



(RESEARCH ARTICLE)



Revision of Coastal Dynamics and Morphometric Study of Andoni -Bonny Beach, Rivers State, Nigeria

Mbikan Roseline Mowon ¹, Abam Tamunoene Kingdom Simeon ¹, Youdeowei P. O ¹, Ngerebara Owajioke Dago ², Jonah Iyowuna Benjamin ³, Uyi Hanson ⁴ and Tombari Bodo ^{5,*}

¹ Institute of Geosciences and Environmental Management, Rivers State University, Port Harcourt, Rivers State, Nigeria.

² Department of Geology, Rivers State University, Port Harcourt, Rivers State, Nigeria.

³ Faculty of Environmental Sciences, Rivers State University, Port Harcourt, Rivers State, Nigeria.

⁴ Institute of Pollution Studies, Rivers State University, Port Harcourt, Rivers State, Nigeria.

⁵ Department of Environment and Development, University of Uyo, Uyo, Akwa Ibom State, Nigeria.

International Journal of Science and Research Archive, 2025, 17(02), 412-420

Publication history: Received on 30 September 2025; revised on 08 November 2025; accepted on 12 November 2025

Article DOI: <https://doi.org/10.30574/ijrsra.2025.17.2.3036>

Abstract

Coastal dynamics is pivotal to seasonal alterations of beaches, even as natural and or anthropogenic activities may be implicated in such dynamics. This study unveiled coastal dynamics and its consequences along Andoni and Bonny beaches of Rivers State, Nigeria, using divers' techniques of Morphometric Analysis at the beach/ shoreline, such as Remote Sensing, Geographic Information Systems (GIS), Field Survey and Laboratory Analysis. Values were extracted from Satellite Imageries of Landsat 7 (2005), Landsat 7(2015) Enhanced Thematic Mapper (ETM), and Landsat 9 (2025). The slope variation from shuttle Rader Topographic Mission (SRTM) ranged from 0.1 – 4.3m and the Landsat Slope ranged from 0.1 – 50.22m. This indicated a variation on the shoreline/beach slope. Wire frame results indicated a depression at 12m, 10m and 8m along Bonny Beach/ shoreline, but Andoni beach counterpart had a depression at 6m, 4m and 2m respectively. The inter-variable covariance, inter-variable correlation and inter-variable rank-correlation showed a change in height value along the shore. The laboratory results of grain size (fines 91- 94%), bulk density (1.10 – 1.40g/cm³), porosity (37 – 48%), moisture content (22 – 28%) and texture (silt loam) also indicated shoreline prone to erosion. Bonny beach had a comparatively high sediment load to Andoni beach; (1.68%) and (-1.00%) respectively, which unveiled an intense hydrodynamic activity in Bonny beaches which was consistent with high energy coastal system while Andoni showed a low energy environment. The alteration between high and low water zones unveiled the role of tidal dynamics in sediment redistribution along Andoni and Bonny Beaches/Shoreline. This study, besides unveiling the dynamics on the coast of Andoni and Bonny beaches, upholds the significance of applying morphometric parameters in coastal zone management.

Keywords: Hydrodynamics; Morphometric Parameters; Beach; Shoreline; Coastal Zone Management; Coastal Dynamics.

1. Introduction

Beach environmental conditions (wave, tide, sediment, geology etc) of geographical variability are responsible for spatial morphological alteration of Beaches in course of time and influence of hydrodynamic forces such as waves and population. Thus it is imperative to understand and grasp the historical shift in land for safe guarding coastal benefits in addition to the process at work in coastal environment (Nwilo et al., 2020; Pietro et al., 2024); but this is not in isolation of the determinant process of physical configuration of a coast, which are both anthropogenic and natural,

* Corresponding author: Tombari Bodo

even as they are a dynamic interfaces shaped by interplay of Land Cover (LC) and land use (Peter et al., 2020; Pietro et al., 2024).

Deltaic coast; particularly, dynamic geographic system experience continuous changes at various spatial and temporal dimensions (Emmanuel et al., 2024); However, the Niger Delta formation (in which Andoni and Bonny are included) is ascribed to the opening of the Atlantic Ocean (Abam et al., 2004). The morphology of the coastal land forms and patterns of sediment movement (including the Niger Delta) has been in existence and studied over the years (Ngerebara et al., 2012); thereby elucidating and creating awareness on the numerous propelled changes in our coast and beaches, which necessitates concerted efforts at mitigating environmental negative consequences (erosion, loss of biodiversity, pollution, etc) through applicable knowledge – based approach.

Environmental development has soil erosion as the most important challenge, even as beach erosion remains a complex process influenced by multiple spatial proportion (Bashir & Alsalman, 2024; Bozzeda et al., 2023). Its opposite counterpart “Accretion could also be of concern. As opined by Liu et al., 2023; “The erosion and accretion index play a pivotal role in forecasting shift in coastal erosion and accretion: amongst other costal dynamic unveiled herein through morphometric approach.

2. Materials and Methods

2.1. Mapping Method

The pacing traverse method was used in mapping the beach. The azimuthal directions were determined with the use of Hand-held Global Positioning System (GPS) German 72 H, and the pacing distance at 500m interval for each of the four stations of the respective beaches of Andoni and Bonny. The total distance covered for the four stations was 1.5km (1,500m). This was used to prepare the map of the study area which served as a control for sampling points.

2.2. Sampling Method

The sampling was done according to the Tidal Times Chart of June, 2025 collected from the internet, ranging from High Tide, Mid-Tide and Low Tide together with the use of Hand-Auger. Tide collected from the internet, with the use of Hand-Auger at a depth of 0-25cm. All sediment/ water samples were taken from the subsurface depth of 0-25cm. The subsurface samples collected from both Andoni and Bonny beaches respectively at designated as follows: Andoni Transect (AN. T) and Bonny Transect (BN. T.) There are four stations located at both Andoni and Bonny beaches designated as (AN.T.0.1 – 0.3, AN.T.1.1 – 1.3, AN.T. 2.1 -2.3, AN.T.3.1 -3.3) and (BN. T. 0.1 -0.3, BN. T. 1.1 -1.3, BN.T.2.1 -2.3, BN.T.3.1 -3.3). Both AN.T.0.1 -0.3 and BN.T. 0.1 -0.3 were used as control (Baseline). Three sediment samples were collected from each Transect of each station of both Andoni and Bonny Beaches/shoreline. A total of 24 sediment samples were collected from both the Andoni and Bonny beaches, this was signifying 12 samples from each beach. Each of the sampling point taken was in a linear pattern that ran normal to the coast/shoreline.

Water samples were also collected from High and Low Tide for the analysis of sediment load. 8 water samples were collected from each of the beach (Andoni and Bonny). A total of 16 water samples and 24 sediment samples were taken for Laboratory analysis at Jaros Inspection Services Limited located at Jarose Base-Ignatius Ajuru University of Education Road, Rumuepirikom, Port Harcourt, River State.

2.3. Laboratory Methods

2.3.1. Grain -size Analysis

This is the analysis carried out to determine the individual size of the particles of the sediment such as clay, silt, sand, gravel etc that made up a sediment deposit while grain size was the diameter of the individual particles contained in the sediments. It is measured through grain size analysis in which particles are separated by size. This defines the depositional environment and the transport energy of the sediment.

3. Results

3.1. Result for Assessment of Morphometric Parameters Along the Andoni (AN. T) and Bonny (BN. T) Beaches in Rivers State

The result of the particle size distribution along the Andoni (AN. T) and Bonny (BN. T) beaches in Rivers State is presented in Table 1. The particle size was carried out for very coarse sand, coarse sand, medium sand, fine sand and very fine sand, while percentage total sand, total silt and total clay was calculated and overall texture deduced to be silty loam. Table 2 presents Bulk density, Porosity and Moisture content and Table.3, the Sediment load content. The chart in Figure1 shows the graphical representation of particle size distribution of sediment samples (Andoni and Bonny Beach/Shorelines).

Table 1 Particle-Size Distributions Along the Andoni (AN.T) and Bonny (BN.T) Beaches in Rivers State

PARTICLE SIZE										
S/N	Field Code	Very coarse sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	%Total Sand	% Total Silt	% Total Clay	Texture
1	ANT 0.1 HW	0	0	1.48	2.51	1.94	6	71	23	Silty Loam
2	ANT 0.2 MID	0	0.42	1.48	2.42	1.26	6	77	17	Silty Loam
3	ANT 0.3 LW	0	0.91	1.72	3.03	2.02	8	78	14	Silty Loam
4	ANT 1.1 HW	0	1.12	3.14	3.7	1.46	9	80	11	Silty Loam
5	ANT 1.2 MID	0	0	0.91	2.05	1.14	4	80	16	Silty Loam
6	ANT 1.3 LW	0	0	0.56	1.34	1.56	3	77	20	Silty Loam
7	ANT 2.1 HW	0	0	0.95	1.48	1.79	4	79	17	Silty Loam
8	ANT 2.2 MID	0	0	1.01	1.34	0.9	3	79	18	Silty Loam
9	ANT 2.3 LW	0	0.79	1.13	2.03	1.24	5	76	19	Silty Loam
10	ANT3.1 HW	0	0	0.6	1.2	1.1	3	80	17	Silty Loam
11	ANT 3.2 MID	0	0	0.63	1.56	1.46	4	75	21	Silty Loam
12	ANT 3.3 LW	0	0	0.39	1.08	1.38	3	68	29	Silty Loam
13	BN 0.1 HW	0	0	0.41	0.92	1.02	2	80	18	Silty Loam
14	BN 0.2 MID	0	0	0.1	0.6	0.8	2	76	22	Silty Loam
15	BN 0.3 LW	0	0.47	1.12	2.05	1.02	5	79	16	Silty Loam
16	BN 1.1 HW	0	0	1.35	2.9	1.76	6	40	54	Silty Loam
17	BN 1.2 MID	0	0.74	2.13	3.51	2.76	9	65	26	Silty Loam
18	BN 1.3 LW	0	0	0	0.43	0.97	1	72	27	Silty Loam
19	BN 2.1 HW	0	0	0.22	1.51	1.19	3	72	25	Silty Loam
20	BN 2.2 MID	0	0	0.08	0.41	0.41	1	75	24	Silty Loam

21	BN 2.3 LW	0	0	0.09	0.69	0.77	2	73	25	Silty Loam
22	BN 31 HW	0	0	0.09	0.98	0.71	2	80	18	Silty Loam
23	BN 3.2 MID	0	0	0	0.58	0.82	1	88	11	Silty Loam
24	BN 3.3 LW	0	0	0.39	0	0.94	1	75	24	Silty Loam

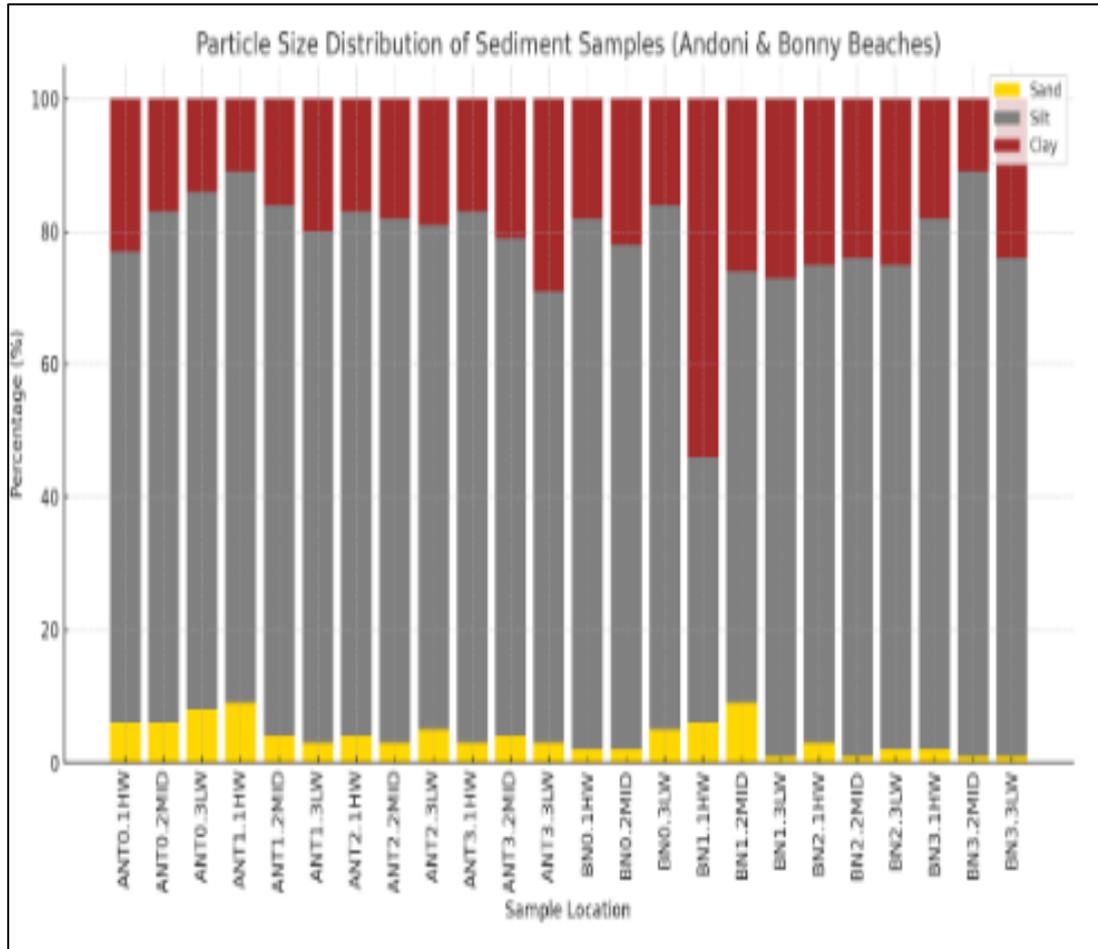


Figure 1 Graphical Representation of Particle size Distribution of Sediment Samples (Andoni and Bonny Beaches)

Table 2 Bulk density, Porosity and Moisture content Along the Andoni (AN.T) and Bonny (BN.T) Beaches in Rivers State

S/N	Field Code	Bulk Density (g/cm ³)	Porosity (%)	Moisture Content (%)
1	ANT 0.1 HW	1.2	45	25
2	ANT 0.2 MID	1.3	37	23
3	ANT 0.3 LW	1.2	39	25
4	ANT 1.1 HW	1.1	41	24
5	ANT 1.2 MID	1.3	39	24
6	ANT 1.3 LW	1.2	38	24
7	ANT 2.1 HW	1.3	45	26
8	ANT 2.2 MID	1.3	47	25

9	ANT 2.3 LW	1.3	46	25
10	ANT3.1 HW	1.4	39	23
11	ANT 3.2 MID	1.3	39	22
12	ANT 3.3 LW	1.3	40	24
13	BN 0.1 HW	1.4	44	27
14	BN 0.2 MID	1.5	45	28
15	BN 0.3 LW	1.4	45	27
16	BN 11 HW	1.5	44	27
17	BN 1.2 MID	1.4	41	27
18	BN 1.3 LW	1.4	42	28
19	BN 21 HW	1.4	46	28
20	BN 2.2 MID	1.5	48	28
21	BN 2.3 LW	1.5	46	28
22	BN 31 HW	1.4	47	27
23	BN 3.2 MID	1.5	47	28
24	BN 3.3 LW	1.6	47	27

NOTE: No Standard Limits for above Parameters

Table 3 Sediment Load Content along the Andoni and Bonny Beaches in Rivers State

S/N	Field Code	Sediment Load (%)
1	BN 0.1 HW	1.6
2	BN 0.2 LW	1.02
3	BN 1.1 HW	1.68
4	BN 1.2 LW	0.98
5	BN 2.1 HW	1.52
6	BN 2.2 LW	0.96
7	BN 3.1 HW	1.42
8	BN 3.2 LW	1.02
9	ANT 0.1 HW	1.04
10	ANT 0.2 LW	1.04
11	ANT 1.1 HW	1.14
12	ANT 1.2 LW	0.86
13	ANT 2.1 HW	0.8
14	ANT 2.2 LW	1.04
15	ANT 3.1 HW	0.92
16	ANT 3.2 LW	1.02

NOTE: No Standard Limits for above Parameters

4. Discussions

4.1. Assessment of Morphometric Parameters along the Andoni (AN. T) and Bonny (BN. T) Beaches in Rivers State

The particle size distribution data in the Table1 provides insight into the sediment texture and soil structure characteristics across the study locations in Andoni (AN.T) and Bonny (BN.T) beaches, Rivers State, Nigeria. Overall, the sediments are predominantly silty loam, reflecting a mixture of sand, silt, and clay fractions with a strong dominance of the silt component.

4.1.1. Dominance of Silt

The silt content across all samples is consistently high, ranging from 68% to 88%, indicating that the sediments are mainly composed of fine-grained particles (FAO, 2015). For instance, the highest silt content is recorded at BN.T 3.2 MID (88%), while the lowest is observed at AN.T 3.3 LW (68%). High silt content typically indicates a low-energy depositional environment, where fine particles settle and accumulate, such as estuaries and tidal flats (Folk & Ward, 1957).

4.1.2. Sand Fractions

The total sand fraction is relatively low, ranging from 1 - 9%, with medium and fine sand contributing the most to this component. For example, AN. T 1.1 High Water/Tide (HW) shows a relatively higher sand content (9%) compared to BN 3.2 MID with only 1% sand. The absence of very coarse sand across all samples suggests that high-energy processes such as strong wave action or storm surges are less dominant in these areas (Blott & Pye, 2001).

4.1.3. Clay Content

The clay content varies moderately between 11% and 54%, with the highest clay proportion recorded at BN.T 1.1 HW (54%) and the lowest at AN.T 1.1 HW (11%). A higher clay percentage often suggests reduced drainage capacity, higher compaction, and increased potential for pollutant retention in sediments (Adebowale et al., 2009). Samples with higher clay fractions, such as BN 1.1 HW and BN 2.3 Low water (LW)/Low Tide, may therefore exhibit greater capacity for binding heavy metals and other contaminants due to their higher surface area and cation exchange capacity (Brady & Weil, 2017).

4.1.4. Spatial Variations

Spatially, the Bonny (BN.T) samples generally show slightly higher clay percentages compared to Andoni (AN.T) samples, implying that BN sediments are finer and more compact, possibly due to greater fluvial input or reduced tidal flushing in the Bonny area (Nwaichi et al., 2017). Conversely, Andoni samples, with slightly higher sand fractions in some locations (e.g., AN.T 1.1 HW), suggest a somewhat more dynamic hydrodynamic setting.

This graphical insight supports the interpretation that the Andoni and Bonny beaches are predominantly influenced by fine-grained sediment deposition, often associated with low-energy environments (Allison & Kepple, 2001).

Bulk Density, Porosity, and Moisture Content Data from Andoni (AN.T) and Bonny (BN.T) Beaches

The result of Bulk Density, Porosity and Moisture Content data from Andoni and Bonny beaches is presented in Table 2.

4.1.5. Bulk Density

Andoni (AN. T) bulk density values are relatively low (1.10–1.40 g/cm³), typical of silt-dominated, loosely compacted soils (Blake & Hartge, 1986). This low density implies that the sediment is less consolidated, making it more susceptible to erosion under strong wave or tidal force. Bonny (BN), higher bulk density values (1.40–1.60 g/cm³) indicate denser and more compacted sediments. These are often associated with higher sand fractions and more stable substrates that resist erosion (Folk & Ward, 1957).

This difference reflects variations in hydrodynamic energy: Bonny experiences higher wave and tidal energy, which compacts sediments, while Andoni retains finer, loosely compacted deposits.

4.1.6. Porosity

Porosity values across both sites range from 37% to 48%, indicating moderate pore space within sediments. Higher porosity at certain Andoni sites (up to 47%) reflects a looser packing of particles due to higher silt and clay content, facilitating water infiltration and retention but reducing structural stability (Hillel, 1998). Bonny sediments, though denser, still maintain relatively high porosity (~46–48%), suggesting mixed textures that allow moderate fluid exchange, which can influence sediment transport during high-energy events

4.2. Implications for Erosion and Accretion

Andoni Beach (AN. T) lower bulk density and higher porosity mean softer, unconsolidated sediments that are easily eroded during storm surges or seasonal tidal events (Oyegun & Adeyemo, 1999). This aligns with the high vulnerability of Andoni beaches to sediment loss and retreat observed in other morphometric studies.

Bonny Beach (BN) has higher bulk density and moisture suggest more compacted and partially saturated sediments, which resist minor erosion forces but may fail under intense hydrodynamic action such as spring tides or heavy storms (Nwilo & Badejo, 2006). The combination of higher moisture and density supports the presence of more stable shoreline segments, with localized erosion or accretion depending on sediment budget and anthropogenic interference.

4.3. Sediment Load Data for Bonny (BN.T) and Andoni (AN.T) Beaches

Table 3 showed the sediment load (%) data for Bonny (BN) and Andoni (AN) beaches in Rivers State, Nigeria, in relation to coastal erosion and accretion dynamics.

4.3.1. Spatial Variations and Dynamics

Bonny Beach (BN.T): Higher sediment load values are observed, particularly at high water marks (e.g., BN.T 1.1 HW = 1.68%, BN.T 0.1 HW = 1.60%). Lower values are present in low-water zones (e.g. BN 2.2 LW = 0.96%). This indicates active sediment mobilization in high-tide zones, which is typical in high-energy coastlines where tidal forces and wave action resuspend and deposit sediments (Komar, 1998; Anthony & Blivi, 1999).

Andoni (AN.T) Beach: Sediment loads are relatively lower and more uniform (0.80–1.14%), suggesting a less dynamic sediment transport system. This aligns with observations of low-energy conditions and dominance of finer sediment textures previously documented for Andoni beaches (Oyegun & Adeyemo, 1999).

Bonny Beach Dynamics: The higher sediment load suggests that Bonny beach is subject to stronger hydrodynamic processes, including higher wave energy and tidal currents (Komar, 1998). These conditions favour erosion at certain locations but also contribute to rapid deposition where energy dissipates, promoting localized accretion (Anthony & Blivi, 1999). The significant variability between high water (HW) and low water (LW) zones indicates tidal-driven sediment redistribution along the shore profile.

Andoni Beach Dynamics: The lower and stable sediment loads (~1.00%) imply limited sediment transport along this section of the coast. This reflects low wave energy and fine-grained, loosely packed sediments, consistent with the silty loam textures reported in prior analyses. Such low-energy environments are often prone to gradual shoreline retreat, particularly during seasonal changes or storm events (Nwilo & Badejo, 2006).

4.3.2. Implications for Erosion and Accretion

Erosion Risk: Bonny's beach higher sediment load and active transport dynamics mean that erosion rates may be higher, especially during storm surges or high tides. Andoni beach, though less dynamic, remains vulnerable due to the loose, fine sediment composition, making it easily erodible under extreme conditions (Blake & Hartge, 1986).

Accretion Potential: The Bonny coastline may experience localized accretion where wave energy diminishes, allowing suspended sediments to settle.

In contrast, Andoni beach shows less evidence of significant sediment deposition, implying limited accretion potential.

5. Conclusion

The sediment particle size distribution in the Andoni and Bonny beaches highlights a system dominated by fine sediments (silt and clay), with low sand content across the sites. These conditions indicate low-energy depositional

environments with moderate retention capacity for organic matter and pollutants. The spatial variation between Andoni and Bonny beaches/shorelines, reflect differences in hydrodynamic energy and sediment supply.

Recommendations

Implement continuous morphometric monitoring to track sediment dynamics using parameters like bulk density changes over time.

Introduce soft engineering solutions, such as mangrove restoration, to stabilize sediments and buffer hydrodynamic impacts. Continuous Sediment Monitoring: Long-term monitoring of sediment load and morphometric parameters will help predict erosion hotspots and inform adaptive management strategies.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

- [1] Abam, T.K.S, Gobo, A.E & Opuaji, T. (2004). Spatial and Temporal Patterns of Coastal Erosion in the Niger Delta. *Global Journal of Geological Sciences* 2(1), 79-90.
- [2] Adebowale, K. O., Agunbiade, F. O., & Olu-Owolabi, B. I. (2009). Trace metal concentration, site variations and partitioning pattern in water and bottom sediments from coastal area: A case study of Ondo Coast, Nigeria. *Environmental Monitoring and Assessment*, 159(1-4), 491-500.
- [3] Allison, M. A., & Kepple, E. B. (2001). Modern sediment supply to the lower delta plain of the Fly River, Papua New Guinea. *Journal of Geology*, 109(3), 355-370.
- [4] Anthony, E. J., & Blivi, A. (1999). Morphosedimentary evolution of a delta-sourced, drift-aligned sand barrier-lagoon complex, western Bight of Benin. *Marine Geology*, 158(1-4), 161-176.
- [5] Bashir, B & Alsaman, A. (2024). Morphometric and Soil erosion Characterization Based on Geospatial Analysis and Drainage Basin Prioritization of the Rabigh Area Along the Eastern Red Sea Coastal Plain, Saudi Arabia.
- [6] Blake, G. R., & Hartge, K. H. (1986). Bulk density. In A. Klute (Ed.), *Methods of soil analysis, Part 1*. ASA and SSSA.
- [7] Bozzeda, F., Ortega, L., Costa, L. L., Fanini, L., Barboza, C.A.M., Mclachlan, A., & Defeo, O. (2023). Global Patterns in sandy beach erosion: unraveling the roles of anthropogenic, Climatic and Morphodynamic factors.
- [8] Blott, S. J., & Pye, K. (2001). Gradistat: A grain size distribution and statistics package. *Earth Surface Processes and Landforms*, 26(11), 1237-1248.
- [9] Brady, N. C., & Weil, R. R. (2017). *The nature and properties of soils* (15th ed.). Pearson.
- [10] Castelle, B., & Masselink, G (2023). Morphodynamics of wave-dominated beaches-Cambridge Prisms Coastal Futures, 1 e1, 1-13.
- [11] Emmanuel C.D, Bright G.A & Olumese E (2024). Shoreline Position Trends in the Niger Delta: analyzing spatial and temporal changes through Sentinel-1 SAR imagery, *Geomatics. Natural Hazards and Risk*, 15:1,2346150, DOI:10.1080/19475705.2024.2346150.
- [12] FAO. (2015). *World reference base for soil resources*. Food and Agriculture Organization of the United Nations.
- [13] Folk, R. L., & Ward, W. C. (1957). Brazos River bar: A study in the significance of grain size parameters. *Journal of Sedimentary Petrology*, 27(1), 3-26.
- [14] Hillel, D. (1998). *Environmental soil physics*. Academic Press.
- [15] Komar, P. D. (1998). *Beach processes and sedimentation*. Prentice Hall.
- [16] Ngerebara, O.D, Aitsebaomo, F.O, Oduore, T.B, Gobo, A.E and Fakeye, A.M (2012). Mapping shoreline dynamics of Andoni and Bonny Beaches, Nigeria, Using Geographic Information System and Remote Sensing Techniques.

- [17] Nwaichi, E. O., Wegwu, M. O., & Nwosu, U. L. (2017). Distribution and bioaccumulation of heavy metals in selected wetland plants and sediments from crude oil-impacted sites in the Niger Delta, Nigeria. *Journal of Environmental Management*, 200, 171–180.
- [18] Nwilo, P.C, Ibe, A.C, Adegoke, J.O, Obiefuna, J.N, Alademomi, A.S, Okolie, C.J. & Daramola, O.E (2020). Long-term determination of shoreline changes along the coast of Lagos. *Journal of Geomatics*, 14(1), 72-83.
- [19] Nwilo, P. C., & Badejo, O. T. (2006). Impacts and management of oil spill pollution along the Nigerian coastal areas. FIG Working Week.
- [20] Oyegun, C. U., & Adeyemo, A. (1999). Coastal erosion and management in the Niger Delta. *Journal of Environmental Sciences*, 3(2), 136–145.
- [21] Pietro S, Alexandra T, Moises A, Giggio M & Giuseppe C (2024). Mapping decadal Land cover dynamics in Sicily's coastal regions.