Analysis of the Effect of El-Nino Southern Oscillation Phenomenon on Sea Surface Temperature Variability in Nigeria's Maritime Waters

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Abstract—**This study investigates the effect of the El Nino Southern Oscillation Phenomenon (ENSO) on SST variability on Nigeria's maritime waters between 2015 and 2024. ENSO is known to be one of the significant drivers of climate variability on a global scale impacting weather pattern, temperature regimes and precipitation levels in some regions across the world. A quantitative method was employed, utilizing SST data from the National Oceanic and Atmospheric Administration (NOAA) Optimum Interpolation SST version 2.1 dataset. The ENSO variability was examined using Oceanic Nino Index (ONI) values obtained from NOAA's Climate Prediction Centre based on three-month running SST anomalies in the Nino 3.4 region. Analytical methods included time-series analysis, correlation, regression as well as spatial analysis and mapping of the Nigerian Maritime Waters . Particular emphasis was given on the 2015-2016 El Nino event which was considered as one of the strongest events of the 21st century. Results revealed that strong El Nino events in 2015-2016 and 2023-2024 elevated SSTs to anomalous highs exceeding 31-33°C resulting to thermal stress on marine ecosystem, reduced fish productivity and migration. Operational effect on naval, hydrographic and maritime operations altered oceanographic conditions, while prolonged La Nina phases between 2019 and 2022 has reduced the SSTs to about 24°C thereby enhancing nutrients-rich upwellings that are favourable for fisheries and shipping. Statistical analysis also revealed robust ENSO-SST teleconnections, with correlation coefficients ranging from 0.72 to 0.86 and regression slops of about 2.3°C SST with an increase per 1°C anomalies. The study concludes that ENSO-driven SST variability significantly impacts marine ecosystems, Nigeria's Blue Economy and operational planning on the Nigerian Maritime Waters. The study suggest integrating ENSO monitoring and forecasting into national maritime policy to enhance climate resilience, hazard early warning and resource management.**

Index Terms—**Blue Economy, Climate variability, El Nino Southern Oscillation, Nigeria's Maritime Waters, ONI, SST.**

I. INTRODUCTION

El -Niño Southern Oscillation (ENSO) refers to the effect of a band of sea surface temperatures which are anomalously warm or cold for 2 to 7 years that develops off the western coast of South America and affects climatic variability across the Tropics and sub-Tropics (NOAA, 2012). According to Scaife et al; (2019), the El Niño Southern Oscillation (ENSO) phenomenon stands as one of the most significant factors of climate variability on a global scale, impacting weather patterns, precipitation levels, and temperature regimes in various part of the world. It is a phenomenon that has been known to influence seasonal rainfall over East and West Africa as well as in Nigeria (Shehu et al; 2016). Based on Trenberth (2020) the most impacting ENSO events in this 21St century, are the 1997/1998 and 2015/2016 El Nino. Similar study believes ENSO phenomenon also experienced neutral phases during specific periods which serves as transition periods between El Nino and La Nina (Zhang and Feng, 2022). This occurs when SST in the Central and Eastern Tropical Pacific

Ocean are close to average and there is no strong El Nino or La Nina events (World Bank group Report, 2016). Other studies found out that, the effect of ENSO on SST variability in Nigeria's Maritime waters are profound and multifaceted. For instance, study by Salau et al; (2016) indicates that during El Niño events, SST in the Gulf of Guinea (GoG) tend to rise above normal levels, resulting to marine ecosystem degradation, reduced fish productivity, forcing species to search for optimal temperatures and food sources while being under stress. Likewise, some aquatic species move pole ward or deeper to escape and find tolerable temperatures (Chaudhary et al; 2021). The Sea Surface Temperature (SST) anomalies associated with ENSO are linked to variability in key climate parametres, such as temperature, winds, and precipitation over many parts of the globe including Africa. Based on Trenberth (2020) analysis on ENSO, the most impacting ENSO events in this 21St century, is the 1997/1998 and 2015/2016 El Nino. The views of Fasullo et al; (2018) were that ENSO-temperature teleconnections may heightened in the future, leading to increased interannual variability of regional temperature extremes. Accordingly, it is important to understand how ENSO events affected Nigeria's maritime waters. The objective of this study is therefore, is to examines how ENSO-driven variability in SST affects Nigeria's maritime waters and to evaluate its implications for fisheries, naval operations, hydrographic surveys and blue economy.

II. MATERIAL AND METHODS

The study area as presented is located at the Southern part of Nigeria, spanning between Latitude 3.85°N to Latitude 6.38°N and Longitudes 2.45° E to Longitude 8.75°E (Figure 1). This area borders the Atlantic Ocean within the GoG and covers an estimated 288,186 km^2 of maritime space (Kayode, 2013). According to World Bank (2016) the coastline stretches for approximately 853km along nine coastal states of Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Lagos, Ogun, Ondo and Rivers states in Nigeria.

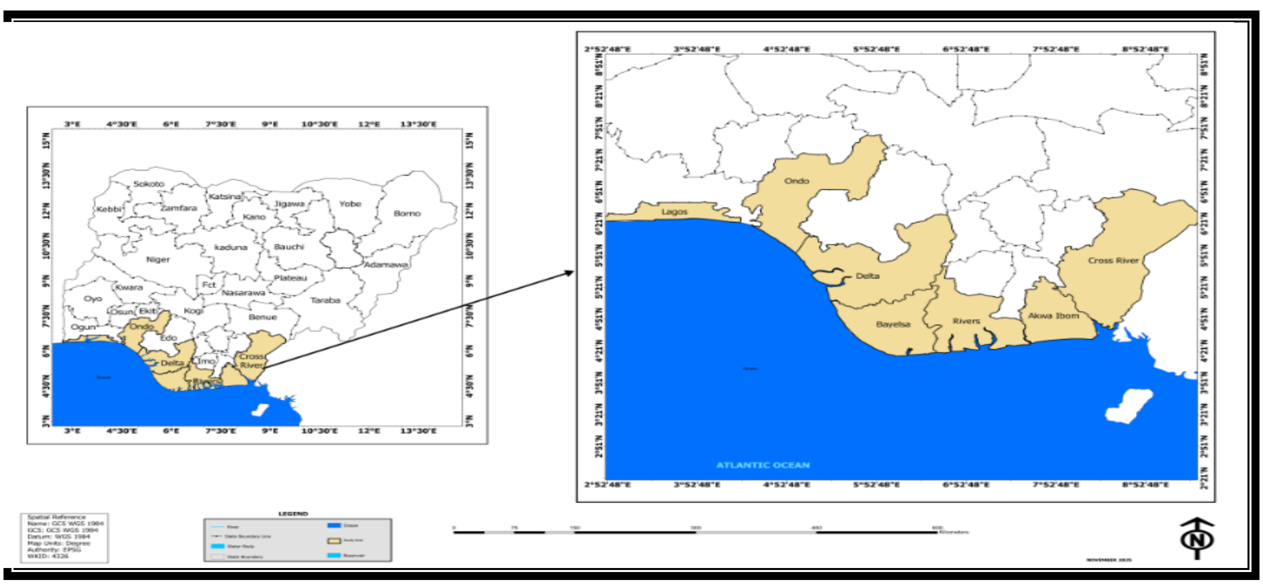

Figure 1 Map of Nigeria showing the study area

The Sea Surface Temperature (SST) data was sourced mainly from the NOAA Optimum Interpolation SST version 2.1(OISST) dataset, which provides daily and monthly average SST measurements at a global scale. Representing an area of approximately 0.25° by 0.25° grid (≈ 25km) which is considered as a high-resolution grid in global oceanography datasets (NOAA National Centers for Environmental Information, 2024). The high resolution consisting of version 2.1 OISST made it possible to observe spatial and temporal variations of the study area. The Oceanic Nino Index (ONI) data was acquired from NOAA's Climate Prediction Centre (CPC) which tracts ENSO variability using a 3-month running of SST anomalies in the Nino 3.4

region that applies to other regions(NOAA Climate Prediction Centre, 2024). Both ONI and SST datasets were downloaded in Comma-Separated Values (CSV) format which facilitated the ease of handling and integration into a GIS environment. These datasets covered the period from 2015 to 2024, with spatial focus on Nigeria's Maritime waters (Table 1 and 2). The SST in CSV format were filtered to isolate grid cells within the Nigerian maritime waters while the ONI data was linked to the SST to determine the correlation, variability and trends. Missing, noise or anomalous entries were identified and handled using filtering algorithm. Processed datasets were imported into Microsoft Excel and GIS environment for correlation analysis.

III. RESULTS AND DISCUSSION

Results from the analysis of the ONI and SST datasets were obtained from NOAA CPC and OISST v2.1, the datasets were utilised to analyse the extent of SST variability, identify ENSO-related SST trends, determine the correlation between ENSO indices and SST as well as determine the effect of ENSO in the study area. The spatial characteristics of SST in the study area exhibited marked spatial and seasonal variability from 2015 to 2024. The analysis across the South-west, South-south and South-east coastal zones showed that SST ranged from 23.8°C to 33.6°C over the decade. The highest SST occurred during the very strong 2015-2016 El Nino, while the coolest conditions were associated with La Nina phases in 2018-2022. ONI values equally fluctuated between a maximum of +2.9°C in 2016 and minimum of -1.3°C during the extended 2018-2022 La Nina events. Seasonal patterns were well defined across all the 3 coastal zones. For example, in South-west zone, warm season SST peaked between April and June rising from 30.4-31.7°C in 2015 to as high as 33.6°C in 2016. The highest SST of 31.7°C derived from Apr-Jun 2015 (Figure 2). On the other hand, the highest SST of 33.6°C from the warming of Apr-Jun 2016 is shown in Figure 3. Conversely, a contrasting cool phase dominated the months of July-September, with SST falling to 23.8-29.4°C. This was during La Nina years 2018-2022. Furthermore, the South-south zone exhibited a warm season with SSTs ranging from 27-30.5°C in 2015 and over 31°C in 2016, followed by a cool phase characterized by minimal SST of 23.8-25°C. The South-east part of the study area consistently recorded the highest temperature, with warm seasonal SSTs reaching 33.6°C during 2015-2016 El Nino and cool seasonal SST values stabilizing around 24-27°C. These spatial differences reflect the combined influence of ENSO-induced basin warming and cooling, modulated by upwelling dynamics, coastal circulation and wind forcing within this area.

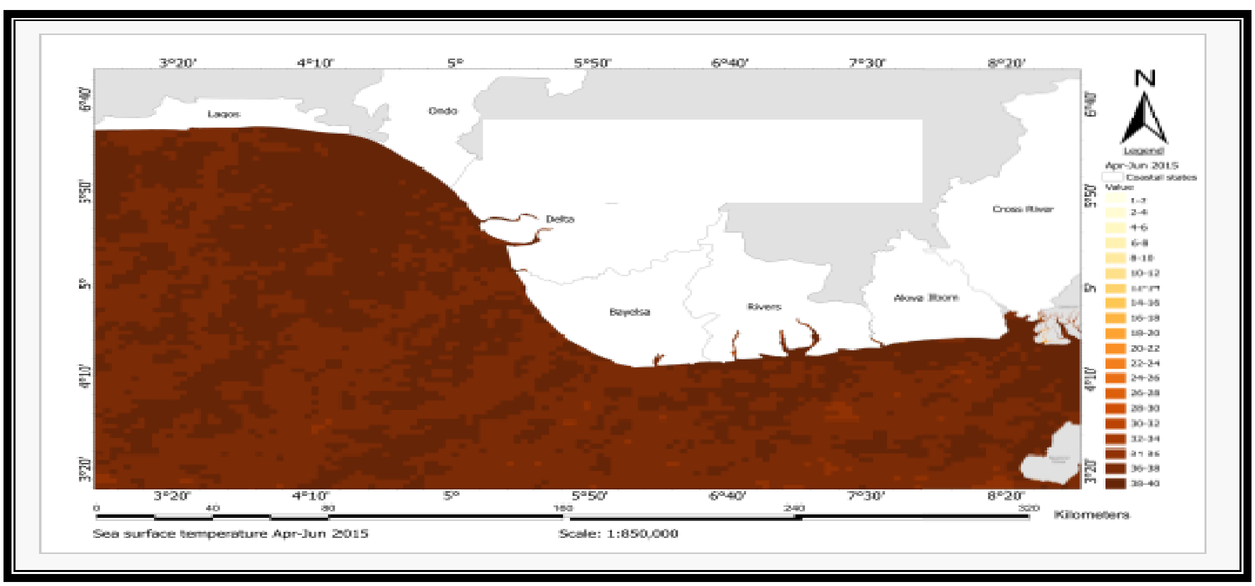

Figure 2 The Sea Surface Temperature (SST) April - June 2015.
Source : Analysis from the study

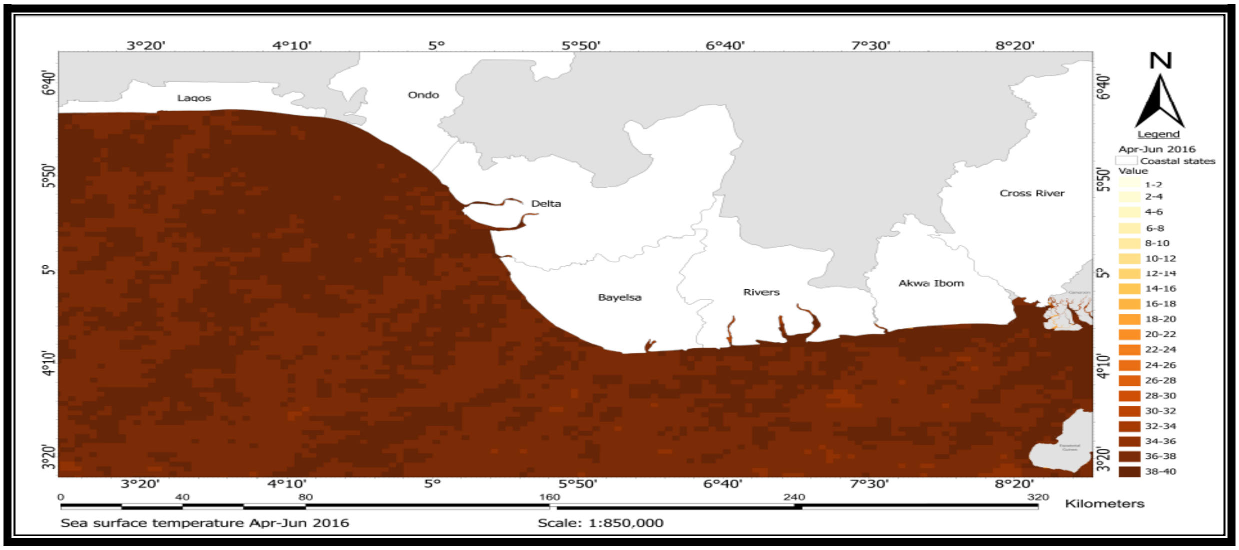

Figure 3 The Sea Surface Temperature (SST) April - June, 2016
Source : Analysis from the study

The decade-long ENSO Sequence and SST Trends (2015-2024) shows a correspondence between ENSO phases and SST variations in the study area. The 2015-2016 El-Niño on the other hand, produced exceptional warm elevating SST to 33.6°C in April 2016 and generating widespread warm anomalies across all coastal sectors within the study area. This was followed by a shift to neutral and moderate La Niña conditions in 2017-2018. This reduced the SSTs and enhanced coastal upwelling with the prolonged La Niña episode between 2019 and 2022. This may have influenced the driving of SSTs down to 23.8-26°C and could have enhanced a favorable fisheries productivity. However, between 2023-2024, the re-emergence of El Niño raised ONI values to approximately +1.5-2.0°C and increased SSTs to about 31.7°C by April 2024. Superimposed on these interannual fluctuations was a gradual warming trend estimated at 0.1-0.4°C per decade, consistent with broader anthropogenic warming patterns that amplified ENSO impacts in the GoG (Figure 4).

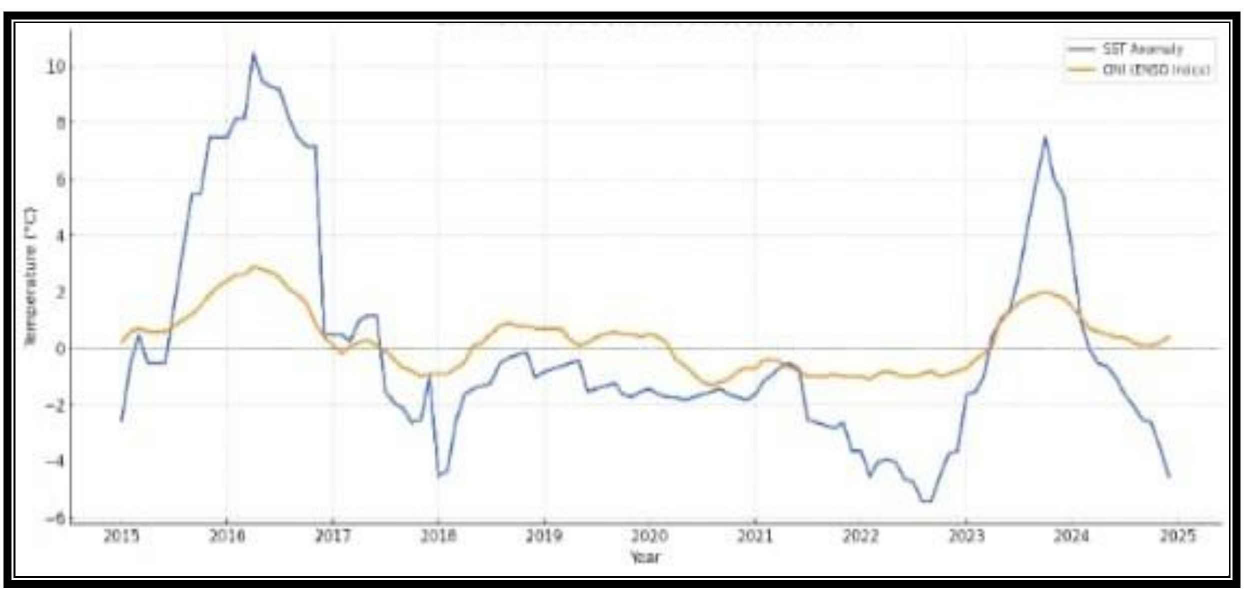

Figure 4 Decadal ENSO Trends within the Study Area

Correlation graphs between the ONI and SST in 2015 and 2016 as presented on Figures 5a and 6a. The association between ONI and SST in 2015 though positive is not very strong as expected However, the influencing factors are anthropogenic and coastal impacts (Figure 5b). On the other hand, the association of these two phenomena in 2016 is equally positive but the influencing factors are anthropogenic, coastal impact and Salinity and upwellings (Figure 6b).

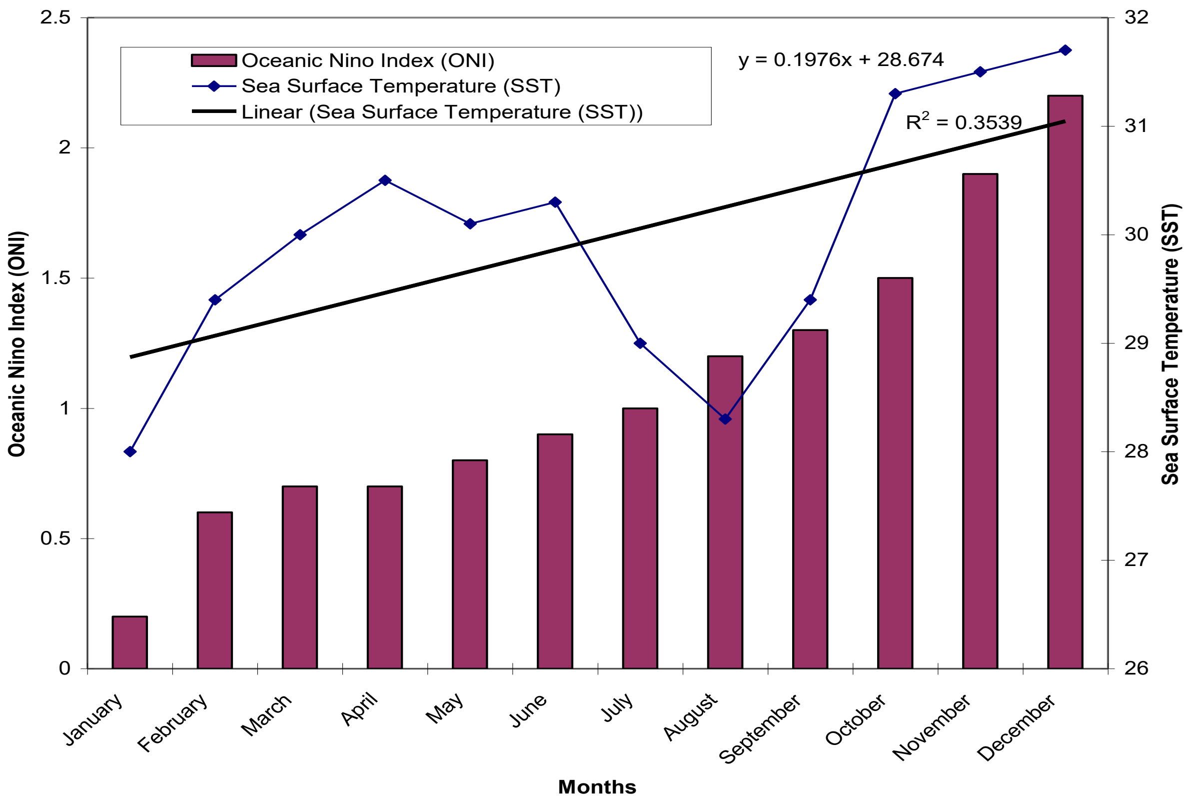

Figure 5(a) Correlation between ONI and SST in 2015

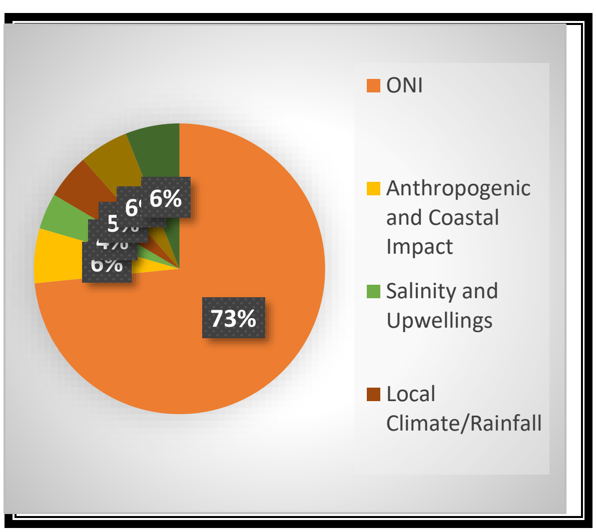

Figure 5 (b) Influencing Factors on SST in 2015.

These results confirmed that the ENSO was the dominant driver of SST variability in the Nigerian Maritime Waters and additionally influenced by local ocean-atmosphere processes including wind regimes, coastal upwelling, rainfall variability, salinity change, and mixed-layer dynamics.

Table 1: Regression Analysis

Year	Slope (m)	Intercept (c)	Equation	R^2 Score
2015	**+2.48**	26.45	SST = **2.48** × ONI + 26.45	0.86
2016	+2.38	22.37	SST = 2.38 × ONI + 22.37	0.72

Source: Author's Analysis, (2024)

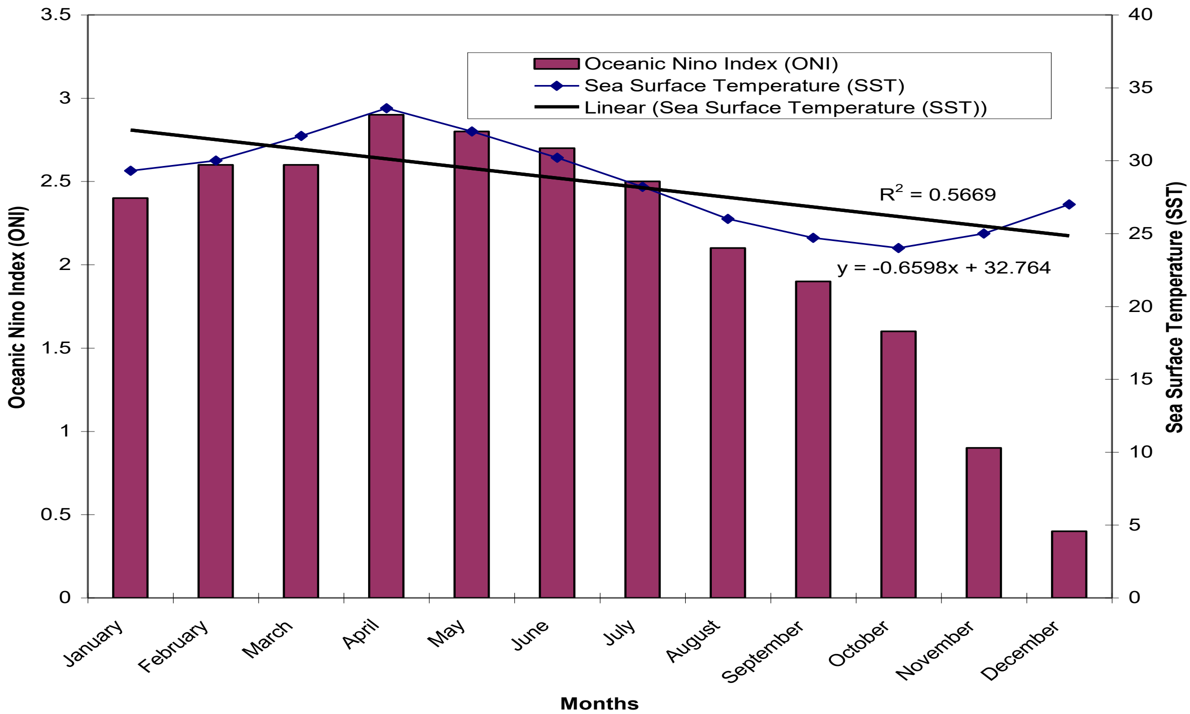

Figure 6(a) Correlation between ONI and SST in 2016

Table 2: Climatological Effects in the Study Area

Year	ONI Peak	SST Peak	ONI Threshold	SST Threshold	Climatological Effects
2015- 2016	2.9°C (AMJ)	33.6°C(Apr)	>+ 0. 5°C	> 28°C	Coastal heatwaves, erratic r/fall, warmer ocean surface
2019 -2022	-1.2°C(SON)	23.8°C (Oct)	< - 0.5	< 28°C	Upwellings, harmattan intensity, reduced humidity
2023 -2024	2.0°C(OND)	31.7°C (Apr)	>+ 0. 5°C	> 28°C	Warmer seas, high evaporation

Source: Author's Analysis, (2024)

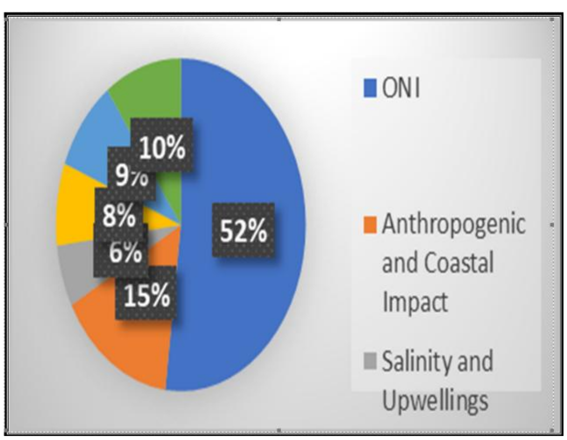

Figure 6 (b) Influencing Factors on SST in 2015.

Regression models further quantified the strength of ENSO teleconnections. In the 2015 (Table 1) the model SST= indicated that each 1°C increases in ONI produced a 2.48°C rise in SST. In 2016, the relationship was captured by SST =2.38×ONI+ 22.37 (R^2 = 0.72), showing a similarly strong response but with a lower intercept reflecting on the onset of La Niña.

These slopes underscore the sensitivity of Nigeria's maritime waters to pacific ENSO anomalies with SST response amplified by regional oceanographic processes.

3.1. OVERALL ENSO EFFECTS IN NIGERIA'S MARITIMEWATERS

Based on this analysis, ENSO phases are influenced key coastal climate characteristics in the Nigerian Maritime Waters. As indicated on Table 2, the El Niño years of 2015-2016 and 2023-2024) were associated with coastal heatwaves, rainfall irregularities, increased evaporation, and thermal expansion, particularly when SST exceeded 30-31℃. In contrast, La Niña years (2018-2022) enhanced upwelling and reduced SST below 28℃, often strengthening harmattan-related cooling and decreasing atmospheric humidity. This finding aligns with the works of (Doni, et al., 2023; Dovlo, et al., 2016 and Oladosu, 2024).

With regards to the effect on Blue Economy and Marine Recourses these El Niño events must have impacted ecological stress thereby altering pelagic fish distributions, reduced fish catch rates, increased coral and habitat vulnerability as well as risk to coastal erosion and storm surge.

Studies such as Bakun et al., 2015 and Barange, et al., 2018 have corroborated with the fact that such ENSO events have affected fisheries, port operations, coastal tourism, as well as infrastructure resilience within the study area. Conversely, La Niña periods enhanced nutrients availability, supported increased primary productivity, improved fish catch outcomes, and temporarily strengthened coastal livelihood through favorable biological conditions. This was also identified by Chaudhary et al; (2021).

On the effect on Hydrographic Survey Operations within the Nigerian Marine Waters, Table 3 shows that ENSO-driven SST variability can also affected hydrographic operations. For example, warm anomalies (>31℃) can sharpened thermoclines and intensify thermal layering thereby necessitating frequent recalibration of multibeam, single-beam, and side-scan sonar systems as observed by Czechowska et al; (2020). Such anomalies are likely to introduce potential errors in bathymetric measurements, tidal datum interpretations, and current profiling.

Cooler La Niña conditions can improve deeper- water acoustic propagation but can increased surface turbulence thereby influencing survey scheduling, safety windows, and instrument performance.

Table 3: Effect on Hydrographic Survey Operations in the Study Area

Period	SST/ONI Levels	Effects
2015 - 2024	SST >31℃, ONI > 2℃	Recalibration required for Single Beam, Multi Beam echo sounders and Side Scan Sonar due to thermal layering

On the effect on underwater and submarine operation, El-Niño-induced thermal anomalies can distort sound propagation path ways thereby creating acoustic shadow zones, increased detection risks for submarines. This can impose heat stress on AUV/ROV systems as far as underwater and submarine and operations are concerned. But for the La-Niña conditions, a modified sonar detection profile and alerted thermocline depth can sometimes enhance concealment and can complicate detection geometry during naval operations. As for navigationm, SAR and General maritime Operations the ENSO variability may influence maritime navigation through changes in surface waves, storm surges, and water density as the analysis have shown. This is because El-Niño event in particular, can produce stronger squalls and alerted vessel buoyancy in the maritime waters, while La Niña event can be strengthened under current and increase mooring loads due to denser water masses. In such situations, Search-and-rescue operations could be affected during El-Niño events thereby reducing visibility through SST-fog interactions and La Niña improving atmospheric clarity (Table 4).

Table 4: Effect of ENSO on Maritime Operations

Aspect	El Nino Effect (ONI >+1℃)	La Nina effect (ONI <1℃)
Navigation	Stronger wave surges, squall and high SST	Strong undercurrents and low SST
Mooring and Anchorage	Buoyancy anomalies, expansion of water mass	Denser water and increase more drag on mooring and anchorage
Search and rescue operations	Delays due to fog and SST fog interaction	Improved line of sight and reduced atmospheric haze over the study area.

Source: Author's Analysis, (2024)

IV. CONCLUSION

This study has highlighted that ENSO phenomenon can exerts significant influence on SST variability in Nigeria's maritime waters. The decadal analysis between 2015 and 2024 period revealed that very strong to strong El Nino events, particularly in 2015-2016 and 2023-2024 respectably, elevated SSTs to anomalous highs exceeding 33℃, while prolonged La Nina phases between 2019 and 2022 reduced SSTs to approximately 23℃. The correlation analysis confirmed that ENSO indices explained more than half of the observed SST variance, with correlation coefficients ranging from 0.72 to 0.86, underscoring the robustness of ENSO -SST teleconnection in the GoG. The findings further highlighted the broader ecological and operational implications of ENSO variability in GoG. The study shown that elevated SSTs during El Nino phases disrupted marine ecosystems, reduced fisheries productivity and post challenges to hydrographic and naval operations. Conversely, La Nina phases enhanced nutrient upwelling, supported fisheries, and the overall Nigeria's blue economy. These outcomes emphasise the influence of ENSO as the determinant of Nigeria's blue economy, affecting fisheries, maritime trade and naval operations. Other studies should extend ENSO research from terrestrial impacts in Nigeria to the marine dimension. There is also the need for integrated monitoring and adaptive management strategies that account for ENSO-driven variability in SST in the GoG. The Nigeria's maritime sector should prioritise preparedness, resilience and sustainable resource management to mitigate risks associated with ENSO cycles.

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CONFLICT OF INTEREST

The authors upholds that there are no conflicts of interest.

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