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RESEARCH ARTICLE

Epochal Assessment of Sea Level Rise Across the Coastal Waters of Nigeria

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Abstract

Sea level rise remains one of the most critical challenges confronting coastal regions worldwide, threatening ecosystems, infrastructure, and livelihoods. This study carried out an epochal assessment of Sea Level Rise (SLR) along the Nigerian coastline between 2004 to 2024. The research adopted remote sensing techniques for collecting spatial data. A multi-mission satellite altimetry dataset, including Jason-3, TOPEX/Poseidon, and Envisat, accessed from the Copernicus Climate Data Store (CDS) in NetCDF-4 format. Using ArcGIS 10.8, the yearly gridded data of Sea Surface Height (SSH), Mean Sea Surface (MSS), and Sea Level Anomaly (SLA) were extracted through spatial operations such as raster clipping, raster-to-point conversion. The results revealed a consistent increase in MSS from 2004 until 2014, suggesting a rising trend, followed by a significant decline extending towards 2024. SLA, on the other hand, remained predominantly negative during most of the study period, only showing a reversal to positive values in 2024. These contrasting patterns reflect the influence of both global climate drivers, such as thermal expansion and melting of ice sheets, and localized anthropogenic activities, and coastal modification. The study highlighted that while Global Mean Sea Level (GMSL) has risen steadily at rates of 4.3–5.9 mm/yr, the Nigerian coast recorded localized rates of approximately 2mm/yr between 2004 to 2014 and 4mm/yr between 2014 to 2024. The correlation between the MSS and SLA is 0.42; this is a weak positive correlation. The findings underscore the need for sustained monitoring of SLA and MSS patterns as they directly impact on coastal flooding, flood risk assessment, and shoreline management.

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1. INTRODUCTION

Sea-level rise (SLR) poses a major threat to most lands along the coast and also major developments having direct access to the shoreline, especially in cities and other forms of development within the low-lying area around the coast (McGranahan, Balk & Anderson, 2007). This is evident by the forecast concerning Global Mean Sea-level Rise by the Intergovernmental Panel for Climate Change (IPCC, 2007), of a projection that by the year 2020, about 75 to 250 million people would encounter the challenge of increased water (flooding) through climate change. A rise in sea level usually increases the flooding depth and extends the area that stays wet in the dry season (Brammer, 2013).

Sea level is the base level for measuring elevation and depth on Earth. The surface of the ocean can be used as a reference point for measuring land elevation and ocean depth, because the concept of the ocean is one continuous body of water and its surface tends to seek the same level throughout the world.

Mean Sea level is determined by taking hourly measurements of sea levels over a period of 19 years at various locations, and then averaging all of the measurements, to describe a stable average over time, filtering out short-term variations.

SLR refers to the increasing average level of the Earth's oceans, primarily due to two main factors: the melting of glaciers and ice sheets, and the thermal expansion of seawater as it warms. As global temperature rises due to climate change, more ice melts, contributing additional water to the oceans. At the same time, warmer water expands, further raising sea levels. This phenomenon poses significant risks to coastal communities, ecosystems and infrastructure, such as more frequent coastal flooding, erosion of shorelines, and the salinization of freshwater resources.

There are different projections of the variation of sea level, but sea levels are expected to continue rising throughout the 21st century and beyond, with potential impacts on millions of people living near coastlines worldwide, as reported by Church *et.al*. (2013); Ericson *et.al*. (2006). It is projected that global sea level will rise to 60 cm by 2100 (IPCC, 2007), but with the recent accelerated decline of the polar ice sheet, there is the possibility of future SLR being more than 1m and close to 2m by 2100, as reported by Nicholls & Cazenave, (2010). Rising sea levels can affect sustainable development, such as the energy systems, loss of life, transportation facilities, loss of man hour, agricultural lands, water infrastructures, in the coastal areas due to the low capacity of the soil to absorb precipitation as reported in the Sustainable Development Goal (SDG13) by (Zhang, 2011; Shen & Shim, 2022).

Sea level is measured by two main methods, namely the tide gauges and satellite altimeters. Tide gauge stations from around the world have measured the daily high and low tides for more than a century, using a variety of manual and automatic sensors. Using data from scores of stations around the world, scientists can calculate a global average and adjust it for seasonal differences. Since the early 1990s, sea level has been measured from space using radar altimeters, which determine the height of the sea surface by measuring the return speed and intensity of a radar pulse directed at the ocean. The higher the sea level, the faster and stronger the return signals (Lindsey *et al.*, 2022). Studying local sea level rise (SLR) is critical for understanding the unique dynamics and contributing factors in specific regions, which in turn supports evidence-based land use planning, infrastructure development, and disaster risk reduction in vulnerable coastal areas. Nigeria's coastal zone, stretching over 850 km along the Atlantic Ocean, represents one of the country's most important socio-economic and ecological corridors, hosting vital oil and gas operations, commercial ports, fisheries, and rapidly expanding urban centers such as Lagos, Port Harcourt, and Calabar.

However, these low-lying coastal areas are increasingly threatened by sea level rise, a major consequence of global climate change, with evidence from tide gauge records, satellite altimetry, and climate projections pointing to progressive inundation, shoreline retreat, saltwater intrusion, and ecosystem degradation. These impacts pose serious risks to livelihoods, infrastructure, and natural systems, while also undermining the progress toward Sustainable Development Goals (SDG-13 and 14), including poverty reduction, food security, clean water access, sustainable cities, climate action, and marine biodiversity conservation. SDG 1 (No Poverty) and SDG 2 (Zero Hunger) are threatened by the loss of livelihoods in agriculture and fisheries due to saline intrusion and coastal flooding. SDG 11 (Sustainable Cities and Communities) is at risk from the destruction of coastal infrastructure and displacement of populations.

Despite these threats, systematic and long-term assessments of sea level rise across Nigeria's coastline remain limited, as most existing studies are fragmented, localized, or short-term. Traditional tide gauge measurements are sparse, expensive, and often vulnerable to both natural and human challenges, making them inadequate for comprehensive monitoring. The absence of integrated, multi-decadal analyses hampers Nigeria's capacity for informed policymaking, climate adaptation planning, and resilience building, thereby increasing the risks of economic losses, forced migration, and ecological decline. The study assessed the sea level rise across the Nigerian coastline from 2004 to 2024 using satellite-based data with the following objectives:

a) Extract Mean Sea Surface (MSS) and Sea Surface Height (SSH) from satellite altimeter sources from 2004 to 2024,
b) Evaluate Sea Level Anomaly (SLA) derived from MSS and SSH,
c) Examine SLA correlation between 2004-2014 and 2014-2024.

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2. STUDY AREA

The Nigerian Coast is composed of four distinct geomorphology units namely the Barrier-Lagoon Complex; the Mud Coast; the Arcuate Niger Delta and the Strand Coast. Nigeria's coastline runs along Africa's West coast, in the Gulf of Guinea. It stretches from the Nigeria Benin Republic border at Seme, Lagos State, to the Nigeria-Cameroon border at Ikang, Cross River State, tilting into the Atlantic Ocean.

Nigeria's coastline runs along Africa's west coast, in the Gulf of Guinea. It stretches from the Nigeria Benin Republic border at Seme, Lagos State, to the Nigeria-Cameroon border at Ikang, Cross River State, tilting into the Atlantic Ocean. The coastline is located between latitude 4˚10′ – 6˚20′ N and longitude 2˚45′ – 8˚32 E; it can broadly be divided between the western coast (the Lagos-Ogun axis) and the eastern coast (the Niger Delta region), spanning eight southern Nigerian states, and is host to several coastal cities. These include Lagos, one of the World's most rapidly expanding megacities in addition to Warri and Port Harcourt, located in the Niger Delta region and home to Nigeria's oil and gas sector (Elum, Mopipi & Henri-Ukoha, 2016; Bello & Nwaeke, 2020). The study area map is shown on Figure 1.

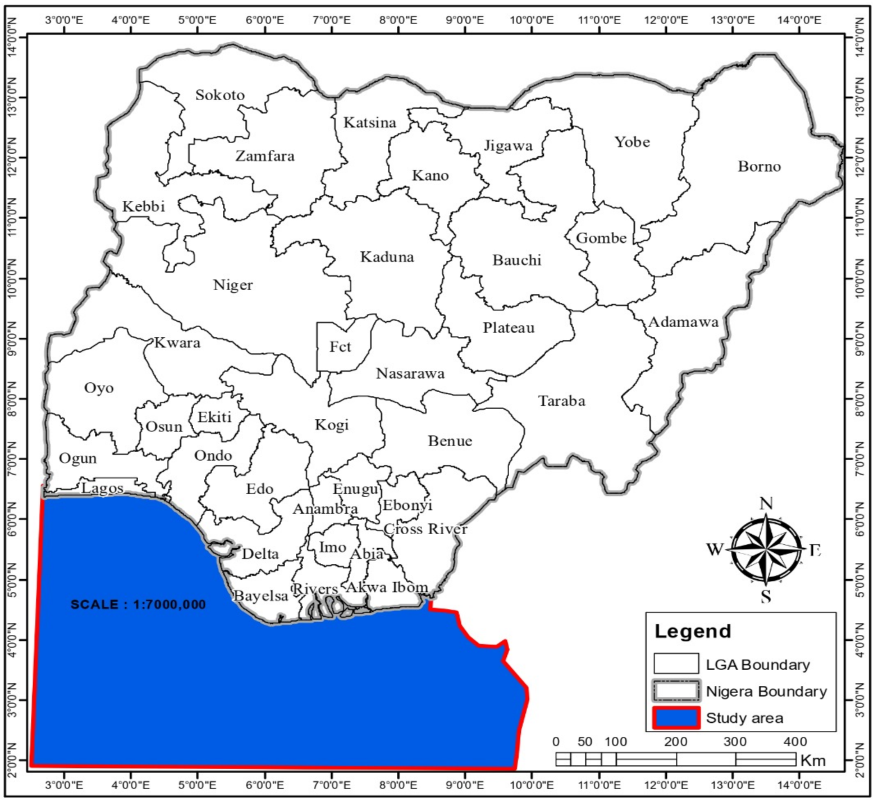

Figure 1: Map of Nigeria and its Coastal Waters
Office of the Surveyor General Rivers State (2025)

3. METHODOLOGY

3.1 Materials and Methods

3.1.1 Data Acquisition

Satellite altimeter data was used to study the total changes of global sea level. In this study, the Sea level gridded data from satellite observations for the global ocean of 2004, 2014 and 2024 were downloaded from Climate Data Store (CDS). This dataset provides gridded monthly mean sea level anomaly estimates, derived from satellite altimetric measurements. These measurements are based on radar pulses emitted by satellites such as Jason-3, TOPEX/Poseidon, and Envisat to measure the distance between the satellite and the ocean's surface. They emit microwave pulses that bounce off the sea surface and return to the satellite by precisely measuring the time it takes for the pulses to return, the sea surface height was calculated. Modern satellite altimeters like TOPEX/Poseidon, Jason-3, and Envisat achieve centimeter-level accuracy through a combination of precise measurements, corrections, and orbit determination. This high level of precision allows scientists to track even small changes in sea level over time. The continuous and global coverage of the oceans provided by satellites enables the monitoring of sea level changes worldwide. This is a significant advantage over traditional tide gauges, which provide only localized measurements.

The file format is NetCDF-4 (Network Common Data Form) facilitates efficient data manipulation and analysis, enabling the integration of these sea level data with other climate variables, such as ocean currents, temperature, and precipitation. This comprehensive approach will allow for a nuanced understanding of sea level rise drivers, including ocean dynamics, ice sheet melting, and anthropogenic factors. Furthermore, the high-resolution gridded data, as shown in Figure 2, enabled the regional assessments of sea level impacts on coastal ecosystems, infrastructure, and communities, informing adaptation and mitigation strategies. By exploring these satellite-derived sea level data, this study aims to contribute to the ongoing conversation on climate-driven sea level rise, its consequences, and the development of effective management policies.

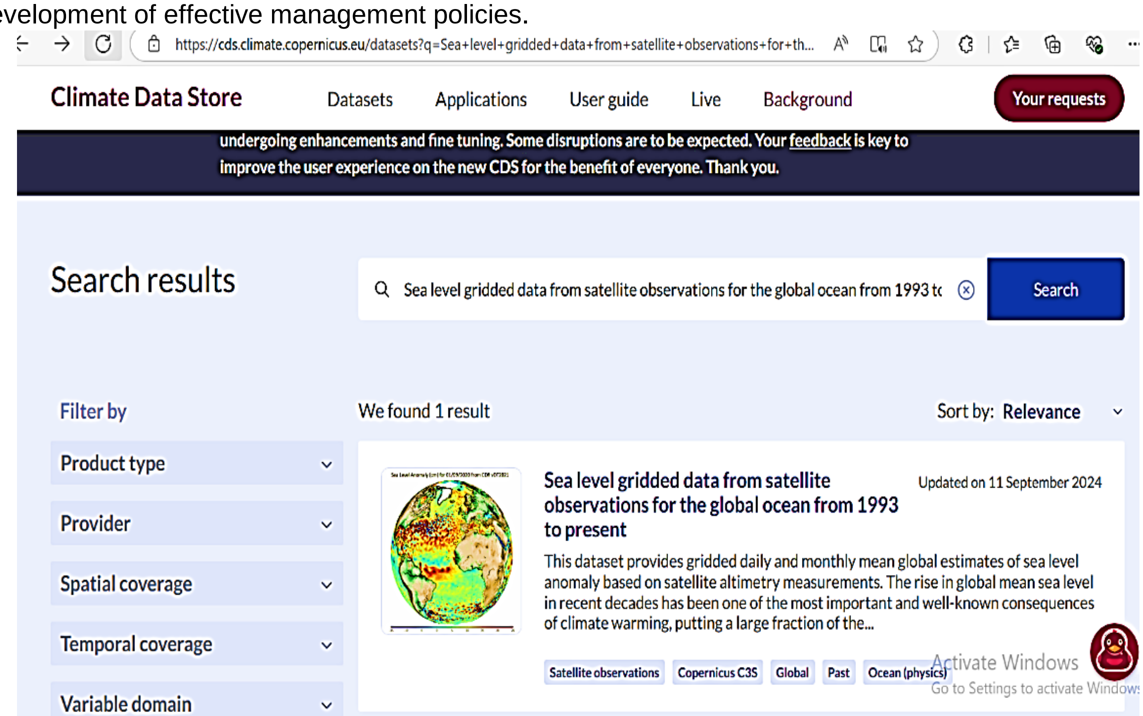

Figure 2: Climate Data Store (CDS) Website for Mean Sea Surface Level Data
Source: Copernicus C3S Software (2025).

3.1.2 Data Processing

The process began with the creation of an account on the Copernicus Data Space Ecosystem (CDSE) data platform, which requires user registration to access its repository. Once logged in, datasets for Sea Surface Height (SSH) and Mean Sea Surface (MSS) were identified and downloaded. The Nigeria Coastal Shape file served as the boundary delineation for defining the Area of Interest (AOI). Subsequent spatial analysis involved clipping the dataset to the study area boundaries, as illustrated in the figure (3.4) below. These datasets were provided in NetCDF format, a widely used file format for multidimensional scientific data. To make the data compatible with GIS software, the NetCDF files were imported into SNAP (Sentinel Application Platform), a software developed by ESA for processing Earth Observation data. Within SNAP, the NetCDF files were visualized, and a data conversion process was performed to export the SSH and MSS Datasets into GeoTIFF format. GeoTIFF was chosen due to its geospatial compatibility with GIS software like ArcGIS. The dataset was imported and visualized using the Geographic Information System tool ArcGIS 10.8. To extract Mean Sea Surface (MSS) and Sea Surface Height (SSH) coordinates, the Raster-to-Point conversion tool was employed. This process yielded ϕ, λ, h coordinates, which were then exported to Microsoft Excel for further statistical analysis and data manipulation.

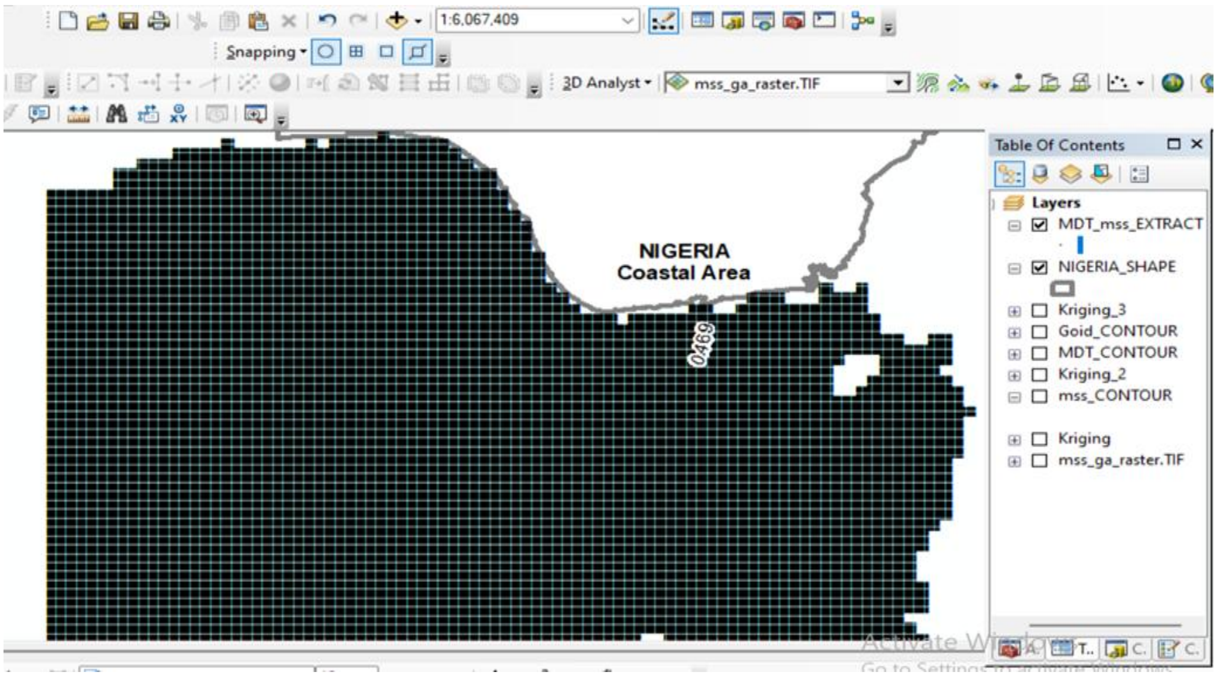

Figure 2: Extraction Process of ϕ point in ArcGIS 10.8 environment.
Source: (CopernicusC3S Software)

3.1.3 Mean Sea Surface (MSS)

Mean Sea Surface is a height above a reference ellipsoid, it represents the average sea surface height over a specific period and to eliminate annual, semi-annual, seasonal and spurious sea surface height signals. It serves as a reference surface for measuring sea level changes and ocean currents.

$$MSS = SSH - SLA \quad \ldots (1)$$

3.1.4 Sea Surface Height (SSH)

The sea surface height (SSH) is the instantaneous sea surface height as observed by the satellite altimetry mission, this is the height of the sea surface above the ellipsoid, it is calculated by subtracting the measured distance from the satellite altitude.

Sea Surface Height (SSH) is calculated as: $SSH = R_T - (R + \Delta)$ … (2)

$$SSH = R - O + Corrections \quad \ldots (3)$$

Where:

SSH = Sea Surface Height

$R_T =$ Distance from satellite to Earths center (orbit radius)

$R =$ Distance from satellite to sea surface (measured by radar)

$\Delta =$ Corrections (atmospheric delay and tides.)

R =Altimeter Range; the distance from the satellite to the sea surface, measured by the altimeter

O= Orbital Altitude; the satellites' height above a reference ellipsoid (WGS84).

3.1.5 Sea level Anomaly (SLA)

The Sea level Anomaly refers to the difference between the SSH and MSS, representing the deviation from the mean sea surface.

$$\mathrm{SLA} = \mathrm{SSH} - \mathrm{MSS} \quad \ldots (4)$$

where:

SLA= Sea Level Anomaly
SSH= Sea Surface Height
MSS= Mean Sea Surface

3.1.6 Global Mean Sea Level (GMSL)

Global Mean Sea Level refers to- the average height of the ocean's surface across the entire planet, used as a baseline to monitor changes in sea level over time. It is calculated by averaging SLA data over the global ocean. Statistical methods are used to account for data gaps and uncertainties.

Global Mean Sea Level (GMSL) is the spatial average of Sea Surface Height (SSH) relative to a reference Earth ellipsoid over the world's oceans. By averaging SLA over the global researchers estimate, the global mean sea level rise can be determined.

$$GMSL(t) = \frac{1}{A}\int_{A} SSH(x,t)dA \quad \ldots (5)$$

Where:

x= location vector over ocean area

A= total ocean surface area

$SSH(x,t)$ =Sea surface height at location x and time t

Radar signals are delayed by the atmosphere and affected by sea surface conditions. Corrections are applied to account for delays caused by Ionospheric delay, which is a frequency-dependent delay, and it is corrected using dual-frequency altimeters. Tropospheric delay, which is water vapor slows radar pulse, and it is corrected using meteorological data such as onboard microwave radiometers and numerical weather models. Tidal Corrections: Tides significantly influence local sea levels, and tidal signals such as ocean, solid Earth, and pole tides were modeled and removed from the altimetry data. Geoid Corrections: The geoid represents the Earth's gravity field and is the equipotential surface that best approximates mean sea level. To obtain the absolute sea level, the geoid height must be accounted for. Other Corrections include Wave height, sea state, and instrument biases also require corrections.

4. RESULTS

4.1 Results

The results of this research work are dependent on the objectives and are presented below as follows. Table 1 and figures 4 and 5 and Table 2 shows sample of MSS and SSH data for 2004, 2014, and 2024 at various geolocated points (Latitude and Longitude) along the Nigerian coast waters.

Table 1: Sample of the Mean Sea Surface Data across the Study Area

Piont_ID	Latitude (ϕ)	Longitude (λ)	MSS 2004(m)	MSS 2014(m)	MSS 2024(m)
1.	4° 07' 30.000"	3° 7' 30.000"	0.0731	0.0676	0.0863
2.	3° 52' 30.000"	3° 52' 0.000"	0.0675	0.0626	0.0826
3.	3° 52' 30.000"	3° 22' 0.000"	0.0703	0.0645	0.0794
4.	4° 22' 30.000"	3° 7' 30.000"	0.0751	0.0670	0.0765
5.	4° 07' 30.000"	3° 37' 0.000"	0.0691	0.0627	0.0774
6.	4° 22' 30.000"	3° 22' 0.000"	0.0733	0.0631	0.0769
7.	4° 22' 30.000"	3° 37' 0.000"	0.0706	0.0593	0.0763
8.	3° 22' 30.000"	5° 22' 0.000"	0.0637	0.0596	0.0760
9.	4° 07' 30.000"	4° 22' 0.000"	0.0626	0.0553	0.0925
10.	4° 07' 30.000"	4° 37' 0.000"	0.0595	0.0529	0.0854
11.	4° 37' 30.000"	3° 7' 30.000"	0.0755	0.0627	0.0930
12.	3° 37' 30.000"	5° 22' 0.000"	0.0590	0.0556	0.0945
13.	4° 22' 30.000"	3° 52' 0.000"	0.0670	0.0562	0.0933
14.	4° 22' 30.000"	4° 7' 30.000"	0.0633	0.0530	0.0904
15.	4° 07' 30.000"	4° 52' 0.000"	0.0558	0.0505	0.0889
16.	4° 22' 30.000"	4° 22' 0.000"	0.0594	0.0503	0.0906
17.	4° 22' 30.000"	4° 37' 0.000"	0.0560	0.0479	0.1019
18.	4° 07' 30.000"	5° 7' 30.000"	0.0518	0.0475	0.0800
19.	4° 37' 30.000"	3° 37' 0.000"	0.0708	0.0545	0.0956
20.	3° 52' 30.000"	5° 22' 0.000"	0.0536	0.0506	0.0966
21.	5° 07' 30.000"	2° 22' 0.000"	0.0692	0.0594	0.0956
22.	4° 07' 30.000"	5° 22' 0.000"	0.0481	0.0462	0.0899
23.	4° 52' 30.000"	3° 7' 30.000"	0.0739	0.0555	0.0793
24.	4° 37' 30.000"	4° 37' 0.000"	0.0522	0.0433	0.0980
25.	5° 22' 30.000"	5° 7' 30.000"	0.0428	0.0370	0.0919
26.	5° 07' 30.000"	5° 7' 30.000"	0.0420	0.0370	0.0922
27.	3° 37' 30.000"	5° 52' 0.000"	0.0542	0.0551	0.0946
28.	4° 37' 30.000"	5° 7' 30.000"	0.0431	0.0402	0.0952
29.	3° 37' 30.000"	5° 37' 0.000"	0.0566	0.0548	0.0982
30.	4° 37' 30.000"	3° 52' 0.000"	0.0670	0.0512	0.0967

(Authors Lab. 2025)

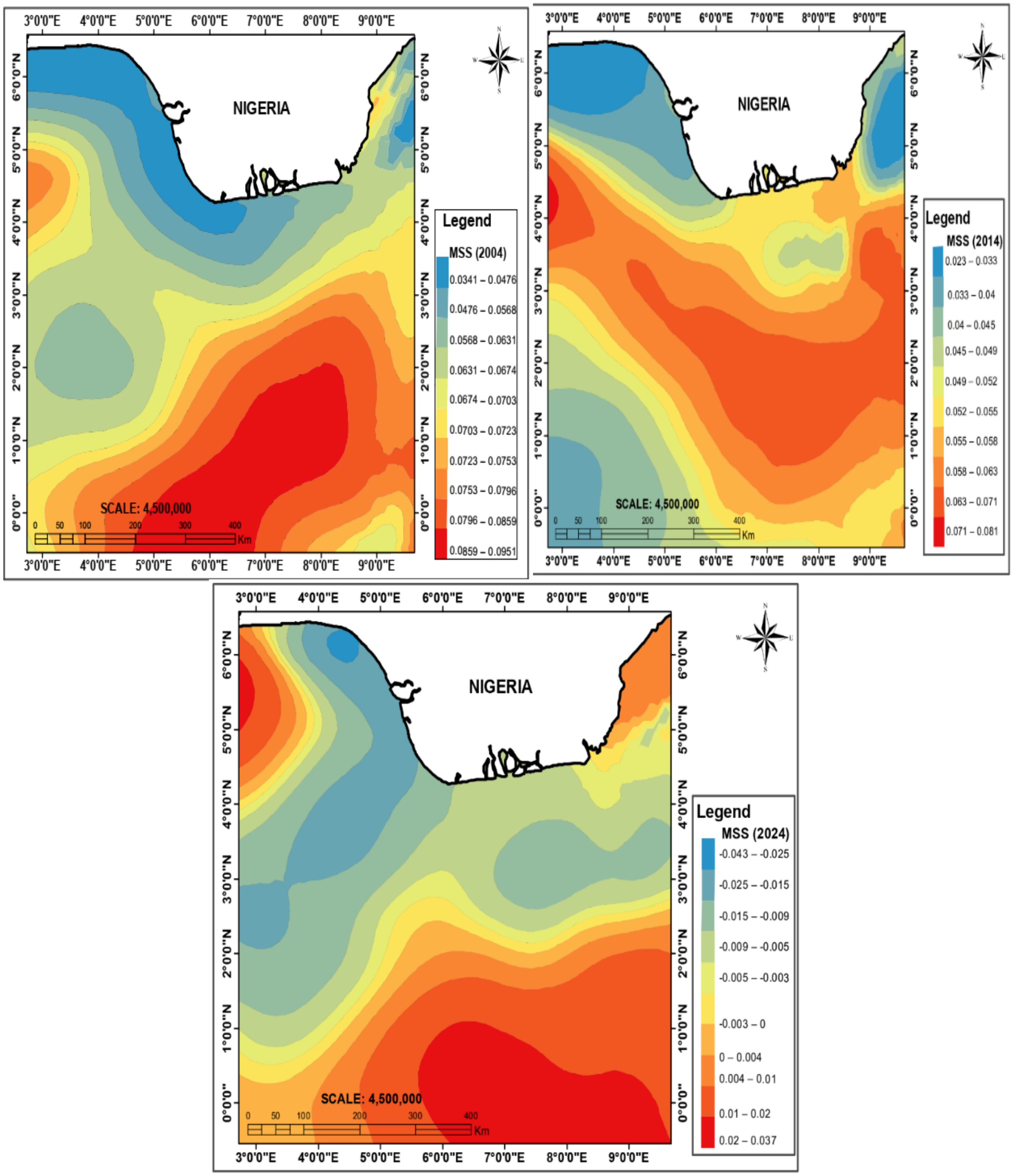

Figure 4: Map showing Mean Sea Surface (MSS) for 2004 -2024

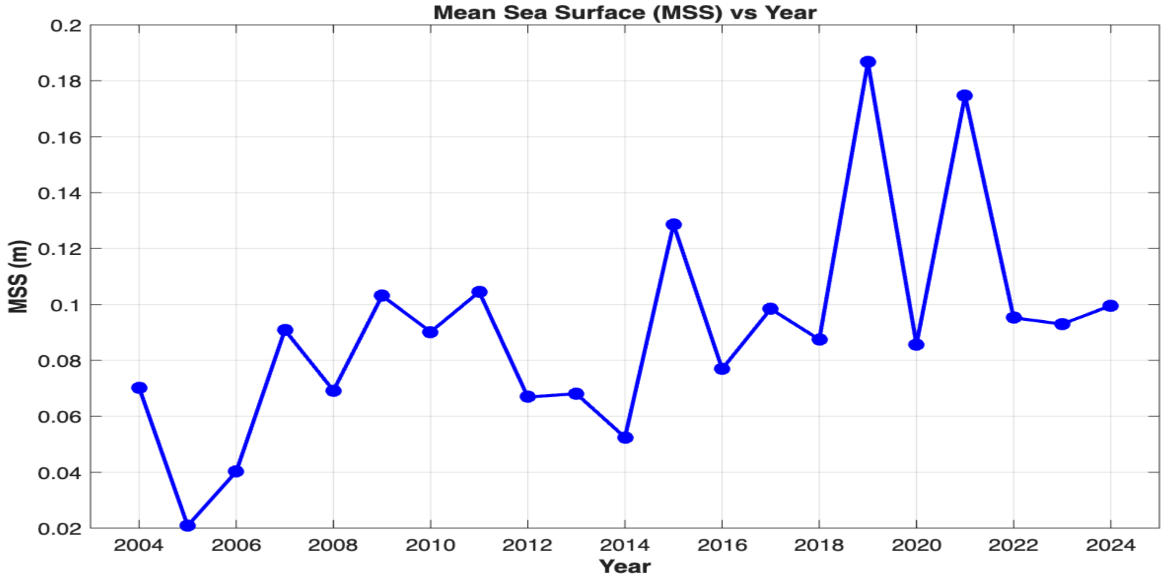

Figure 5: Graph of Trend and Pattern of Coastal MSS Between 2004 – 2024

Table 2: Sample of the Sea Surface Height Data across the Study Area

Point_ID	Latitude (ϕ)	Longitude (λ)	SSH 2004(m)	SSH 2014(m)	SSH 2024(m)
1.	4° 7' 30.000"	3° 7' 30.000"	0.0436	0.0583	0.0743
2.	3° 52' 30.000"	3° 52' 0.000"	0.0387	0.0549	0.0709
3.	3° 52' 30.000"	3° 22' 0.000"	0.0406	0.0545	0.0741
4.	4° 22' 30.000"	3° 7' 30.000"	0.0436	0.0583	0.0743
5.	4° 7' 30.000"	3° 37' 0.000"	0.0415	0.0591	0.0712
6.	4° 22' 30.000"	3° 22' 0.000"	0.0436	0.0583	0.0743
7.	4° 22' 30.000"	3° 37' 0.000"	0.0415	0.0591	0.0712
8.	3° 22' 30.000"	5° 22' 0.000"	0.0418	0.0607	0.0565
9.	4° 7' 30.000"	4° 22" 0.000"	0.0385	0.0606	0.0668
10.	4° 7' 30.000"	4° 37' 0.000"	0.0361	0.0631	0.0610
11.	4° 37' 30.000"	3° 7' 30.000"	0.0462	0.0603	0.0754
12.	3° 37' 30.000"	5° 22' 0.000"	0.0400	0.0643	0.0548
13.	4° 22' 30.000"	3° 52' 0.000"	0.0415	0.0591	0.0712
14.	4° 22' 30.000"	4° 7' 30.000"	0.0385	0.0606	0.0668
15.	4° 7' 30.000"	4° 52' 0.000"	0.0361	0.0631	0.0610
16.	4° 22' 30.000"	4° 22' 0.000"	0.0385	0.0606	0.0668
17.	4° 22' 30.000"	4° 37' 0.000"	0.0361	0.0631	0.0610
18.	4° 7' 30.000"	5° 7' 30.000"	0.0365	0.0667	0.0541
19.	4° 37' 30.000"	3° 37' 0.000"	0.0438	0.0614	0.0725
20.	3° 52' 30.000"	5° 22' 0.000"	0.0400	0.0643	0.0548
21.	5° 7' 30.000"	2° 22' 0.000"	0.0489	0.0614	0.0798
22.	4° 7' 30.000"	5° 22' 0.000"	0.0365	0.0667	0.0541
23.	4° 52' 30.000"	3° 7' 30.000"	0.0462	0.0603	0.0754
24.	4° 37' 30.000"	4° 37' 0.000"	0.0350	0.0652	0.0622
25.	5° 22' 30.000"	5° 7' 30.000"	0.0291	0.0683	0.0569
26.	5° 7' 30.000"	5° 7' 30.000"	0.0291	0.0683	0.0569
27.	3° 37' 30.000"	5° 52' 0.000"	0.0474	0.0701	0.0483
28.	4° 37' 30.000"	5° 7' 30.000"	0.0326	0.0680	0.0547
29.	3° 37' 30.000"	5° 37' 0.000"	0.0474	0.0701	0.0483
30.	4° 37' 30.000"	3° 52' 0.000"	0.0438	0.0614	0.0725

(Authors Lab. 2025)

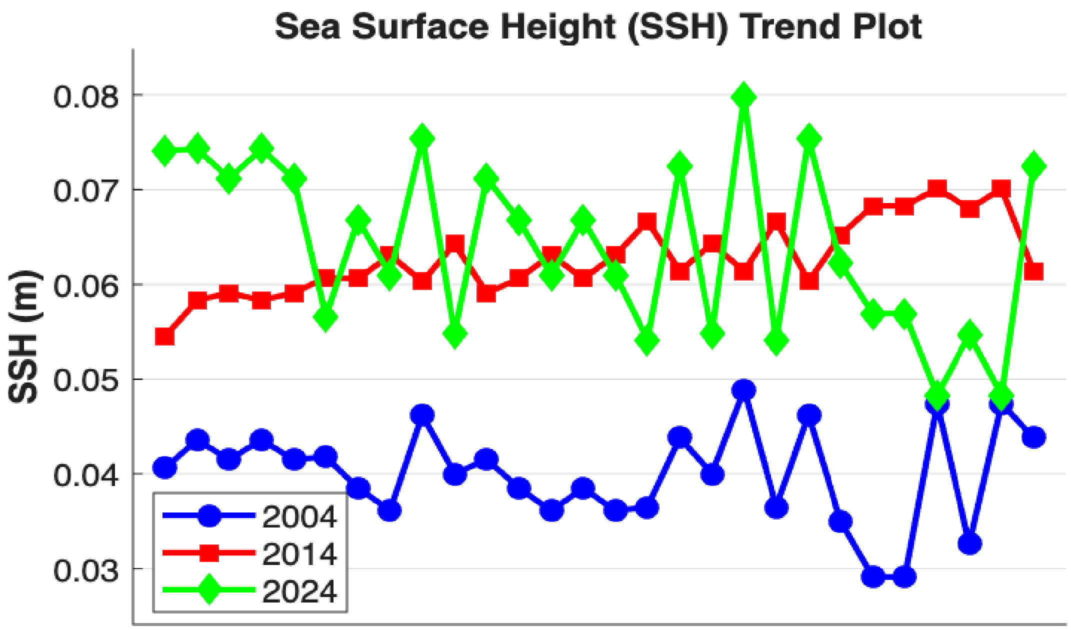

Figure 6: Graph of Trend and Pattern of SSH for 2004, 2014 and 2024

To satisfy objective two, Table 3 and figures 7 and 8 shows the Sea Level Anomaly (SLA) data for 2004 - 2024 at various geolocated points (Latitude and Longitude) along the Nigerian coastline. This data was computed from the difference between SSH and MSS data for various epochs using equation 4. The SLA values are one of the indicators of Sea Level Rise across coastal waters amongst other factors.

Table 3: Computation of Epochal Sea Level Anomaly (2004 - 2024)

Point_ID	Latitude (ϕ)	Longitude (λ)	SLA 2004(m)	SLA 2014(m)	SLA 2024(m)
1.	4° 7' 30.000"	3° 7' 30.000"	-0.0295	-0.0093	-0.0120
2.	3° 52' 30.000"	3° 52' 0.000"	-0.0288	-0.0077	-0.0117
3.	3° 52' 30.000"	3° 22' 0.000"	-0.0297	-0.0100	-0.0053
4.	4° 22' 30.000"	3° 7' 30.000"	-0.0315	-0.0087	-0.0022
5.	4° 7' 30.000"	3° 37' 0.000"	-0.0276	-0.0036	-0.0062
6.	4° 22' 30.000"	3° 22' 0.000"	-0.0297	-0.0048	-0.0026
7.	4° 22' 30.000"	3° 37' 0.000"	-0.0291	-0.0002	-0.0051
8.	3° 22' 30.000"	5° 22' 0.000"	-0.0219	0.0011	-0.0195
9.	4° 7' 30.000"	4° 22" 0.000"	-0.0241	0.0053	-0.0257
10.	4° 7' 30.000"	4° 37' 0.000"	-0.0234	0.0102	-0.0244
11.	4° 37' 30.000"	3° 7' 30.000"	-0.0293	-0.0024	-0.0176
12.	3° 37' 30.000"	5° 22' 0.000"	-0.0190	0.0087	-0.0397
13.	4° 22' 30.000"	3° 52' 0.000"	-0.0255	0.0029	-0.0221
14.	4° 22' 30.000"	4° 7' 30.000"	-0.0248	0.0076	-0.0236
15.	4° 7' 30.000"	4° 52' 0.000"	-0.0197	0.0126	-0.0279
16.	4° 22' 30.000"	4° 22' 0.000"	-0.0209	0.0103	-0.0238
17.	4° 22' 30.000"	4° 37' 0.000"	-0.0199	0.0152	-0.0409
18.	4° 7' 30.000"	5° 7' 30.000"	-0.0153	0.0192	-0.0259
19.	4° 37' 30.000"	3° 37' 0.000"	-0.0270	0.0069	-0.0231
20.	3° 52' 30.000"	5° 22' 0.000"	-0.0136	0.0137	-0.0418
21.	5° 7' 30.000"	2° 22' 0.000"	-0.0203	0.0020	-0.0158
22.	4° 7' 30.000"	5° 22' 0.000"	-0.0116	0.0205	-0.0358
23.	4° 52' 30.000"	3° 7' 30.000"	-0.0277	0.0048	-0.0039
24.	4° 37' 30.000"	4° 37' 0.000"	-0.0172	0.0219	-0.0358
25.	5° 22' 30.000"	5° 7' 30.000"	-0.0137	0.0313	-0.0350
26.	5° 7' 30.000"	5° 7' 30.000"	-0.0129	0.0313	-0.0353
27.	3° 37' 30.000"	5° 52' 0.000"	-0.0068	0.0150	-0.0463
28.	4° 37' 30.000"	5° 7' 30.000"	-0.0105	0.0278	-0.0405
29.	3° 37' 30.000"	5° 37' 0.000"	-0.0092	0.0153	-0.0499
30.	4° 37' 30.000"	3° 52' 0.000"	-0.0232	0.0102	-0.0242

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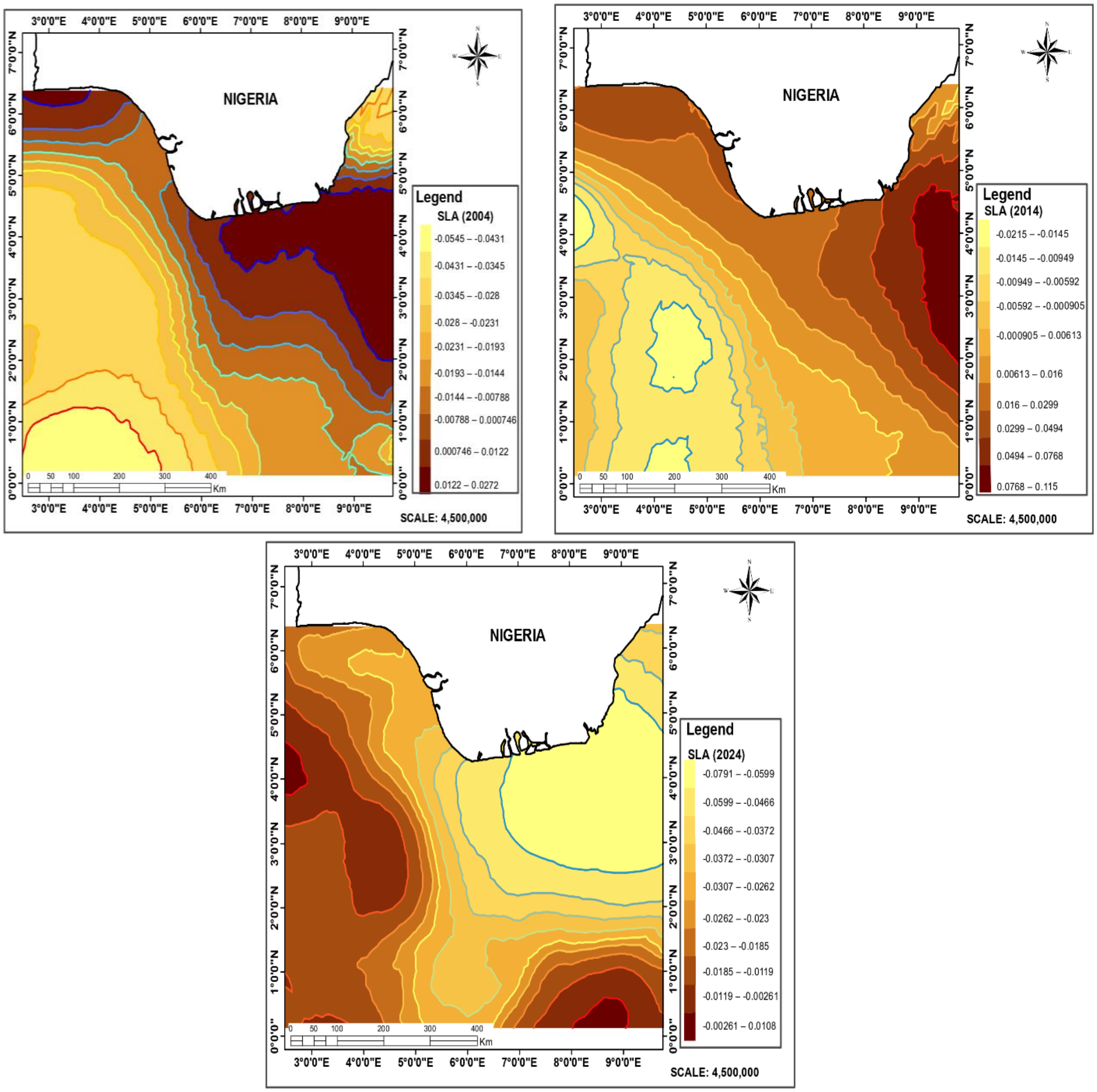

Figure 7: Map showing the Sea Level Anomaly of 2004, 2014 and 2024

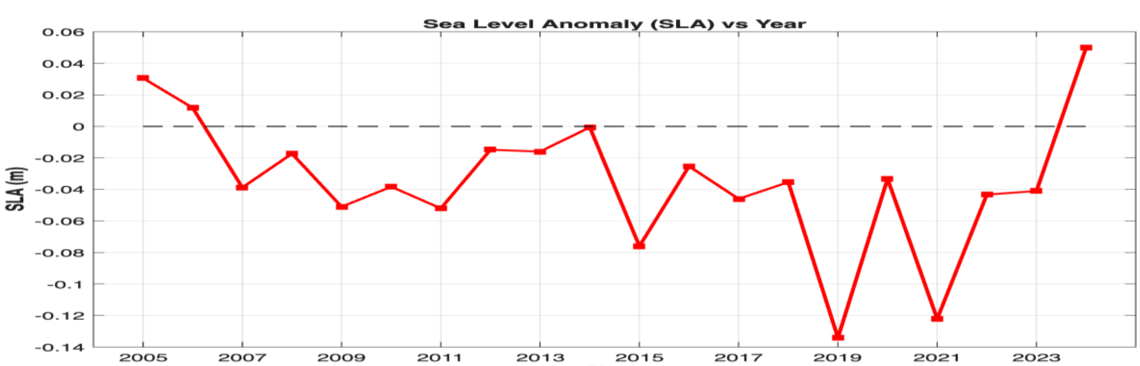

Figure 8: Graph of Trend and Pattern of SLA between 2004-2024

Table 4: Mean of Coastal Mean Sea Surface and Sea Level Anomaly from 2004-2024

Year	MSS (m)	SLA (m)
2004	0.07024	-0.01860
2005	0.02085	0.03060
2006	0.04027	0.01173
2007	0.09086	-0.03880
2008	0.06920	-0.01730
2009	0.10311	-0.05100
2010	0.09017	-0.03830
2011	0.10451	-0.05200
2012	0.06690	-0.01480
2013	0.06806	-0.01600
2014	0.05246	-0.00060
2015	0.12863	-0.07600
2016	0.07692	-0.02530
2017	0.09841	-0.04600
2018	0.08746	-0.03540
2019	0.18665	-0.13410
2020	0.08573	-0.03330
2021	0.17471	-0.12210
2022	0.09524	-0.04330
2023	0.09297	-0.04100
2024	0.09960	0.04983

To satisfy objective three, the SLA for two epochs (i.e. 2004-2014 and 2004-2024) were evaluated including the correlation within these epochs as shown on Table 5.

Table 5: Rate and Correlation between the two epochs of 2004-2014 and 2014-2024

Rate and Correlation	Value
Sea Level Rate (2004-2014)	2 mm/year
Sea Level Rate (2014-2024)	4 mm/year
Sea Level Rate (2004-2024)	2 mm/year
Correlation of SLA (2004-2014) Correlation of SLA (2014-2024)	0.42

5. DISSCUSSION

The epochal assessment of sea level rise along the Nigerian coastline for the periods 2004, 2014, and 2024 reveals a complex and, in some respects, counterintuitive pattern when compared with global sea level rise trends. While the Global Mean Sea Level (GMSL) has been steadily increasing at rates between 4.3 mm/yr and 5.9 mm/yr, largely attributed to thermal expansion of seawater and the accelerated melting of ice sheets and glaciers, the localized trend along the Nigerian coast shows a lower average of approximately 2 mm/yr. The maps of the Mean Sea Surface (MSS) (figures 4 and 5) from 2004 to 2024 reveal significant yearly fluctuations in the sea surface height. The highest values were observed in 2019 and 2020, peaking around 0.16 m, indicating a period of elevated sea surface levels. On the other hand, the lowest values were recorded in 2005 and 2008, dipping to around 0.04 m, reflecting years of lower-than-average sea surface heights. Throughout the period, the MSS values fluctuated between 0.04 m and 0.16 m, showing no clear long-term upward or downward trend, suggesting that the sea surface was influenced by varying factors over time. In the mid-2010s, the values experienced considerable shifts, possibly due to changes in oceanographic conditions or climatic events.

From 2021 to 2024, the graph stabilizes within a relatively narrow range of 0.08m to 0.12m, suggesting that sea surface height variations were less pronounced during these years. Overall, the fluctuations reflect a dynamic ocean environment, influenced by a mix of natural variability and potentially climate-related factors, without a strong overall trend in the data. In 2004, the MSS values (Figures 4 and 5) showed a range of positive values, indicating a baseline sea surface elevation. By 2014 (Figure 4), there was a discernible shift, with some areas exhibiting lower MSS values compared to 2004. However, the most striking observation is the prevalence of cooler colors (blues and greens) representing negative MSS values in 2024 (Figure 4). This widespread occurrence of negative MSS values suggests a substantial fall in the mean sea surface across many areas of the Nigerian coastline by 2024.

This localized sea level fall, if confirmed, stands in contrast to the global trend of accelerating sea level rise (Nerem *et al.,* 2018). Several factors could contribute to such a localized phenomenon, for example Vertical Land Motion (VLM); this is a tectonic uplift or subsidence, and particularly land subsidence due to groundwater extraction or hydrocarbon exploration, can significantly influence relative sea level. If the Nigerian coast is experiencing significant subsidence, it could mask or even reverse the signal of global sea level rise (Nicholls et al., 2014). The Niger Delta, for instance, is known for its high rates of subsidence due to sediment compaction and hydrocarbon extraction (Syvitski *et. al*., 2009). This subsidence could be a dominant factor in the observed negative MSS values.

In addition, regional oceanographic processes (oceanic dynamics), such as changes in ocean currents, steric effects (density changes due to temperature and salinity variations), or large-scale ocean oscillations, can lead to localized sea level variations that deviate from the global mean values (Cazenave & Llovel, 2010). While less likely to cause such a pronounced and widespread negative trend over two decades, their influence cannot be entirely discounted without further oceanographic analysis. Sedimentation and Deltaic Processes: In highly dynamic deltaic environments like the Niger Delta, large-scale sedimentation or erosion patterns can alter local bathymetry and thus influence observed sea levels. The observed negative MSS values in 2024 warrants further investigation**s** to disentangle the contributions of eustatic sea level change, isostatic adjustments, and anthropogenic subsidence. Understanding the dominant drivers is critical for accurate future projections and coastal management strategies.

In 2004, the sea surface heights ranged between 0.04 to 0.08 m, with frequent variations indicating the dynamic nature of sea surface heights. There are sharp peaks and troughs, reflecting the variability in sea surface height due to factors like ocean currents and atmospheric conditions. In 2014 SSH varies approximately from 0.05 and 0.17 m, with several sharp peaks and troughs throughout 2014. And, in 2024 the fluctuations are between approximately 0.05 and 0.12 m, with moderate variations throughout the year. The SSH shows some sharp spikes, particularly in the early months, suggesting occasional disturbances or changes in sea surface height due to dynamic factors like ocean currents, wind, or other atmospheric events

Figure 8, depicting the spatial distribution of SLA of 2004, The SLA fluctuates in the negative range, showing values between −0.02 and 0.02 m. The graph of SLA shows an overall increasing trend, suggesting that the sea levels during 2004 were predominantly lower than the long-term average. The warmer shades indicate higher positive anomalies, particularly in the Cross River and deeper offshore regions. This aligns with global and regional observations of sea level rise during this period (Church & White, 2011).
Despite these fluctuations, the overall indication for 2004-2014 is a general trend of sea level increase, consistent with global patterns of thermal expansion and ice melting contributing to rising sea levels (Oppenheimer *et. al*., 2019).

The SLA map for 2014 (Figure 4), shows fluctuation between −0.05 and 0.10m. The SLA indicates a gradual increase over time, reflecting that the sea levels in 2014 were predominantly lower than the long-term average**.** This indicates a significant and accelerated sea level rise in the later decade compared to the previous one. The highest positive anomalies are concentrated in the eastern parts of the study area and deeper offshore, suggesting regional variations in the rate of rise.

The corresponding graph (Figure 8) for 2014 strongly supports this finding, showing a clear and consistent positive SLA for most of the period, ranging from approximately 0.05 meters to over 0.15 meters. This consistent positive anomaly suggests a sustained and substantial sea level rise during this decade. The acceleration of SLA in 2014-2024 aligns with global observations of an accelerating rate of sea level rise (WMO, 2024).

This acceleration is primarily driven by increased rates of ice sheet and glacier melt, in addition to continued thermal expansion of ocean waters (Chen *et. al*., 2017). The localized high anomalies in the eastern parts of the Nigerian coast could be influenced by a combination of global factors and regional oceanographic processes, as well as the potential for localized subsidence, which could exacerbate the effects of rising sea levels.

Overall, the epochal assessment demonstrates that Nigerian coastal waters exhibit significant deviations from the global sea level rise trend, particularly in the 2024 epoch where localized decreases dominate. This highlights the complexity of sea level behavior in deltaic and subsidence-prone environments and emphasizes the necessity of continuous satellite altimetry monitoring.

The findings underscore that while global sea level is rising, local dynamics can result in highly variable patterns, including localized falls, with serious implications for coastal planning, flood management, and ecosystem sustainability. The study therefore provides a critical foundation for integrating satellite-based sea level monitoring into Nigeria's coastal management framework and strengthens the case for establishing a comprehensive coastal observation network that combines altimetry with upgraded tide gauges to improve long-term resilience.

6. CONCLUSION

The results reveal a complex and partly anomalous pattern of sea level change along the Nigerian coastline. While global sea level continues to rise, the analysis of Mean Sea Surface (MSS) and Coastal Mean Sea Level (CMSL) indicates a localized fall in relative sea level, most pronounced by 2024. This divergence strongly suggests that localized processes, particularly land subsidence driven by natural sediment compaction and anthropogenic activities such as hydrocarbon extraction and groundwater abstraction, are exerting a dominant influence.

Conversely, the Sea Level Anomaly (SLA) analysis shows a consistent and accelerating positive anomaly between 2014 and 2024, confirming that sea surface height is rising in line with global eustatic sea level rise. The discrepancy between relative sea level (land-based perspective) and absolute sea level (ocean-based perspective) underscores the importance of distinguishing these concepts in coastal vulnerability assessments. These findings carry significant implications: even when relative sea levels appear to fall, subsidence-driven land sinking can amplify risks of inundation, erosion, and saltwater intrusion, thereby increasing coastal vulnerability.

The analysis of coastal mean sea level fluctuations within Nigeria's coastal waters revealed a dynamic and non-uniform pattern across the studied epochs of 2004, 2014, and 2024. Unlike the global trend of a steady sea level rise, the Nigerian coastline exhibited alternating phases of rise and fall, indicating that localized environmental and anthropogenic factors play a dominant role in shaping sea level variations. Activities such as hydrocarbon exploration, groundwater abstraction, dredging, and land subsidence were observed to significantly influence the fluctuations, while natural processes including tidal forces, sedimentation, and climatic variability further contributed to the observed trends.

This demonstrates the efficiency of modern geospatial techniques in monitoring sea level changes and highlights their relevance in providing accurate data for coastal management. Overall, the findings underscore the need for continuous and detailed observation of mean sea level in Nigeria's coastal waters to better understand its implications for coastal communities, infrastructure, and the environment.

6.1 Recommendation

Based on the findings of this study, the following recommendations are proposed:

1) Conduct Detailed Geodetic Surveys for Vertical Land Motion: it is crucial to conduct comprehensive and high-resolution geodetic surveys using techniques such as GPS and Interferometric Synthetic Aperture Radar (InSAR). These surveys will accurately quantify the rates and spatial patterns of vertical land motion across the Nigerian coastline, particularly in the Niger Delta region. This data is essential for disentangling the contributions of land motion from eustatic sea level change.

2) Establish an Integrated Coastal Sea Level Monitoring Network**:** Develop and implement an integrated monitoring network that combines continuous tidal gauge observations with satellite altimetry data and geodetic measurements. This network should include:

a. Upgraded Tidal Gauge Stations**:** Modernize existing tidal gauges and establish new ones in critical coastal areas, ensuring real-time data transmission and consistent data quality.

b. Regular Satellite Altimetry Data Analysis**:** Continue to utilize and analyze satellite altimetry data from current and future missions (e.g., Sentinel-6, SWOT) to monitor absolute sea surface height.

c. Permanent GPS Stations**:** Install permanent GPS stations co-located with tidal gauges to measure absolute vertical land motion.

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