International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

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Impact of swash and backwash waves in selected coastal communities in Bayelsa State, Nigeria

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International Journal of Science and Research Archive, 2025, 14(03), 1426-1433

Publication history: Received on 01 February 2025; revised on 25 March 2025; accepted on 27 March 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.14.3.0871

Abstract

This study focuses on analysng the impact of swash and backwash on the shorelines of Foropa, Sangana, and Brass in Bayelsa State, Nigeria. The objective of this study is to examine the temporal behavior of swash and backwash on shorelines in the study area. To achieve the aim of the study, stopwatch was utilized to conduct in-situ measurements of wave break rates at the Shores of Foropa, Sangana, and Brass settlements. Additionally, Pearson correlation analysis was employed to examine whether the temporal behavior of backwash is significantly associated with shoreline changes in the study area. Analysis from the study show that that the shorelines of Foropa, and Sangana settlements are experiencing wave break rates of 10 waves or more per minute all through the year. The results also revealed a gradual increase in wave break rates from April to July, followed by a decline from August to December. This heightened wave activity from April to August is attributed to the impact of the tropical maritime air mass, which typically occurs between June and July. The study also suggests that the occurrences or factors contributing to coastal erosion in the various settlements may be similar or identical. Among its recommendations, the study proposes the implementation of a coastal zone management program for the region, among other measures.

Keywords: Digital Shoreline Analysis System; End Point Rate; Geographic Information System; Shoreline; Temporal

1. Introduction

The land near to a sea or a huge water body is referred to as the shore. It is the region that is exposed at low tide and lies between the markers for high and low tide (Mayhew, 2009). The shoreline refers to the line where the shore and water meet (Bunnett & Okurotifa, 2013). Shorelines worldwide have a vital role in protecting coastal communities. They possess significant economic and ecological importance, acting as essential sources of livelihood and providing defense against coastal storms by absorbing floodwaters and dispersing wave energy. Yet, the synergy of adverse natural factors and escalating human activities has significantly hindered shorelines' capacity to meet these critical roles. The effects of natural factors and human activities in coastal areas results to imbalance in cause

Despite numerous countries worldwide, implementing diverse local environmental regulations, including coastal and marine area protection, and participating in international agreements and conventions aimed at safeguarding the coastal environment, shoreline erosion remains an enduring global issue. The adverse effects shoreline erosion often results in coastal ecosystem destruction, biodiversity loss and destruction of properties (Misra & Balaji, 2015; Oyedotun et al. 2018; Odubo & Eli 2024a). Bayelsa State, Nigeria recorded devastating impacts of shoreline erosion on properties, drinking water sources, buildings, farms, and human health (Olali, 2016; Odubo, 2024; Odubo & Eli, 2024b). Further, Jonathan (2016) recorded displacement of people.

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In response to the evident and significant adverse impacts on coastal areas and their shorelines, many countries worldwide have launched initiatives to tackle these issues through both research and practical mitigation measures. For example, concerns regarding shoreline issues have been thoroughly investigated and addressed in various regions, such as the shores of Florida along the Gulf of Mexico (Morton, 2005), the coast of Bali (Prasetya and Black, 2003), and the South Gujarat Coastline in India (Misra and Balaji, 2015).

Human intervention along the Nigerian coast, particularly in the Gulf of Guinea, reflects similar patterns observed elsewhere. Clear mitigation measures have been implemented across various areas, including Lagos Bar Beach, Lekki Island in Lagos state, Ugborodo shoreline in Warri, Delta State, and Ogulagha shores in Delta State. These efforts have been documented by Etuonovbe (2006) and Nwilo et al. (2020).

In a previous research effort, Odubo and Mienye (2024) conducted a study on the temporal behavior of backwash and swash waves along the Bayelsa State Coast. The focus was on examining the effects of these waves at the shorelines of Agge, Koluama 2, and Okpoama settlements in Bayelsa State, Nigeria. However, understanding that such studies not only offer detailed experimental data analyses of swash and backwash effects on shorelines but also aid in interpreting physical changes on beaches and provide data references for further numerical modeling and shoreline management guidelines, it is essential to expand the scale of the study to other settlements along the state shoreline.

Hence, this study seeks to fill this gap by conducting thorough empirical research and analysis on how the temporal behavior of swash and backwash impacts the shorelines of Foropa, Sangana, , and Brass settlements in Bayelsa State, Nigeria. The research will employ in-situ recording of wave breaking rates to evaluate the extent and nature of changes occurring along the Agge, Foropa, and Koluama2 shorelines in Bayelsa State.

1.1. Study Area

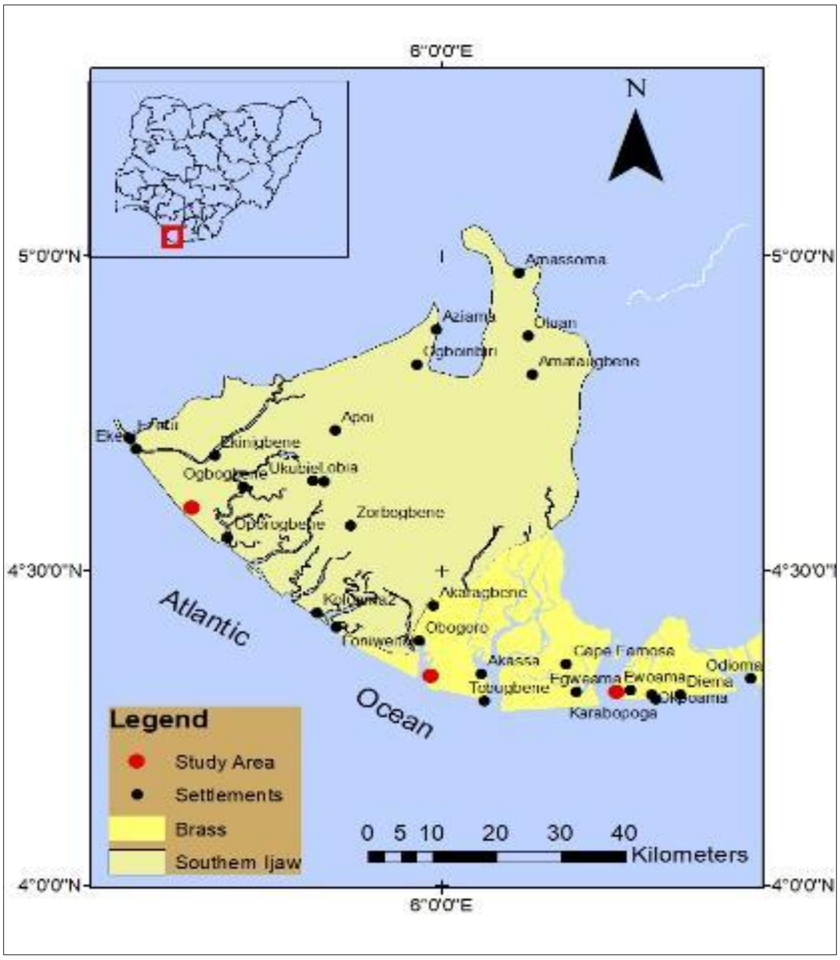

Figure 1 Map showing study area and settelements in Southern Ijaw LGA, and Brass LGA

This research focuses on three settlements in Bayelsa State: Foropa, Sangana, and Brass. Foropa settlement is located in the Southern Ijaw, while Sangana and Brass settlements are located in Brass local government areas. These settlements are located between longitudes 5º30' East and 6º30' East of the Prime Meridian and latitudes 4º00' North and 5º15' North of the equator (Fig. 1.0). Their geographical coordinates place them next to the Atlantic Ocean, which borders them to the south and southwest. This proximity to water and strategic location significantly influence the area's physical features and climate. Bayelsa State has about 185 km of coastline (Google Earth Image, 2021).

Bayelsa State's terrain gradually slopes from north to south toward the Atlantic Ocean. Numerous rivers along its coastline, such as the Ramos, Dodo, Pennington, Digatoru, Middleton, Koluama, Fishtown, Sangana, Nun, Brass, St. Nicholas, and Santa Barbara, flow into the Atlantic Ocean (Ojile et al., 2017). The climate of Bayelsa State is classified as a humid semi-hot equatorial Köppen-Geiger Af type, influenced by two tropical air masses: a moist tropical maritime air mass and a dry, dust-laden tropical continental air mass (Oyegun, 1999). The primary soil type in the study area is found in the beach ridge zone. This ridge-barrier complex creates an outer chain of sediments that protects the tidal basins of the Niger Delta from the direct impact of breaking swell waves (Oyegun, 1999). Shoreline erosion due to wave effect have significantly affected the socio - economic and physical setting of the settlements. Odubo (2024) recorded that changes on shoreline at the study areas have impact on source of livelihood, damage to infrastructure, housing location, etc.

1.2. Conceptual Review

1.2.1. Concept of Swash and Backwash

When waves approach the shore at an angle, they result in a unique phenomenon: as they wash onto the beach, they do so at an angle, but upon receding, the water flows straight down the beach slope. This process which is the upward movement of water is referred to as the swash, carries sediment particles along the beach, while the downward movement, known as the backwash, returns them straight back. This repeated cycle causes sediment particles to move along the beach in a zigzag pattern.

The combined effects of sediment transport within the surf zone by the longshore current and sediment movement along the beach by swash and backwash are collectively termed longshore drift. This phenomenon moves vast amounts of sediment along coasts worldwide, including oceans and large lakes. Longshore drift plays a significant role in shaping various depositional features.

Swash and backwash are essential elements of wave action, playing a crucial role in the formation of both constructive and destructive waves. Constructive waves are characterized by a forward motion known as the swash, which carries water up the beach. As the swash progresses, it deposits sediment, contributing to the buildup of the beach profile. Conversely, the backwash refers to the return flow of water back to the sea, typically weaker than the swash and carrying minimal sediment. This asymmetry results in a net accumulation of sediment on the beach, gradually enhancing its elevation and width.

In destructive waves, the backwash exceeds the swash in strength, causing erosion and the removal of sediment from the beach. This is due to the steep slope, short wavelength, and high frequency of destructive waves, which concentrate their energy near the shore. As a result, the backwash of these waves pulls sand and other sediment seaward, leading to the gradual loss of elevation and width of the beach

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1.3. Theoretical Framework

1.3.1. System

Lalande and Baumeister (2015) presented the idea that systems are complex entities made up of interacting components. This viewpoint has motivated systems scientists in both natural and social sciences to explore the interactions among these components, seeking a deeper understanding of the intricacies of reality. Expanding on this idea, Arnold and Wade (2015) provide a more detailed definition, describing a system as "groups or combinations of interrelated, interdependent, or interacting elements forming collective entities." Essentially, a system is a collection of interconnected parts working together as a unified whole to achieve a common goal. An illustration of this can be seen in the different components within a school organization, which collaborate to support its overall operation (Bozkus, 2014). Emphasizing the significance of systems in education, John (2010) highlights their vital role in developing human resources. John (2010) explains the concept of a production function in education, which links input quantities and intervening factors to the creation of a specific quality of outcome. Chorley and Kennedy (1971) defined process and response by focusing on the study of how interconnected elements influence one another, emphasizing causal relationships. This includes examining how one variable, X, affects another variable, Y. In geomorphology, a natural system is formed by combining at least one morphological system with one cascading system. As a result, process response system will play an important role in showing the relationship between form and processes. Chorley and Kennedy's (1971) definition are therefore more relevant

1.3.2. Process-response systems

According to Chorley and Kennedy (1971), process-response systems examine causal relationships among various processes. Their description of systems as process-response systems is highly relevant to the objectives of this study. This is because these systems consist of an energy flow system connected to a form of system, where system operations can modify the system's form, which in turn influences the system's operations. Additionally, a control system regulates or manages these interactions. A geomorphic system responds to the imposition of a disturbance or change in driving force (a perturbation) by altering one or more of its constituent parts. In a beach system, coastal processes can also impact the equilibrium between wave energy and sediment supply. Changes in this equilibrium are evident in the shoreline. Stability is achieved when sediment supply and wave energy remain consistent. Any alteration in these components will cause the shoreline to move. For example, storms can increase wave energy, leading to the offshore movement of fine-grained beach sand and the formation of cobble or pebble beaches, provided sediment supply remains stable (Nelson, 2018). Therefore, interventions in a system can impact its operation, resulting in various outcomes. Moreover, seasonal winds affecting wave energy can cause beaches to experience different effects, such as erosion or accretion, during different seasons.

2. Methods and Materials

The study employed a quantitative approach to gather information regarding the frequency of wave breaking along the shoreline. Both primary and secondary sources contributed to the data collection process, with a stopwatch being the instrument used for data collection. Both the constructive and destructive waves were determined by using a stopwatch to obtain in-situ measurements of wave break rates. The waves were categorise into constructive waves, where swash is stronger than backwash, and are identified by wave breaks occurring at a rate of 10 or fewer waves per minute. Conversely, destructive waves, are determined where the backwash is stronger, and are identified by a wave break rate of 10 or more waves per minute (Bunnett & Okunrotifa, 2013).

In order, to test if the temporal behavior of backwash is related to shoreline changes in the study area, the Pearson Moment Correlation analysis was utilized.

All data collected were processed using Microsoft Excel for data analysis. As such, various excel tools and functions were used to compute statistical measures, visualize data trends, and generate reports, which are essential for interpreting the results of the wave analysis.

3. Result and Discussion

Table 1 Mean Wave Breaking Rate of wave for the year 2021

Mean Wave Breaking Rate												
Settlements	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Foropa	14	14	12	13	16	13	17	11	10	10	11	12
Sangana	16	14	13	15	13	15	17	12	10	11	11	12
Brass	10	9	8	16	12	13	12	11	10	10	11	10

Source: Author's Fieldwork, 2021

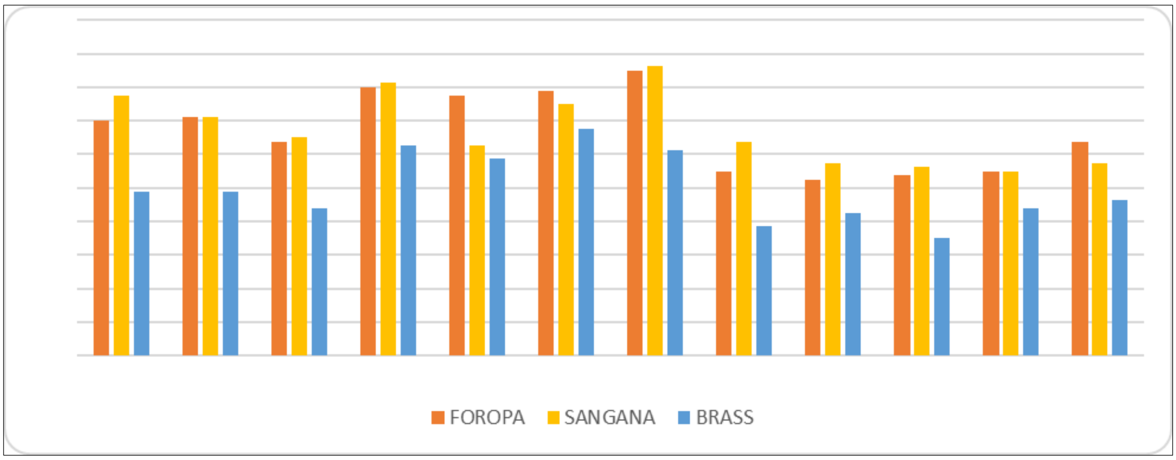

Figure 2 Disparity of Swash values for the various months

3.1. Source: Author's Fieldwork, 2021

Table 1.0 shows the breaking rate of waves (Swash) along shorelines in the study area. The field measurements obtained in table 1.0 in the month of January, show that the mean wave breaking rate is at a rate of 10 waves or more per minute for the three settlements under study.

In the month of February, wave break records show that Brass settlement recorded wave break at a rate of 9 waves per minute, while every other community recorded 10 waves or more per minutes. In the month of March, apart from Brass which recorded 8 waves per minute, the other settlements under study recorded wave break at a rate of 10 waves or more per minute. For the month of April, May, June and July wave break records show that wave breaks at rate of 10 waves or more per minute in all the three settlements. In the month of August, Brass and settlement recorded wave break of 8 waves per minute. Records from the other two studied settlements of Foropa, and Sangana all have wave break records of 10 minutes and more per minute. For the month of September, Brass settlement recorded wave break records of 9 waves per minute Foropa and Sangana have records showing 10 waves or more per minute. In the month of October, the wave break rate measurements for Brass were 6 waves per minute. Foropa, and Sangana show records of 10 waves or more per minute. For the month of November, Brass settlement shows wave break records at a rate of 8 waves per minute. Wave breaking records for Foropa and Sangana show records of 10 waves or more per minute. For the month of December, all three settlements show wave break measurements of 10 waves or more per minute.

Fig 2.0 shows the difference in waves for the various study settlements for one (1) year. From the results, the values for swash for the various months were lesser during the dry season, that is between the months of September to December, while for the months of April to July, the values for swash were higher in the different settlements. The results thus shw some degree of seasonality.

Table 2 Pearson Correlation Analysis

		Foropa	Sangana	Brass
Foropa	Pearson Correlation	1.0	0.838**	0.921**
	Sig. (2-tailed)		0.001	0.000
Sangana	Pearson Correlation	0.838**	1.0	0.723**
	Sig. (2-tailed)	0.001		0.008
Brass	Pearson Correlation	0.921**	0.723**	1.0
	Sig. (2-tailed)	0.000	0.008	

**. Correlation is significant at the 0.01 level (2-tailed).

b. Listwise N=12

Utilizing data contained in Table 1.0, further analysis was conducted to test if the temporal behavior of backwash is significantly related to shoreline changes in the study area. Results from Table 2.0 show that Pearson correlation indicate a strong positive correlation at a 0.01 probability level in terms of the fact that backwash actually cause shoreline change in the study area.

Findings from table 1.0 show results on the impact of waves breaking rates at the shoreline of the three settlements under study (Foropa, Sangana, and Brass).

Analysis of the rate of wave break results show that the shorelines of Foropa, and Sangana settlements are experiencing wave break rates of 10 waves or more per occurring per minute at all though the year. This indicates that the shorelines of these settlements are impacted by destructive waves whose backwash is more powerful than the swash. This trend implies that erosion which is caused by destructive waves is the dormant event taking place along these shorelines. However, in the settlement of Brass, erosion is also observed to be the major event occurring at the shoreline. This is due to the fact that destructive waves occur in months that are more than half part of the year. The measurement of rates of wave breaks at the shore to determine destructive waves and shoreline erosion in this study is in line with the work of Bunnett & Okunrotifa (2013).

Results from table 1.0 also reveal a progressive increase of wave break rate from the month of April to July and becomes regressive from the month of August to December. This trend implies that erosion is at its peak during seasonal period of the month of April to July. This phase coincides with the June/July period when the marine tropical air mass blows from the high-pressure region over the south Atlantic. The increased frequency of wave breaks occurring between April and August could be attributed to the impact of the tropical maritime air mass. Based on results from table 1.0, the shorelines of all the three settlements under study can be categorized as high energy coasts, based on the classification of energy input in the coasts, which shows that wave break at a rates of 10 waves or more per minute all though the year, thus revealing a strong backwash. This indicates that erosion will be dominant all through the year. This result is consistent with Davis's (1973) findings, who asserted that high energy coast are susceptible to erosion due to the fact that they are unprotected and have shallow offshore topography and are subject to waves with the highest energy.

4. Conclusion

Breaking rates of waves at the shores of the three communities was measured. The result further revealed a progressive increase of wave break rate from the month of April to July and becomes regressive from the month of August to December. This trend implies that erosion is at its peak during the seasonal period of the month of April to July. This high rate of wave breaks in the month of April to August is attributed to the impact of the tropical maritime air mass which occurs within the period of June and July. The results from the study further shows disparity of Swash values for the various months therefore indicating some degree of seasonality.

Recommendations

Following the findings of the study, the following recommendations were made;

- Settlements and Bayelsa State government are encouraged to invest in coastal restoration projects. These projects restore the shoreline to its undeveloped state.
- 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.
- 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.
- In order to eliminate harmful environmental practices, the government, citizens, and nongovernmental organisations (NGOs) should occasionally participate in advocacy campaigns and trainings for resource utilization in the studied region.

The development of an integrated coastal zone management programme is encouraged by this study.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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