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Analysis of Sea Surface Temperature Pattern, Variability and Rainfall Dynamics over the Gulf of Guinea†

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Abstract: Spatial pattern and variability of sea surface temperature SST and its influence on seasonal rainfall dynamics over the Gulf of Guinea (GOG) were examined in this study. SST data of 50 years (1970-2022) from ERA5 and NOAA CPC at 0.25^0 x 0.25^0 and 0.5^0 x 0.5^0 resolution was obtained from specific locations namely longitudes 20 °W and 10 °E and latitudes 15 °N and 2 °N. Twelve rainfall-gridded stations distributed throughout the Gulf of Guinea (GoG) were used to characterize the rainfall-SST variability across the region. To investigate the relationship between the rainfall anomalies in GoG at seasonal, inter-annual, and decadal scales, cross-correlation analyses and composites were used while IDW from the ArcGIS Spatial Analyst Tool, Ferret, and CDO were used to obtain the decadal rainfall and SST maps. The result of the decadal analysis of SST variability from 1970-1980,1980-1990, 1990-2000,2000-2010,2010-2020 and 2022 indicate that SST was highest from 2010 to 2020 at 28.91oC and fluctuated between 1970-1980 (28.49°C) and 1980-1990 (28.08°C). The decadal pattern of rainfall variability indicates that 1970-1980 was characterized by low rainfall variability while 2020-2020 was the decade of normal and above rainfall. To assess the teleconnection between SST and precipitation dynamics, statistical analysis was used to generate plots of SST and rainfall anomalies in nine stations namely Abidjan and Accra, showing positive correlation. The study provides a framework for climate change risk assessment in the study domain.

Keywords: Air-sea interaction, sea surface temperature, rainfall variability, Anomalies, Gulf of Guinea, West Africa

1. Introduction

The ocean plays an important role in the earth's climate system owing to its large heat storage capacity with approximately 3.5m of water containing as much energy as the entire atmosphere column (Deser, et, al, 2010). Similarly, more than 70% of the entire Earth's surface is covered by the ocean and therefore exerts an enormous influence on boundary layer atmospheric processes (Siedler, et al, 2013). Ocean circulation therefore has profound impacts on the means state and variability of the climate system. This is evidenced in the meridional transport of heat to the poles from the equator and its loss to the atmosphere moderates the climate, particularly in the mid to high latitude. In addition, changes in equatorial upwelling and currents play a critical role in driving El Nino and La Nina phenomena and thus exert enormous influence on global climate on inter-annual to decadal timescale and modulating the intensity of human-induced climate change (Kosaka and Xue, 2016).

To explain the observed changes and variability of the West African precipitation system characterized by extreme rainfall leading to severe floods and droughts, Sea surface temperature anomalies have been identified as the explanatory variable driving climate extremes in the region (Vizy and Cook, 2001, Paeth and Stuck, 2004, Rodwell, 2013 and Meynadier, et al, 2016). Some of the notable historical droughts with devastating

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impact in West Africa include 1913-1914, 1931-1932,1942-1943, 1972-1993a and the 1983-1984,1970,1980,2013 and 2019 while 1946, 1950, 1952, 1953, 1954, 1955, 1957, 1958, and 1966, 1979,1996, 1980, 2013 and 2019 were the some of the worst flood years (Grist and Nicholson, 2001, Odekunle and Eludoyin, 2008).

Given the scale and intensification of extreme climate change impacts already manifesting in Africa owing to her vulnerability to human-induced global warming and climate change (UNFCCC, 2021). Furthermore, the coastal regions of the GOG have seen an upsurge in rainfall in recent years culminating in damaging floods with huge loss of human lives and infrastructure damage. The death toll and infrastructure loss triggered by flooding indicate a high level of vulnerability of the coastal regions of the GOG to SST anomalies and extreme rainfall.

It has become imperative to investigate the pattern of sea surface variability of the gulf of Gulf of Guinea on rainfall dynamics over West Africa. This is aptly important as rainfall variability is a major meteorological parameter that is critical to human life and socio-economic systems in West Africa. Most of the region's population is largely dependent on rain-fed agriculture and pastures for livestock and the water resources sector, thus, making them highly vulnerable to rainfall fluctuations. Arising from above, it has become pertinent to understand the pattern and variability of SST anomalies on rainfall dynamics over the Gulf of Guinea and this is the relevance of the study.

2. Materials and Methods

The study used SST and rainfall data of 50 years (1970-2022) from ERA5 and NOAA CPC at 0.25^0 x 0.25 and 0.5^0 x 0.5^0 resolutions from specific locations namely longitudes 20 °W and 10 °E and latitudes 15 °N and 2 °N along the gulf of Guinea obtained *at* https://cds.climate.copernicus.eu/ and https://iridl.ideo.columbia.edu/sources/noaa. The inverse distance weighted (IDW) method of interpolation, ArcGIS spatial Analyst tool, Ferret, Panoply, and climate data operator CDO were used in the study to produce the spatial patterns of SST and rainfall variability at decadal and seasonal timescale covering decade 1 (1970-1980), Decade 2 (1980-1990), Decade 3 (1990-2000), Decade 4 (2000-2010), Decade 5 (Decade (2010-2020), while statistical and standardized anomaly index was used for the teleconnection analysis.

2. The Study Area

The study area is the GOG region of the Atlantic Ocean (Figure 1). The area lies between longitudes 10 °W and 8 °E and latitudes 5 °N and 5 °S, and thus, south of West Africa. The hydrography of the GOG is directly affected by five main currents, namely, Benguela, the South Equatorial, the Canary, the Counter Equatorial, and the Guinea Currents (Ojo,1977) as shown below.

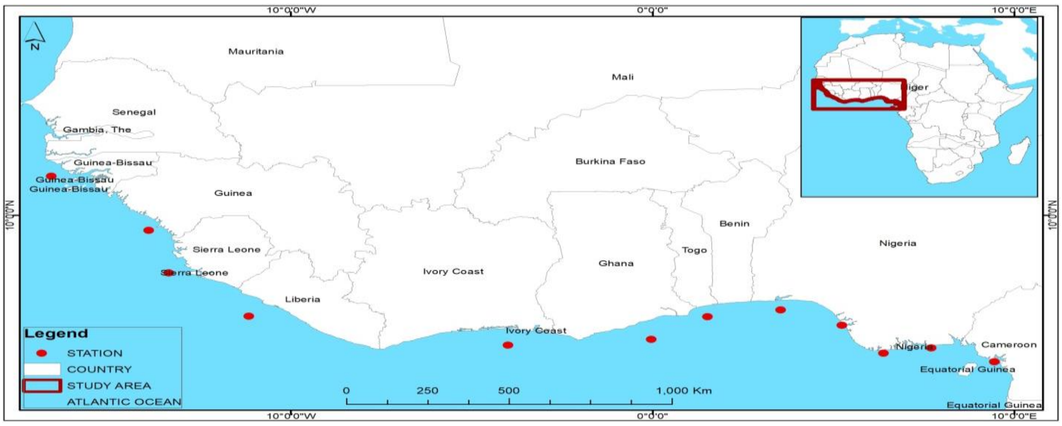

Figure 1. Map of the Gulf of Guinea.

3.1. Results

The results of the spatio-temporal variability of SST and rainfall are presented as follows.

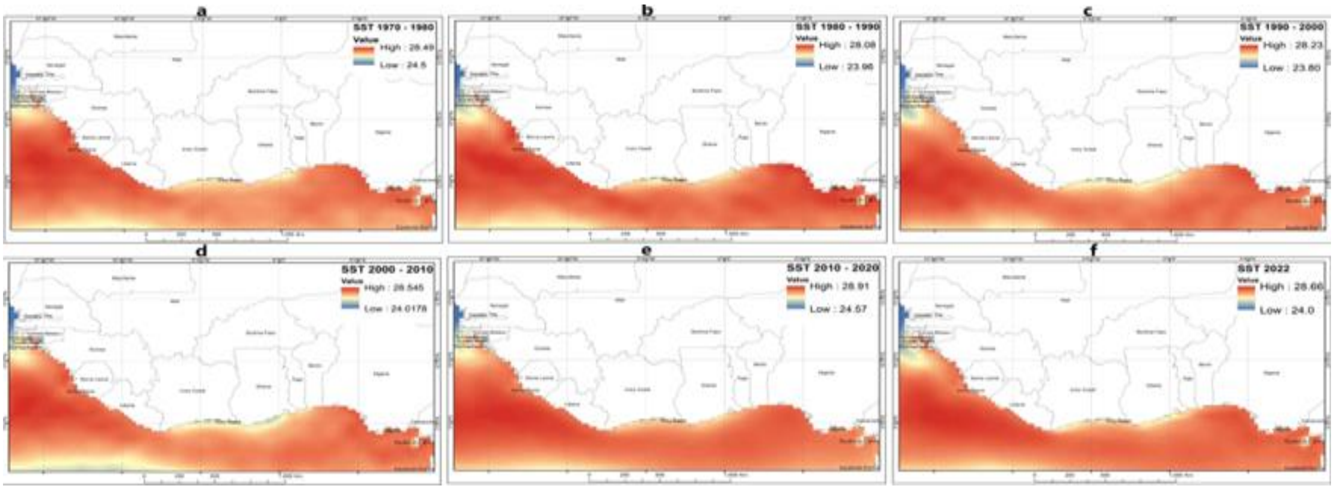

Figure 2. Decadal pattern of SST variability.

It is well known that variations in sea surface temperatures (SSTs) are partly responsible for large anomalies of seasonal mean rainfall over many areas of Africa. Generally, it decreases westward and the northern parts with a significant increase in the south and Eastern axis of the Gulf of Guinea. The 1970 -1980 and the 1990 periods where the sea surface temperature was the lowest corresponds with the periods of different drought episodes that characterized West Africa in the early 1970s and 1980s. The result further shows that coastal SST has increased rapidly over the study period leading to intensification of rainfall anomalies while colder SST dominates the Western part leading to reduced rainfall and drought. Extensive studies were conducted by Odekunle and Eludoyin, 2008; Akinbobola, et al, 2015, Rowell, 2013; Vizy and Cook, 2001 and Giannini,2016.

Furthermore, the pattern of decadal variation observed in this study confirms the influence of El-Nino on the warming of the tropical Atlantic Ocean and the continuous rise of SST of the GOG. An ENSO episode manifests through the appearance of SST anomalies, and this was evident in the analysis performed in the study.

3.2. Seasonal Pattern of SST Variability

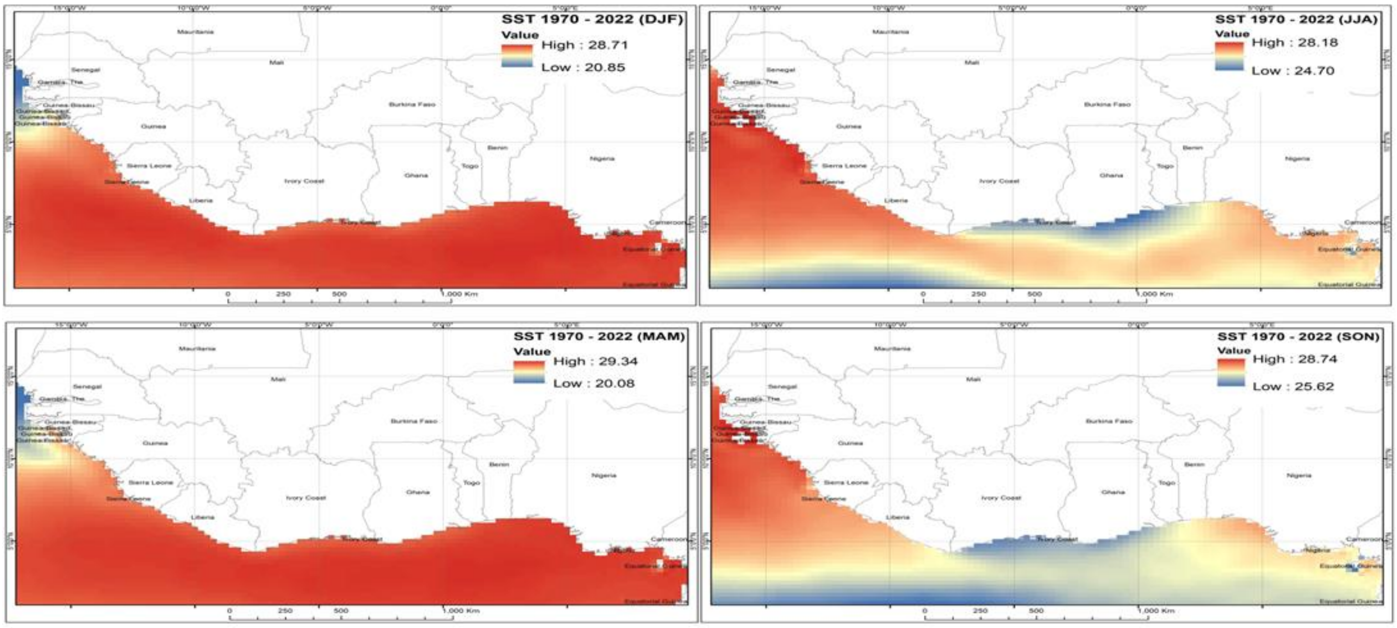

Figure 3. Seasonal pattern of SST Variability.

The analysis of the seasonal pattern of SST anomalies conducted in this study shows marked variability as SST was lowest (28.18^{o}C) for June July and August, JJA, 29.34^{O}C, 28.71^{o}C,, and 28.74^{o}C for March April May, MAM, December, January February DJF, and September, October November SON respectively for the Guinean Coast. In the Southwestern flank bordering the Sahel region, the variability values are 20.08^{O}C for MAM, 20.85^{o}C for DJF while JJA recorded 24.7^{o}C and SON 25.82^{o}C. The Guinean Coast in July and August and highest in March, April, and March MAM followed by December, January, and February DJF and September, October, and November SON respectively. The anomalously colder SST observed in June July August, JJA, and September, October November along the Guinea coast is attributed to the influence of coastal upwelling.

3.2. Rainfall Variability

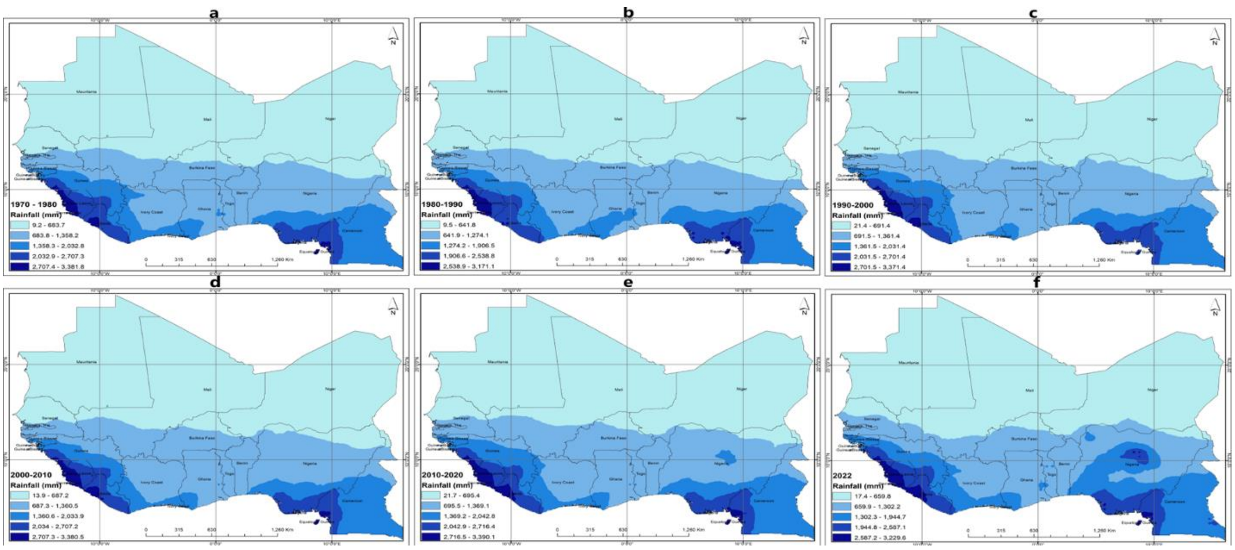

Figure 4. rainfall variability.

Precipitation variability is an important climate factor that impacts human activities, agriculture, and the environment in West Africa. The outcome of the decadal rainfall variability from 1970 to 1980 shows a maximum of 2.707.4-3.81mm. In the second decade, 1980-1990, was characterized by a period of high rainfall variability as a significant reduction in rainfall was observed declining from 2.7074-3.381.8mm in the 1970-1980 phase to 1.906.6-2.538.8mm in the 1980-1990 phase. The pattern of rainfall variation observed in the 1980-1990 era synchronized well with the decadal pattern of SST in 1980-1990. In the discussion on SST pattern, mention was made of anomalously low SST between 1970-1980 and 1980-1990. Remarkably, the anomalously low SST reported for the first and second decades correspond well with the rainfall variability of the 1980 decade thus providing further insight into the SST rainfall teleconnection over the Gulf of Guinea which is the motivation for the study.

The pattern of SST-rainfall teleconnection revealed in this study supports previous studies by Rodwell, 2013, Cook and Vizy 2001, Cook and Vizy, 2006, Nicholson,2013, Akinbobola 2015 and Meynadler,2016 on the recent air-sea coupling of West Africa Precipitation

3.3. Statistical Analysis of SST-rainfall Teleconnection in West Africa

Statistical analysis of annual sea surface temperature and rainfall pattern of a few sample points namely Abidjan and Accra, located along the Gulf of Guinea for standardized SST anomalies trend and teleconnection from 1970-2022. The standardized SST and rainfall anomaly calculated for Abidjan as shown below indicates that the early 1970s and 1980 had negative SST values indicative of decreased SST implying low rainfall while positive SST observed late in 2000 all have negative values implying abnormally dry years while the positive values are considered upward trend of rainfall. The model summary result of the regression analysis was however positive with SST a coefficient of determination of R^2=0.0625 ($P<0.05$). The standardized rainfall anomaly agrees with the trend analysis as negative SST was recorded in the late 1970s while positive SST values were observed from 2020-2022 indicative of increasing rainfall.

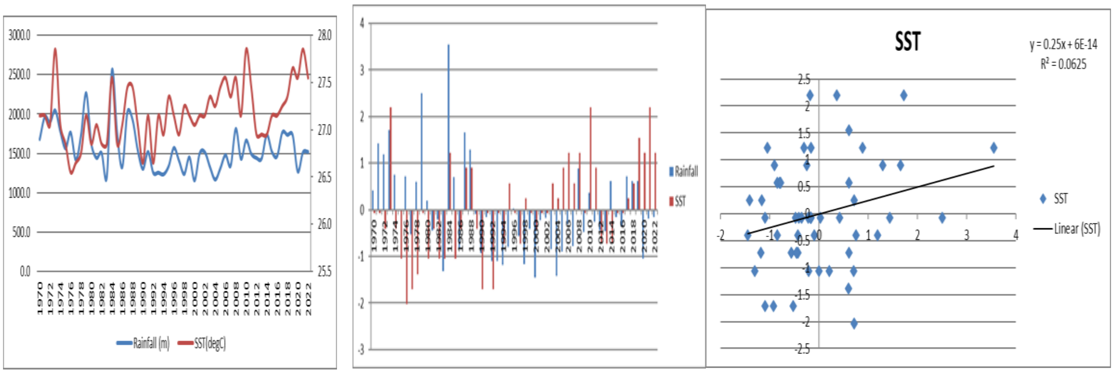

Figure 5. SST and Rainfall Trend analysis for Abidjan Cote d'Ivoire.

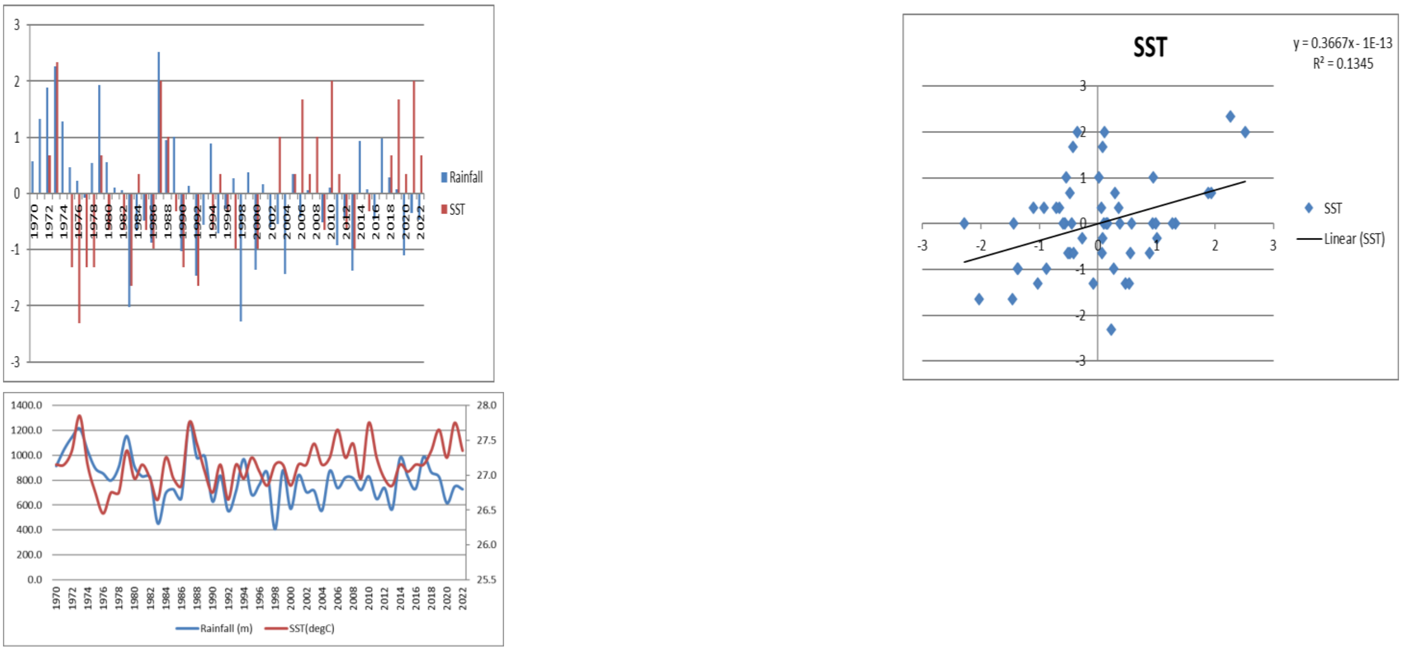

Figure 6. SST and rainfall trend analysis for Accra Ghana.

For Accra Ghana, the trend analysis indicates negative SST in 1976-1979 while rainfall anomaly was recorded in 1997 implying reduced rainfall. Similarly positive rainfall trend dominated the location from early 2000 to 2022 implying an increased rainfall trend. The summary result of the regression analysis indicates a positive coefficient of determination and a statistically significant relationship R^2=0.1345 (($P<0.05$) as shown in figure 6.

4. Discussion

The outcome of the decadal analysis of SST variability in the Gulf of Guinea was generally on the increase with 2010-2020 as the period with the highest warming followed by 2022 (28.91°C) while the decade with the lowest SST was 1980-1990 followed by the decade of 1990-2000 phase with consecutive increases. The result established here agrees with previous studies carried out by (Odekunle and Eludoyin, 2008)

Generally, SST decreases westward and the northern parts with a significant increase in the south and Eastern axes of the Gulf of Guinea (Lubbecke,2018). The 1970 -1980 and the 1990 periods are associated with low SST which corresponds well with the periods of different drought episodes that characterized West Africa in the early 1970s and 1980s.

Similarly, the decadal rainfall variability from 1970-1980 shows a maximum of 2.707.4-3.81mm with Nigeria, Cameron, Guinea, Sierre-Leon, and Liberia as areas of major concentration. Areas with latitude 20°N constitute the low rainfall region. The second decade, 1980-1990, was characterized by a period of high rainfall variability as a significant reduction in rainfall was observed declining from 2.7074-3.381.8mm in the 1970-1980 phase to 1.906.6-2.538.8mm in the 1980-1990 phase. The standardized rainfall and SST anomaly carried out reveals composite wet and dry years with anomalously low SST years more pronounced in the 1970s and early 1980s across all the stations while plots of the SST monthly climatology revealed that SST was anomalously low in the summer months of June, July, August, and September before peaking up in the fall months of October, November and December as this was evident across all the stations except Conakry which lends credence to earlier study conducted by (Akinbobola, et al, 2015).

5. Conclusion

The study examined spatial patterns, variability, and projection of SST in the GOG and highlighted their implications on rainfall dynamics over the GOG West Africa. The decadal and seasonal pattern of SST shows marked variability both in the Guinea coast and the Western Sahel

The implication of this low SST indicates that coastal regions will experience below-normal rainfall in the months of JJA, and SON is irresponsive to its geographical location on the coast. Coastal upwelling has been implicated as the causative mechanism and is responsible for erratic rainfall in the mid-summer thus giving rise to the phenomenon of Little Dry Season LDS. The study also revealed that SST decreases westward and increases along the coast while the rainfall variability analysis also indicates that 2010-2020 recorded more intensities than the rest of the period studied. The study concludes that the spatial variability of SST established in this study has enormous implications on rainfall dynamics and the West African climate system.

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