoping strategies adopted
Sentinel 2	ESA	10m/2024	image processing for Land Use Information
Digital Elevation Model	USGS	30m	To generate Slope, Stream Power Index
Rainfall data	**C**limate **H**azards Group **I**nfra**r**ed **P**recipitation with **S**tation		Spatial coverage of Average rainfall in the study area.
Soil	Harmonized World Soil database (HWSD)		To determine Soil textural type
Road map	ArcGIS, Open Street map		To create the study area map

Field surveys were conducted to collect data on and gully locations. GPS devices were utilized for georeferencing and spatial data collection to ensure accurate location information for analysis. Satellite imagery covering the study area was acquired to map land use and built-up density. Also, data on soil was derived from FAO website while the DEM used in developing slope was downloaded from CGIAR-SRTM website. Field survey data and remote sensing imagery were integrated into GIS databases for spatial analysis. Thematic maps were developed to visualize the spatial distribution of relevant factors.

3.2 Method of Data Analysis

The factors considered in establishing the relationship between urbanization and gully erosion process include land use, built up density, distance to road and towns, distance to towns (urbanization variables), gully density and gully sites distance (gully processes variables) as well as slope, elevation and soil types (topographic variables). Spatial analysis tools for quantifying gully erosion extent, density, and distribution. In essence, density analysis to quantify the concentration of gully erosion within specific urban zones while distance analysis was used in understanding the level of proximity to urban

infrastructures and gully locations (Adediji & Ibitoye, 2013; Fabolude & Aighewi, 2022; Wang et al., 2018). Correlation analysis was conducted to examine the relationships between gully erosion and various factors, including land use, built-up density, and distance to roads, distance to gullies, and distance to town, elevation, slope, and soil type. Regression analysis was utilized to model the influence of these factors on gully erosion severity and extent, identifying significant predictors and estimating their impact. Results of correlation and regression analyses were interpreted to understand the relative importance of different factors in driving gully erosion in the study area.

4.0 RESULTS

4.1 Overview of Trends of Urbanization

Benin City has experienced significant urbanization over the past decades, characterized by rapid population growth, expansion of built-up areas, and changes in land use patterns. There have been a steady increase in the city's population, driven by factors such as natural population growth and rural-to-urban migration (Fabolude & Aighewi, 2022). As a result, the urban footprint of Benin City has expanded, with agricultural lands being converted into residential, commercial, and industrial zones (Figure 1). This urban sprawl has been accompanied by infrastructural development, including the construction of roads, buildings, and other urban amenities. These trends reflect the ongoing urbanization process shaping the landscape of Benin City (Fabolude & Aighewi, 2022; Merem et al., 2019).

4.2 Identification and mapping of gully erosion sites

Through a combination of field surveys, remote sensing techniques, and GIS analysis, gully erosion sites were identified and mapped across the study area. Field surveys provided ground truthing data, allowing for the validation of gully erosion features (Table 1). Two gully sites are located around UNIBEN axis while others are located around the urban areas (Asoro, Ikpo Oba Hill and Queen Ede gulls).

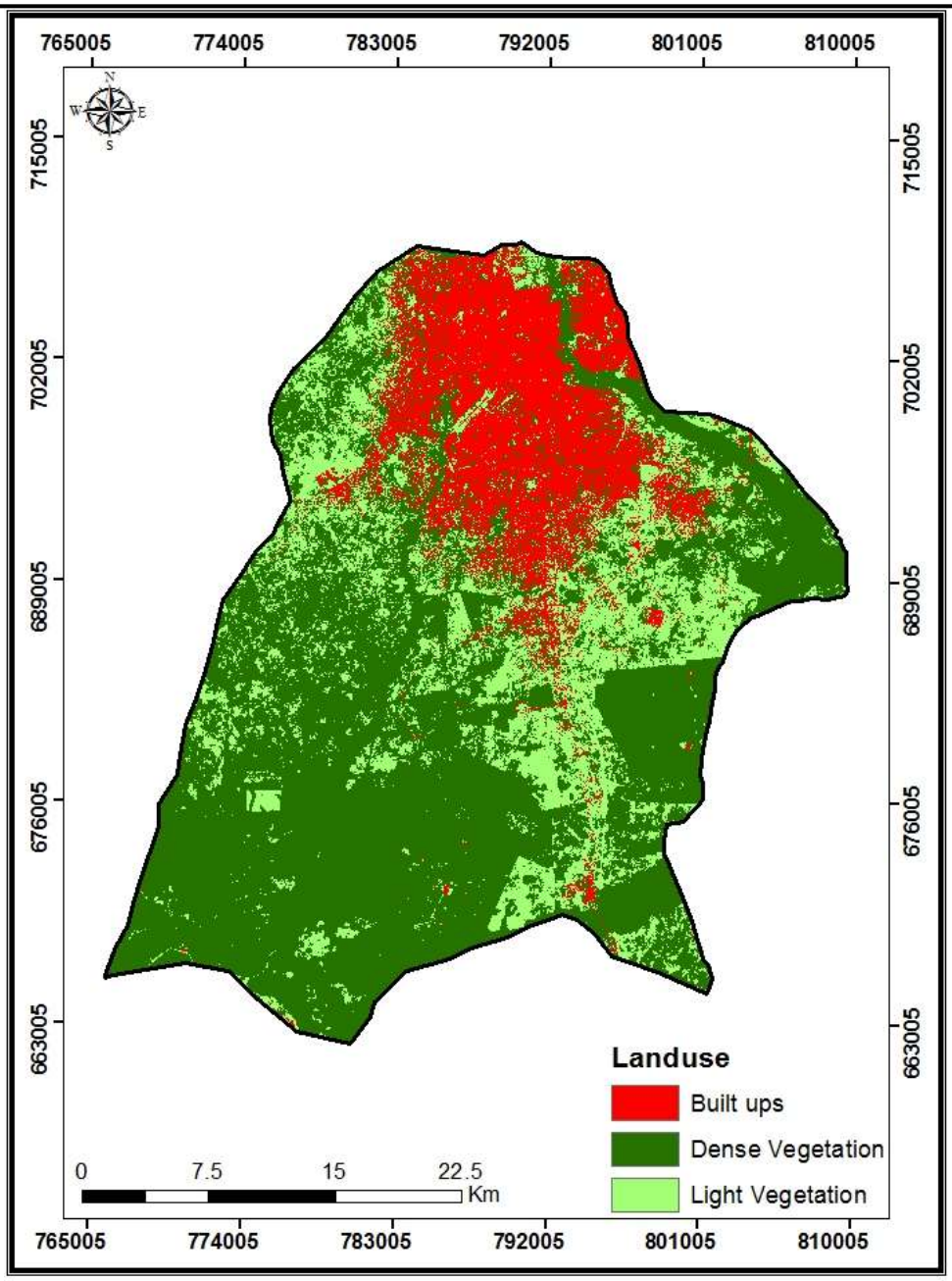

Figure 1: Land use land cover of Benin City

Table 1: Location of Gully Sites in Benin City

Gully Name	Latitude	Longitude	LGA
Queen Ede	6.336909	5.677741	Ikpoba Okah
UNIBEN 1	6.406605	5.629332	Ikpoba Okah
UNIBEN 2	6.398863	5.634179	Ikpoba Okah
Asoro	6.323963	5.584301	Oredo
Ikpoba hill	6.330895	5.661164	Ikpoba Okah
Ogboko	6.282811	5.717879	Ikpoba Okah

4.3 Analysis of factors contributing to gully erosion in urban areas

Results revealed significant correlations between gully erosion severity and certain factors, such as land use intensity and built-up density. As indicated in Table 2, the inferences can be made –

- **Built-up Density vs. Gully Site Density**: There is a positive correlation (0.710) between built-up density and gully site density. This suggests that areas with higher built-up density tend to have slightly higher gully erosion sites.
- **Distance to Gully Sites vs. Gully Site Density**: There is a strong positive correlation (0.622) between distance to gully sites and gully site density. This implies that areas closer to existing gully erosion sites tend to have higher densities of gully erosion sites, which is an expected result.
- **Distance to Town Locations vs. Gully Site Density**: There is a moderate positive correlation (0.385) between distance to town locations and gully site density. Closer areas have greater impact on gully formation.
- **Elevation vs. Gully Site Density**: There is a strong negative correlation (-0.546) between elevation and gully site density. This indicates that areas with higher elevations tend to have lower densities of gully erosion sites, which is expected as gully erosion is often more prevalent in low-lying areas.

Table 2: Correlation analysis between factors

Correlations									
		Built ups Density	Gully Site Density	Distance to Roads	Distance to gully sites	Distance to Town Locations	Elevation	Slope	Soil_Type
Built ups Density	Pearson Correlation	--							
Gully Site Density	Pearson Correlation	-.7110	--						
Distance to Roads	Pearson Correlation	.184**	-.115	--					
Distance to gully sites	Pearson Correlation	.622**	-.201**	.242**	--				
Distance to Town Locations	Pearson Correlation	.385**	-.128	-.039	.694**	--			
Elevation	Pearson Correlation	-.546**	.176*	-.308**	-.795**	-.468**	--		
Slope	Pearson Correlation	-.130	.046	.112	-.036	.029	.016	--	
Soil_Type	Pearson Correlation	-.076	.010	.080	.065	.012	.053	-.002	--
*. Correlation is significant at the 0.05 level (2-tailed).									

Regression models further elucidated the influence of these factors on erosion dynamics, highlighting the role of urbanization in exacerbating gully erosion processes. These findings underscored the complex interplay between human activities and environmental processes in driving erosion phenomena within urban landscapes. This is shown in Table 3 and 4.

The multiple correlation coefficient (R) indicates the strength and direction of the linear relationship between the predictors (independent variables) and the outcome variable (dependent variable). It ranges from -1 to 1, where 1 represents a perfect positive correlation, -1 represents a perfect negative correlation, and 0 represents no correlation. In this context, R values of around 0.646 to 0.648 suggest moderate positive correlations between the predictors and the outcome variable as shown in the three model scenarios.

Also, the coefficient of determination (R Square) represents the proportion of variance in the outcome variable that is explained by the predictors in the regression model. It ranges from 0 to 1, with higher values indicating a greater proportion of variance explained. In this case, R Square values of approximately 0.417 to 0.420 indicate that the predictors included in the models collectively account for around 41.7% to 42.0% of the variance in the outcome variable.

Table 3: Summary of the Regression Model

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.646[a]	.417	.402	818.7476935155
2	.647[b]	.419	.401	819.4425344661
3	.648[c]	.420	.399	820.5365980084
a. Predictors: (Constant), Gully Site Density, Soil Type, Slope, Elevation, Distance to gully sites				
b. Predictors: (Constant), Gully Site Density, Soil Type, Slope, Elevation, Distance to gully sites, Distance to Roads				
c. Predictors: (Constant), Gully Site Density, Soil Type, Slope, Elevation, Distance to gully sites, Distance to Roads, Distance to Town Locations				

Also, as shown in the model scenarios, there is a positive relationship between variables representing urbanization (Building density and land use) and gully erosion parameters (as shown in Appendix). For instance, there is a positive relationship between gully density and building density in all 3 model scenarios as well as distance to gully sites represented with the unstandardized coefficient (B). This is similar in finding with research on urbanization impact on gully (Mahamba et al., 2023; Iroye, 2016).

4.3.1 Automatic Linear Regression Modeling

To further investigate deeper relationship between urbanization and gully processes, it was shown that distance to gully site is the most important variable that depict the positive relation along with land use and slope (Figure 2). Also, in Figure 3, distance to gully sites and built up density was depicted to have a positive relationship. This indicate that in terms of urbanization and its impact on gully, gully erosion tends to be more pronounced in areas with higher levels of urbanization. This finding emphasizes the influence of human activities and land use changes on gully erosion processes. Furthermore, the positive relationship between distance to gully sites and slope highlights the role of topography in exacerbating gully erosion within urbanized landscapes. Steeper slopes are more prone to erosion due to increased runoff velocities and soil instability, especially when coupled with urban development activities that modify natural drainage patterns.

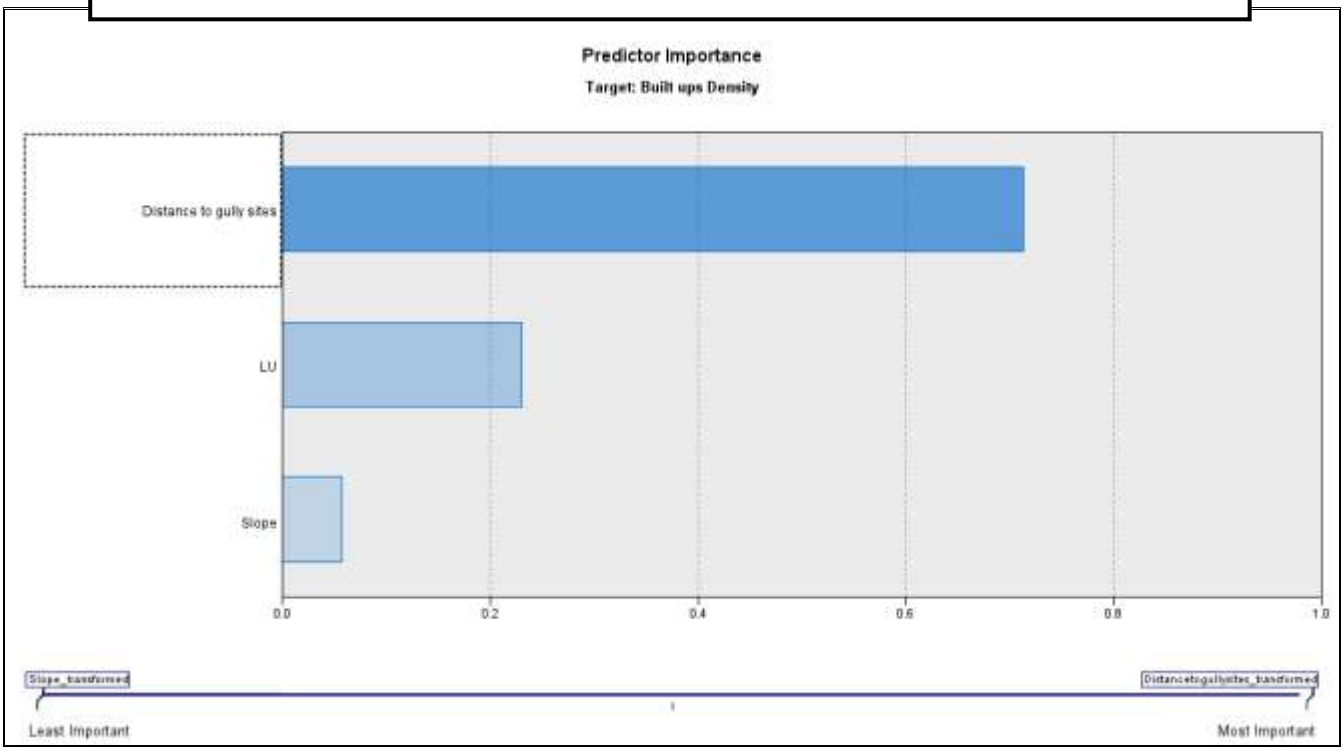

Figure 2: Regression model showing variables impacted by urbanization.

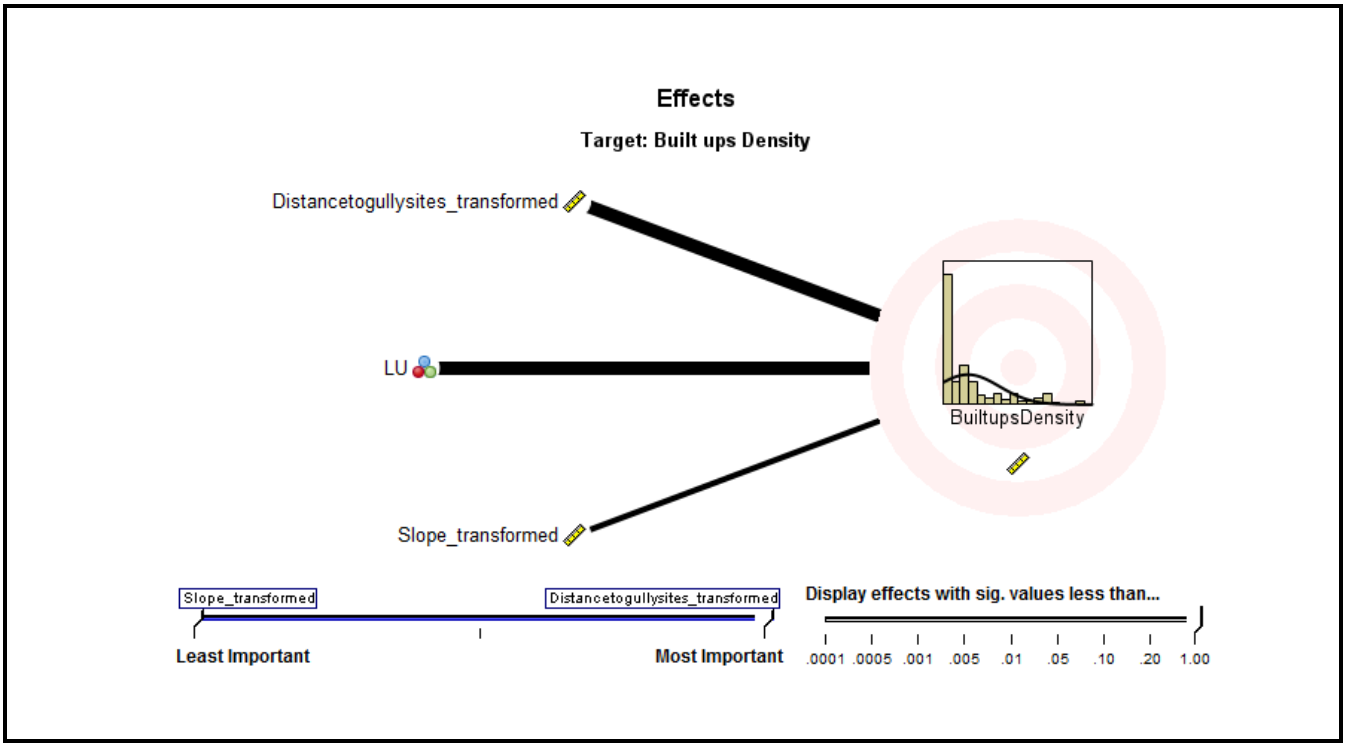

Figure 3: Model Prediction on Urbanization and Gully Site Process

4.3.2 Examination of Influencing Factors

1. **Built-up Density**: Areas with higher built-up density typically have more impervious surfaces, such as roads, buildings, and pavement. These surfaces prevent water from infiltrating into the soil, leading to increased surface runoff during rainfall events. The runoff can concentrate in certain areas, increasing erosion potential and contributing to the formation of gullies.
2. **Distance to Roads**: Proximity to roads can impact gully erosion through several mechanisms. Roads often act as conduits for surface runoff, directing water flow and sediment transport. Areas closer to roads often experience higher levels of disturbance, such as land clearing and construction activities, which can accelerate erosion processes. Additionally, road construction can alter natural drainage patterns, leading to localized erosion and gully formation.
3. **Distance to Gully Sites**: The distance to existing gully erosion sites can influence erosion dynamics in nearby areas. Gullies tend to propagate downslope and extend over time, affecting adjacent areas through sediment transport and channel incision. Areas closer to existing gully sites may therefore be more susceptible to erosion, as they are within the influence of sediment transport and runoff pathways.
4. **Distance to Town Locations**: Distance to town locations may reflect patterns of urbanization and land development. Areas closer to towns can experience higher levels of human activity, infrastructure development, and land use changes, which can increase erosion risk. Conversely, areas farther away from towns may have more natural or undisturbed landscapes, with lower levels of anthropogenic influence on erosion processes.
5. **Elevation**: Elevation influences gully erosion by affecting the flow of water and sediment across the landscape. Low-lying areas are more prone to accumulation of surface runoff, which can lead to concentrated flow and erosion. In contrast, higher elevations may experience less erosion due to reduced water accumulation and decreased flow velocities. However, steep slopes at higher elevations may still be susceptible to erosion, particularly during intense rainfall events.
6. **Slope**: Slope gradient plays a critical role in determining the erosional susceptibility of an area. Steeper slopes are more prone to erosion due to increased runoff velocity and reduced soil stability. The force of gravity acts to transport soil and sediment downslope, leading to the formation of gullies and channel incision.

CONCLUSION

In conclusion, this study sheds light on the intricate relationship between urbanization and gully erosion processes in Benin City, Edo State. Through comprehensive analysis of various factors, including distance to gully sites, land use, slope, and built-up density, key insights was gained into the drivers and dynamics of gully erosion within urban landscapes.

The findings reveal that proximity to gully sites, along with the intensity of built-up development and steepness of slopes, play crucial roles in shaping the extent and severity of gully erosion in urban areas. The positive relationships observed between distance to gully sites and built-up density, as well as between distance to gully sites and slope, emphasize the influence of human activities and topographic factors on erosion processes.

These results recommend the need for integrated approaches to urban planning, land management, and erosion control that take into account the complex interactions between urbanization and gully erosion. Strategies aimed at reducing erosion risk and promoting sustainable urban development should consider factors such as land use zoning, slope stabilization measures, green infrastructure initiatives, and community engagement in erosion mitigation efforts.

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APPENDIX
REGRESSION MODELS

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	303.437	325.693		.932	.353
	Distance to gully sites	.058	.010	.536	5.810	.000
	Elevation	-4.945	3.870	-.117	-1.278	.203
	Slope	-41.539	20.689	-.110	-2.008	.046
	Soil Type	-.157	.084	-.105	-1.875	.062
	Gully Site Density	1263.464	2860.072	.025	.442	.659
2	(Constant)	218.373	342.107		.638	.524
	Distance to gully sites	.058	.010	.538	5.825	.000
	Elevation	-4.264	3.962	-.101	-1.076	.283
	Slope	-43.699	20.874	-.116	-2.093	.038
	Soil Type	-.164	.084	-.109	-1.949	.053
	Gully Site Density	1437.220	2870.346	.028	.501	.617
	Distance to Roads	.013	.016	.048	.819	.414
3	(Constant)	206.970	342.955		.603	.547
	Distance to gully sites	.063	.013	.589	5.017	.000
	Elevation	-3.844	4.013	-.091	-.958	.339
	Slope	-41.941	21.053	-.111	-1.992	.048
	Soil_Type	-.167	.084	-.112	-1.983	.049
	Gully Site Density	1415.259	2874.351	.028	.492	.623
	Distance to Roads	.010	.017	.036	.595	.552
	Distance to Town Locations	-.026	.037	-.057	-.697	.487