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Effects of Variations in Sea and Land Surface Temperature on Rainfall Pattern over Nigerian Coastal Zone

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Abstract
This study evaluated the variations in sea and land temperature from 1901 to 2013 with a view to examining their effects on rainfall pattern in the coastal zone of Nigeria. It used the National Oceanic and Atmospheric Administration (NOAA) monthly mean sea surface temperature (SST) over the Atlantic Ocean (longitude 0^o E - $8^o.20^{'}$ E and latitude 1^oN - $3^o.50^{'}$ N). Land Surface Temperature (LST) and rainfall dataset sourced from the archive of the University of Delaware (UDEL) and ground station observations (NIMET) over four selected coastal locations (Calabar, Lagos, Port-Harcourt and Warri) were also used. The mean observations of rainfall and temperature of NIMET and UDEL for the overlapping period (*i.e.* 1974-2013) were compared Using paired T-test and Percent Bias. The annual and seasonal trends in these climatic variables were examined using their deviations from means and trend analyses. The study then employed Pearson multiple linear regression analysis to evaluate the combined effects of LST and SST on rainfall pattern over the study areas. The results revealed the highest values of SST and LST in MAM and the lowest in JJA season. It rained in all months across the stations with the maximum rainfall (163.5 - 471.2 mm/month) in JJA and the least (24.0 - 47.2mm/month) in DJF. The comparison of both UDEL and NIMET observations suggested no significant difference between both datasets at P = .05. The results demonstrated increasing trends in both SST (0.012^{o}C year^{-1}) and LST (0.003 to 0.007^{o}C year^{-1}). Both SST and LST significantly influenced rainfall pattern ($0.445 \geq R \leq 0.731$; R > 39%) at P = .05. The contributions of SST to rainfall variations were, however, significantly higher (0.530: 0.422) than those of LST (0.452: 0.215) in Lagos and Port-Harcourt due to the proximity and locations of these stations to the Atlantic Ocean.
Keywords: Sea and land surface temperature, rainfall variations, effects, coastal zone

1.0 Introduction

The oceans cover about 70% of the earth's surface and play important roles in influencing the earth's climate system through, evaporation and cloud formation, wind and precipitation pattern as well as the transport of enormous amount of heat around the globe (Herr and Galland, 2009; Talley, 2009). The oceans' thermal inertia is communicated to the atmosphere via turbulent and radiative energy exchange at the sea surface. These energy fluxes in turn depend on a single oceanic quantity, the sea surface temperature (SST), as well as several atmospheric parameters including wind speed, air temperature, humidity, and cloudiness. The SSTs thus play a key role in regulating climate and its variability (Clara *et al*., 2010). In the same vein, Land Surface Temperature (LST) influences the atmosphere through heat flux on the land and thus it is a critical variable to understand land-atmosphere interactions and a key parameter in meteorological and hydrological studies, which involve energy, fluxes (Niclòs *et al.,* 2009).

Better knowledge and understanding of LST provide information on the temporal and spatial variations of the surface equilibrium state and is of fundamental importance in many applications (Kerr *et al*., 2000). As such, the LST is widely used in a variety of fields including evapotranspiration, climate change, hydrological cycle, vegetation monitoring, urban climate and environmental studies, among others (Arnfield, 2003; Voogt and Oke, 2003; Kalma *et al*., 2008; Weng, 2009; Hansen *et al*., 2010). Understanding the variations in sea and land surface temperature is of importance to the study of variety of processes in the sea, land and atmosphere. These processes range from local air-sea interaction and their relationship to local weather which includes rainfall (Voogt and Oke, 2003; Niclòs *et al*., 2009; Akinbobola *et al*., 2014).

However, studies have shown that the heat content of the world ocean is on increase due to global warming (IPCC, 1999; IPCC, 2007). Nigeria is no exception as evidences of warming in recent years have been established (Obioha, 2008; Odjuibo, 2010; Abiodun *et al*., 2011). The question on variation is no longer debatable, what is not clear is the nature of variations, its effects and trends in specific regions most especially the coastal region. A critical evaluation of the nature and long term variability in sea and land surface temperature and effects on rainfall is therefore an important pre-requisite for understanding and developing effective adaptation strategies to cope with the vagaries of climate. Hence, this study therefore examines the changes and trends in sea and land surface temperatures and assesses the effects of variations in sea and land surface temperature on rainfall pattern over the Nigerian coastal zone.

2. The Study Area

The study area lies between latitudes 4º 10′ N to 14º 00′ N and longitudes 2º 15′ E to 8º 32′ E (Fig. 1). This region is boarded to the south by the Atlantic Ocean to the west by the Republic of Benin and to the east Cameroon Republic. The Nigerian coastal area and its resources have vast implications for the economy of Nigeria. Much of the country's economic activities are located along the coast with over 20% of the population inhabiting coastal areas. The country is a maritime state with a coastline of approximately 853 km. Her sovereignty extends beyond her internal waters to her territorial sea of 30 nautical miles. In 1978, Nigeria established an Exclusive Economic Zone (EEZ) which is an area beyond and adjacent to the territorial sea extending 200 nautical miles from the baseline (Akinbobola *et al*., 2014). The study covered four coastal land stations, namely Port-Harcourt, Calabar, and Lagos and Warri, and the Gulf of Guinea area. Figure 2 describes the elevations of these stations in ascending order as 60 (Warri), 180 (Port-Harcourt), 380 (Lagos) and 630 m (Calabar).

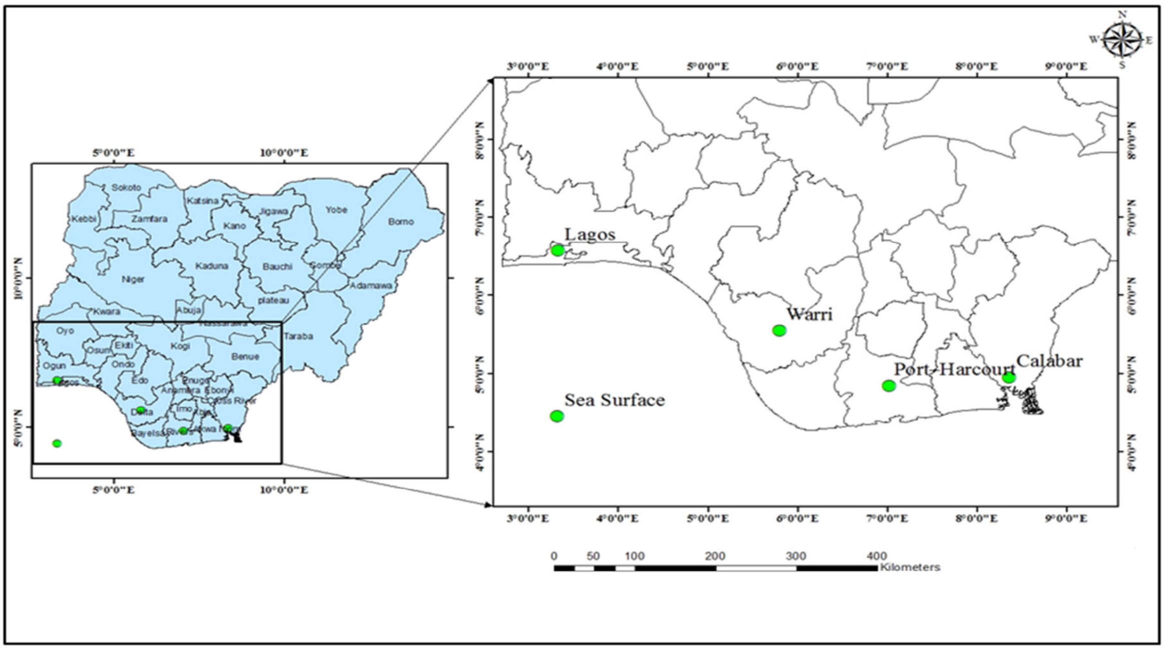

Figure 1: Location of the selected meteorological stations in the Map of Nigeria

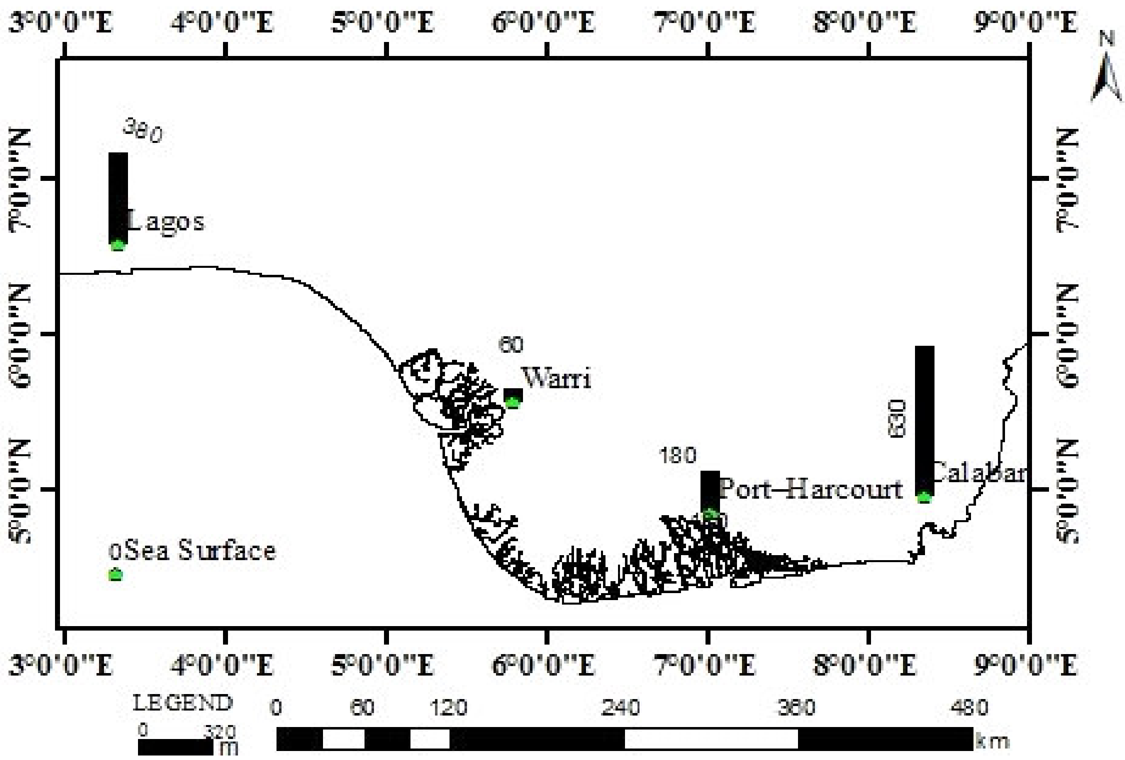

Figure 2: The elevations of the selected stations in meters

3. Materials and Methods

Land surface temperature and precipitation data over four selected meteorological stations in the coastal zone of Nigeria (Calabar, Lagos, Port-Harcourt and Warri) were sourced from the Nigerian Meteorological Agency, Abuja and the archive of the University of Delaware. The ground station observations (christened NIMET) covered the period of 1974 to 2013 while the global network observations were for 1901 and 2013 period. Version 4.01 of the University of Delaware (UDEL) observation dataset, which consists of monthly climatology of precipitation at 0.5° x 0.5° latitude/longitude grid and time series spanning 1900 to 2014, were used. A complete description of the data as given by the providers, related datasets and references to relevant papers were reported in NCAR (2016). The monthly mean SST over the Gulf of Guinea (longitude 0º E : 8º 20′ E and latitude 1º N : 3º 50′ N), which is an extended reconstructed SST with spatial coverage of 2.0° x 2.0° global grid spanning between 1901 and 2013 was sourced from the archive of the National Oceanic and Atmospheric Administration (NOAA). The mean observations of rainfall and temperature of NIMET and UDEL for the overlapping period (*i.e.* 1974-2013) were compared using at 95% confidence level and Percent Bias (PBIAS) with a view to validating the UDEL network observation data over the study area. The PBIAS describes the mean relative difference of the simulated series to the observed series in percentages over the whole observation period. It was calculated using the equation.

$$\text{PBIAS} = \sum_{i=1}^{n} \frac{(Y^{obs} - Y^{sim}) * 100}{\sum_{i=1}^{n}(Y^{obs})} \quad (1)$$

The quality of the UDEL data was evaluated using the method adopted from Kronenberg *et al.,* (2013). In this approach, PBIAS of less than ±10 was classified as very good; good when greater than ±10 but less than ±15; fair when greater than ±15 and less than ±25 and bad when greater of equal to ±25. Similarly, the annual and seasonal means of climatic variables from UDEL and NOAA were then estimated for 1901-2013 period while the changes and trends of climatic variables were examined using their deviation from mean and trend analysis. The study then employed Pearson multiple linear regression analysis to evaluate the potential effects of LST and SST (independent variable) on rainfall (dependent variable) pattern over the study areas.

4. Results

4.1 Mean Temperature and Rainfall Climatology over the Study Area

Figure 3 presents the mean annual temperature and rainfall in the study area during the study period. The highest and lowest mean temperatures were 27.0°C (in Lagos) and 26.0°C (Calabar) respectively (Fig.3a). A mean temperature of 26.8°C was recorded in both Warri and Port-Harcourt stations. The observed annual mean SST over the Gulf of Guinea was about 26.9°C. Annual mean rainfalls were 2992.3, 2800.6, 2194.4 and 1497.8 mm in Calabar, Port-Harcourt, Warri and Lagos respectively (Fig. 3b). Seasonal changes in temperature and rainfall are described in Figure 4. The SST values ranged between 25.5°C (JJA) and 28.3°C (MAM). Similarly, the seasonal temperatures over land ranged between 25.26-25.91°C in JJA and 26.9 -28.3°C in MAM season. Furthermore, the lowest mean temperatures (25.3-26.85°C) were observed in Calabar across the seasons. Figure 5 illustrates the variations in seasonal mean rainfall. The results indicated that it rained in all months across all the stations. However, the maximum rainfall values of 163.5 - 471.2 mm/month were recorded in JJA with the least ranging between 24.0 and 47.2mm/month in DJF.

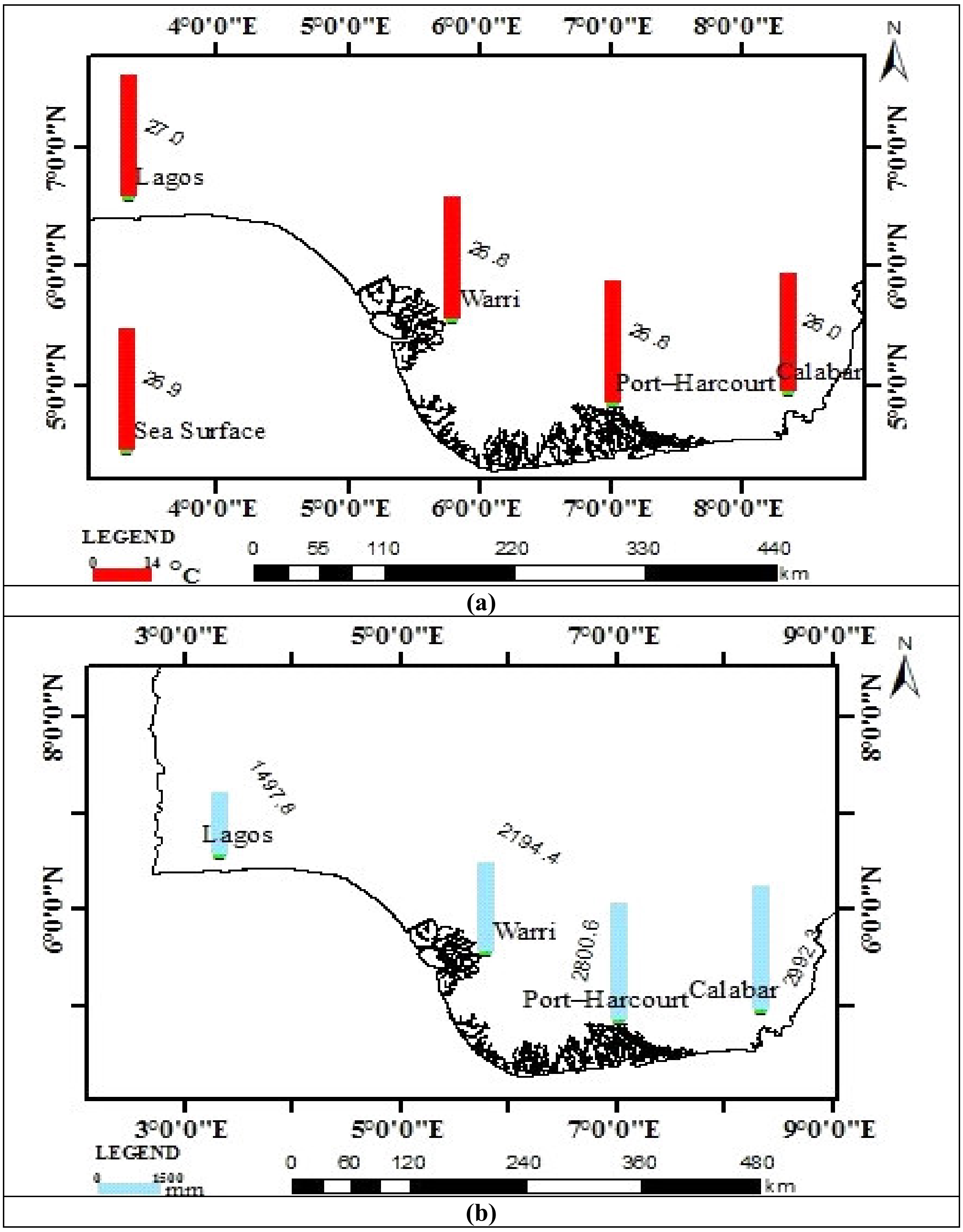

Figure 3: Annual mean **(a)** temperature (^{o}C) and **(b)** rainfall (mm) in the selected stations.

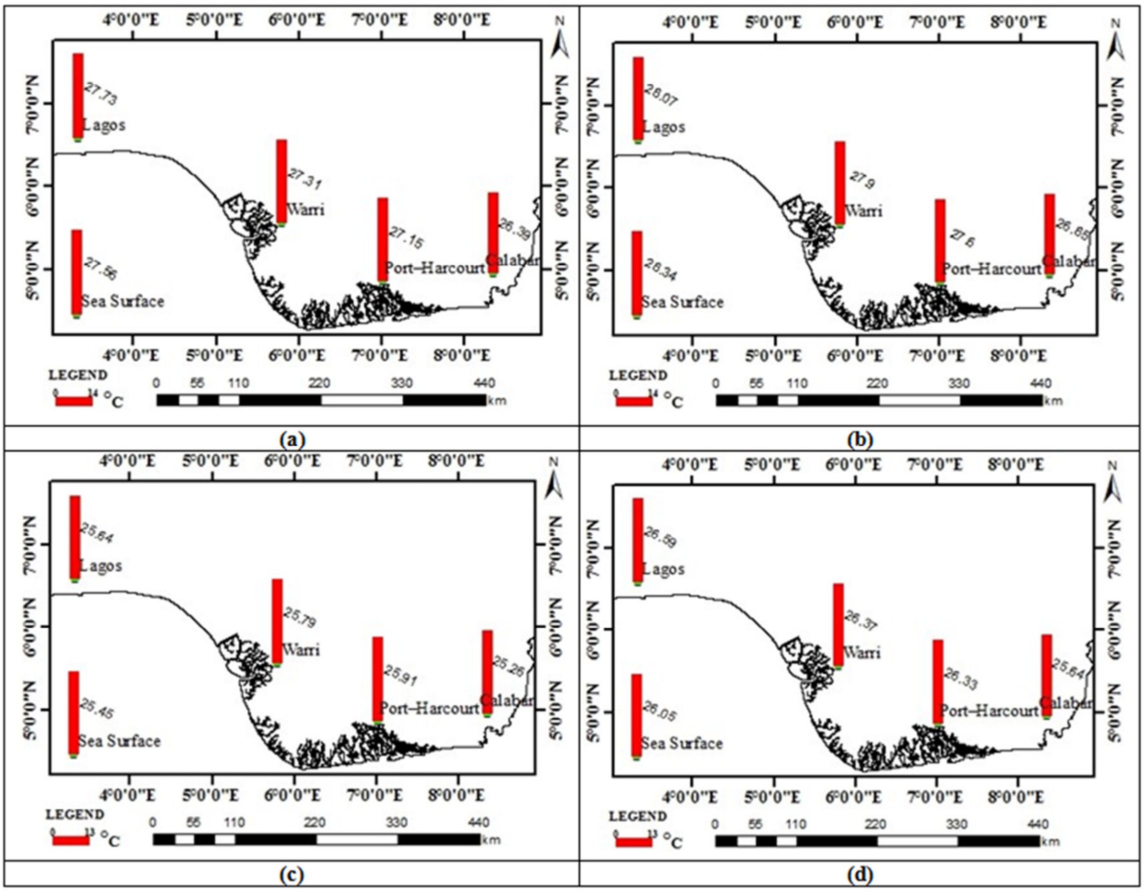

Figure 4: Seasonal mean temperature (°C) in the selected stations: (a) DJF, (b) MAM, (c) JJA, and (d) SON.

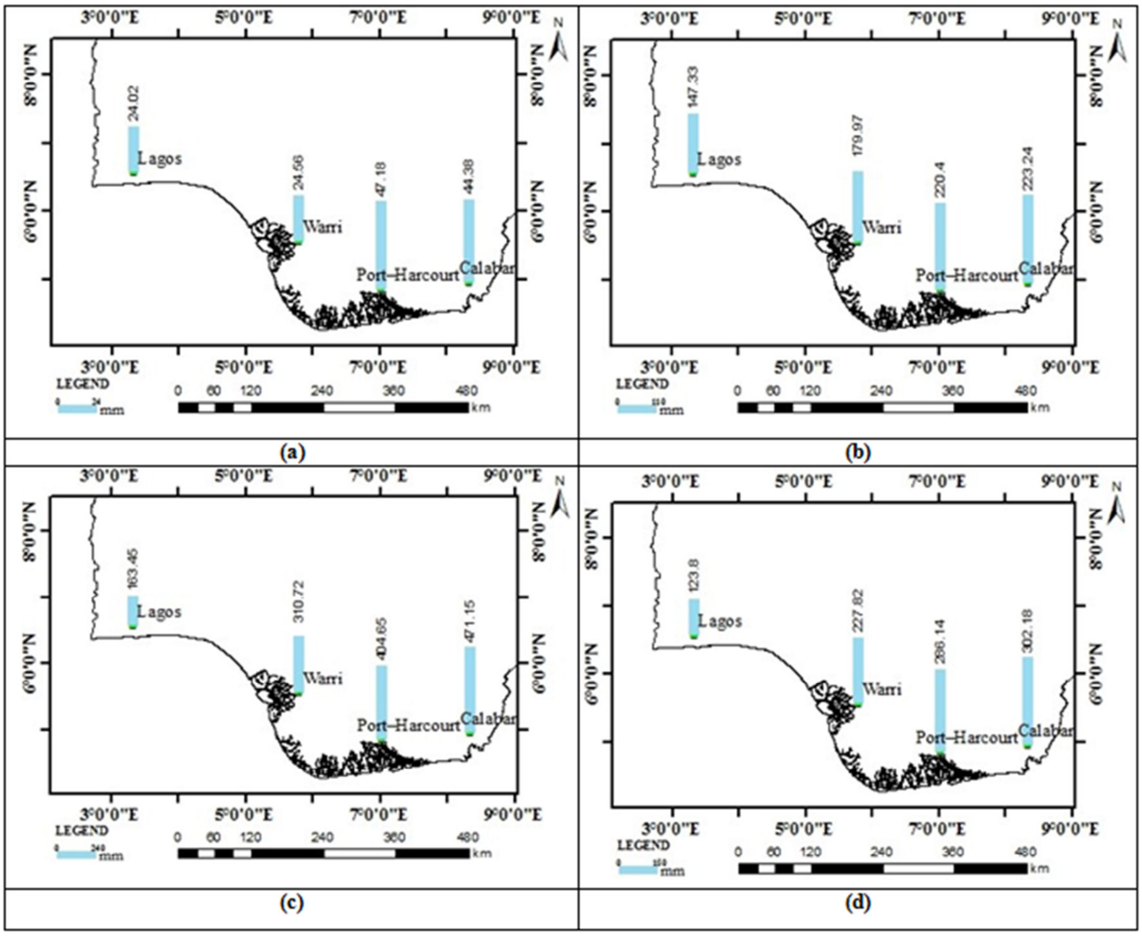

Figure 5: Seasonal mean rainfall (mm) in the selected stations: (a) DJF, (b) MAM, (c) JJA, and (d) SON.

4.2 Comparison of NIMET and UDEL Datasets

Table 1 provides the summary of the results of the paired T-Test analysis between the ground station (NIMET) and the global network dataset (UDEL) observations. The standard deviations in annual mean temperatures were 0.3 (Calabar), 0.4 (Port-Harcourt), 0.5 (Lagos) and 0.9°C (Warri). For the annual man rainfall, the standard deviations were 377 (Warri), 384 (Lagos) and 401 mm (Calabar) and 443 mm (Port-Harcourt). The results showed that the mean monthly variations in both temperature and rainfall were not significantly different at 95% confidence level over all the selected coastal stations.

Table 1: Results of the paired T-Test for NIMET and UDEL annual mean observations (1974-2013)

S/N	Climatic Variable	Station	SD	T	df	Sig
Pair 1	**Temperature**	**Lagos**	0.496	0.042	35	0.463
Pair 2		**Warri**	0.900	-0.235	35	0.815
Pair 3		**Port-Harcourt**	0.431	- 0.225	35	0.135
Pair 4		**Calabar**	0.288	5.822	35	0.100
Pair 5	**Rainfall**	**Lagos**	384.046	0.356	35	0.724
Pair 6		**Warri**	377.510	0.491	35	0.626
Pair 7		**Port-Harcourt**	443.613	-0.126	35	0.900
Pair 8		**Calabar**	401.460	0.511	35	0.612

SD= Standard deviation
df = Degree of freedom
* = Significant at $P = .05$

The results of the quality test for UDEL observations compared with the ground station data were presented in Table 2. The PBIAS in UDEL temperature and rainfall ranged between ±10 to ±15 for all the stations except for temperature in Calabar with PBIAS value of > ±17.

Table 2: Percent BIAS in UDEL observations of LST and rainfall

Parameter	Station	PBIAS	Quality
LST	Lagos	13.03	Good
	Warri	11.66	Good
	Port-Harcourt	11.53	Good
	Calabar	-17	fair
Rainfall	Lagos	13.00	Good
	Warri	13.60	Good
	Port-Harcourt	-14.56	Good
	Calabar	13.49	Good

4.3 Changes and Trends of SST and LST

Figure 6 summaries the changes in the trends of the sea surface temperature in the Gulf of Guinea. The results show that the SST was increasing at a rate of 0.012°C per year. The coefficient of determinant (R^2 =0.6841) shows 68% variation in SST over the study period. Figures 7-10 illustrate the trends of LST in Calabar, Port-Harcourt, Lagos and Warri stations respectively. The temperature increased annually by 0.007°C in Calabar, Port-Harcourt, and Warri (Figs. 7-9) but it increased by 0.003°C per annum in Lagos (Fig.10). The maximum temperature variation of 27% as R^2 = 0.2686 was obtained in Warri and the least (3%) in Lagos during the study period.

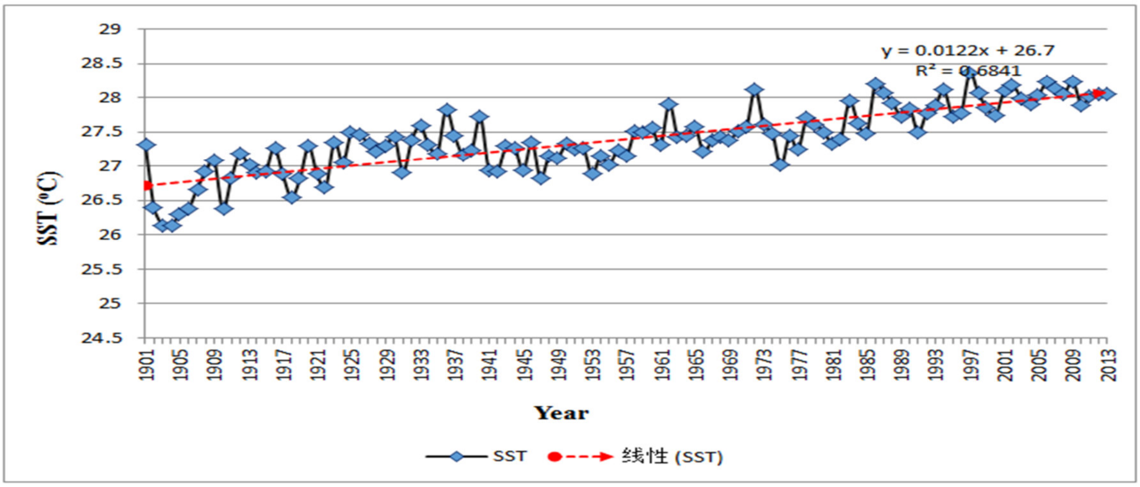

Figure 6: Linear trend of sea surface temperature (1901-2013)

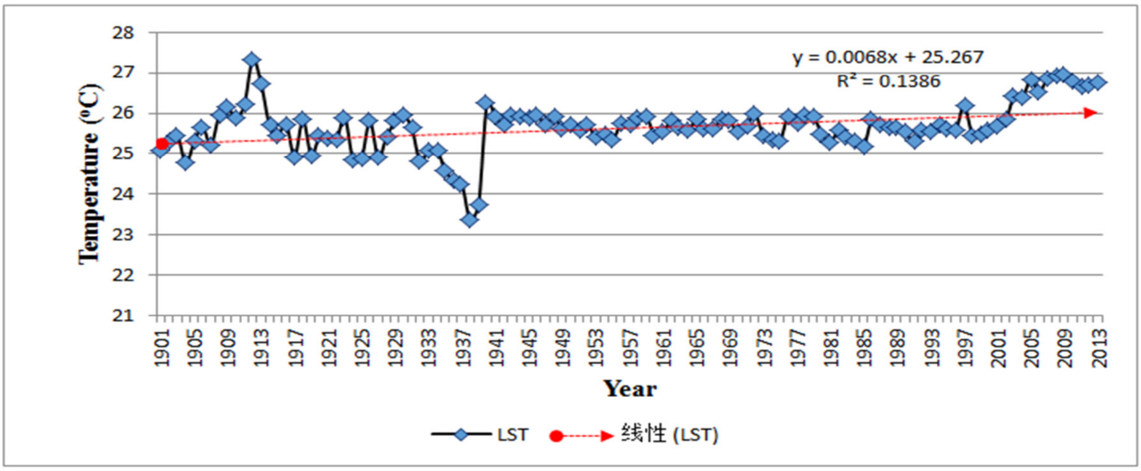

Figure 7: Linear trend of land surface temperature in Calabar station

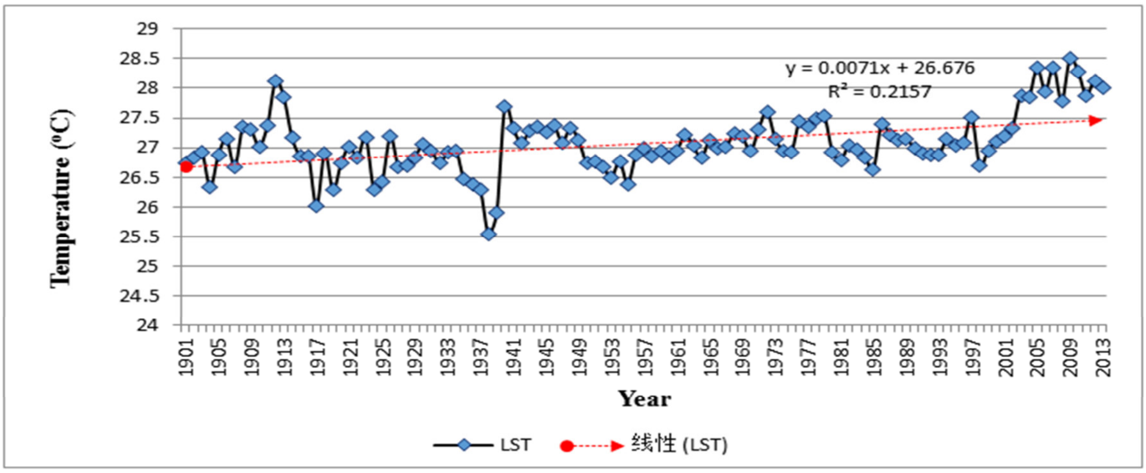

Figure 8: Linear trend of land surface temperature in Port-Harcourt station

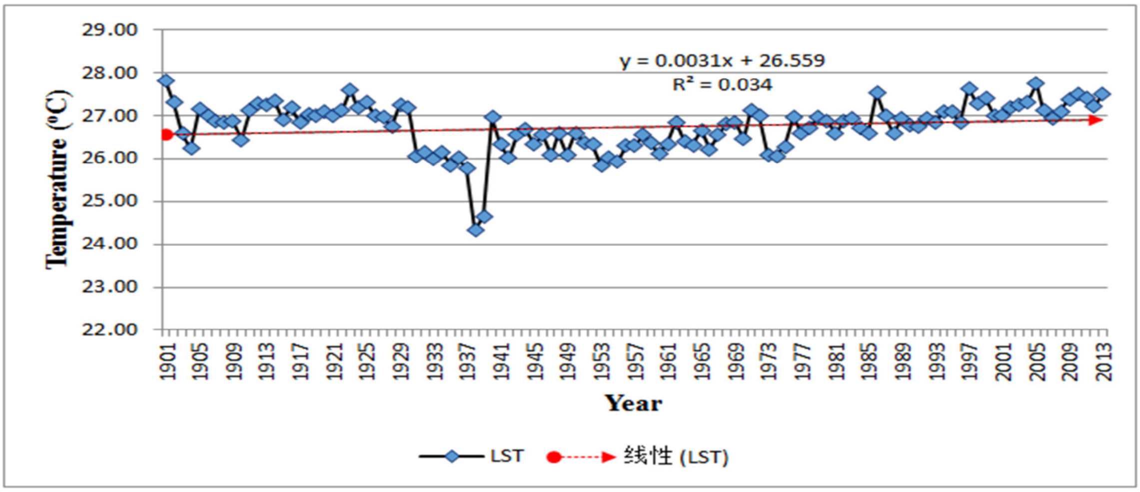

Figure 9: Linear trend of land surface temperature in Lagos station

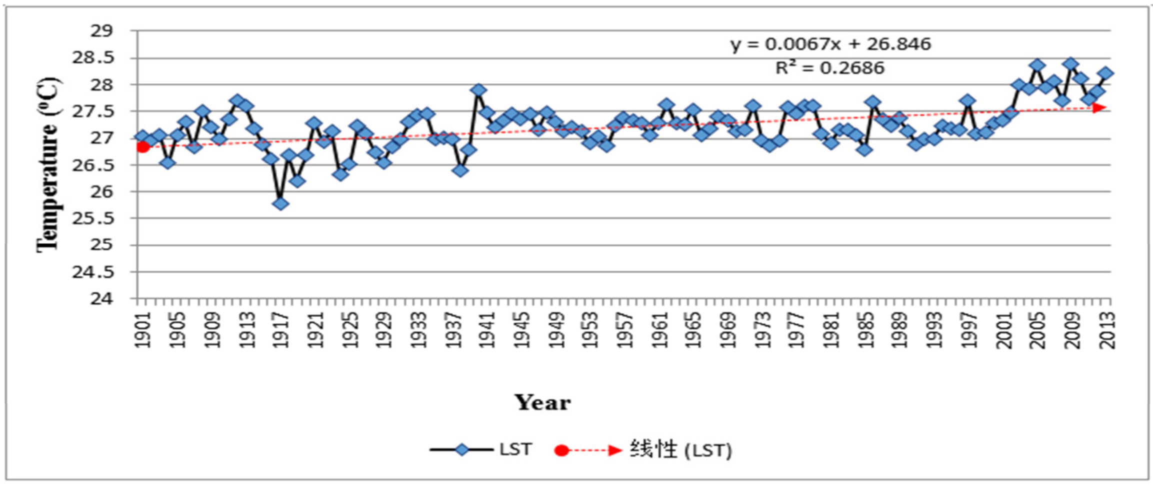

Figure 10: Linear trend of land surface temperature in Warri station

4.4 Effects of SST and LST on Rainfall

Table 3 depicts the results of the analysis of impacts of SST and LST on rainfall in the selected coastal stations. Positive correlation coefficients, *r*, were obtained between both SST and LST and rainfall. For example, *r* values for SST and rainfall were 0.647, 0.565, 0.530, and 0.422 in Warri, Calabar, Lagos and Port-Harcourt respectively. Similarly, *r* values for LST and rainfall were 0.651, 0.585, 0.452, and 0.215 in Warri, Calabar, Lagos and Port-

Harcourt respectively. The estimated combined correlation coefficient and R-squared values were 0.731: 0.534 (Warri), 0.655: 0.429 (Calabar), 0.311: 0.558: (Lagos) and 0.445: 0.198 (Port-Harcourt) all significant at *P* = .05.

Table 3: Regression analysis of annual sea and land surface temperature on rainfall

Station	Parameter	r	R	Sig	R^2
Calabar	LST	0.585	0.655	0.002*	0.429
	SST	0.565			
Port-Harcourt	LST	0.215	0.445	0.000*	0.198
	SST	0.422			
Lagos	LST	0.452	0.558	0.000*	0.311
	SST	0.530			
Warri	LST	0.651	0.731	0.000*	0.534
	SST	0.647			

* Significant at (*P* = .05)

Results of the regression analysis of seasonal sea and land surface temperature on rainfall are presented in Tables 4. The highest *R* values (0.780, 0.717, 0.662, and 0.625 in Calabar, Lagos, Warri, Port-Harcourt and Lagos respectively) were obtained in JJA season. However, the *R* values were very low in other seasons with the least (0.343, 0.312, 0.433 and 0.438 in Calabar, Port-Harcourt, Lagos and Warri respectively) in DJF season. The comparison of the effects of each independent variable on rainfall as illustrated in Figure 11 shows that SST had higher correlation with rainfall than LST in Port-Harcourt (*r*= 0.422:0.215) and Lagos (*r*=0.530: 0.452). However, LST had higher correlation with rainfall than SST in Calabar and Warri.

Table 4: Regression analysis of seasonal sea and land surface temperature on rainfall

Station	Month	Climatic Parameter	r	R	R^2	Sig
Calabar	DJF	SST	0.343	0.563	0.317	0.000*
		LST	0.540			
	MAM	SST	0.450	0.474	0.225	0.000*
		LST	0.534			
	JJA	SST	0.684	0.780	0.608	0.001*
		LST	0.437			
	SON	SST	0.541	0.606	0.367	0.002*
		LST	0.501			
Port-Harcourt	DJF	SST	0.312	0.548	0.300	0.000*
		LST	0.454			
	MAM	SST	0.462	0.502	0.252	0.012*
		LST	0.452			
	JJA	SST	0.508	0.625	0.390	0.000*
		LST	0.443			
	SON	SST	0.483	0.605	0.366	0.023*
		LST	0.506			
Lagos	DJF	SST	0.433	0.656	0.430	0.001*
		LST	0.542			
	MAM	SST	0.442	0.501	0.251	0.010*
		LST	0.430			
	JJA	SST	0.654	0.717	0.494	0.002*
		LST	0.402			
	SON	SST	0.671	0.716	0.512	0.010*
		LST	0.443			
Warri	DJF	SST	0.438	0.567	0.322	0.001*
		LST	0.520			
	MAM	SST	0.451	0.486	0.236	0.000*
		LST	0.533			
	JJA	SST	0.631	0.662	0.438	0.000*
		LST	0.431			
	SON	SST	0.542	0.601	0.361	0.022*
		LST	0.547			

Dependent variable: Rainfall
*Significant at (*P* = .05)

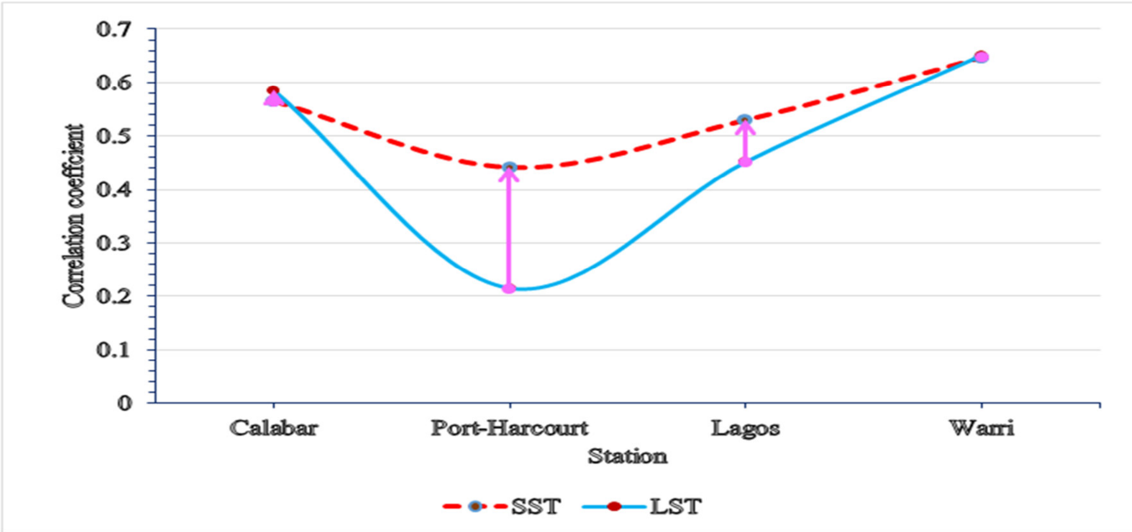

Figure 11: Correlation coefficients (at P = .05) between rainfall and sea-and-land surface temperature at the selected coastal stations

5. Discussion

Results demonstrated that Lagos and Calabar were the warmest and coldest coastal stations respectively. The seasonal temperatures over land and the sea were the highest in MAM and the lowest in JJA season. The heaviest annual rainfall was observed in Calabar and the lightest in Lagos. There were indications that it rained all through the year in the coastal zone of Nigeria. However, uniformly low rainfall was observed in DJF, while it rained the most in JJA season. This may be related to the migration of the Inter-tropical convergence zone. These results are in agreements with the previous findings of Olaniran (2002) on rainfall anomalies in Nigeria.

Comparisons between the ground station (NIMET) and UDEL network datasets produced very good correlation between the two datasets. This is because the values of performance evaluation index (PBAIS) used lied within good quality range and no significant difference (at $p < 0.05$) were observed between them. Across the seasons, the correlations were the highest in in JJA and lowest in DJF season. This observation could be linked to the fact that rainfall is at its peak in JJA and the lowest in DJF season. The overall results suggested that the UDEL observations were of good quality compared with NIMET station observations. Thus, the UDEL observations could be considered as good data source for climate studies over the study area.

Furthermore, results showed increasing trend of 0.012^{o}C per year and 68% variation in annual SST during the study period. The LST with 3-27% variations also increased annually by 0.003-0.007^{o}C. This increasing trend in LST could be attributed to the effects of human-induced climate change in the study area. These results corroborate the findings of Akinbobola *et al.* (2014) and Abiodun *et al.* (2011) in their independent studies on climate parameters over Nigeria.

Both LST and SST were shown to have significant impacts on rainfall variations. This is evident from the very strong corrections (0.731-0.445) and high coefficients of determination (0.198-0.534) obtained. By implication, the results indicated that 20 - 53% variation in rainfall was explained by sea and land surface temperature. However, SST had greater impact on rainfall than LST in Port-Harcourt and Lagos. However, the case was a reverse in Calabar and Warri stations. The greater influence of SST on rainfall could be attributed to the positions and proximity of the stations to the sea. The impacts were the highest in JJA which as the peak of the wet season and the lowest in DJF (peak of the dry season).

6. Conclusion

This study assessed the changes and trends in sea and land temperatures. This was with a view to examining their effects on rainfall pattern in the coastal zone of Nigeria. To achieve this objective, it used the National Oceanic and Atmospheric Administration monthly mean sea surface temperature (SST) over the Atlantic Ocean, Land Surface Temperature (LST) and rainfall dataset sourced from the archive of the University of Delaware (UDEL) and ground station observations (NIMET) over four selected coastal locations in Nigeria. The UDEL mean observations were validated with the NIMET dataset of rainfall and temperature for the period that the ground observations were available (*i.e.* 1974-2013). Then, the annual and seasonal trends in these climatic variables between 1901 and 2013 were examined and the combined effects of LST and SST on rainfall pattern were investigated. The UDEL observations were found to be good data source for climate change studies. This is evident from the fact that the percentage bias (PBIAS) values lie within good quality range and proof of no significant difference (at P = .05) obtained between the ground observations and UDEL dataset. The study also revealed increasing trend of 0.012^{o}C per year and 68% variation in SST during the study period. The LST also increased annually by 0.003-0.007^{o}C, suggestive of a high rate of variability in LST in most of the stations. There were strong positive correlation coefficients (0.731-0.445) and high coefficients of determination (0.198-0.534). The implications are that 20 -53% variation in rainfall was explained by both LST and SST. These demonstrate significant impacts of both SST and LST on rainfall variations. The impacts were the highest in JJA and the lowest in DJF season. However, SST had greater impact on rainfall than LST in Port-Harcourt and Lagos. This was attributed to the proximity of the stations to the sea.

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