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Predicting future gully development in south-east Nigeria: A 10- Year Forecast (2020-2030)

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Abstract

This study investigates the trajectory of gully erosion in South-East Nigeria over the past decade (2010-2020) and employs an artificial neural network model to predict future gully development for the next ten years (2020-2030). The analysis reveals a substantial increase in gully areas across the states of Abia, Anambra, Enugu, Ebonyi, and Imo from 2010 to 2020, indicating a pressing environmental concern. The predictive model, validated at 79.24% correctness, anticipates a significant expansion of gully coverage by 2030. The implications of these predictions highlight the need for proactive measures to counteract the adverse effects of gully erosion on the environment, infrastructure, and communities. This study provides valuable insights for regional planning, resource allocation, and policy formulation, emphasizing the urgency of collaborative efforts to address the escalating threat of gully erosion in South-East Nigeria.

Keywords: Erosion Control; Gully Development; Land Degradation; Prediction; South-East Nigeria

1 Introduction

The South-East region of Nigeria has grappled with the persistent and escalating challenge of gully erosion, presenting a significant threat to the environment, infrastructure, and local communities. Gully erosion, characterized by the formation of deep channels and ravines, poses severe consequences, including land degradation, loss of agricultural productivity, and disruption of settlements. The urgency to understand and mitigate this issue has led to a surge in research efforts, with scholars delving into various aspects of gully erosion dynamics.

Gully erosion has been a longstanding concern in South-East Nigeria, with numerous studies highlighting its detrimental impact (Adekalu et al., 2007; Okpala, 1990). The region's vulnerability to erosion is exacerbated by factors such as climatic conditions, topography, and human activities (Nwankwo and Nwankwoala, 2018a). These studies underscore the need for continuous monitoring and proactive measures to address the escalating gully erosion menace.

The consequences of gully erosion extend beyond immediate environmental degradation. Hundreds of people are directly affected annually, leading to the relocation of communities (Egboka and Orajaka, 1990). Agricultural lands become unsuitable for cultivation, impacting food security and livelihoods (Igbokwe et al., 2008). The socio-economic implications highlight the urgency for predictive models to inform mitigation strategies (Nwankwo and Nwankwoala, 2018b).

While previous studies have provided valuable insights into gully erosion dynamics, there remain gaps in understanding the evolving patterns and future trajectories. Existing maps and assessments often lack the depth required for proactive planning and timely interventions (Akpokodje et al., 2010). New approaches are needed to comprehensively assess the dynamic nature of gully development.

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The urgency of the gully erosion crisis necessitates a forward-looking approach. Anticipating future gully development trends is crucial for effective planning, resource allocation, and the formulation of sustainable mitigation strategies (Ward et al., 2000). Accurate predictions for the next decade (2020–2030) will empower stakeholders to implement targeted measures and reduce the adverse impact on the environment and communities.

Recent advancements in remote sensing technologies and predictive modeling techniques offer promising avenues for forecasting gully development. Integrating these tools can enhance the precision and reliability of predictions (Prasannakumar et al., 2012). Machine learning approaches, such as artificial neural networks, have demonstrated efficacy in mapping and predicting erosion features (Alexakis et al., 2013).

Despite the existing body of knowledge on gully erosion, there is a notable research gap in predicting future developments with a sufficient temporal scope. This study aims to address this gap by employing advanced methodologies and leveraging available data sources for a comprehensive 10-year forecast (2020–2030).

1.1 Study Area

South-East Nigeria constitutes one of Nigeria's geopolitical zones (refer to Figure 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 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.

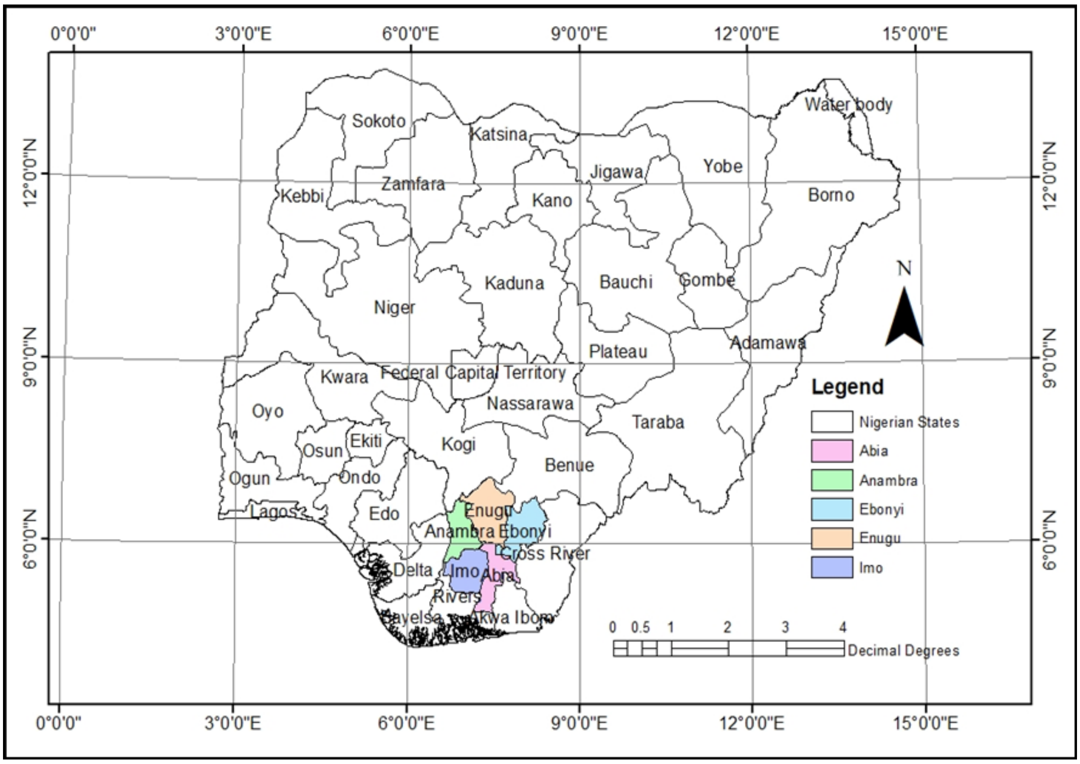
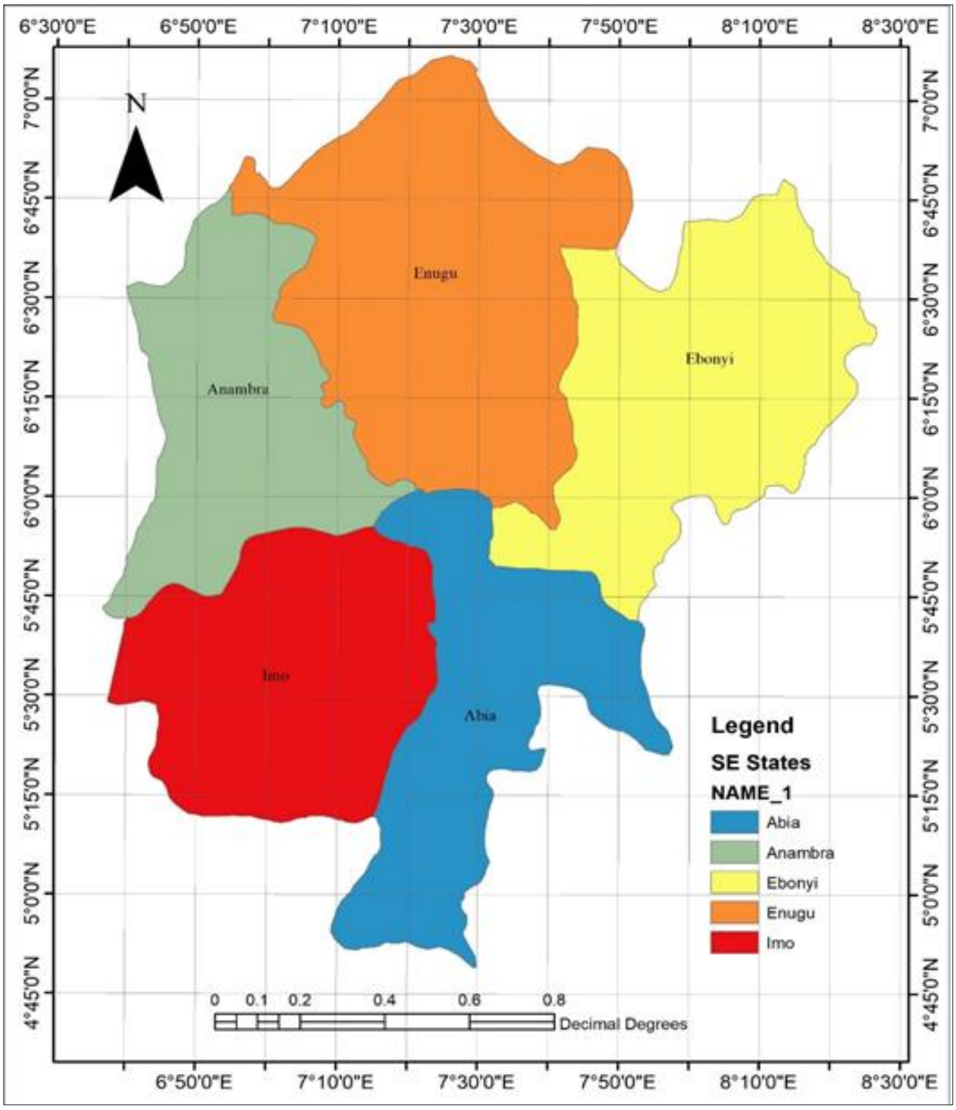


Figure 1 Map of Nigeria



(Source: Department of Surveying and Geoinformatics, NAU)

Figure 2 Map of South East, Nigeria

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:

- **Kompsat-3 Imagery:** High-resolution satellite images were utilized to capture detailed visuals of the study area in South East Nigeria.
- **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.
- **Topographic Maps:** Topographic maps were consulted to obtain additional contextual information about the terrain and geographical features.
- **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.

2.4 Future Prediction

To anticipate future gully development, an integrated approach was employed, leveraging a range of spatial and topographic variables. Gully erosion maps from 2010, 2015, and 2020, alongside slope, terrain ruggedness index, stream power index, and topographic wetness index, were chosen as inputs for the model. Calibration was a pivotal step, necessitating the resampling of raster layers to ensure uniform geometry with the gully erosion maps.

The model input process comprised several steps

- Selection of the early image (2010) from the software interface.
- Selection of the later image (2020) from the software interface.
- Addition of spatial variables (slope, terrain ruggedness index, stream power index, and topographic wetness index) from the software interface.
- Execution of geometry checks to ensure conformity between input datasets.

Following this, the model underwent training using an artificial neural network, employing the classic realization of a multilayer perceptron. The target output data was the change map, and the model engaged in initial preprocessing, including dummy coding and normalization. Subsequently, the model performed sampling and training, utilizing the multilayer perceptron with the numpy.tanh sigmoid function. Notably, the target variables (change map categories) were scaled to the (-1, 1) interval during dummy coding.

Key steps in the training process included

- Division of the training set into a learning set (80% of samples by default) and a validation set (20% of samples).
- On-line learning with stochastic: a random sample was selected from the learning set, and the weights of the net were updated during forward/backward propagation.
- Calculation of the error fitting equation, representing the average square error of partial outputs of the net.

Upon completion of training, the model provided valuable information about learning, including: i. A graph illustrating the average square errors on the learning and validation sets after each epoch. ii. The minimum validation overall error, denoting the best currently achieved result, with the weights of the net stored and returned as the best net after training. iii. Delta overall accuracy, representing the difference between the minimum validation error and the current validation error. iv. Current validation kappa, indicating the kappa statistic achieved on the validation set.

Transition potential modeling involved the following software procedure:

- Definition of the number of samples (1000 random samples were utilized).
- Selection of the method for training transition potential (Artificial neural network).
- Determination of the neighborhood sampling point (1px).
- Specification of the learning rate (0.100).
- Setting of the maximum number of iterations (1000).

Finally, the model was employed to predict future gully development in 2030, integrating the insights gained from the comprehensive training and calibration processes.

3 Results and discussion

3.1 Gully Erosion Mapping of South East Nigeria in 2010

The gully erosion distribution of South East Nigeria in 2010 as shown in figure 3 and Table.1 revealed a total gullied area of 67.98 km^2. The gullies in Abia state covered 21.30% of the study area with an area of 14.48 km^2, Anambra State had 31.73% gully coverage with an area of 21.57 km^2, Enugu State had a gully coverage of 17.40% with an area of 11.83 km^2, Ebonyi State had a gully coverage of 13.93% with an area of 9.47 km^2, and lastly, Imo State had a coverage of 15.64% with an area of 10.63 km^2.

Table 1 South East Gully Erosion distribution for 2010

S/N	State	Area	Percentage
1	Abia	14.48	21.30
2	Anambra	21.57	31.73
3	Enugu	11.83	17.40
4	Ebonyi	9.47	13.93
5	Imo	10.63	15.64
	Total	67.98	100

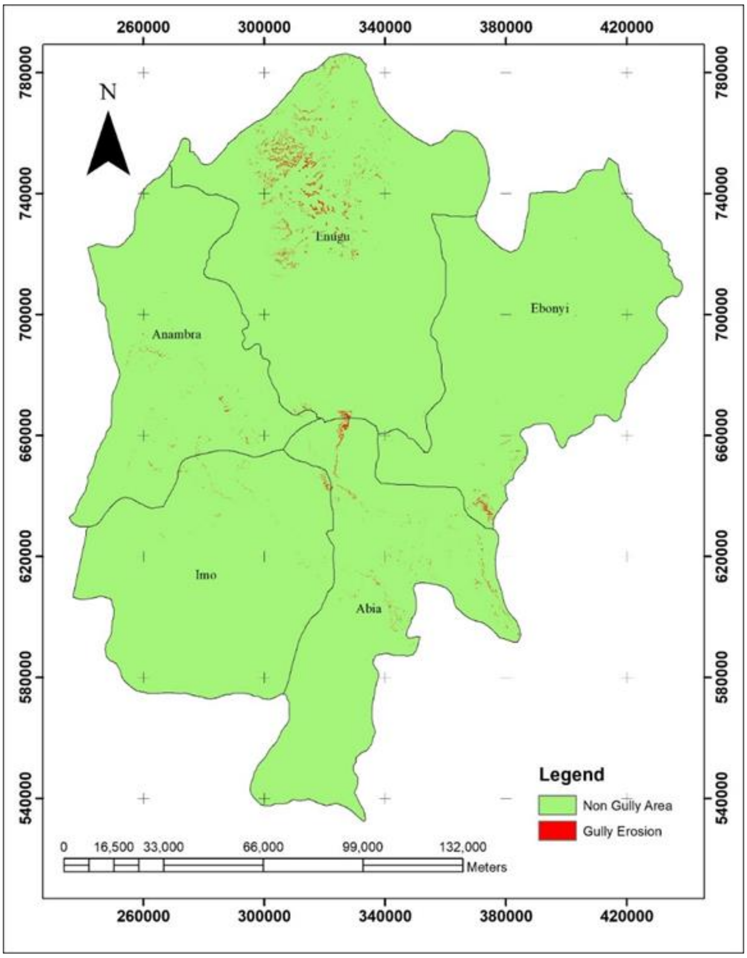


Figure 3 South East Gully Erosion Map in 2010

3.2 Gully Erosion Mapping of South East Nigeria in 2015

The gully erosion distribution of South East Nigeria in 2015 as shown in figure 4 and Table 2 revealed a total gullied area of 99.21 km^2. The gullies in Abia state covered 21.43% of the study area with an area of 21.26 km^2, Anambra State had 34.09% gully coverage with an area of 33.82 km^2, Enugu State had a gully coverage of 16.90% with an area of 16.77 km^2, Ebonyi State had a gully coverage of 12.74% with an area of 12.64 km^2, and lastly, Imo State had a coverage of 14.84% with an area of 14.72 km^2.

Table 2 South East Gully Erosion distribution for 2015

S/N	State	Area	Percentage
1	Abia	21.26	21.43
2	Anambra	33.82	34.09
3	Enugu	16.77	16.90
4	Ebonyi	12.64	12.74
5	Imo	14.72	14.84
	Total	99.21	100

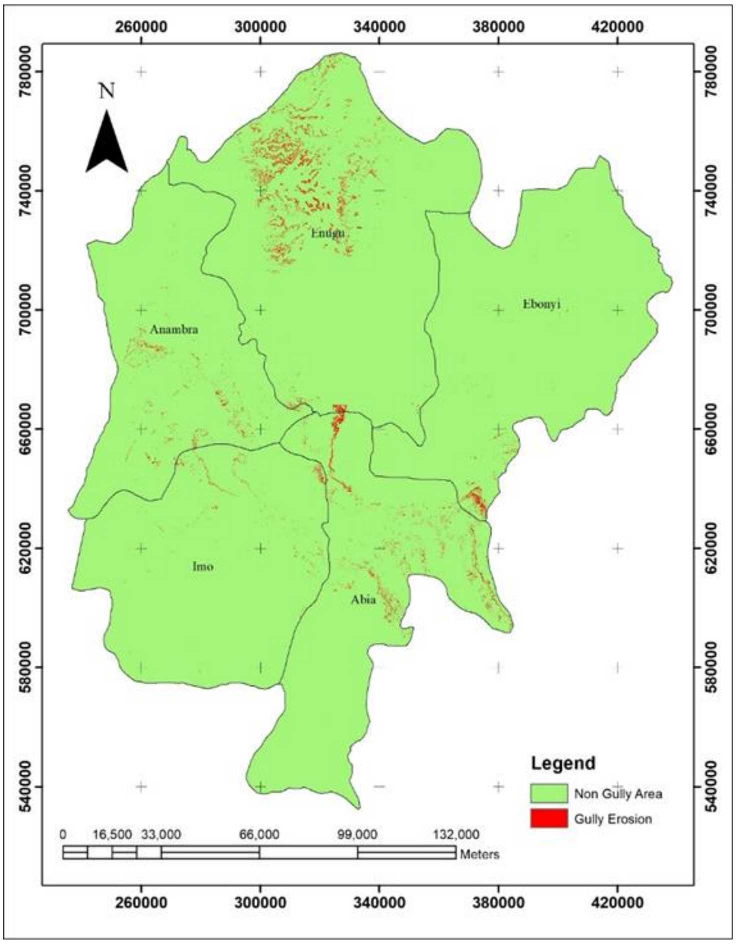


Figure 4 South East Gully Erosion Map in 2015

3.3 Gully Erosion Mapping of South East Nigeria in 2020

The gully erosion distribution of South East Nigeria in 2020 as shown in figure 5 and Table 3 revealed a total gullied area of 148.77 km^2. The gullies in Abia state covered 24.29% of the study area with an area of 36.14 km^2, Anambra State had 33.75% gully coverage with an area of 50.21 km^2, Enugu State had a gully coverage of 13.69% with an area of 20.37 km^2, Ebonyi State had a gully coverage of 15.20% with an area of 22.61 km^2, and lastly, Imo State had a coverage of 13.07% with an area of 19.44 km^2.

Table 3 South East Gully Erosion distribution for 2020

S/N	State	Area	Percentage
1	Abia	36.14	24.29
2	Anambra	50.21	33.75
3	Enugu	20.37	13.69
4	Ebonyi	22.61	15.20
5	Imo	19.44	13.07
	Total	148.77	100

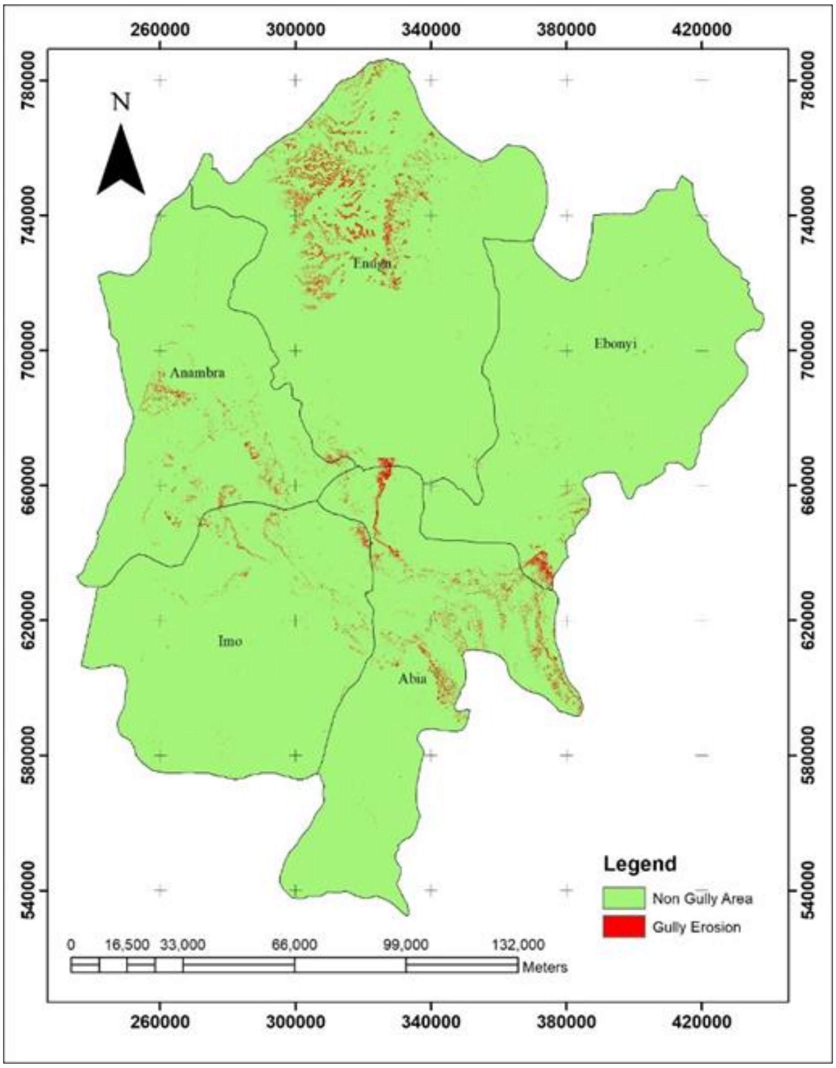


Figure 5 South East Gully Erosion Map in 2020

3.4 Summary of gully erosion mapping in South East, Nigeria from 2010 to 2020

The summary of the gully erosion mapping between 2010 and 2020 is displayed in Table 4 and figure 6 and summarily discussed below.

Table 4 South East Gully Erosion distribution from 2010 - 2020

S/N	Year	2010	2015	2020
	State	**Gully Area Cover**		
1	Abia	14.48	21.26	36.14
2	Anambra	21.57	33.82	50.21
3	Enugu	11.83	16.77	20.37
4	Ebonyi	9.47	12.64	22.61
5	Imo	10.63	14.72	19.44
	Total	67.98	99.21	148.77

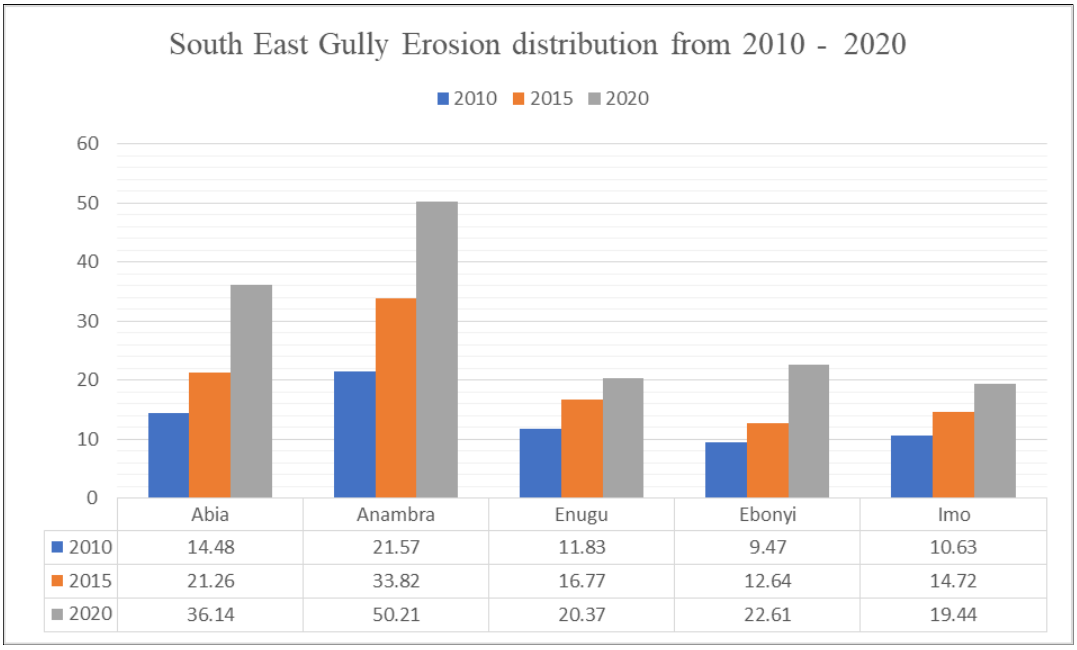


Figure 6 Histogram of South East Gully Erosion distribution from 2010 - 2020

From Table 4 and figure 6, the results of gully erosion distribution in South East Nigeria in 2010, 2015, and 2020 indicate significant changes in the gullied areas across the five states (Abia, Anambra, Enugu, Ebonyi, and Imo) over the period.

In 2010, the total gullied area was 67.98 km^2. Abia state had a gully coverage of 21.30% (14.48 km^2), Anambra state had 31.73% coverage (21.57 km^2), Enugu state had 17.40% coverage (11.83 km^2), Ebonyi state had 13.93% coverage (9.47 km^2), and Imo state had 15.64% coverage (10.63 km^2).

By 2015, the gullied area increased to 99.21 km^2. Abia state still had a gully coverage of 21.43% (21.26 km^2), Anambra state had 34.09% coverage (33.82 km^2), Enugu state had 16.90% coverage (16.77 km^2), Ebonyi state had 12.74% coverage (12.64 km^2), and Imo state had 14.84% coverage (14.72 km^2).

In 2020, the gullied area increased to 148.77 km^2. Abia state had a gully coverage of 24.29% (36.14 km^2), Anambra State had 33.75% gully coverage (50.21 km^2) Enugu State had a gully coverage of 13.69% (20.37 km^2), Ebonyi State had a gully coverage of 15.20% (22.61 km^2), and lastly, Imo State had a coverage of 13.07% (19.44 km^2).

These results highlight the persistence of gully erosion in the South East Nigeria region over the studied period. The significant increase in gullied areas between 2010 and 2020 indicates a worsening situation.

The implications of these findings are substantial. Gully erosion can lead to land degradation, loss of arable land, and environmental degradation. The observed gully expansions emphasize the need for effective soil and water conservation measures, as well as sustainable land management practices in the region. The results can inform policymakers, land managers, and local communities to prioritize gully erosion control and mitigation strategies, focusing on areas experiencing the highest rates of gully expansion. Furthermore, the data can serve as a baseline for future monitoring and assessment of gully erosion dynamics in South East Nigeria.

3.5 Future Prediction of gully development for the next 10 years (2020 – 2030)

Future gully development prediction was done based on historical change from 2010 to 2020, using influencing factors like slope, terrain ruggedness index , stream power index, and topographic wetness index. The change assessed between 2010 and 2020 are identified and trained as transitions from one gully state to another using an artificial neural network model.

After the training, the model was used to predict the change to 2020, and was validated using a gully erosion data produced from 2020 Kompsat imagery, see figure 7. The validation exercise gave an overall percentage of correctness of 79.24%, this signifies a good predictive result. Following the validation results, a prediction was made to 2030, see Table 5 for results.

Table 5 Future Gully Distribution in 2030

S/N	State	Area	Percentage
1	Abia	40.81	23.64
2	Anambra	57.46	33.28
3	Enugu	26.52	15.36
4	Ebonyi	25.88	14.99
5	Imo	21.98	12.73
	Total	172.65	100

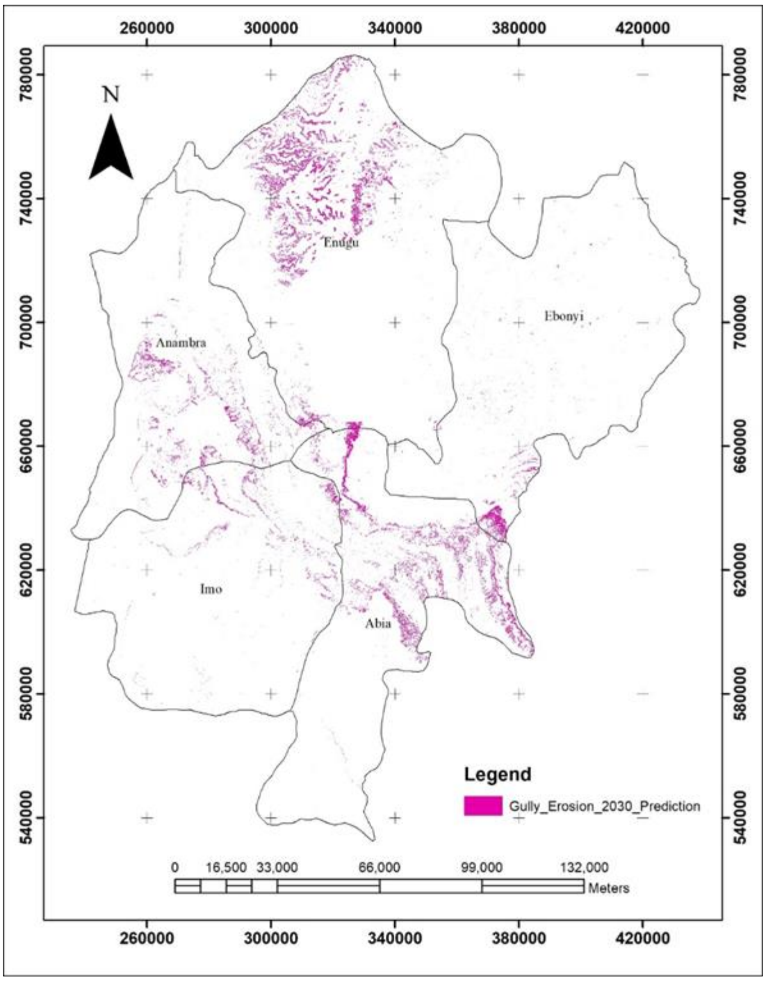


Figure 7 2030 Gully Development Prediction

The findings (as shown in Table 5) indicate that there will be a significant increase in the distribution of gully erosion, covering a total area of 172.65 km^2.

In Abia state, gully erosion will extend to 23.64% of the study area, covering an estimated area of 40.81 km^2. This represents a considerable expansion of gullies within the state. Anambra State will experience a 33.28% increase in gully coverage, with an area of 57.46 km^2 being affected by erosion. Enugu State will witness a 15.36% increase in gully coverage, resulting in an area of 26.52 km^2 affected by erosion. Ebonyi State will also face an increase in gully coverage by 14.99%, leading to an area of 25.88 km^2 impacted by erosion. Lastly, Imo State will experience a 12.73% increase in gully coverage, affecting an area of 21.98 km^2.

These findings hold significant implications for the affected regions. Gully erosion poses a severe threat to the environment, infrastructure, and livelihoods of the local communities. It can lead to the loss of arable land, degradation of soil quality, destruction of vegetation, and alteration of drainage patterns. The increased gully coverage predicted for South East Nigeria in 2030 suggests a heightened risk of soil erosion, landslides, and the displacement of communities.

The significance of this prediction lies in the need for proactive measures to mitigate the impacts of gully erosion. Remote sensing technologies play a crucial role in monitoring and mapping the extent of gullies over large areas. By providing accurate spatial information, remote sensing enables the identification of vulnerable regions and supports effective planning and resource allocation for erosion control and land management strategies.

To address the implications of increased gully erosion, stakeholders, including government agencies, environmental organizations, and local communities, should collaborate to implement sustainable land-use practices, afforestation programs, and erosion control measures. The findings from this prediction can serve as a valuable tool for decision-makers, helping them prioritize intervention areas and allocate resources to mitigate the negative impacts of gully erosion in South East Nigeria.

4 Conclusion

The comprehensive analysis of gully erosion distribution in South East Nigeria between 2010 and 2020 reveals alarming trends. The significant increase in gullied areas points to a worsening environmental scenario, demanding urgent attention. Gully erosion persistence signifies a potential threat to land resources, agriculture, and ecosystems, emphasizing the critical need for effective intervention.

The observed expansion of gully erosion holds immense significance for regional planning and environmental management. Policymakers, researchers, and local communities can use this data to prioritize areas for intervention, allocate resources strategically, and develop targeted mitigation plans. The study's significance extends beyond academia, offering practical insights for sustainable land use and ecosystem preservation.

The implications of escalating gully erosion in South East Nigeria are multifaceted. Land degradation, loss of arable land, and disruptions to ecosystems pose challenges to both rural and urban communities. These findings underscore the need for a collaborative and multidisciplinary approach involving government agencies, environmental organizations, and local communities to implement adaptive measures.

As the study addresses historical trends, future research should focus on dynamic monitoring and predictive modeling. Integrating advanced technologies such as machine learning and remote sensing can enhance the accuracy of predictions. Additionally, exploring the socio-economic impacts of gully erosion and assessing the effectiveness of implemented mitigation strategies will contribute to a more holistic understanding of the issue.

The predictive model utilized in this study, with a validation correctness of 79.24%, provides a valuable tool for anticipating gully development. Further refinements and validations of the model could enhance its reliability. Future studies could explore the integration of additional influencing factors and refine the model to capture finer spatial and temporal variations in gully erosion dynamics.

Given the transboundary nature of environmental challenges, fostering collaboration among states within the South East region and neighboring regions is essential. Shared resources, expertise, and collaborative initiatives can amplify the impact of erosion control and land management efforts. A regional approach can contribute to a more comprehensive understanding and effective mitigation of gully erosion.

Engaging local communities in the monitoring and mitigation process is crucial for the sustainability of interventions. Community-based initiatives, awareness programs, and capacity-building efforts can empower residents to actively participate in erosion control measures. This approach ensures that solutions align with local needs and harness traditional knowledge in tandem with modern methodologies.

The study's findings and predictions should inform policy formulation at both state and federal levels. Integrating erosion control policies into broader environmental sustainability frameworks can contribute to a more resilient and adaptive approach. Allocating resources for continuous monitoring, research, and the implementation of proven mitigation strategies should be prioritized in policy agendas.

In conclusion, while the study sheds light on the pressing issue of gully erosion in South East Nigeria, it also points toward a roadmap for future research, collaborative efforts, and policy actions aimed at ensuring the long-term environmental health and resilience of the region.

Compliance with ethical standards

Disclosure of conflict of interest

The author(s) declared no potential conflicts of interest.

References

[1] Adekalu, K. O., Olorunfemi, I. E., & Osunbitan, J. A. (2007). Soil erosion and sediment yield in a watershed in southwestern Nigeria: A remote sensing and GIS approach. CATENA, 70(2), 201-207.

[2] Okpala, D. C. (1990). Gully erosion in Anambra State of Nigeria. Geomorphology, 3(4), 339-349.

[3] Nwankwo, C. I., & Nwankwoala, H. O. (2018a). Prediction of soil erosion hazard and sediment yield in Imo State, Nigeria, using Revised Universal Soil Loss Equation (RUSLE). Journal of Agricultural Science, 10(3), 59-73.

[4] Nwankwo, C. I., & Nwankwoala, H. O. (2018b). GIS-based prediction of soil erosion risk in Imo State, Nigeria. Journal of Environmental Management and Tourism, 9(1), 122-133.

[5] Igbokwe, E. M., Nwankwor, G. I., & Ibem, O. E. (2008). The socio-economic and environmental impacts of gully erosion in Southeastern Nigeria. Global Journal of Environmental Research, 2(1), 38-46.

[6] Egboka, B. C., & Orajaka, S. (1990). Gully erosion in southeastern Nigeria: causes, problems and remedies. Catena, 17(2-3), 345-357.

[7] Akpokodje, E. G., Akpokodje, J. E., & Ogbodo, E. N. (2010). Gully erosion in southeastern Nigeria: Causes and remediation. International Journal of Natural and Applied Sciences, 6(2), 181-187.

[8] Ward, P. S., Trimble, S. W., & Kittrick, J. A. (2000). Gully erosion in southeast Arizona, USA: Physical processes, modeling, and the role of Quaternary alluvium. Earth Surface Processes and Landforms, 25(6), 603-617.

[9] Prasannakumar, V., Vijith, H., Abinod, S., Geetha, N., & Sreekanth, P. D. (2012). Spatial prediction of soil erosion risk using remote sensing and GIS: A case study of the Kali watershed, South India. International Journal of Applied Earth Observation and Geoinformation, 19, 37-48.

[10] Alexakis, D. D., Hadjimitsis, D. G., & Agapiou, A. (2013). Use of remote sensing and GIS for the assessment of soil erosion potential in the region of Paphos, Cyprus. Natural Hazards, 69(1), 643-663.