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RESEARCH ARTICLE

A GIS APPROACH TO ANALYSING THE OBSERVABLE SPATIO-TEMPORAL SHORELINE CHANGES AT KOLUAMA2 SETTLEMENT, BAYELSA STATE, NIGERIA (1990-2020)

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ABSTRACT

This study is aimed at analyzing shoreline changes, for the purpose of promoting better understanding of the trends, causes and impact of shoreline changes along the coastline of Koluama2 settlement in Southern Ijaw local government area of Bayelsa state, Nigeria. To achieve this aim, the study therefore examined the spatio temporal changes along the Koluama2 shoreline with respect to analyzing the long term and short term shoreline changes. The study adopted a Geographic Information System (GIS) technique for data analysis. The GIS analyses adopted the use of Digital Shoreline Analysis System (DSAS) of ArcGIS 10.8.2 to detect, measure and determine changes in the shoreline position through the End Point Rate (EPR) statistics. The EPR results for the long term shoreline change reveal that the transects line cast on the shore of the study area recorded statistically significant erosion value of 100%. This trend indicates that in the long term, erosion is the dominant event along the shoreline of Koluama2 settlement. Analysis of the short term shoreline change reveals that erosion was recorded as the most dominant event on the shore of the study area. The study recommended amongst others the execution of coastal zone management for the region.

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INTRODUCTION

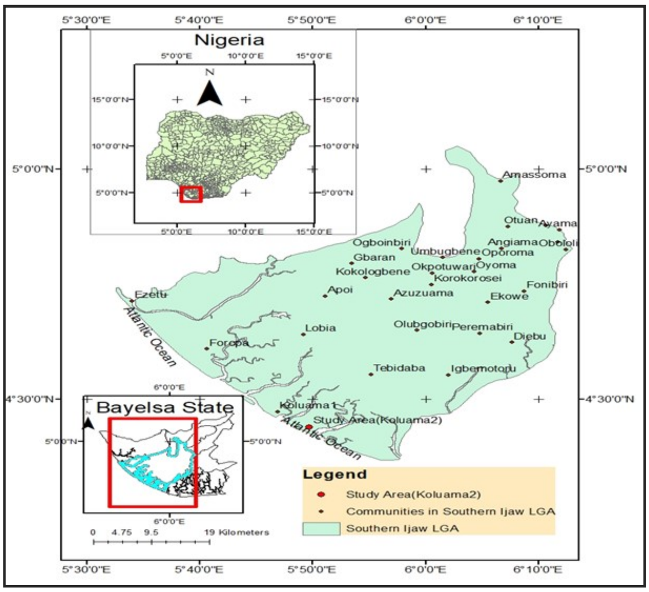
Shorelines all over the globe have remained very critical to the protection of coastal communities. The shore of the coast is economically and ecologically valuable. The shores very importantly serve as a significant source of livelihood as well as defence against coastal storms by absorbing floodwaters and releasing wave energy. A combination of unfavorable natural factors and the growing damaging impact of human activities has seriously jeopardized the shoreline's ability to continue providing the aforementioned important functions. Studies by Oyegun *et al*. (2016), Udo-Akuaibit (2017), and Oyedotun *et al*. (2018) have documented these challenges to coastline sustainability. The results of these studies demonstrate how critical it is to manage and address these issues in order to protect the important services that shorelines offer to both human communities and natural ecosystems. Although many countries in the world have instituted a variety of local environmental (coastal and area marine protection) regulations and other edicts, including signatory to international charters and conventions to protect the coastal environment, shoreline loss remains one of the most challenging problems globally. Resulting from the obviously significant negative impacts on coastlands and their shorelines, several nations of the world have started making moves for interventions through studies and pragmatic mitigating measures. For instance, shoreline problems along the Gulf of Mexico (Morton, 2015), shores of Florida (Houston and Dean, 2014), coast of Bali (Prasetya and Black, 2003), as well as the South Gujarat Coastline in India (Misra and Balaji, 2015), have been studied and intervened upon.

In such studies, spatio-temporal analysis which supports the inquiry of trend over time have been adopted. Spatial analysis is able to capture information at a specific location in time (Richardson *et al*., 2006). In addition, the proper utilization of spatio-temporal analysis ccaptures localized clusters that could be linked to unfolding environmental risk or consistent errors in the data recording process.

The Gulf of Guinea along the Nigerian coast is not an exception to such human intervention. There are obvious mitigating measures practically carried out along the shores of Lagos Bar Beach, Lekki Island in Lagos state, Ugborodo shoreline in Warri, Delta State and Ogulagha shores in Delta State(Etuonovbe, 2006; Nwilo *et al*., 2020). On the coast of Bayelsa State, some studies have been carried out by some renowned scholars of geomorphology and Botany. Oyegun (1999) have focused on description of geomorphic units along the Bayelsa State coast. Mmom& Chukwu-Okeah (2011), and Ojile *et al*. (2017) have actually focused their attention on shoreline changes on the Bayelsa State and Niger Delta coast. They considered the vulnerability and adaptation strategies of communities along the considered coast. Also Nyananyo (1999) considered mainly, the vegetation zones along the coast of Bayelsa State. However, these studies did not obviously state significant empirical values in analyzing and quantifying shoreline retreat and changes, therefore, the need for continuous empirical research and analysis on the trend in shoreline changes, which will be appropriate to inform policies and programmes on the sustainable use and management of the coastal area. Nonetheless, in Bayelsa State and Koluama 2 settlement in particular, there is dearth of empirical studies carried out on shorelines to determine trend in shoreline changes.

As such the enormity of the problem is not known. Furthermore, despite the cries of coastal settlers in Bayelsa State over the years about the displacement of residents due to shoreline change, and the pushing of most settlements to the brink of extinction, it is still unknown the extent of shoreline changes. However, efficiency in managing shorelines as part of coastal zone management will be facilitated if the trend in shoreline change is properly understood. This will require stronger informed decision making and effective institutional interventions with a nuanced understanding of the complexities that underlay shoreline changes. The basis of this research is to make adequate empirical studies and analysis through the integration of remote sensing, GIS and historical satellite images, where the shoreline of Koluama 2 settlement and its areal extent will be obviously determined; the degree and extent of changes along shoreline established with regards to long and short term shoreline rate of change, and appropriate recommendations and measures for the management of the shoreline. This study will highlight the importance of functionally linking all key components of coastal area development and locating realistic choices to improve the sustainable usage of coastal areas. Therefore, there are significant overlaps between this research and current national and international policy initiatives that seek to improve coastal areas around the world. As a result, this study intersects with a number of Sustainable Development Goals (SDGs) while also highlighting the significance, national legal frameworks for integrated coastal zone management will bring to the coastal area.

Study Area



Source: Author's Adaptation from Bayelsa State Administrative Map, 2010 and Google Earth Pro Image, 2020

Fig. 1.0. Bayelsa State map showing Study Areas and Settlements

The research area is situated in the Southern Ijaw local government area of Bayelsa state, Nigeria (Figure 1.0). Its geographical coordinates lie between latitude 4º 00' 00"E and 4° 30' 00"E, and longitude 5º 40' 00"N and 5° 50' 00"N. The soil composition in this area encompasses the beach ridge zone and the mangrove zone (Okony *et al*., 1999). The geomorphic unit of the ridge barrier island complex within the study area constitutes a segment of the outer sediment chain that shields the tidal basins of the Niger Delta from the direct impact of breaking swell waves (Okony *et al*., 1999). The vegetation in this locale predominantly falls under the category of brackish water swamp forest, inclusive of mangrove forest and coastal vegetation (Nyanayo, 1999). Koluama 2 community belongs to the Bassan subdivision of the Ijoid language, and the Bassan people are renowned as adept intermediaries in trade across the Niger Delta. They are particularly known for distributing pots and cassava meal harvested by them (Alagoa, 1999). Originally, Koluama 1 and Koluama 2 were part of a larger entity under the ancient Koluama kingdom, consisting of several villages. Historical records indicate that the kingdom has been affected by shoreline erosion (Amaize, 2012; Mieye and Odubo, 2016). However, in 1953, due to a combination of recurrent high floods in the lower Niger Delta basin and coastal erosion triggered by powerful explosions from oil and gas exploration and seismic activities by the then Shell D'Arcy, the precursor of the current Shell Petroleum Development Corporation, the kingdom split into the present-day Koluama 1 and Koluama 2 communities. Presently, Koluama II community faces a threat from tidal waves, endangering it with submersion (Oyadongha, 20). There have been recent appeals to the Federal Government and the Niger-Delta Development Commission, NDDC, to intervene with shoreline protection before the ocean engulfs the settlement (Amaize and Omafuame 2012).

Previous Studies: Any study of data that considers the process and approach of looking at these data, as well as whether the data are located in absolute or relative positions in three-dimensional space, is referred to as spatio-temporal analysis (Dong & Guo, 2021). Unlike spatial analysis, spatio-temporal analysis is more useful, as it regards both spatial and temporal correlations and provides an avenue for the observation of geographical and temporal distribution of phenomena through visualization of data that has both space and time information (Byun *et al*., 2021). Also, spatio-temporal modeling supports the inquiry of trend over time, while spatial modeling is able to capture information at a specific location in time (Richardson *et al*., 2006). In addition, the proper utilization of spatio-temporal analysis can capture localized clusters that could be linked to unfolding environmental risk or consistent errors in the data recording process. The effects of episodic and unpredictable weather events such as flooding, earthquake, tsunamis and so forth, that vary in spatial scale and magnitude that can cause localized short term changes in landscape have often been analysed using spatio temporal analysis (O' Mara, 2019). Application of spatio-temporal analysis is possible in a wide range of contexts. The following research (Weje & Dappa, 2018; Cheng *et al*, 2019; Odubo *et al*, 2022) ably document applications of spatio-temporal analysis. The use of spatio-temporal analysis to track changes in shorelines is one area of application where it has gained significant importance. Jena *et al*. (2017) stating that shifting shorelines are a depiction of the dynamics of coastal processes and anthropogenic influences in the coastal region. Natural factors such storms, marine currents, beach geomorphology, tides, and human interference in coastal processes cause spatiotemporal dynamics along the shoreline (Ogoro, 2016; Jena *et al*., 2017). According to Bunnet & Okunrotifa (2013), numerous features that are created along the beach in the coastal area are caused by wave erosion and wave deposition. Understanding the dynamics and growth of coastal areas through the study of shoreline change is a crucial first step. It may also help stakeholders lower the danger of coastal erosion and lessen social, physical, and financial loss. It is possible to map and quantify shoreline changes in detail using repeated measurements of the shoreline throughout time (Patel & Bhandari, 2018). One of the most crucial factors in determining coastal erosion and accretion through spatio-temporal analysis is by shoreline quantification (Baig *et al*., 2020).

At several temporal, spectral, and spatial scales, shoreline quantification investigations have been used (Oyegun *et al*., 2016). According to Leon and Correa (2004), Hapke and Henderson (2015), and Addo and Addo (2016), shoreline quantification has been used by various stakeholders to identify areas that are susceptible to erosion, choose the best beach defence system to use along eroding shorelines, and adopt as an early warming signal to investigate activities that are harming the coastal environment. Addo and Addo (2016) indicated that shoreline change rates are the results obtained from shoreline quantification studies. Akinluyi *et al*. (2018) emphasised the significance of shoreline change rate in managing coastal areas. They stress the importance of assessing the rate of shoreline change and comprehending the processes that cause shoreline change for effective coastal management. This is consistent with prior research by Limber *et al*. (2007), who noted that shoreline change analysis has grown to be a crucial method for understanding the temporal and spatial trends of beach erosion and accretion brought on by both natural and human-caused influences. In order to reveal significant erosion and accretion phenomena, shoreline spatiotemporal studies and quantification analysis have been used by a variety of stakeholders. The findings can be used to provide complete information that would aid researchers, decision-makers, and those in charge of planning and managing the coastal zone. These studies are thoroughly explained in Boye (2015), Akinluyi *et al*. (2018), and Guerrera & Martin-Martin 2021). Patterns at both large and small scales that can be connected to changing environmental events can be captured via spatiotemporal analysis. Oyedotun *et al*. (2018) stated that historical and current events have a significant impact on spatio-temporal studies in addition to their influence on geographical coverage. Oyedotun *et al*. (2018) while carrying out spatio- temporal analysis of shoreline changes in Cerritos, a city in the southern state of Sinaloa, concluded the city is suffering increased rates of erosion at -1.0 + 1.5m year -1 Adebola *et al.* (2017) used Landsat imagery to highlight coastline positions throughout the whole Rivers State shoreline in Nigeria during the years 1984, 2000, and 2016. Furthermore, Oyedotun etal. (2018) contend that human activity near the coast has a significant impact on many of the observed changes in shorelines. This position was previously supported by Moran (2003), who claimed that long-term historical data are essential for coastal analysis in order to comprehend how the coast responds to changes in the coastline. Jackson *et al*. (2012) stated that majority of studies employ GIS software to quantify the lengths and rates of shoreline shifts through human measurements or digital analysis tools. The Digital Shoreline Analysis System (DSAS), SCARPS, Beach Tools, and the Analysing Moving Boundaries Using R(AMBUR) are some of the few tools available specifically for studying shoreline change (Jackson *et al*., 2012). However, in order to use these technologies, a GIS is needed.

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 statistics enable the evaluation and discussion of the dynamics and trends in alteration of the shoreline (Himmelstoss *et al*., 2018). The separation between shorelines that are the oldest and youngest is known as the net shoreline movement (NSM) for each transect. By multiplying this equation by the number of metres separating the two shoreline location measurements, the end point rate (EPR) is determined. The EPR is most commonly used because of the simplicity of calculation and the necessity of merely using two dates at the coast. As stated earlier, the EPR uses only two shoreline to carry out these computations. However, studies that have utilized DSAS EPR to analyze shoreline change rate are well documented (Cheng, 2016; Barik *et al*, 2019; Baig *et al*., 2020; Nath *et al*., 2021). Similarly, other studies have adopted the same procedures to compute for shoreline change rate between different periods (Barik *et al*., 2019; Borzi *et al*., 2021). In this case, different consecutive time spans shorelines are arranged to provide an overview of the EPR interpretation. For example, the different spans can be 2005 – 2010, and 2010 – 2015, and so forth.

Theoretical Framework

Systems: The study of systems as currently understood was first introduced into the geography literature by Chorley in 1962. David Easton introduced a model for studying political systems. This model, encompasses Easton's policy-making process, functions as a mechanism that transforms societal demands into policies. These demands can range from wage and working hour laws to educational opportunities, recreational facilities, and transportation infrastructure. Support, viewed as the energy manifested through actions or organizations advocating or resisting the political system, encompasses material contributions like tax payments and adherence to laws. The political system receives inputs in the form of demands and support from the external environment, which undergo a conversion process within the system, resulting in outputs. A feedback mechanism is established, ensuring that the outcomes and consequences of the outputs are reintegrated into the system as inputs. They referred to morphological systems as representing static relationships, indicating connections between elements. They further emphasized that systems are very important in the field of geomorphology, due to the fact that a conceptual framework is formed by the interconnection of physical attributes within a natural (geomorphological) system. Lalande and Baumeister (2015) presented systems as a composite entity consisting of interacting parts, prompting systems scientists in both the natural and social sciences to explore the interactions among these components to gain a deeper understanding of the intricacies of reality. Further clarification by Arnold and Wade (2015) defines a system as "groups or combinations of interrelated, interdependent, or interacting elements forming collective entities." In essence, a system is a collection of interrelated parts working together as a whole to accomplish a common purpose, such as the various components within a school organization that collectively enable its functioning (Bozkus, 2014).

Highlighting the significance of systems in education, John (2010) emphasizes its crucial role in producing human resources. The concept of a production function in education, as outlined by John (2010), establishes a relationship between input quantities, intervening factors, and the generation of a specific quality of outcome. An education production function, therefore, signifies a functional connection between school and student inputs and a corresponding measure of school outputs. For this production function to effectively meet societal needs, policymakers and managers in education must establish clear and precise objectives. They must also carefully select inputs and strategies, which, when subjected to the productive process, result in a qualified product possessing competences such as skills, abilities, and knowledge. These competences can then be efficiently and effectively transferred to the productive sector of the economy (John, 2010). Chorley and Kennedy (1971), definition is the most relevant to the objectives of this study, given the emphasis it places on representing static relationships, indicating connections between elements. Although Lalande and Baumeister (2015), like Chorley and Kennedy (1971), say systems are composite entity consisting of interacting parts, but do not show the interconnection of physical attributes in their definition.

Morphological systems

According to Chorley and Kennedy (1971), morphological systems portray the physical relationship between elements influences or have an impact on how energy passes from one element to another. Chorley and Kennedy (1971), shows that the physical characteristics of a beach, such as the seaward slope angle, average grain size, and porosity, may exhibit a systematic relationship, thereby establishing a morphological system. Similarly, the geometric features of a valley-side slope often demonstrate correlations with specific attributes of soil and vegetation. These factors often demonstrate correlations with specific attributes of geomorphic features that determinine processes of causal interrelationships. Chorley and Kennedy (1971) approach to systems is important for this study as it allows us to determine the physical relationship between elements. For example, shorelines that are not sheltered, causes impact of high energy waves which are destructive and the shoreline orientation to incident waves is consistent with large net movement of sediments from the shoreline.

METHODS AND MATERIALS

This study adopted the embedded mixed research design. Both primary and secondary sources of data were used. Landsat Imageries of Bayelsa state were downloaded from the website repository of the United Geological Survey for the years 1990, 2000, 2010 and 2020. The High Water Line (HWL) digitized from historical images via Google Earth images was used as the shoreline indicator. The high water line uncertainty values at the time of the survey (Upd), georeferencing uncertainty (Ua), and digitising uncertainty (Ud) were used in this investigation as based on erroneous estimations (Hapke *et al*. 2010). Equation (2) was used to obtain the total uncertainty value, and equation (3) to determine the endpoint shoreline change uncertainty for a single transect.

$$U_p = \sqrt{U_g^2 + U_d^2 + U_{pd}^2} \quad \text{Eq. 2}$$

$$U_E = \frac{\sqrt{U_1^2 + U_{21}^2}}{year2 - year1} \quad \text{Eq. 3}$$

Where terms of U_1 and U_2 in Eq. (2) are the total uncertainty values for each shoreline position. Change rate analysis was conducted on the difference in shoreline rates across different periods and the net shoreline change rate was utilized to examine the observable spatio-temporal shoreline changes in Koluama2 settlement. The Digital Shoreline Analysis System (DSAS) version 5.0 extension running in ESRI ArcGIS version 10.8.2 Desktop software was used to analyse the data. A time series of shoreline vector data is used to calculate rate-of-change statistics using DSAS end point rate (EPR).

According to variations in coastline positions over time (1990 to 2020), shoreline rates of change were calculated using a variety of methodologies. The stated rates were expressed in metres of change annually and were measured along transects. Analyses of vector shorelines that were derived from images offer a way to measure the rate of change in shorelines from 1990 to 2020. The shoreline change rate between individual periods such as between 1990-2000, 2000-2010, and 2010-2020 can also be achieved using the same procedure. The steps in this assessment are:

- Extract historical shoreline data of 1990, 2000, 2010, and 2020 from google earth pro.
- Export the shoreline data to ArcGIS utilizing the (kml) extension in google earth pro.
- While in ArcGIS merge the shorelines in order to create baseline.
- Create a geodatabase in order to add to the geodatabase
- Set metadata
- Cast transect
- Calculate rate of change of shoreline with DSAS dialogue box.

RESULTS AND DISCUSSION

Net shoreline change rate: Analysis of result from Table 1.0, EPR results for Koluama 2 indicate that 2.2km of shoreline was analyzed. The total number of transect cast were 44 and the average of erosional rates was recorded as -7.74m per annum. All 44 transects are erosional and all have 100% statistically significant erosion values. The number of accretion transects is zero. Findings from the net shoreline change rate in table 1.0 reveal that there is sufficient proof to demonstrate that shoreline erosion is occurring along the shoreline of the area under study, and it is having adverse effects on the settlement and requires management actions taken immediately. Proof from field investigation (Plate 1 and 2) shows evidences of vegetation loss and land loss at Koluama II settlement, and as well as other recent studies, including Olali (2015), Oyegun *et al*. (2016), Mienye & Odubo (2016), Adebola *et al*. (2017), and Eteli *et al*. (2021), clearly illustrate the effects on the environment, economy, society, and physical well-beingof shoreline erosion problem along the shoreline of Bayelsa State and Koluama2 settlement.

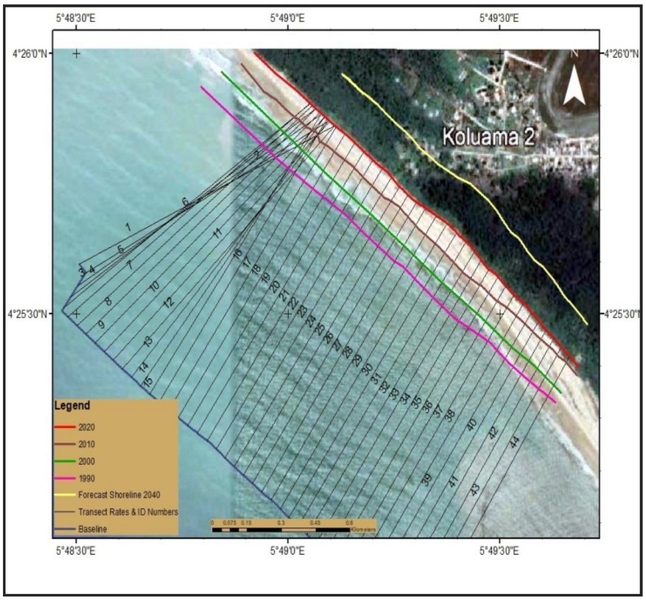
The net shoreline results analyzed in table 1.0. shows widespread erosion along the shoreline of Koluama2 settlement during the 30year period of study. In this study, the transect recorded along the shorelines were all undergoing 100% erosion. Fig. 2.0 shows DSAS analysis of shoreline rate of change for 1990 – 2000, 2000 – 2010 and 2010 – 2020 for Koluama 2 community. Analysis of the result show that erosion occurred all through the different periods of study, 1990 – 2000, 2000 – 2010 and 2010 – 2020.

Shoreline Change rate between different time periods

Table 2.0: Average Rate of Erosion Per Annum

Settlement	1990 – 2000	2000 – 2010		2010 – 2020	
	Average rate of Erosion per annum (m)	Average rate of Erosion per annum (m)	Average rate of Accretion per annum (m)	Average rate of Erosion per annum (m)	Average rate of Accretion per annum (m)
Koluama 2	7.40	8.73		6.86	

Table. 2.0 shows the EPR result of average rate of erosion per annum for Koluama 2 community. Analysis of the data indicate a trend of fluctuating erosion rate of change from high erosion rate to low erosion rate. Observations from the study indicate that erosion is the dominant event taking place in area under study (table 2.0). This trend may be as a result of the geological lithology of the shore of the settlement under study. The shore of Koluama2 settlement is made up of sand, which are unconsolidated and can move freely. Shephard (1973) suggest that beaches are easily eroded by action of waves and wind due to soft geology.



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

Fig. 2.0. DSAS Analysis of Shoreline Rate of Change for 1990 - 2000, 2000 – 2010, 2010 - 2020 for Koluama 2 Settlement

Table 1.0. DSAS Summary of Shoreline Rate of Change for Koluama2 Settlement within the periods of 1990 to 2020

S/N	SETTLEMENT	END POINT RATE (EPR)	
1	KOLUAMA2	Transcect spacing	50
		Total number of transects	44
		Average rate (m)	-7.44
		Number of erosional transects	44
		Percent of all transects that are erosional (%)	100
		Average of all erosional rates (m)	-7.44
		Percent of all of all transects that are accretional (%)	0
		Average of all accretional rates	0

Analysis of results from Fig. 2.0 shows DSAS analysis of shoreline rate of change, 1990 to 2000, 2000 to 2010, and 2010 to 2020 for

Koluama 2. The results indicate erosion has been dominant all through the three time study period. The average of erosion rates per annum was recorded respectively for 1990 to 2000, 2000 to 2010, and 2010 to 2020, as -7.4m/year, -8.73m/year and -6.86m/year (Table 2.0). The dominant erosion occurring along the shoreline of Koluama 2 settlement segment of the Bayelsa State shoreline is most likely caused by natural processes due to the fact that the shorelines are not sheltered, causing the impact of high energy waves which are destructive. Also, the shoreline orientation to incident waves is consistent large net movement of sediments from the shoreline. This observation is in line with Davis (1973), which states that coasts classified based on high energy wave input, are unprotected and have surface offshore terrain and obtain maximum energy.

Source: Author's Fieldwork (2021)

Plate 1. Vegetation loss at Koluama II Community

Source: Author's Fieldwork (2021)

Plate 2. Farm land loss at Koluama II Community

CONCLUSION AND RECOMMENDATION

Understanding the pattern of erosion and accretion is crucial for the development of coastal areas, and could assist stakeholders in bringing down the rate of coastal erosion and also reduce social, physical and economic loss. Researchers have taken advantage of spatio-temporal analysis to support the inquiry of trend over time. Proper utilization of spatio-temporal analysis aid to capture localized clusters that could be linked to unfolding environmental risk. Results in this study have been used to reveal the observable spatio-temporal shoreline changes in Koluama settlement. For the net shoreline change, shoreline information was derived from Google Earth Images of 1990, 2000, 2010 and 2020. The study revealed that shoreline erosion is occurring within the 30 years period of study (1990 – 2020). Sea level rise and human intervention in coastal processes may be to blame for the erosion effects shown in the net shoreline change. Observations from the study reveal that the geological lithology of the shores in all the communities under study is constituted of sand, which are unconsolidated and move freely when impacted by strong waves. Therefore, erosion is supported and dominant in all the three period of study. Short term shoreline change observations from the study also show that Koluama 2 settlement shoreline is undergoing erosion all through the three time study periods. The dominant erosion event occurring along the shoreline of Koluama 2 settlement is most likely caused by natural processes due to the fact that the shorelines are not sheltered especially from the impacts of destructive waves and shoreline orientation to incident waves which enhances large net movement of sediments from the shoreline. In order to identify significant erosion and accretion phenomena, shoreline spatiotemporal studies and quantification analysis have been used by a variety of stakeholders. The findings are used to provide complete information that would be beneficial to scholars, policymakers, and others responsible for organising and overseeing the coastal zone. Patterns at both large and small scales that can be connected to changing environmental events can be captured via spatiotemporal analysis. As a result, this study urges researchers from universities and other research institutions, government ministries, agencies, and departments, among others, to conduct continuous spatiotemporal studies of the coastal zone in order to monitor, identify, and provide solutions for areas that are vulnerable to erosion and experiencing significant erosion disaster.

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