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Geographical Analysis of Gully Erosion Site in Ekwueme Square, Awka Using Remote Sensing and GIS Techniques

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Abstract

This research work focused on the Geographical Analysis of Alex Ekwueme Square Gully Erosion Site Awka, employing advanced techniques in Remote Sensing and Geographic Information Systems (GIS). Key findings include a V-shaped head indicating subsoil resistance, a trapezoidal mid-section suggesting increased bank erosion, and a flat-tailed end signifying initial intense runoff. The site's elevations varied from 90m to 103m at the head, indicating erosion-resistant subsoil. Elevations at the tail ranged from 58m to 64m, showcasing a consistent cross-section profile and intense surface runoff during initial development. The gully site is located at the foot of the Ifite hill, sloping towards the Obibia River. Slope analysis revealed inclined landscapes ranging from 0° to 21.5°, contributing to surface runoff and erosion. The highest slope regions, predominantly facing eastward and north-eastward, converge in the gully site, indicating potential for increased gully erosion. Land use and land cover changes from 2012 to 2023 revealed urban development encroaching on vegetated areas, with built-up areas increasing from 0.51 sq.km. in 2012 to 0.83 sq.km. in 2023. The vegetation class suffered significant spatial losses, indicating an increasing trend of urban development impacting densely vegetated areas. Over the period the gully's length fluctuated, peaking at 1,384m in 2018, which prompted Nigeria Erosion and Watershed Management Project (NEWMAP) to commence GRASS project. This research paper recommends establishing monitoring systems using remote sensing and GIS technologies to track changes in the gully site over time.

Keywords: Gully erosion, geographical analysis, Satellite Remote sensing, GIS technique and Alex Ekwueme Square Gully Site

Introduction

Soil erosion is a major ecological problem in the south eastern part of Nigeria and is gradually expanding in size annually (Amanbagara, Njoku and Obenade, 2015; Iro,2020). Certain factors including geology, topography, slope, soil composition, climate, and landscape and infrastructure development are the major contributors to soil erosion(Igwe, 2012; Iro, 2021; Iro, Duru and Achalonu, 2022). Soil erosion is gradually taking up roads, buildings, arable land and infrastructure in the south eastern part of Nigeria (Ofomata, 2008). Soil erosion may impact soil productivity, surface water sources, their quality, ecological balance, and landscape

(Hitouri et al., 2024; Issaka & Ashraf, 2017 and Igwe, 2012). It has also led to the destruction of arable lands, flooding, and landslides. According to (Iloeje, 2010), there are four types of erosion and gully erosion stands out as the most complex and hazardous forms, given its capacity to displace substantial amounts of soil. A gully is characterized as a deep, relatively permanent canal with vertical walls on either side that allow passing water currents for a short period. Gully erosion occurs when runoff erodes deep, narrow channels, during or after heavy rainfall or melting snow, removing and transporting the eroded surface soil to a considerable depth. According to Abdulfatai, Okunlola, Akande and Ibrahim (2014), gully erosion is more prevalent in the sedimentary terrain of Nigeria.

One of the most important techniques for managing this phenomenon is understanding the variables influencing the incidence of this form of erosion and its zoning. According to Feliciano (2008), gully erosion is an incised cut steep-sided channel with an eroding head cut and slumping side walls. The process of gully erosion typically begins with concentrated surface runoff, often caused by intense rainfall events or the rapid melting of snow or ice (Igwe, 2012). As the water gains velocity, it concentrates into flow pathways, gradually eroding the soil and creating narrow channels. Over time, these channels deepen and widen, as more sediment is removed and transported downstream. The head ward erosion process causes the gully to extend further into the landscape, altering its shape and size.

Anambra State is highly susceptibility to soil erosion which prompted Federal Government of Nigeria to declare state of emergency on erosion in 2019. The Alex Ekwueme Square Gully erosion site has been threatening the stability of the surrounding ecosystem and potentially impacting human activities and livelihoods. Despite its importance, the underlying causes and spatial patterns of gully erosion at this specific site remain poorly understood. While gully erosion has been extensively studied in various regions, a comprehensive geographical analysis of this particular site using GIS software has not been conducted to date. Understanding the factors contributing to gully formation and the spatial distribution of these erosional features is crucial for effective land management and devising appropriate mitigation strategies. The aim of this paper is to analyze the geographical aspects of gully erosion at Ekwueme Square using satellite remote sensing and GIS techniques. Ultimately, the findings of this research endeavor to offer guidance for mitigating gully erosion risks and safeguarding the integrity of the study area's landscape and surrounding environment.

Study Area

Alex Ekwueme gully erosion site is located in Umuzocha village, Awka in Awka South Local Government Area of Anambra State. It lies between longitude 06 12 55.9 and 06 14 28 North; and latitude 07 $^{0}50^{0}4^{11}$ and 07 $^{0}4$ 912 East near the Federal High Court/Federal Secretariat Complex, Awka. The area is situated in the tropical continental climate characterized by uniformly high temperature and a seasonal distribution of precipitation and a high relative humidity. The area experiences distinct wet and dry seasons with eight months of rainfall and four months of dry season in the year. The rainy season begins in March and ends in October, while the dry season runs through the months of November to February of each year climate. The Ekwueme Square gully site, Awka is mainly underlain by the Imo shale formation. This consists of thick clayey shale, fine-textured, dark-grey to bluish-grey with occasional admixture of clay ironstones and thin sandstone bands. The area is underlain by hydromorphic soils developed on the Mamu plain, east of the cuesta, and extending northwards into the eastern part of Anambra River plain where the underlying impervious clayey shales cause water logging of the soils during the rainy season.

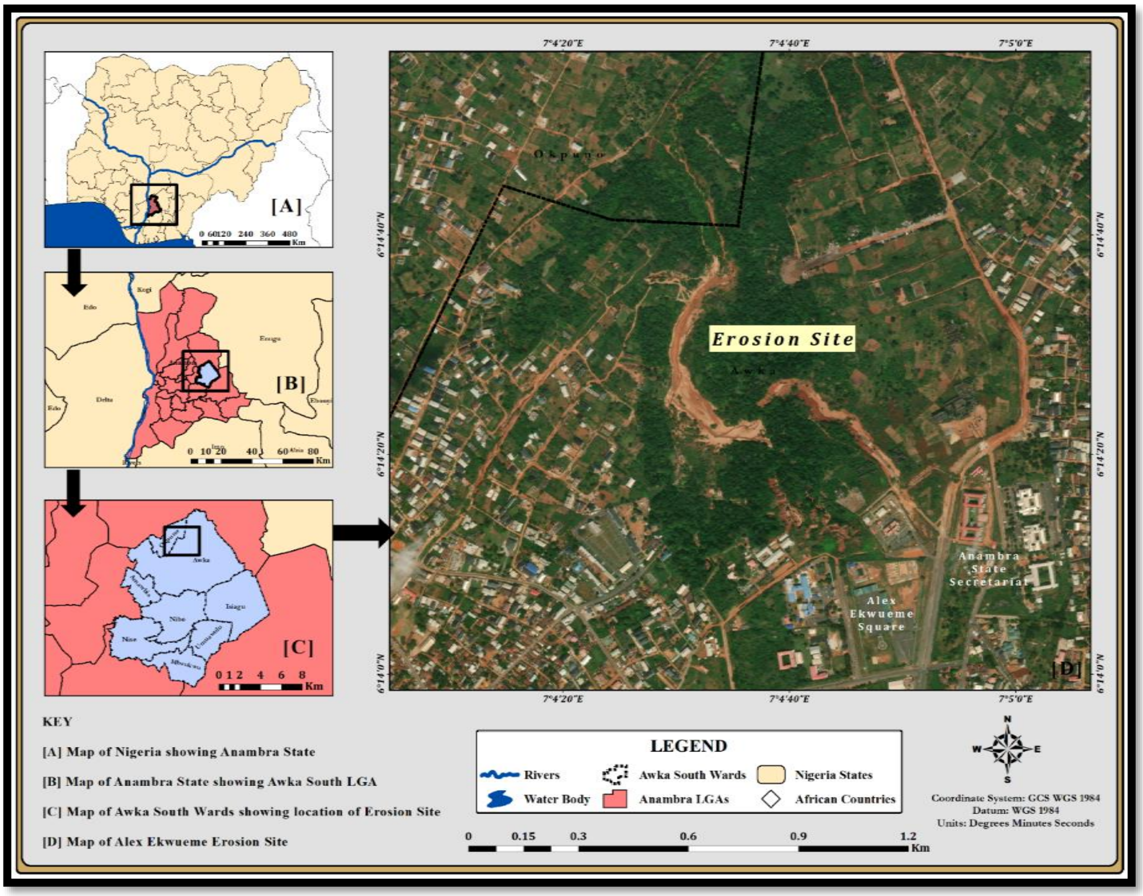

Figure 1: Study Area Map (Source; Researcher's GIS Mapping)

Methodology

The study uses remote sensing and geographic information system tools in processing satellite data. The data required include high resolution elevation data, mid-resolution satellite imagery for LULC assessment, and high-resolution historical satellite imagery for assessing the spatial and temporal trend of the gully development. The major data sources are primary and secondary data sources. The primary data utilized is field work to collect information about coordinates for cross-section analysis. The secondary data include a 10m resolution Sentinel-1 elevation data from data hub of the Copernicus Data Space Ecosystem for 2023; a 30m LANDSAT imagery from the United States Geological Survey (USGS) from 2012 to 2023 and a high-resolution historical satellite imagery from Google Earth Pro for 2012 to 2023. The high-resolution satellite imagery served as a crucial component, providing a visual representation of the gully erosion site and its surrounding area. This aided in elucidating landscape features, gully morphology, and changes in land cover over time. Historical aerial photographs offered temporal insights into the gully's evolution, especially with the availability of long-term data. Additionally, a high-resolution Digital Elevation Model (DEM) of the study area facilitated terrain analysis, aiding in the identification of slopes and a deeper comprehension of the gully's topography.

Methods of Data Analysis

The Sentinel-1 satellite data of the study area was processed within a GIS software environment to generate required terrain features such as slope, aspect, and elevation. Sequential steps of data pre-processing were performed using Arc GIS 10.8 and ERDAS Imagine software.Supervised Image Classification was conducted to assign different spectral signature from the dataset to several classes based on reflectance attributes of the diverse types of Land Use Land Cover analysisusing the ArcGIS 10.8 software and the images were combined in the order of band 6, 5 and 3 for 2012 and 2023 data.Using high resolution Google historical imagery, the spatial extents of the gully site are carefully delineated for each of the years (2012, 2014, 2016, 2018, 2020, 2023) and extracted to KMZ to enable GIS analysis and mapping in the ArcGIS platform. The areal and longitudinal extents of the gully site per year is estimated using this process. Equally, the elevation profiles are extracted from Google Earth terrain analysis. A field work was carried out to acquire elevation data at different points of the gully site for cross- sectional assessment (Figure 2). By acquiring five (5) evenly-spread GPS coordinates with elevation data on each of them, and overlaying on Google Earth, the cross-section profile for the entire gully was evaluated.

Figure 2: Alex Ekwueme Gully Erosion Site, Awka

Results

To assess the cross-section of the gully site, elevation data is collected at various locations of the gully site development at five locations from the gully head to its end. A satellite map of the locations is displayed below (Figure 3) and depicts the evenly distributed sample sites. This enables accurate display of the different stages of gully erosion development in the study location.

Figure 3: Satellite image of sample points (Source; Researcher's Field Work & Google Earth Pro)

The gully site is digitized to enable accurate assessment of its spatial extent and the sample points are overlaid on it in Figure 4.

Figure 4: Digitized Map of Sample Points (Source; Researcher's Field Work and GIS Mapping)

The elevation of each point is extracted and deployed in the cross-sectional analysis. It is revealed that at Point A, the gully profile is characterized as 'V-shaped' which indicates that at the head of the gully site, its subsoil has more resistance against erosion than topsoil, according to (Poesen et al., 2002; Desta and Adugna, 2012). This occurrence explains why the topsoil has been increasingly eroding further down the gully site, as the longitudinal analysis in further sections of this research reveals. The elevation ranged from 103m at the highest to 90m at its lowest, with an average of 98m.The topography analysis of the gully site includes the elevation in DEM and TIN, slope, and aspect of the location. These factors are important to determine major causes of the erosion development, and its potential for further occurrence. The Digital Elevation Model (DEM) map reveals that the elevation of the region where the gully site is located ranges between 56m to 148m above sea levels (Figure 5). This indicates that the region is characterized by a high relief, thus pointing to a propensity for gully erosion development. The high relief of the area (highest elevation minus lowest elevation) which stands at 92m, encourages surface runoff due to the high difference between the elevation extremes.

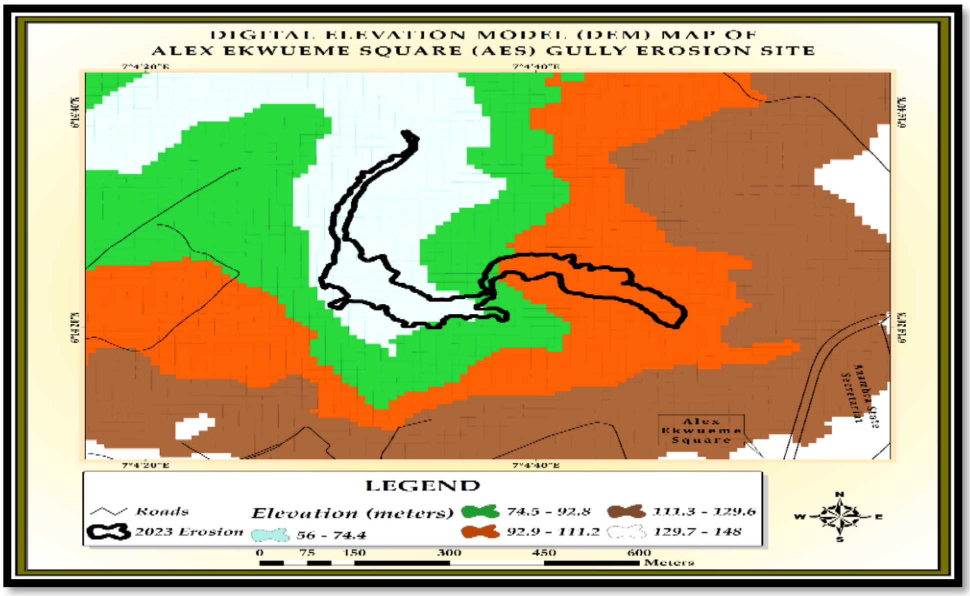

Figure5: DEM Elevation of Gully Site (Source; Researcher's GIS Analysis)

However, the gully erosion site is located in elevations ranging from 56m to 111.2m, with the gully head associated with higher elevations while the tail is found at regions with low elevation. The result of the Triangular Irregular Network (TIN) typically used for high-precision modelling of the elevation of small areas reflects the results of the DEM elevation (Figure 6) but visually reveals the undulating nature of the region.

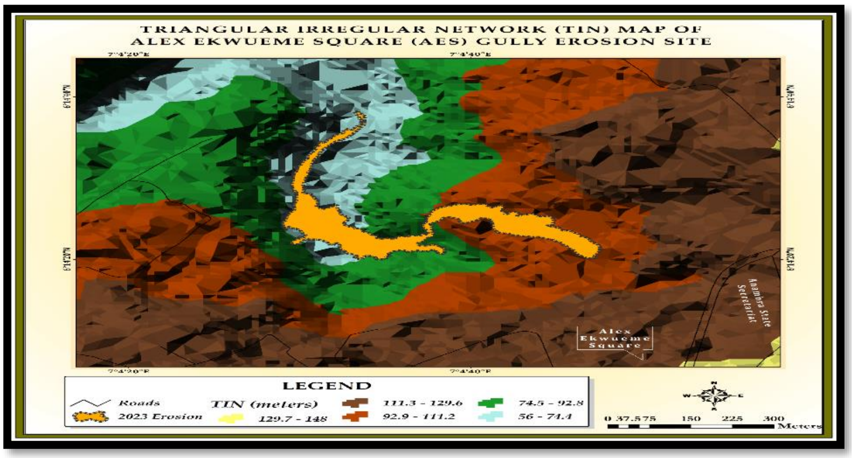

Figure5: TIN Map of Elevation (Source; Researcher's GIS Analysis)

The slope of the gully site region is indicative of an area with steep landscapes with encourage runoff and top soil runoff, making the site more prone to severe cases of erosion. The slope values of 0° - 21.5° further corroborates these findings, as high degrees of inclination in a region with poor soil quality will lead to erosion and subsequent gully formations. The slope is highest in the regions towards the southwest, which is also the part of the gully site with the worst cases of erosion. The aspect of slope direction assessment identifies the compass direction that each slope cell faces for each location. This enables analysis of directions which the surface is facing. It is observed from that the regions associated with the highest slope are mostly facing eastward and north-eastward while the regions opposite that area are facing the south, southwest and west. The Land Use and Land Cover (LULC) Assessment analyzed the land use and cover in the region around the gully erosion site in order to determine the rate of change in natural cover and anthropogenic development. A 3sq.km. extent of satellite imagery around the site was utilized to provide consistency. Four LULC classes were used in this analysis - Bare Surface/Erosion Site/Farmland (BS/ES/F), Built Up Areas (BU), Dense Vegetation (DV) and Sparse Vegetation (SV). It is observed from Table 1 below that in 2012, the BS/ES/F class is estimated to cover 0.14 sq. km. of the area, about 4 percent of the area but increased to 0.32 sq.km. (about 11 percent) in 2023.Built up areas, an indicator of urban development in an area, increased from 0.51 sq.km. in 2012, to 0.83 sq.km. in 2023 with estimated increase from 17% in 2012 to 27% in 2023. Dense vegetation decreased from 2.21 sq.km. in 2012 to 1.81 sq.km. in 2023 (74% to 61% coverage), while sparse vegetation covered 0.13 sq.km. in 2012 and reduced to 0.04 sq.km. in 2023 (5% to 1% covered).

Table 1: LULC spatial extents in AES gully erosion site region

	2012		2023	
CLASS NAME	**Area (sq. km.)**	**(%)**	**Area (sq. km.)**	**(%)**
Bare Surface/Erosion Site/Farmland (BS/ES/F)	0.14	4	0.32	11
Built Up Areas (BU)	0.51	17	0.83	27
Dense Vegetation (DV)	2.21	74	1.81	61
Sparse Vegetation (SV)	0.13	5	0.04	1
TOTAL	3	100	3	100

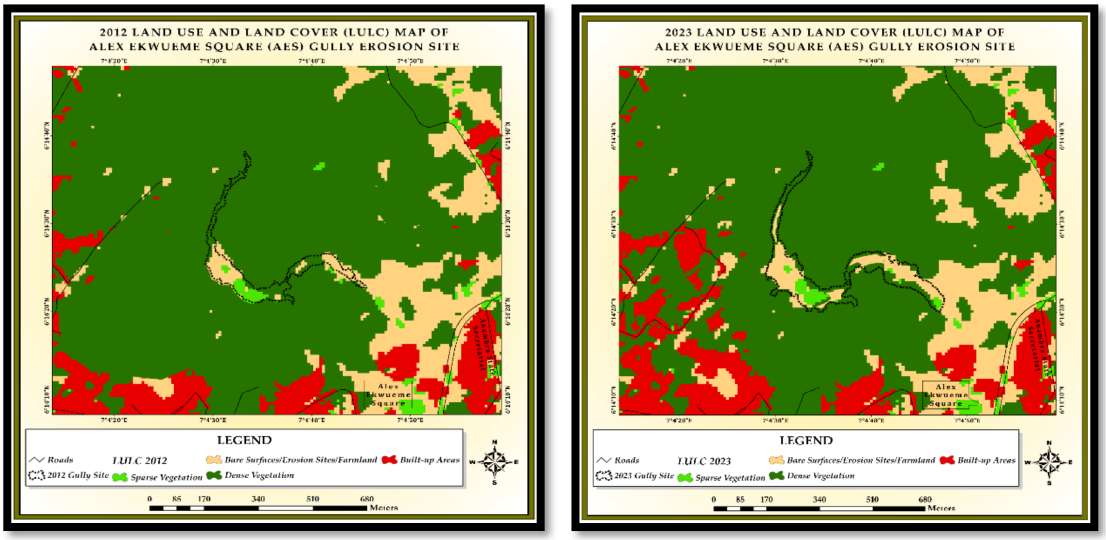

Figure 7: LULC Map of AES Erosion Site in 2012 and 2023 (Source; Researcher's GIS Analysis)

The LULC map displays the spatial dominance of the DV class in 2012, as it covered a large percentage of the study area, about 74%. By 2023, the urban land use had gained significantly against other classes, as it advanced northwards, an indicator of the rapid development the area had undergone in about 11 years. However, the development is advancing towards the erosion site, which puts future development at risk of exacerbating the issue and causing further destruction in the region. DV reduced significantly, most likely due to the BU and BS/ES/F classes. The latter class is mostly prevalent in the regions around the 2023 gully erosion site as loss of vegetation, surface runoff and a combination of topographic factors encouraged the prevalence of eroded lands in the area. It is observed that over the study period (2012 to 2023), the BS/ES/F class increased by 0.18 sq km., while the BU class increased by 0.32 sq.km. over the same period. Thus, the BU is the class with the highest positive change, indicating that urban development is occurring rapidly in this area. Alternatively, DV reduced by a total of 0.40 sq.km. while SV lost 0.09 sq.km. During the same period. The loss in vegetation can be directly attributed to the increase in erosion sites/bare surfaces, as vegetative cover is a major adaptive factor in combating the menace of erosion in any given location, in addition to other factors.

By utilizing high resolution historical satellite imagery, the spatial extents of the Alex Ekwueme Square gully erosion site were extracted in two-year intervals to display the trend of erosion gully development in the region. The result is shown in Figure 8 which depicts that the gully head is associated with the highest elevation values, and the site keeps reducing in elevation till it gets to the tail. The gully elevation in 2012 ranges between 89m at the head to 60m at the tail.

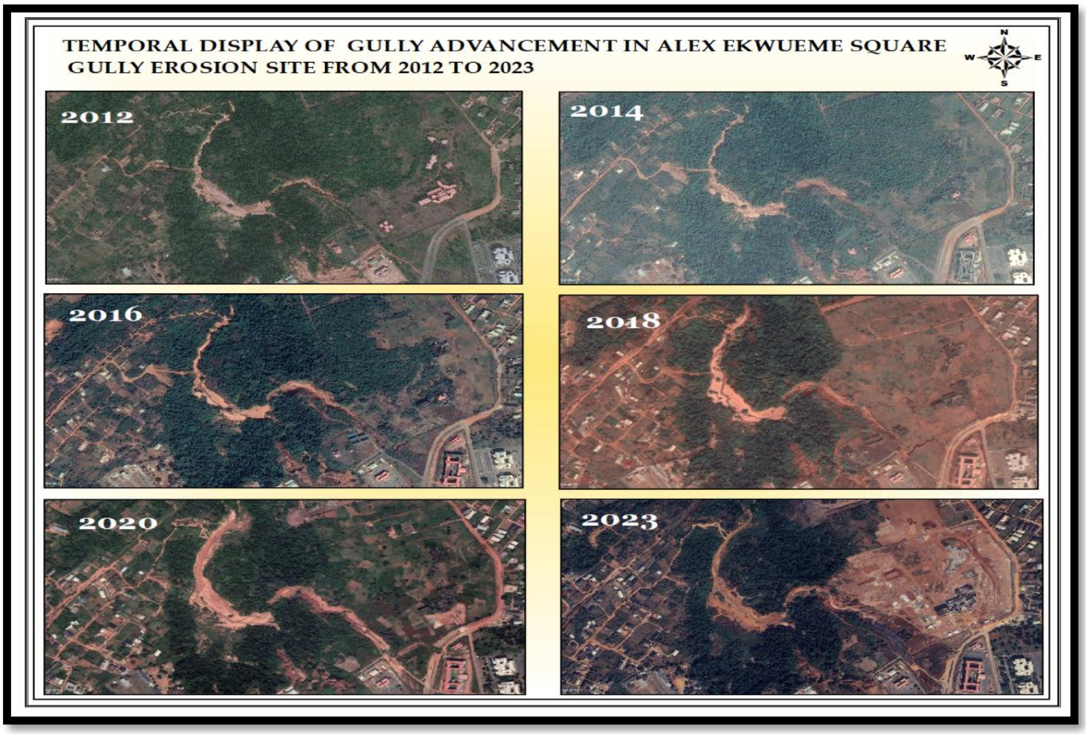

Figure 8: Display of Temporal Gully Site Advancement (Source; Google Earth Historical Imagery)

Based on these results, the spatial extents of the gully sites in each of the years from 2012 to 2023 are extracted and calculated to display their temporal trends. It is observed that the gully site head advanced from 2012 to 2018, before retreating in 2020 and 2023.

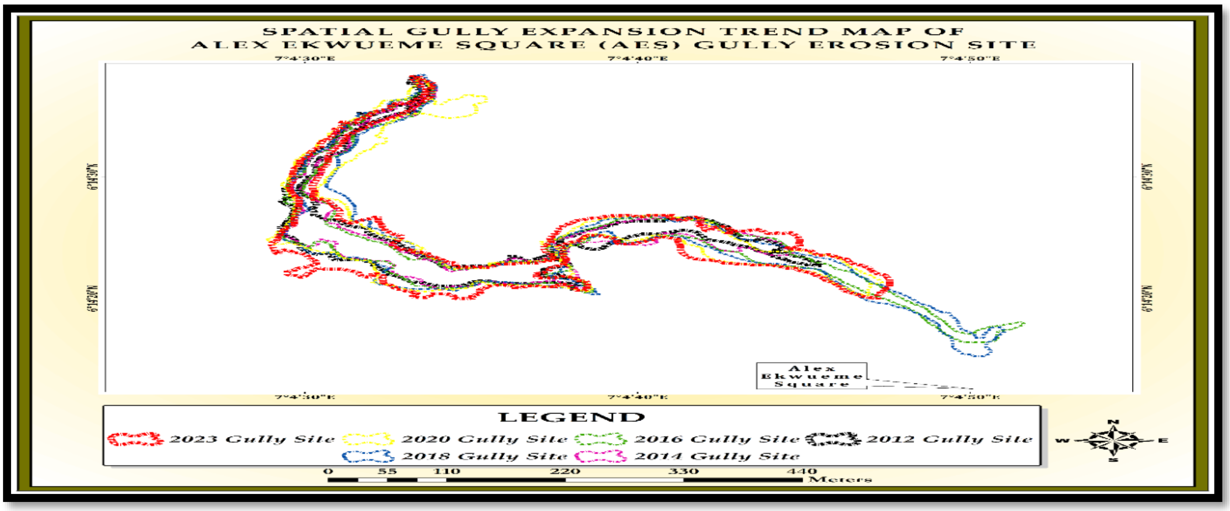

Figure 9: Composited Gully Expansion Map from 2012 to 2023

Discussion of Findings

By deploying remote sensing and GIS as tool for assessing the geographical characteristics of the AES gully erosion site in Awka, it is observed from the assessment of its cross-sectional profile that the site has a head characterized as a V-shape which indicates that at the head of the gully site, its subsoil has more resistance against erosion than topsoil. Thus, it is evident that the topsoil has been washing off downwards towards the tail of the site. This is the reason for its advancement over time, as loose topsoil easily gets removed, thus exposing the surrounding regions to further degradation. The elevation at the head gully ranged between 90m and 103m. By the mid-section, the gully had developed into a trapezoidal shaped site, indicating that by this point the gully floor is made of more resistant material than the topsoil and subsoil, leading to greater erosion rate along the banks. This indicates the potential for further erosion along the banks especially as various other factors come into play such as climate change, infrastructural development and changes in physicochemical properties of the soil. The tail end of the site displayed a flat profile, ranging between 58m to 64m in elevation, with a consistent cross-section profile. This indicates that the AES gully site experienced intense surface and subsurface runoff during its initial development process, but slowed down towards the tail end. The elevation assessment further corroborated this observation, as the gully head is located in elevations ranging between 92.9 m and 111.2m, whereas the tail is located in elevations ranging between 56m and 74.4m. The gully site is located at the foot of the Ifite hill, and slopes towards the Obibia River. The slope map revealed that the region is characterized by sloping landscapes that instigate and propagate surface runoff, as the area slopes between 0° - 21.5°. This high degree of land inclination in a region with poor soil quality will lead to erosion and subsequent gully formations. The slope is highest in the regions towards the southwest, which is also the part of the gully site with the most eroded lands. Furthermore, by assessing the aspect of slope direction, it is observed that the regions associated with the highest slope are mostly facing eastward and north-eastward, while the regions opposite that area are facing the south, southwest and west, and associated with high slopes as well. Their convergence in the region where the gully site is situated further confirms the development of a gully site in this area, and exposes the potential for increased levels of gully erosion development. Based on the soil quality of the area, which is mostly porous, loose, and friable ferralitic soils (NEWMAP, 2018), when combined with slopes and high rainfalls, the further development of gully erosion sites is inevitable. Assessing the land use and land cover of the area between 2012 and 2023 revealed that urban development and classes associated with erosion sites increased concurrently. The vegetation in the region suffered significant losses in spatial extents, despite being the dominant class, which points to an increasing trend of urban development encroaching on densely vegetated areas and converting them to infrastructural lands. The implications of this include the removal of vegetative surface cover, thus exposing the land to further risk of gully erosion development. The increase in spatial extent of the bare surfaces class indicates that this is likely happening in the area already, especially in the regions towards the northeast of the gully site.

The trend of spatial trends of the gully site from 2012 to 2023 depicted that the longitudinal extent of the gully from its head to tail fluctuated reaching its peak in 20218. Gully Rapid Action and Slope Stabilization (GRASS) project by NEWMAP was commissioned to contain this menace. This project involved the construction of engineering canals to channel the storm water drainage away from the road and back to the main gully site, as can be seen from the historical satellite imagery. In 2020-2023, the lengths had reduced. Despite the success of the NEWMAP GRASS project commissioned in late 2018, the erosion site stopped expanding at its head, and shifted to the midsection to expand from there, encroaching on hitherto untouched lands. When lengths of gully sites are correlated with their associated areal extents, it is revealed that a positive relationship exists, indicating that higher spatial extents of gully sites are also high in their longitudinal extents. A major implication of this good relationship is that, if further development of erosion occurs, it will cause significant damage in the region as it is projected to increase in areal and longitudinal extents over time.

The accuracy assessment revealed that the LULC maps utilized in this study are highly suitable for implementation in any decision-making process as they had an overall accuracy of 91%, against the benchmark of 85%.

Conclusion

The use of advanced techniques in Remote Sensing and GIS, in studying of Alex Ekwueme gully erosion site has significantly enhanced our understanding of the dynamics and contributing factors of erosion site. The findings underscore the importance of proactive and sustainable erosion management strategies. The recommendations provided, ranging from continuous monitoring to community engagement and policy collaboration, form a comprehensive framework for addressing the challenges posed by gully erosion. By implementing these measures, we can not only mitigate the current impacts on the studied site but also contribute to broader regional land management practices. This study emphasizes the critical role of integrated technological solutions and community involvement in fostering resilience against gully erosion and promoting a sustainable approach to land use planning.

Recommendations

Based on the findings of the Geographical Analysis of the Gully Erosion Site, the following recommendations are proposed:

Implement Monitoring Systems: Establish continuous monitoring systems utilizing remote sensing and GIS technologies to track changes in the gully erosion site over time, enabling timely responses to evolving conditions.

Integrate Erosion Control Measures: Apply targeted erosion control measures in areas identified as high-risk through GIS-based risk assessments, including the implementation of vegetation cover, check dams, or other appropriate engineering solutions.

Enhance Land Use Planning: Integrate the study results into regional land use planning to minimize activities that contribute to erosion and promote sustainable land management practices.

Community Engagement and Awareness: Engage local communities in awareness programs about the causes and consequences of gully erosion, fostering a sense of responsibility and collaboration in erosion prevention efforts.

Research on Mitigation Strategies: Invest in further research to explore and develop innovative and context-specific mitigation strategies, considering the unique characteristics of the gully erosion site.

Collaborate with Environmental Agencies: Foster collaboration with environmental agencies to implement and enforce policies that regulate land use and prevent activities contributing to gully erosion in the broader region.

Educational Initiatives: Support educational initiatives at various levels to increase knowledge about gully erosion, its impact on ecosystems, and the importance of sustainable land use practices.

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