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Evaluating Gully Patterns and Trends in South-East Nigeria: A Decadal Analysis from 2010 to 2020

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Abstract
This study delves into the evolving landscape of gully erosion in South-East Nigeria, conducting a thorough analysis of trends and patterns over the decade from 2010 to 2020. The research unveils significant variations in gully area changes across states, emphasizing the dynamic nature of this environmental challenge. Key findings highlight the severity of gully erosion in Anambra State, with distinct trends and growth patterns identified in each region. The increasing trend in gully areas underscores the urgency for tailored erosion control strategies, while spatial metrics reveal dominant growth types, guiding region-specific interventions. The study's implications emphasize the need for adaptive management practices and continuous monitoring to address the evolving nature of gully erosion challenges. Overall, this research contributes essential insights for policymakers, researchers, and local communities, informing targeted and effective erosion control measures in South-East Nigeria.

Keywords: Adaptive Management, Gully Erosion, Pattern, Spatial Metrics, Trend

1. Introduction

The South-East region of Nigeria has been grappling with the severe environmental challenge of gully erosion, characterized by the formation and expansion of deep channels in the landscape over the years. Gully erosion poses a significant threat to the socio-economic and ecological well-being of the region, leading to soil loss, agricultural productivity decline, and disruption of local communities (Adekalu et al., 2007; Okpala, 1990; Nwankwo and Nwankwoala, 2018a).

The phenomenon of gully erosion has become a pressing environmental concern, prompting numerous studies to understand its dynamics, causes, and impacts in South-East Nigeria. Researchers such as Igbokwe et al. (2008) have documented the existence of several gully sites with varying dimensions, depths, and lengths in the region, emphasizing the need for comprehensive mapping and monitoring efforts. These gullies, including notable ones like Amucha, Okwudor, Umuagor, Urualla, and Isu Njaba, have not only grown in size but have also become tourist attractions, underscoring the urgency of addressing the issue (Onu and Okpara, 2012; Nwankwo and Nwankwoala, 2018b; Amangabara, 2014; Akpokodje et al., 2010).

Rainfall and climatic factors have been identified as natural causes of gully erosion in the region, leading to the development of erosion hazard maps to assess the risk and vulnerability of settlements and infrastructure (Nwilo et al., 2011; Anejionu et al., 2013). However, these studies have faced limitations in providing a complete understanding of gully dynamics, growth patterns, and expansion rates over time.

While previous research has made valuable contributions to the understanding of gully erosion in South-East Nigeria, there is a critical gap in the availability of up-to-date and detailed information on gully patterns and trends, especially from 2011 to 2020. Anejionu et al. (2013) acknowledged this limitation in their erosion vulnerability assessment between 1986 and 2011, leaving a significant temporal gap in knowledge regarding the development of new gullies in the past decade.

Efforts by researchers such as Ogbonna (2012) and Akpokodje et al. (2010) to map gully erosion using GIS and appraise gully expansion in the region provide valuable insights. However, these studies did not delve into the rate of gully expansion over time, emphasizing the need for a more comprehensive and continuous assessment of gully patterns to inform effective erosion control and management strategies (Ward et al., 2000).

In light of these considerations, this study aims to bridge the existing gap by conducting a detailed and up-to-date decadal analysis of gully patterns and trends in South-East Nigeria from 2010 to 2020. By employing advanced mapping techniques, including machine learning and remote sensing, the research seeks to provide a nuanced understanding of the spatial and temporal variations in gully erosion. The findings are anticipated to contribute significantly to the development of sustainable environmental management strategies, helping policymakers, researchers, and local communities mitigate the adverse effects of gully erosion in the region.

1. Study Area

South-East Nigeria constitutes one of Nigeria's geopolitical zones (refer to Figure 1.1) and encompasses the states of Abia, Anambra, Enugu, Imo, and Ebonyi. Positioned between latitudes 4°45N and 7°15N and longitudes 6°30E and 8°30E (see Figure 1.2), the region spans approximately 28,570.24 square kilometers (Igbokwe et al., 2008). It shares borders with Edo and Delta States to the East, Kogi and Ebonyi to the North, Rivers and Akwa Ibom to the South, and Cross River State to the West.

The demographic landscape of the states is predominantly characterized by the Igbo ethnic group, known for their roles as farmers, fishermen, craftsmen, and traders. Agriculture forms a vital part of their livelihoods, with cultivation of crops such as yam, palm produce, rice, cassava, cocoyam, vegetables, and various fruit trees. The riverine communities engage significantly in fishing, contributing to the region's economic activities. Additionally, the Igbo people are acclaimed for their craftsmanship, manifesting in nationally and internationally recognized iron smithing works, bronze sculptures, and other artistic endeavors.

The cultural richness of the Southeast is evident in its plethora of art centers and the presence of magnificent bronze works, iron works, pottery commercials, and renowned artists. This cultural vibrancy positions the region among the most culturally endowed states in Nigeria.

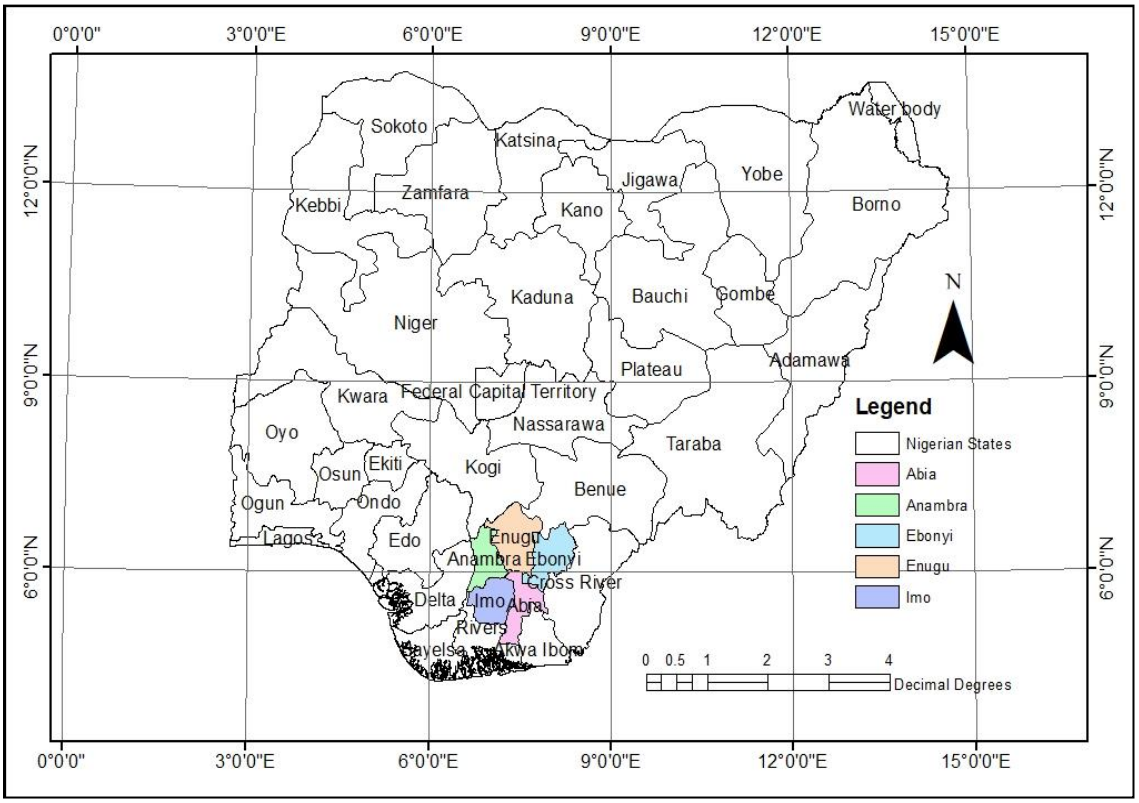

Figure1.1: Map of Nigeria

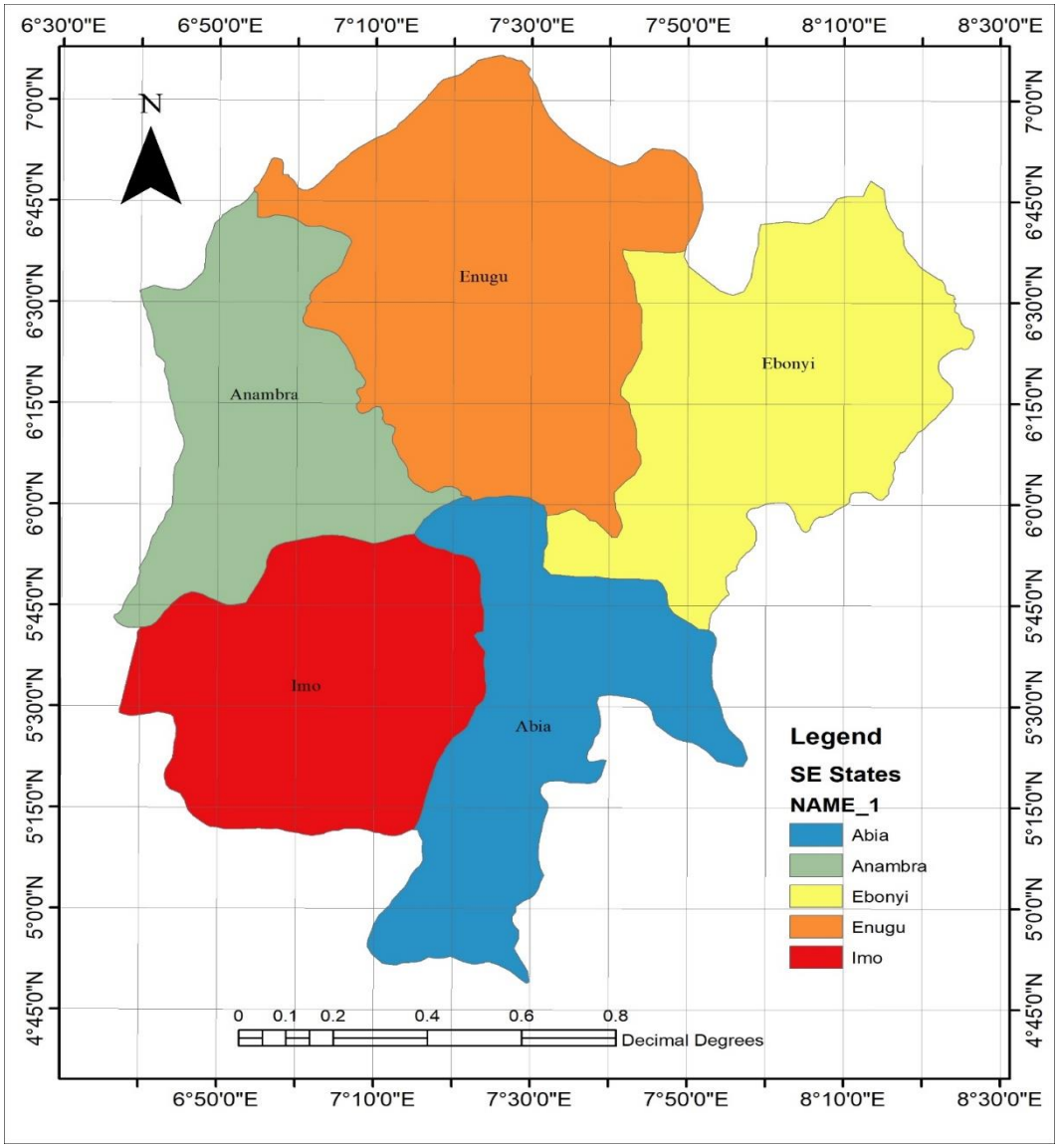

Figure 1.2: Map of South East, Nigeria.

(Source: Department of Surveying and Geoinformatics, NAU)

2. Materials and Methods

2.1. Data Requirements and Sources

This research leveraged various sources of data to conduct a comprehensive analysis. The datasets employed in this study encompassed:

a. **Kompsat-3 Imagery:** High-resolution satellite images were utilized to capture detailed visuals of the study area in South East Nigeria.
b. **Ground Coordinates:** Precise geographical coordinates of gully erosion sites within the region were collected for both image analysis and accuracy assessment. These coordinates served as reference points for validation.
c. **Topographic Maps:** Topographic maps were consulted to obtain additional contextual information about the terrain and geographical features.
d. **Existing Gully Erosion Maps:** Maps depicting the spatial extents of existing gully erosions were employed to supplement the analysis.

2.2.Trend Analysis

To comprehensively understand the pattern and trend of gully erosion in South-East Nigeria from 2010 to 2020, this study employed a meticulous trend analysis methodology utilizing a machine learning algorithm. The approach, inspired by Long et al. (2007), involved calculating and comparing the area of resulting land

cover and land use types for each year. This comparative analysis facilitated the identification of percentage changes, trends, and the rate of change during the specified decade.

To determine the rate of gully erosion change, the decade (2010-2020) was subdivided into two distinct sub-periods: 2010-2015 and 2015-2020. A thorough comparative analysis focused on these sub-periods and the spatial distribution of the average annual rate of land cover and land use change across the three periods (Long et al., 2007).

The calculation of percentage change, a crucial element in determining the trend of change, was executed by dividing the observed change by the sum of the area of the particular land cover or land use type in that period, multiplied by 100. This calculation was expressed as follows:

(Trend) % change = Observed change x 100 / Total Area ... (3.1)

Here, the observed change is determined as the difference between the area of the land cover or land use type before and after the specified year, while the total area represents the sum of the total area of both years. The annual percentage rate was then calculated by dividing the trend percentage change by the number of years in consideration.

A positive trend percentage indicates an increase in the gully type over the specified period, while a negative value suggests a decrease in the gully type over time.

2.3.Pattern of Development

To assess the spatial dimension of gully development patterns, this study employed spatial metrics, specifically focusing on the landscape expansion index (LEI). This index, inspired by Xiaoping et al. (2010), is a quantitative method that distinguishes various gully growth types, including infilling, edge expansion, and spontaneous growth.

The LEI is calculated as follows:

$$LEI = \frac{L_C}{P} \quad \text{... (3.2)}$$

Where LEI represents the Landscape Expansion Index, LC denotes the length of the common boundary of a newly grown patch and the pre-growth patches, and P signifies the perimeter of the newly grown patch.

The identification of gully growth types is based on the LEI values:

- Infilling when LEI>0.5LEI>0.5
- Edge expansion when 0<LEI≤0.50<LEI≤0.5
- Spontaneous growth when LEI=0LEI=0, indicating no shared boundary

This spatial metric analysis provides valuable insights into the dynamics of gully development patterns, offering a detailed understanding of how gullies evolve over time in terms of infilling, edge expansion, or spontaneous growth.

3. Results

4.1. Trend Analysis and Gully Development Pattern

4.1.1. Trend Analysis

In this study, between 2010 and 2020, the difference in area for gullies in Abia State was 6.78 km^2 between 2010 and 2015, and 14.88 km^2 between 2015 and 2020. The difference in area for gullies in Anambra State was 12.25 km^2 between 2010 and 2015, and 16.39 km^2 between 2015 and 2020. The difference in area for gullies in Enugu State was 4.94 km^2 between 2010 and 2015, and 3.6 km^2 between 2015 and 2020. the difference in area for gullies in Ebonyi State was 3.17km^2 between 2010 and 2015, and 9.97 km^2 between 2015 and 2020. the difference in area for gullies in Imo State was 4.09 km^2 between 2010 and 2015, and 4.72 km^2 between 2015 and 2020, see Table 4.1 for details.

Table 4.1: Difference in gully area between 2010 and 2020

Epoch	2010-2015	2015-2020
Abia	6.78	14.88
Anambra	12.25	16.39
Enugu	4.94	3.6
Ebonyi	3.17	9.97
Imo	4.09	4.72

Furthermore, the total area for gullies in Abia State was 35.74 km^2 between 2010 and 2015, and 57.4 km^2 between 2015 and 2020. The total area for gullies in Anambra State was 55.39km^2 between 2010 and 2015, and 84.03 km^2 between 2015 and 2020. The total area for gullies in Enugu State was 28.6 km^2 between 2010 and 2015, and 37.14 km^2 between 2015 and 2020. the total area in area for gullies in Ebonyi State was 22.11km^2 between 2010 and 2015, and 35.25 km^2 between 2015 and 2020. the total area for gullies in Imo State was 25.35 km^2 between 2010 and 2015, and 34.16 km^2 between 2015 and 2020, see Table 4.2 for details.

Table 4.2: Difference in gully area between 2010 and 2020

Epoch	2010-2015	2015-2020
Abia	35.74	57.4
Anambra	55.39	84.03
Enugu	28.6	37.14
Ebonyi	22.11	35.25
Imo	25.35	34.16

The trend of change of gullies in Abia State was given as 18.97% between 2010 and 2015, and 25.92% between 2015 and 2020. The trend of change of gullies in Anambra State was 22.12% between 2010 and 2015, and 19.50% between 2015 and 2020. trend of change of gullies in Enugu State was 17.27% between 2010 and 2015, and 9.69% between 2015 and 2020. trend of change of gullies in Ebonyi State was 14.34% between 2010 and 2015, and 28.28% between 2015 and 2020. trend of change of gullies in Imo State was 16.13% between 2010 and 2015, and 13.82% between 2015 and 2020, see figure 4.1 for details.

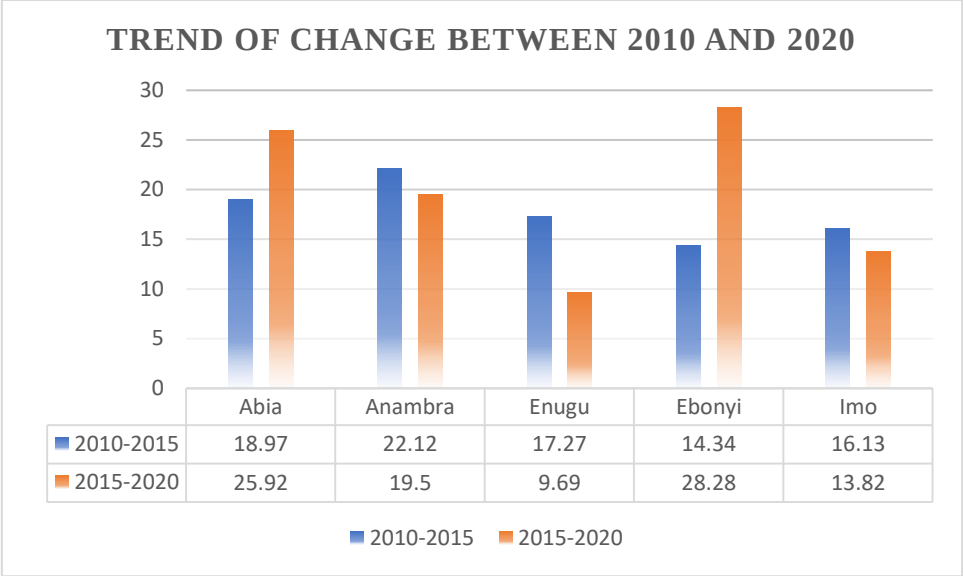

Figure 4.1: Trend of changeof gullies between 2010 and 2020

The annual rate of change of gullies in Abia State was given as 3.79% between 2010 and 2015, and 5.18% between 2015 and 2020. The annual rate of change of gullies in Anambra State was 4.42% between 2010 and 2015, and 3.9% between 2015 and 2020. annual rate of change of gullies in Enugu State was 3.45% between 2010 and 2015, and 1.93% between 2015 and 2020. annual rate of change of gullies in Ebonyi State was 2.86% between 2010 and 2015, and 5.65% between 2015 and 2020. annual rate of change of gullies in Imo State was 3.22% between 2010 and 2015, and 2.76% between 2015 and 2020, see figure 4.2 for details.

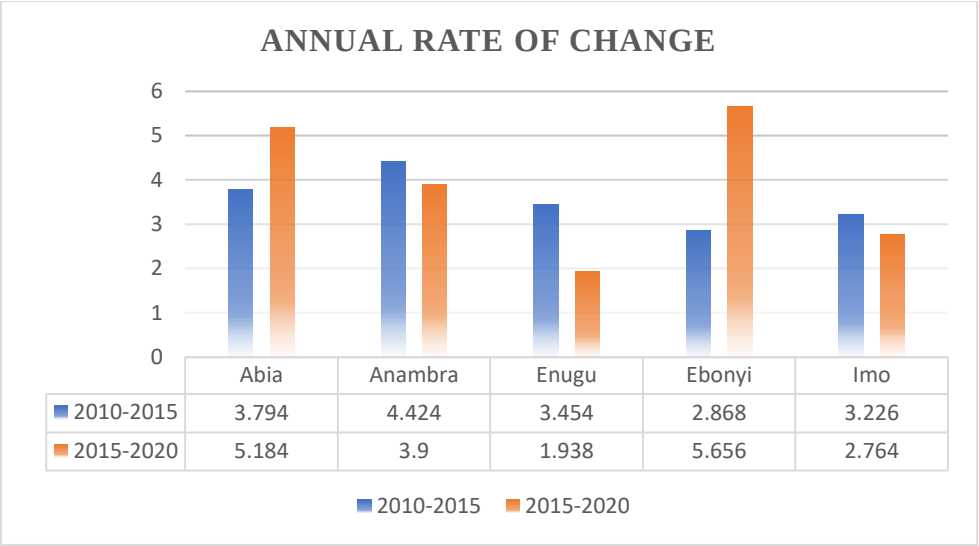

Figure 4.2: Annual rate of change of gullies between 2010 and 2020

4.1.2 Gully Development Pattern within South East, Nigeria

A quantitative method by Xiaoping *et al*, (2010) was used to map gully growth types: infilling, edge expansion, and spontaneous growth.

The results show two types of growth within the study area. Between 2010 and 2015, 73.3% of overall growth in the study area was attributed to edge expansion, while 26.7% were attributed to Spontaneous growth, with Anambra State having a high percentage of edge-expansion and spontaneous growth in the said period.

In the last epoch between 2015 and 2020, edge-expansion and spontaneous growth expansion were also the two dominant pattern in the study area with 64.2% and 35.8% respectively. Edge expansion is seen

dominant in Abia State, Anambra State and Enugu State. Spontaneous growth is seen dominant in Anambra State, Imo State, and Ebonyi State. The summary of the results is displayed in figures 4.3 - 4.6.

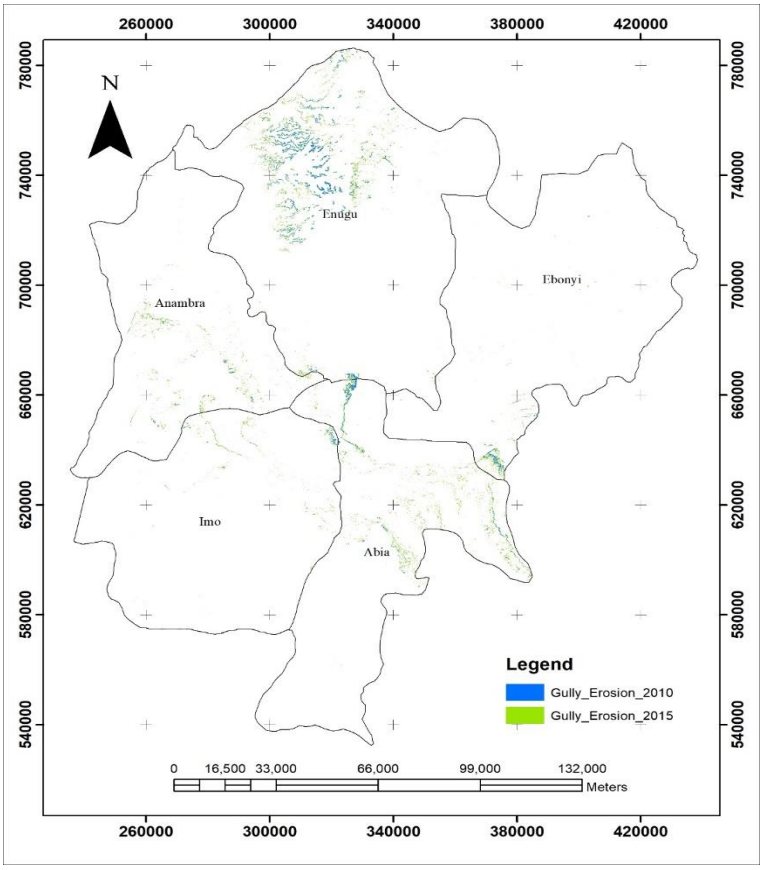

Figure 4.3: Development pattern between 2010 and 2015

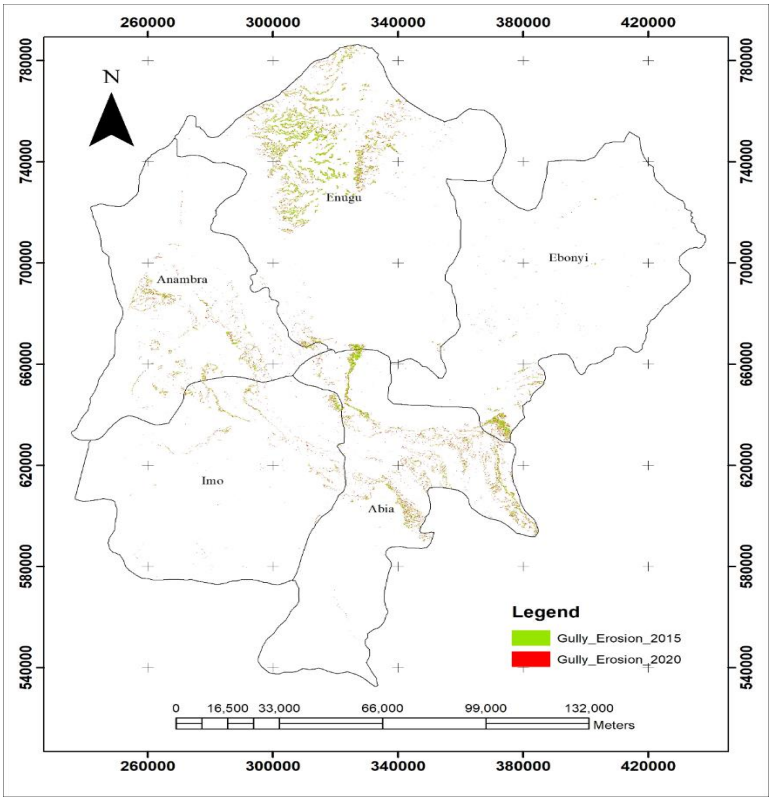

Figure 4.4: Development pattern between 2015 and 2020

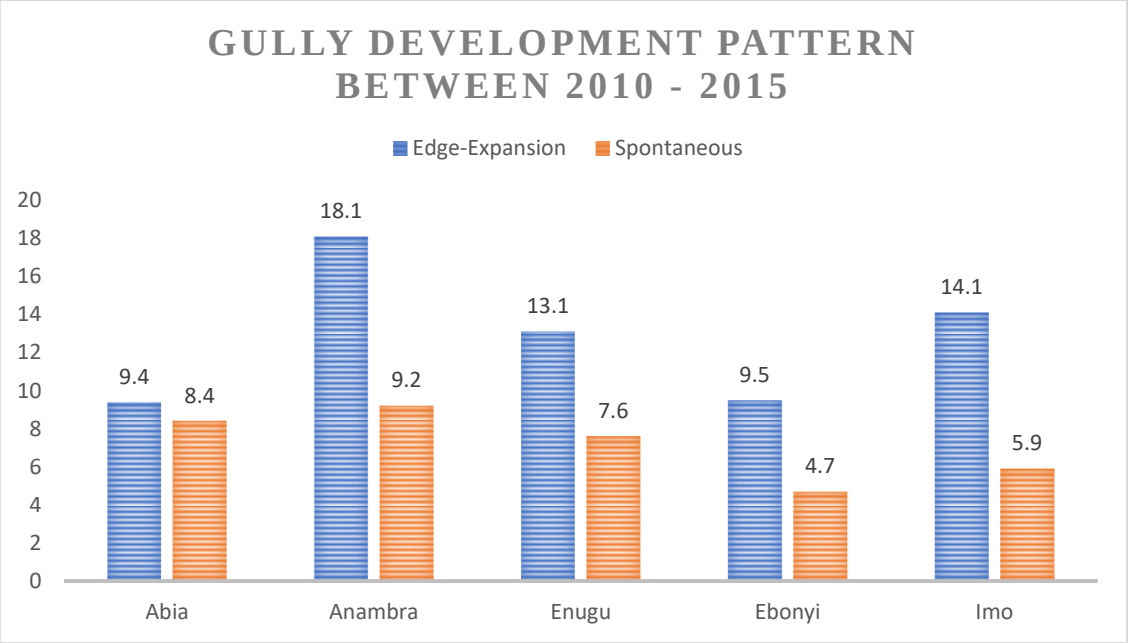

Figure 4.5: Gully Development percentage between 2010 and 2015

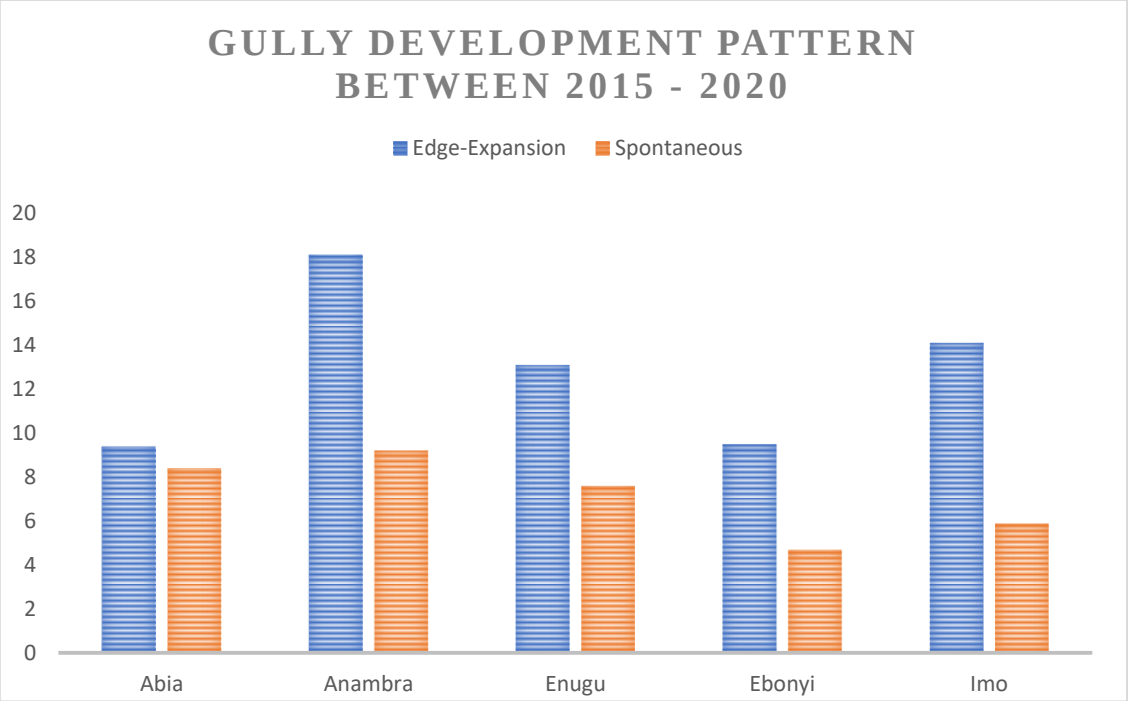

Figure 4.6: Gully Development percentage between 2015 and 2020

4. Conclusion

This study presents a comprehensive analysis of gully erosion trends and patterns in the South-Eastern states of Nigeria over the decade from 2010 to 2020. The results indicate notable variations in the change in gully areas across different states within the region, providing valuable insights into the dynamic nature of gully erosion.

The key findings of the study are:

1. The analysis reveals distinct differences in the change in gully areas for each state during the two sub-periods (2010-2015 and 2015-2020).
2. Anambra State exhibited the highest difference in gully area during both sub-periods, highlighting the severity of gully erosion in this region.

3. The total area covered by gullies increased significantly in all states over the decade, emphasizing the widespread and escalating nature of the gully erosion problem.
4. The trend of change in gullies varied between the two sub-periods, with each state experiencing fluctuations in the rate of change.
5. An overall increasing trend in gully areas was observed in most states, signifying the persistent and escalating nature of gully erosion challenges.
6. The annual rate of change in gullies provides further granularity, revealing varying rates in each state during the two sub-periods.
7. Some states experienced higher annual rates of change, indicating accelerated gully expansion in certain areas.
8. Spatial metrics, specifically the Landscape Expansion Index (LEI), were employed to distinguish gully growth types, including infilling, edge expansion, and spontaneous growth.
9. The results identified two dominant growth patterns—edge expansion and spontaneous growth—within the study area during both sub-periods.
10. Anambra State exhibited a high percentage of both edge expansion and spontaneous growth, emphasizing the diverse nature of gully development within the region.

The findings of this study hold significant implications for understanding the evolving landscape of gully erosion in South-East Nigeria. The identification of distinct trends and growth patterns provides essential information for policymakers, researchers, and local communities to formulate targeted and effective erosion control strategies.

The study results carry the following Implications:

1. The escalating trend in gully areas underscores the urgency for proactive and sustainable erosion control measures to mitigate the socio-economic and environmental impacts.

2. Variation in growth patterns highlights the need for region-specific strategies, considering the diverse nature of gully development in different states.

3. The study emphasizes the importance of continuous monitoring and adaptive management practices to address the dynamic and evolving nature of gully erosion challenges.

In conclusion, the insights derived from this study contribute to the growing body of knowledge on gully erosion in the region and provide a foundation for informed decision-making in erosion control and land management practices.

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