International Journal of Research in Engineering, Science and Management
Volume 8, Issue 3, March 2025
https://www.ijresm.com | ISSN (Online): 2581-5792

Digital Shoreline Analysis System (DSAS) Assessment of Future Shoreline Position at Koluama II Settlement, Bayelsa State, Nigeria

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***Abstract*: This study is aimed at utilizing the Digital Shoreline Analysis System (DSAS) to assess future shoreline position at Koluama II settlement, Bayelsa State, Nigeria, by the year 2040. The objectives of the study are to assess the expected extent of shoreline position at Koluama II settlement by the year 2040 and to evaluate the corresponding changes in land (both gained and loss) from 2020 to 2040. The study employed a quasi-experimental research design and utilized multiple spatio-temporal lands at satellite data set of 1990, 2000, 2010, and 2020. The Digital Shoreline Analysis System (DSAS) in ArcGIS 10.8.2 was used to forecast the future shoreline position, while land gained were determined through the measure analysis tool in ArcGIS 10.8.2. The results reveal that by 2040, erosion will move landward and at a rate of 7.9m/annum, whereas, land loss was computed to be 25ha of land from 2020 to 2040. This implies that land use such as farm lands, infrastructures and white beaches will be lost to erosion, and as such will bring about socio-economic challenges in the future. As part of its recommendations, the study encouraged the establishment of coastal zone for the region.**

***Keywords*: GIS, EPR, DSAS, Shoreline, Spatio-temporal.**

1. Introduction

A. Background to the Study

Shorelines are areas that become visible during low tide and are situated between the high and low tide boundaries (Mayhew, 2009). According to Bunnet and Okurotifa (2013), the shore refers to the stretch of land that exists between the levels of low water (LWL) and high water (HWL). This land defines the boundary where tidal effects are observed (Boak & Turner, 2005). The shoreline is defined as the boundary where the land meets the water (Bunnett & Okurotifa, 2013). The ongoing fluctuation of tides, storms, and sea levels continually alters the position of shorelines through the processes of erosion and accretion. These shifting shoreline positions are important indicators of changes occurring within the coastal zone. Similarly, changes in the shoreline can serve as early indicators for adapting to the impacts of climate change and mitigating human-induced factors that contribute to the degradation of coastal areas.

Shorelines play a crucial role in serving various important functions, one of which is acting as a natural defense against coastal storms by absorbing floodwaters and dissipating wave energy (McLachlan and Defeo, 2017). However, due to adverse natural factors and the increasingly harmful impact of human activities on the shore, the ability of the shoreline to continue providing these essential functions has been compromised (David, 2021; Morales, 2022; Odubo and Eli, 2024a; Odubo and Mienye, 2024). Despite many countries implementing local environmental regulations, including coastal and marine protection laws, and signing international charters and conventions to safeguard the coastal environment, shoreline loss remains one of the most pressing global challenges.

The negative impacts of shoreline erosion often leads to land loss, property damage, ecosystem destruction, biodiversity decline, and annual flooding in nearby settlements (Patterson et al., 2010; Wright et al., 2019; Odubo and Mienye, 2024). Historically, shoreline changes have caused the relocation and adaptation of settlements for millennia, with human intervention through structural mechanisms to stabilize shoreline positions only emerging in more recent centuries (Burningham, 2020). However, this interference has complicated shoreline dynamics, making it more difficult to understand and predict these changes. To effectively address the challenges posed by coastal erosion and future sea level rise, it is crucial to gather accurate data and employ robust methods to delineate shorelines and precisely measure and represent changes in their position.

To uncover significant erosion and accretion patterns, shoreline spatiotemporal studies and quantification analyses have been employed by various stakeholders. The insights gained from these studies can offer comprehensive information to support researchers, decision-makers, and coastal zone planners and managers in making informed decisions. These studies are comprehensively detailed in Boye (2015), Akinluyi et al. (2018), and Guerrera and Martin-Martin (2021). Spatiotemporal analysis can capture patterns at both large and small scales, which can be linked to evolving environmental events. Oyedotun (2014) noted that both historical and contemporary events significantly influence spatiotemporal studies, affecting not only the geographical coverage but also

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the overall analysis. However, analyses of the historical and current events determine the future shoreline position.

Prevoius study carried out by Odubo and Eli (2024b), at Koluama 2 settlement provide adequate analysis through the integration of remote sensing, GIS and historical satellite images, to show the shoreline at Koluama 2 settlement and its areal extent; the degree and extent of changes along shoreline with regards to long- and short-term shoreline rate of change. The basis of this research is to make improvement in the study by Odubo and Eli (2024b), in order to make projection of the future shoreline position at Koluama2 settlement by the year 2040. Furthermore, land loss land gain will be determined between the period of 2020 and 2040. This will certainly allow for better management of the current and future development activities in this area.

B. Study Area

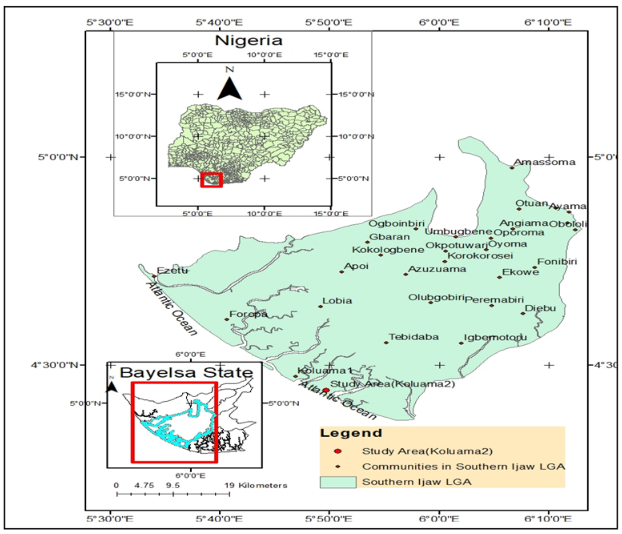

Fig. 1. Bayelsa state map showing study areas and settlements
Source: Author's adaptation from Bayelsa state administrative map, 2010 and Google Earth Pro Image, 2020

The study area is located in the Southern Ijaw Local Government Area of Bayelsa State, Nigeria (see Figure 1.0). It is positioned between latitudes 4º 00' 00"N and 4° 30' 00"N, and longitudes 5º 40' 00"E and 5° 50' 00"E. The soil in this area consists of both the beach ridge and mangrove zones (Okony et al., 1999).

The ridge barrier island complex in the study area is part of the outer sediment chain that protects the tidal basins of the Niger Delta from the direct effects of breaking swell waves (Okony et al., 1999). The vegetation in this region is mainly categorized as brackish water swamp forest, encompassing mangrove forests and coastal vegetation (Nyanayo, 1999). The Koluama 2 community is part of the Bassan subdivision of the Ijoid language group. The Bassan people are well-known for their skills as intermediaries in trade throughout the Niger Delta, particularly for their distribution of pots and cassava meal that they harvest themselves (Alagoa, 1999).

Originally, Koluama 1 and Koluama 2 were components of a larger entity within the ancient Koluama kingdom, which included multiple villages. Historical records reveal that the kingdom has experienced impacts from shoreline erosion (Amaize, 2012; Mieye and Odubo, 2016). However, in 1953, a combination of persistent high floods in the lower Niger Delta basin and coastal erosion caused by powerful explosions from oil and gas exploration, along with seismic activities by Shell D'Arcy (the precursor to Shell Petroleum Development Corporation), led to the division of the kingdom into the present-day Koluama 1 and Koluama 2 communities.

Currently, the Koluama II community is threatened by tidal waves, which pose a risk of submersion (Oyadongha, 2014). Recent appeals have been made to the Federal Government and the Niger-Delta Development Commission (NDDC) for intervention to provide shoreline protection and prevent the ocean from overtaking the community (Amaize and Omafuame, 2012).

2. Conceptual Review

A. Digital Shoreline Analysis System (DSAS)

Most studies use GIS software to measure and quantify shoreline shifts, either through human measurements or digital analysis tools (Jackson et al., 2012). Tools specifically designed for studying shoreline changes include the Digital Shoreline Analysis System (DSAS), SCARPS, Beach Tools, and Analysing Moving Boundaries Using R (AMBUR) (Jackson et al., 2012). However, to utilize these technologies, a GIS platform is required. The AMBUR package for the R programming environment leverages R's statistical, graphical, and geographic capabilities, providing scripts specifically designed to assist in shoreline change studies.But more crucially, the DSAS's capacity to carry out five statistical computations is what makes it more useful than other shoreline processing tools. They are the endpoint rate (EPR), linear regression rate (LRR), net shoreline movement (NSM), weighted linear regression (WLR), and shoreline change envelop (SCE). Calculating rate-of-change statistics is a noteworthy benefit of using statistical tools to analyse time series data for coastline positions. The quantification and evaluation of shoreline changes over time are made possible by these statistical techniques. Researchers and environmental specialists can learn a great deal about the direction and pace of shoreline changes by computing rate-of-change data. This information is essential for comprehending coastal dynamics, erosion or accretion trends, and the effects of different causes on coastal landscapes. Making educated decisions on land use and coastal erosion is crucial for environmental planning, coastal management, and other related fields.

The End Point Rate (EPR) method is widely used due to its straightforward calculation, requiring only two shoreline positions from different dates (Himmelstoss et al., 2018). Alternatively, DSAS v5.0 provides a method for forecasting shoreline positions up to 10 or 20 years into the future using historical shoreline data. The Kalman filter (Kalman, 1960) is employed alongside identified shoreline locations and model-derived positions, as demonstrated by Long & Plant (2012), to estimate future shoreline positions.

The Kalman filter method is selected based on the linear regression rate calculated by DSAS. It estimates the shoreline location and rate every tenth of a year, with each time step including an assessment of positional uncertainty. However, this approach may overlook or be uncertain about several critical aspects due to the complex processes driving shoreline changes, which might not always be incorporated into the model. This methodology assumes that a linear regression of past shoreline positions sufficiently predicts future coastline locations. DSAS has proven to be an effective tool for studying long-term shoreline changes. Cheng (2016) noted that a long temporal scale is essential for assessing these changes because the shoreline is influenced by various factors. For instance, during major wave events, shorelines can shift significantly landward, but sand often migrates back after such events, resulting in minimal net changes in shoreline configuration. Many studies have utilized DSAS to focus on long-term shoreline changes, specifically net shoreline change rates, by measuring the distance between the oldest and youngest shorelines. The use of DSAS's End Point Rate (EPR) to analyze shoreline change rates is well documented in the literature (Barik et al., 2019; Cheng, 2016; Baig et al., 2020; Nath et al., 2021, Odubo, 2024).

3. Methods and Materials

The study adopted the natural quasi experimental research design. The data-sets used for this research were collected from both primary and secondary sources. The primary sources of data involved direct collection of information from the field through careful observations and, measurements. The secondary data-sets were sourced from historically existing records, and these were sourced from the Google earth satellite imagery repository (1990, 2010, 2020). The Global Positioning System was used as the tool for field data collection.

Data analysis involved the use of Change rate analysis. Utilizing the DSAS EPR extension of ArcGis10.8.2 a time series of shoreline vector data for rate-of-change statistics for the net shoreline change rate and the shoreline change rate between different time periods was computed. However, The future shoreline position for 20 years, i.e., 2040, was calculated with respect to the shoreline position of 2020 using DSAS EPR.

4. Results and Discussion

Figure 2 displays the analysis results of shoreline rate of change for the periods 1990–2000, 2000–2010, 2010–2020, and the projected future shoreline position for 2040, with reference to the shoreline position of 2020 for Koluama II Settlement. The results indicate that the future shoreline is expected to move landward by 2040. Additionally, the findings suggest that, when computed from the year 2020, the highest erosion rates are predicted to occur at transects number 29, 30, and 31, with erosion extent of 172.75 meters/ annum, 174.94 meters/ annum, and 174.44m/annum respectively by the year 2040. Furthermore, the rate of movement of erosion will be 7.9m/annum.

Analyses from Figure 3 show that land loss is one of the major problems that plague the area as a result of erosion. The results show that by the year 2040, most part of the community will be eroded into the sea. Land loss at the year 2040 was computed to be 25ha of land.

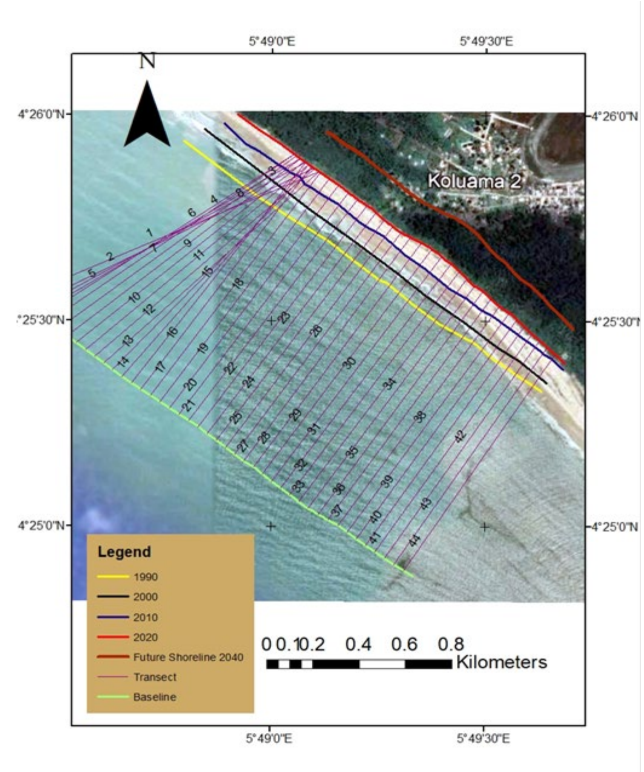

Fig. 2. DSAS Analysis of shoreline rate of change for 1990 – 2000, 2000 – 2010, 2010 – 2020 and future shoreline position at 2040 for Koluama settlement

Source: Author's Adaptation from Google Earth Pro (2022)

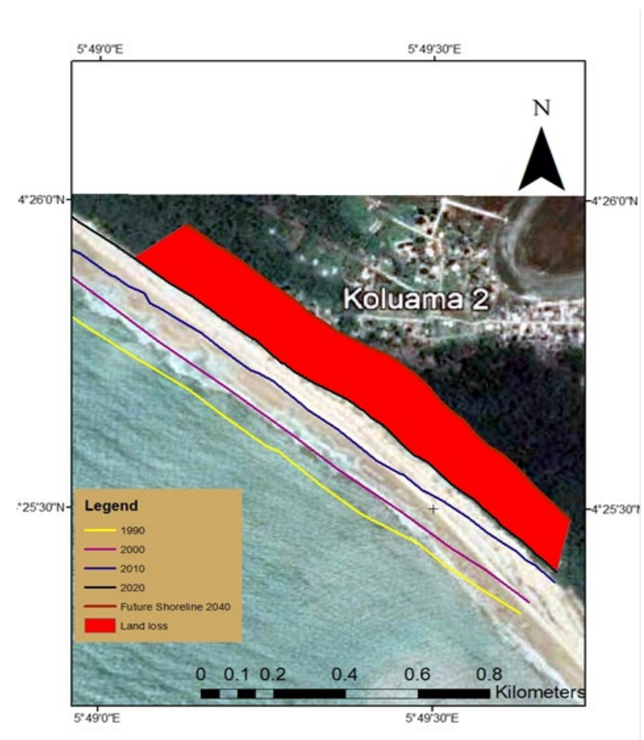

Fig. 3. DSAS Analysis of shoreline rate of change for 1990 – 2000, 2000 – 2010, 2010 – 2020 and land loss of Koluama settlement at the year 2040

Source: Author's Adaptation from Google Earth Pro (2022)

The findings from Figures 2 and 3 of the study indicate that Koluama II's shoreline is undergoing erosion, a trend expected to continue through 2040. This ongoing erosion is influenced by human activities in the coastal zone, which are impacting coastal processes. Consequently, Koluama II is likely to experience continued erosion. The results further show that shoreline segments exposed to the open sea are more severely affected by erosion compared to those near river mouths. The projected landward movement of the shoreline suggests that by 2040, significant portions of the settlement will be submerged by the sea, leading to the loss of agricultural land and potential future impacts on food security.

Findings from Figure 3 indicate that erosion will be the predominant event from 2020 to 2040, leading to significant land loss. This erosion is expected to result in the loss of various assets, including farmland, infrastructure, and white beaches, thereby presenting future socio-economic challenges.

5. Conclusion

In assessing the expected extent of the Bayelsa State shoreline by the year 2040, findings reveal a forecast landward movement of the shoreline. If the current trends of coastal processes, persist, this movement is expected to continue. The trend indicates that by 2040, significant portions of the Koluama II settlement will be submerged under the sea.

6. Recommendations

1. This study urges researchers from universities, research institutions, government ministries, agencies, and other relevant bodies to carry out ongoing spatiotemporal studies of the coastal zone. These studies are essential for monitoring, identifying, and addressing areas vulnerable to erosion and those experiencing significant erosion-related disasters.
2. The government should pursue a comprehensive strategy to studying social networks, social capital, and social resilience because they all help shoreline communities and individuals be less vulnerable to hazards.
3. This study recommends the development of a legal framework specifically designed for managing beaches and coastal area planning, as most of the beaches in the research area are currently unmanaged.
4. Government should embark on beach nourishment projects.
5. This study advocates for the establishment of an integrated coastal management program.

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