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The Nigeria climate zones: Variability, trends and analysis from era-interim data (2010-2015)

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ABSTRACT

This study analyses diurnal weather patterns in the lower atmosphere across four climate domains in Nigeria from Era-Interim data for synoptic hours of 0000, 0600, 1200 and 1800 hours from 2010-2015. The climate domain includes: Port Harcourt (tropical maritime), Enugu (bi-modal tropical continental), Jos (montane), Kano (mono-modal tropical continental) and Maiduguri (semi-arid). Findings revealed that air temperature across the areas indicate strong latitudinal positions with drier and hotter weather pattern northwards. Average air temperature across diurnal hours were 23.2-26oC, 23-29oC, 26-32oC, 26-34oC and 26.6-34 oC for Port Harcourt, Enugu, Jos, Kano and Maiduguri. Average solar radiation peaked at 1200 noon with values 508 W/m2, 639 W/m2, 830 W/m2, 905 W/m2, 832 W/m2 for the areas. Average wind speed increases northwards, i.e. 0.9-1.3m/s, 2.0-2.5m/s, 2.1-2.5m/s, 2.4-3.0m/s and 2.9-3.5m/s respectively. The wind variation is due to the surface characteristics across the areas. Southwesterly winds dominated coastal zone while southeasterly/northeasterly winds dominated the arid zone except during periods of peak rainy season. Average cloud cover for the coastal and northern domains in oktas was: 6-7 and 2-4. Relative humidity shows that prevailing atmospheric conditions at any given time are stronger at the areas close to the sources of influence and the position of Intertropical discontinuity (ITD). Humidity values were: 67-93% and 31-71% for coastal and northern domains. Rainfall amount reduces northwards i.e. 200-46 mm. Rainfall pattern is significantly influenced by the air masses source regions. These regions include closeness to massive water bodies, proximity to Sahara Desert and effects of mountainous barriers.

Contribution/Originality: This study is from the Lead Author's doctoral research with strategic contributions from fellow Authors. The study emphasizes on the nature of the lower atmosphere as it relates to major climate zones in Nigeria from Era Interim Data platform. The study stresses the major factors that enhance the climate zones.

1. INTRODUCTION

Nigeria is dominated by a tropical climate which consists of two unique seasons, the dry and the wet seasons. The rainy stretch begins from March and terminates within the month of November in the South and from May to October while the dry spell dominates the remaining months. Two major air fronts referred to as 'trade winds' influence the climate of Nigeria i.e. the moist maritime air front (mT) from the Atlantic Ocean and the dry and relatively stable tropical continental air front (cT) from the Sahara Desert. The dominance of either of the seasons is impacted by the seasonal shift in ITCZ i.e. the zone of Inter-Tropical Continuity. The mean annual temperatures in Nigeria differ with position and altitude [1]. The far north and the Niger-Benue lowlands are the hottest areas with their mean temperatures over 27°C while the coastal lowlands and the high plateau areas are cool or warm, with mean annual temperatures of about 24°C [1]. Humidity and rainfall in Nigeria vary with the time of the year. Around July, humidity is relatively high varying around 60% to over 80% in the northern and southern parts respectively. In January, humidity is below 25% in the north and a little over 60% in the south. Rainfall amount ranges from about 1000m in the north to over 2500m in the far south. There are four notable seasons observed in southern Nigeria, these are: the lengthy wet season – which begins in late February with a peak in June, lasting up to July, over most part of southern Nigeria; the short dry season – which takes place within August and is due to the ITCZ moving towards the northern part of Nigeria; the short wet season – this peaks in September and terminates in October and the lengthy dry season – This phase begins from November to late February/early March. Two seasons predominant in the North include: a lengthy dry spell (October-April), and the rainy period lasts for five months. The distinct climate sections between the southern and northern end are: the damp equatorial climate in the south, the warm and dry tropical continental up north, the middle belts wet and hot tropical continental climate, and the mild sub-temperate climate around the highlands.

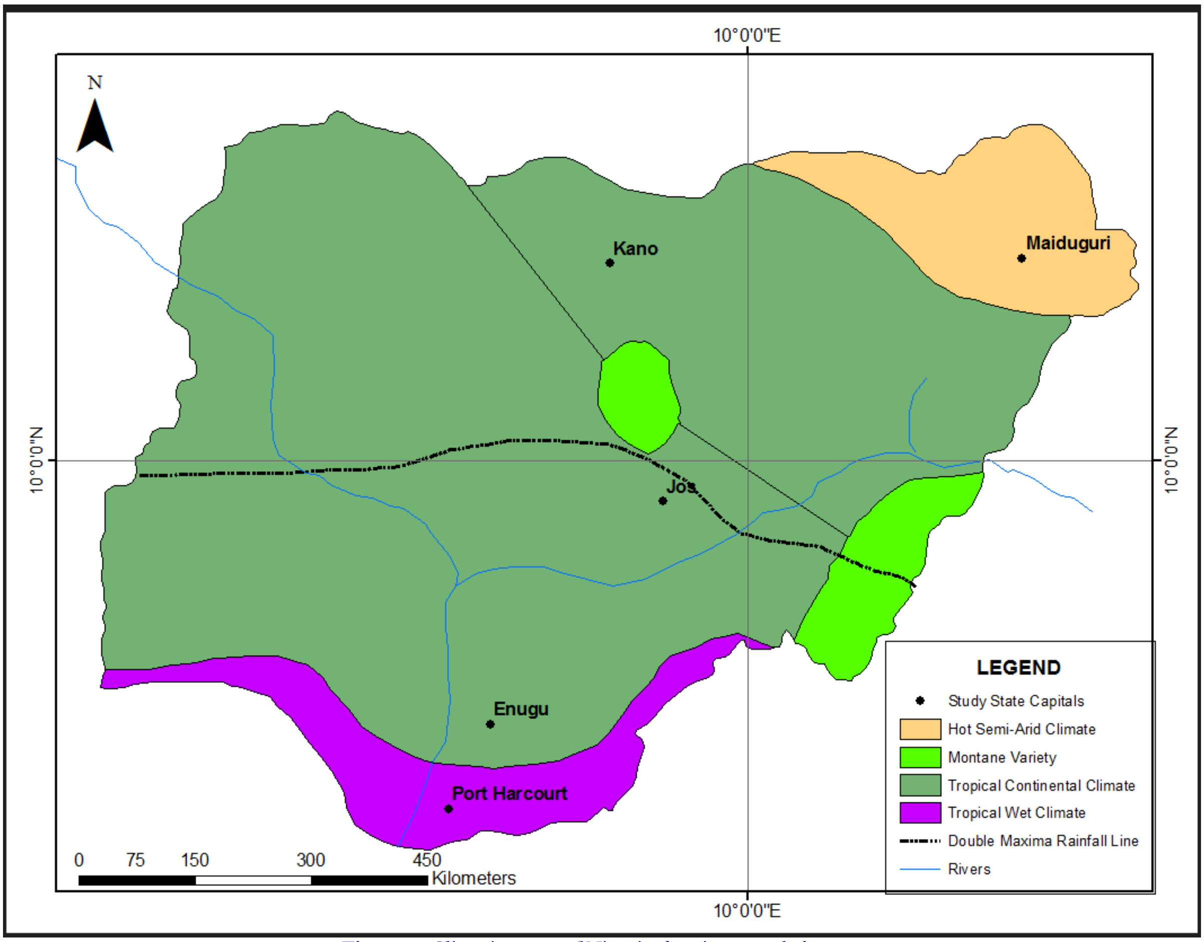


Figure 1. Climatic zones of Nigeria showing sampled areas.

Source: Edokpa [1].

Notably, however, the duration of the distinct seasons in Nigeria depends on the proximity of the locations to the ocean. Particularly, therefore, there is a higher period of precipitation in the locations near the ocean and the intensity of rainfall exceeds that in the parts further from the ocean. A representative example would be the location of Port Harcourt in the Southern end of Nigeria compared to locations far north such as Kano and Maiduguri.

Ogunsote and Prucnal-Ogunsote [2] emphasized four major climatic belts across Nigeria based on the Köppen system of classification. This system of classification is generally accepted for the global evaluation of climatic zones. The major climatic zones in Nigeria include:

1. Hot semi-arid climate (Or Köppen's *BSh* climatic classification).
2. Montane climate (Recognized by another climatologist, Geiger).
3. Tropical continental climate (Or Köppen's *Aw* climatic classification), and
4. Tropical wet climate (Or Köppen's *Am* climatic classification).

The Figure 1 shows the climate zones and boundaries in Nigeria.

1.1. Climate Zones of Nigeria

The Nigeria climate is classified into four distinct zones: *Tropical Wet Climate*, *Tropical Continental Climate*, *Montane Variety* and *Semi-Arid Climate*. The *Tropical Wet Climate* is about 150km from the coast inland [1] and influenced by the moist air from the Atlantic Ocean. Mean annual maximum air temperature values is within 27°C to 32°C. Mean annual relative humidity and rainfall amount are 80% and 2400mm for areas like Port Harcourt. The rainfall pattern is usually conventional in nature due to the region's closeness to the equatorial belt. The double maxima peak rainfall period is June and September.

The *Tropical Continental Climate zone* covers over 80% of Nigeria mainland. The zone is delineated by the double maxima rainfall line south and north of Nigeria. The southern domain has a lower temperature range with higher annual rainfall and shorter dry season of about four months. The northern domain is characteristically of the dry type with longer dry periods. Oluyole, et al. [3] disclosed that this northern end is mostly influenced by the tropical continental air mass (cT) for most of the year. This climate zone has a wide range of relative humidity and mean annual rainfall and temperature vary from about 1700mm and 26.3°C in places like Enugu to below 800mm and 26.1°C in places like Kano [1]. The *Montane Variety Climate* is a high-altitude climate zone which dominates on the Jos, Obudu, Adamawa and Mambilla plateaux [1]. Temperatures are very low both in the wet and dry seasons due to the highlands which is over 1500m above sea level. Mean annual temperature range in this zone is within 20–23°C. The mean annual rainfall in domain such as the Mambilla plateau exceeds 1780mm with peaks in June/July and September. The dry season last between November and February.

The *Semi-Arid Climate zone* is typically of the dry tropical type with distinct wet and dry seasons. The area is of subtropical highs where subsidence dominates with mean minimum and maximum air temperature ranges between 20°C to 25°C and 30.9°C to over 40°C [1]. In this zone, there is a longer and shorter dry and wet seasons from October to May and June to September respectively. The peak wet season is in August due to the presence of moisture laden Inter-tropical discontinuity (ITD). With a mean annual rainfall of 150mm and less than 1000mm, the zone is prone to increasing evapotranspiration, drought and desertification. Mean annual relative humidity ranges between 18-63% with low and high peaks observed during the dry and wet seasons respectively. Mean annual wind speed levels is within 1.5-12m/s. The higher wind speed values are due to the less frictional effects arising from the massive landmass without much vegetation when compared to the rainforest dominated zone in the south. The mean annual sunshine duration for this zone is within 8-11 hours.

1.2. Major Factors Influencing the Climate of Nigeria

1.2.1. Temperature and Altitude

Nigeria is situated within the lowland moist tropics north of the equator and influenced by a high-temperature system [1]. The largely low relief enhances high-temperature all year round. The high temperature range observed is primary because the astronomical variation of insolation and the daily variation in the elevation of the sun observed in low latitude than in high latitudes domains [4]. However, high altitude locations such as the Jos Plateaux, Adamawa highlands, Obudu and the Mambila plateau have a cooler climate than their surrounding lowlands. The lower temperature observed at the highlands is due to temperature decreases with height. Also, the air at higher altitudes is less dense and cannot absorb or retain heat much longer. The factors which influence the distribution of temperature at any location on earth include: the amount of insolation received, nature of the surface, distance from water bodies, relief, nature of prevailing winds and ocean currents. The more closely an area is to the ocean, the lower the temperature due to Land and Sea Breeze effect. Therefore, under this condition, temperature increases as one move inland towards the north. However, as land cools faster than the ocean surface at night, the reversed pressure gradient ensures that areas closer to the ocean are slightly warm at nights than far northward areas. Under this condition, air temperature for northward inland areas becomes lower than areas close to the ocean at night. Also, during the wet season, temperature increases northwards due to the more enhanced cloud cover along the coastal areas. The efficiency of solar heat is being moderated by cloud cover. Therefore, since cloud cover decreases northwards; solar intensity will be very high resulting to increase in diurnal temperature aided by the dry soil as well as the predominant drier air [1].

1.2.2. Pressure, Winds and Air Masses

Like temperature, air pressure in Nigeria oscillates north and south in tune with the movement of the thermal equator influenced by landmass and water bodies. High-pressure systems occur when cold air sinks and it is related with clear skies. Low-pressure systems occur when warm air rises and it is related with condensation and precipitation. When an air mass moves from a location of high pressure to another location where low pressure exists, these differences generate winds. Air masses carry the conditions from which they emerge and these conditions are a combination of two features namely: moisture content and temperature. Aribisala, et al. [4] affirmed that the tropical maritime air mass (mT) originates from the southern high-pressure belt located off the coast of Namibia, and in its trajectory, picks up moisture from over the Atlantic Ocean, crosses the equator and becomes the southwest wind which influences the country during wet season. This occurs when the sun is on the Tropic of Cancer or close to it. The tropical continental (cT) that is created over land begins from the high-pressure belt of the north of the Tropic of Cancer. While on the move it picks up little moisture along its path and it thus dries. Ulor [5] indicated that in December when the sun has moved south to the Tropic of Capricorn, both pressure belt and wind system shift south with it. The Sahara Desert becomes a high-pressure zone from where a dry and cold wind (cT) blows from a north-easterly direction to the low-pressure belt in the south. This dry wind reaches northern Nigeria about early October, gains ground by pushing back on the tropical maritime air mass and by January has moved to the very southern borders, therefore expanding its dominance over a larger part of the country. It starts to retreat by March as the sun moves northwards again on its journey to the Tropic of Cancer, being pushed in turn by the tropical maritime air mass. Odekunle [6] noted that the two air masses approach each other along an inclined surface referred to as the Inter-Tropical Discontinuity (ITD).

1.2.3. The Convergence Zone over Nigeria

The structure of the troposphere over most parts of the tropics is characterized by two major air masses. These air masses include a usually moist but rather cool southerly air with a north-easterly component which forms a wedge under a dry relatively warm air. Ayoade [7] emphasised that the boundary zone between these two air masses over the Atlantic Ocean and Land is referred to as the Inter-Tropical Convergence Zone (ITCZ) and the Inter-Tropical Discontinuity (ITD) respectively. Olaniran [8] referred to the ITD position as a zone of moisture discontinuity. The ITCZ is a zone of convergence where the trade winds meet and moves with the shifting location of the thermal equator. This phenomenon is known as the zone of convergence over the ocean because the two air masses on coming together acquire moisture as well as have the same temperature and other features. The climatological relevance of this phenomenon is that it moves on an annual cycle following the south-north motions being modified by the presence of the land and ocean. Its depth and motion influence the degree to which rainfall is distributed across Nigeria.

Suzuki [9] disclosed the features of the ITCZ which include:

1. It creates massive convective activities.
2. Its rich moisture content is sustained by horizontal vapour flux.
3. Outside but near the ITCZ, shallow convention exists and may act to pre-moisten deep convention.
4. Its seasonal variation is led by altitudinal convective flux in the troposphere due to seasonal alteration in solar radiation.

Ayoade [7] disclosed that in West Africa, the ITD over land assumes its northernmost location around latitude 20oN in August when the region is under the impact of the tropical maritime air mass. In January, it reaches its southernmost part near latitude 6oN which is the peak of the dry season in the region. The wet season at any position in Nigeria commences with the movement of the ITD northwards. Tarhule and Woo [10] specified that the ITD is deep-rooted during the months of June-September in the northern part of Nigeria. Slightly more than 70% of mean annual rainfall is reached over Nigeria during these months. The double maxima rainfall peak experienced in the coastal areas, for instance is as a result of the ITD moving northwards in the early part of the year, bringing rainfall to peak in June and returning southwards later in the year with another peak rainfall in September.

2. METHODS OF DATA COLLECTION/ANALYSIS

Weather data on air temperature, relative humidity, cloud cover, wind speed/direction and sunshine radiation for the synoptic hours: 0000, 0600, 1200 and 1800Hs were obtained from Era-Interim Reanalysis data platform for the climate zones in Nigeria. According to Ayoade [7] meteorological observations are made at fixed observing hours. The main synoptic hours are 0000, 0600, 1200 and 1800 Greenwich Mean Time (GMT). The weather parameters were assessed as diurnal-seasonal values for typical 3-month seasons; that is., December--February (DJF– peak dry season), March–May (MAM – early rainy season), June–August (JJA – peak rainy season), and September-November (SON – early dry season) for the period under review (2010-2015) across the climate zones.

The reanalysis data is generated by the European Centre for Medium-Range Weather Forecast and the gridded products comprise of a large variety of data for surface and upper air. The reanalysis upper air data comparison with that from the Nigeria Meteorological Agency yielded a correlation of 0.6 [1]. Furthermore, the application of Era-Interim data has surpassed expectations and has outstanding successes from global researches in recent years. Okonkwo, et al. [11] affirmed that the data platform provides meteorological parameters the required understanding for enhanced knowledge of the atmospheric circulatory system across West Africa. The data for the specified years was obtained at 0.125o spatial resolution. This low resolution was chosen to acquire a reliable spatial scale.

3. RESULTS AND DISCUSSION

3.1. Analysis of Meteorological Variables for Study Areas

Climatic parameters such as wind speed, temperature profile of the boundary layer, solar radiation, relative humidity, rainfall, cloud cover etc. are critically influenced by topography, altitude, position with respect to large water bodies and desert area as well as other unique geographic sorts. Consequently, for any atmospheric related investigation, it is challenging to contemplate the entire Nigeria as one expanse since diverse areas of the country have dissimilar physical characteristics and microclimates. The data retrieved for this study were analyzed and their drifts, variations and differences for the sample areas detected so as to acquire the understanding to the issue under examination and relate the outcome to bolster valuable information concerning the research.

3.2. Temperature Profile Across Study Areas

Surface air temperature is a regulatory influence of diverse environmental processes. Therefore, it is crucial to many fields of research. From Figures 2-5, analysed air temperature profile across sample areas for the following diurnal hours i.e. 0000, 0600, 1200 and 1800 are shown. Temperature profile across Nigeria shows that average diurnal range are between 24 and 30 °C; 23 and 27 °C; 25.9 and 34 °C; 26 and 34 °C for the respective diurnal hours. Lower values are obtained at the coastal/near in-land domains, while higher values are obtained at the northern band of Nigeria (Figures 2-5). The period of highest temperature trend across the northern fringes of Jos to Maiduguri was during the hours 1200 and 1800 ranging between 32 and 34 °C (Figures 2-5). This was increasing from Jos to Maiduguri. At the southern edge, it was between 24.9 & 27.7 °C and 24.4 & 27.8 °C at 1200 and 1800 hours respectively for Port Harcourt as well as between 25.7 & 30.1 °C and 26.1 & 32.3 °C at the same hours in Enugu. Also, Results have shown the impact of latitudinal positions of study areas in relation to temperature settings and indicates a drier weather pattern as one move from coastal south to the far north. According to Ayoade [7] the sun's altitude decreases with increases in latitude. Therefore, higher elevation in places like Jos receives a large amount of insolation. The lower temperature values observed for Kano and Maiduguri at 0600H is attributed to the massive outgoing of radiation from the surface due to the peculiar surface characteristics such as dryness of the soil and low cloud cover (Figure 3).

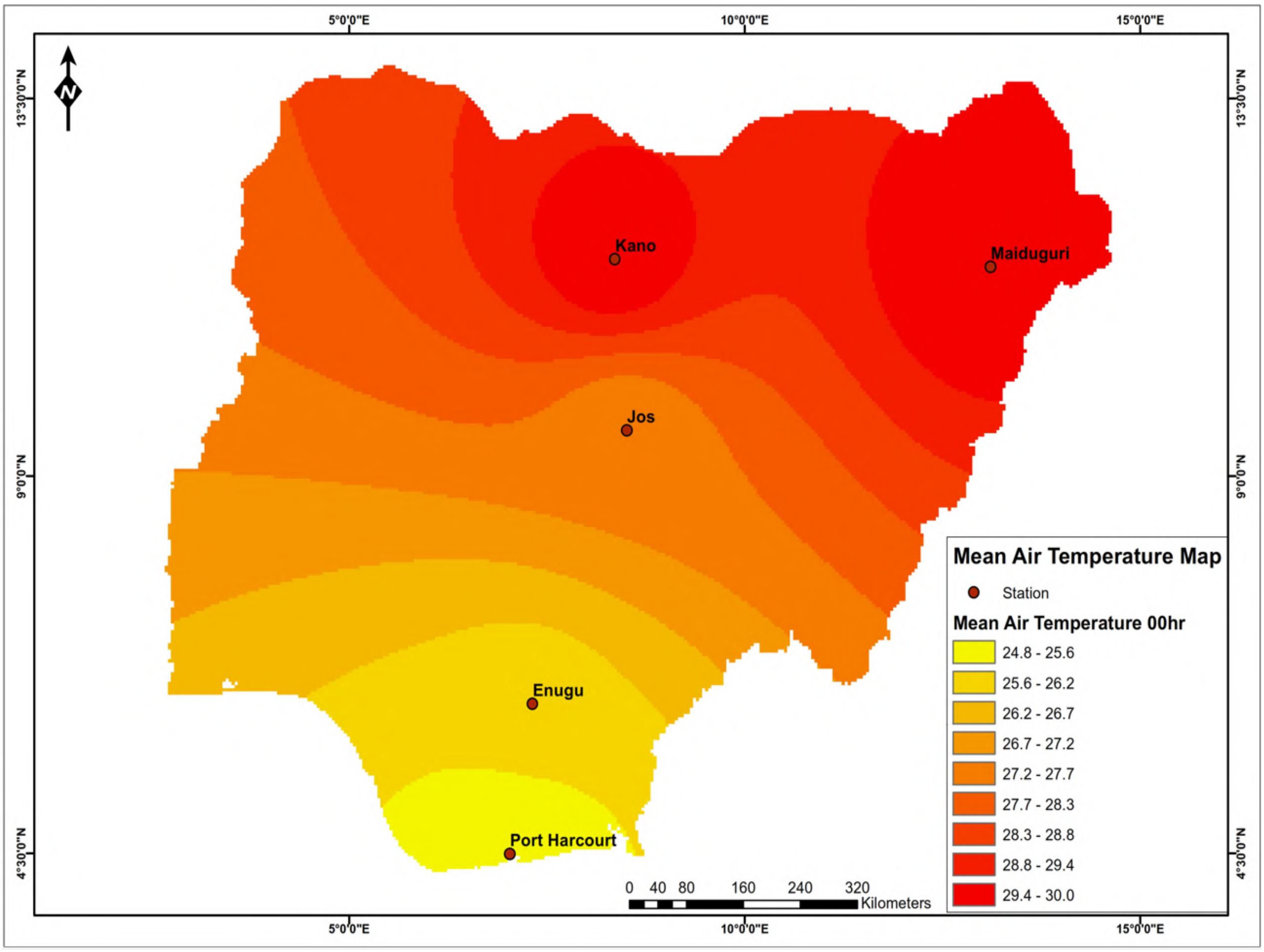


Figure 2. Average temperature (°C) pattern across study areas for 0000 hour.

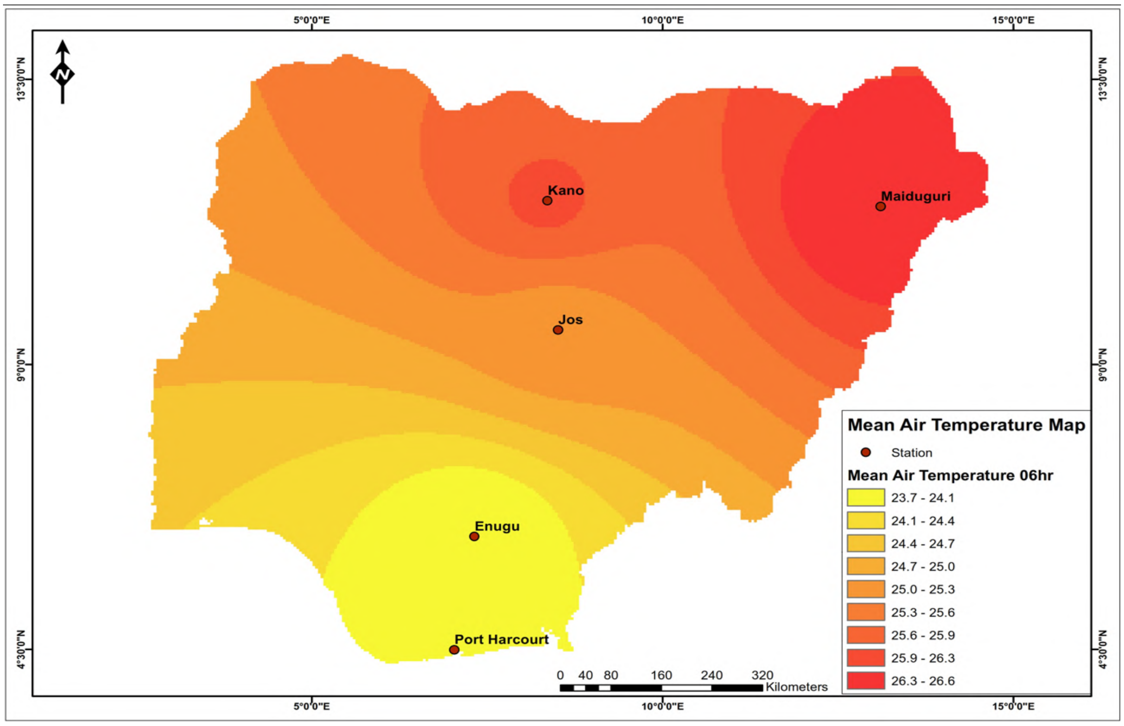


Figure 3. Average temperature (°C) Pattern across study areas for 0600 hour.

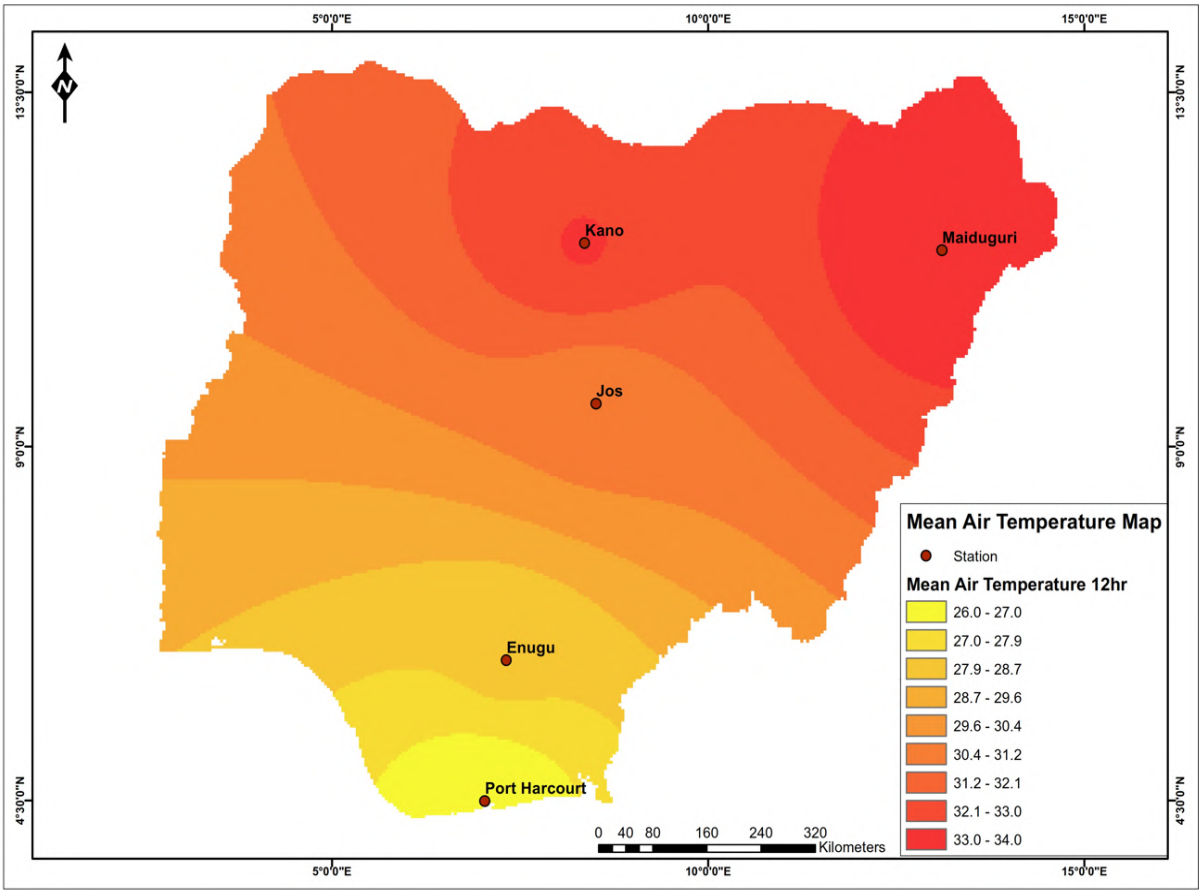
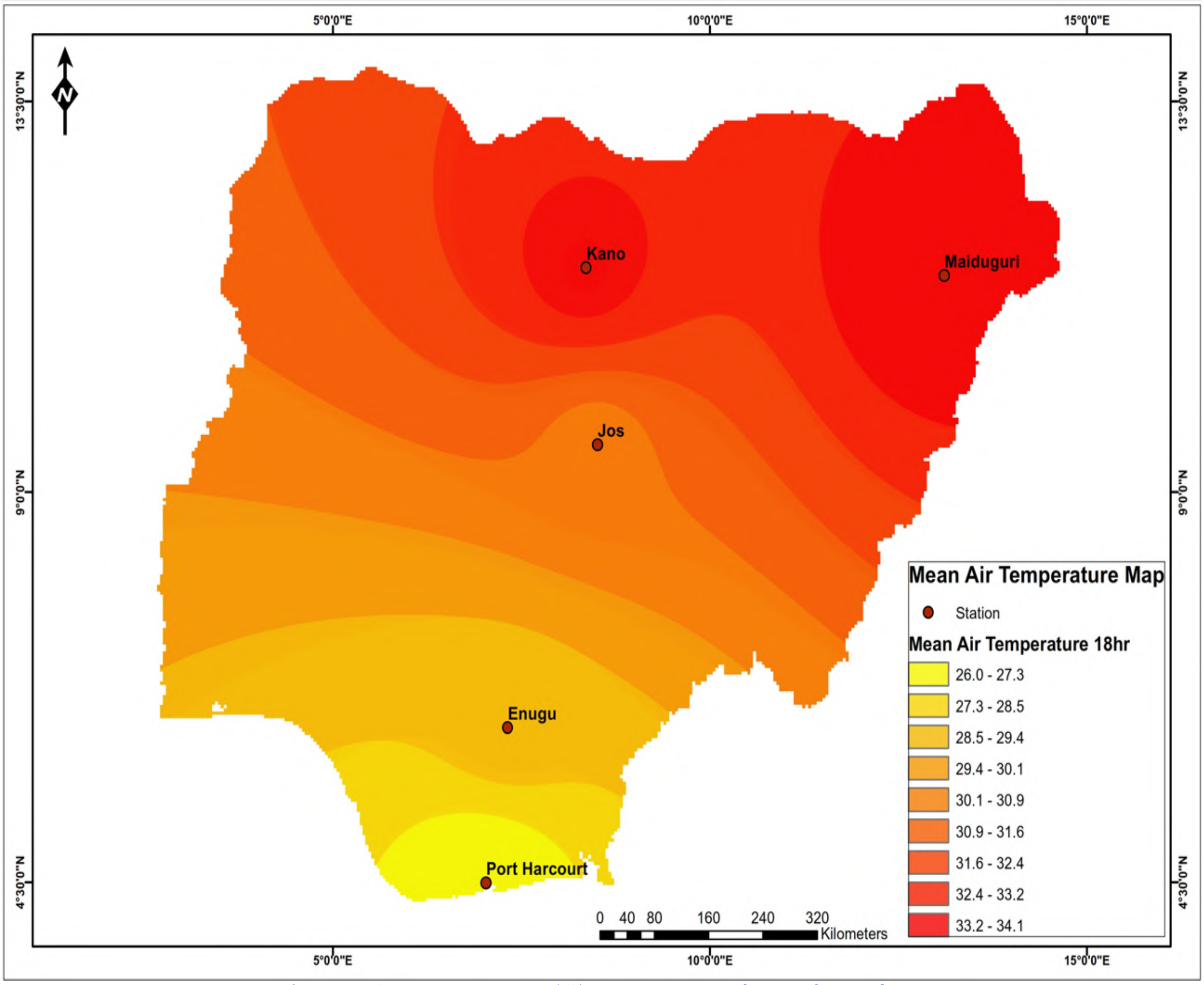


Figure 4. Average temperature (°C) pattern across study areas for 1200 hour.



Figures 5. Average temperature (°C) pattern across study areas for1800 hour.

Table 1. Duirnal temperature values for Jos in 2016 by Nigeria meteorological agency (NIMET).

Period	January	February	March	April	Mean
Day	27.6	30.1	31.1	31.3	30.0
Night	12.0	14.9	17.0	18.7	15.7

Source: Edokpa [1].

Other vital factors that could have enhanced the pattern of temperature trend over sampled areas include closeness/distance from water bodies, cloud cover and the dominance of air mass within the areas. A major force that would have heightened the lower trend and lesser variation of ambient temperature pattern in Port Harcourt and Enugu between March and November is the closeness to large water bodies. Within this tropical location, the prevalence of clouds coupled with high humidity are strongly associated to the coastal band, where the sea-breeze flow conveys moist air that generates near-surface convergence. According to Falayi [12] the prevalence of cloud cover as well as high relative humidity are the vital factors that hinders the sustaining impact of solar radiation across certain areas on the earth surface. For Port Harcourt, the continentality effect coupled with land and sea breeze would have made the area lower than Enugu for most of the seasons. Since marine environment take-in and discharge heat at a degree considerably lower than terrestrial surface, air temperature in places close to the ocean tend to have lesser variations. The circulation that takes place between the massive water bodies with enormous specific heat and the prevailing wind contributes in regulating the air temperature pattern of sampled areas close to marine environment. This is the opposite as extreme temperature pattern are observed in sampled areas near Sahara Desert such as Kano and Maiduguri where there is no large marine environment. Udo and Okujagu [13] acknowledged the attributes of larger land mass in the north compared to the south as one of the reasons for non-regular pattern of temperature values. For highland expanses, such as Jos, the diurnal temperature range pattern is large due to the influence of topography in modifying air temperature. Jos is over 1,000 m above mean sea level (MSL) when compared to Port Harcourt that is below 30 m MSL with a shorter diurnal temperature range. Table 1 presents the predicted diurnal temperature range for Jos in the year 2016.

Efe [14] has revealed that the rise in temperature across Nigerian cities is 28% higher than their neighbouring sides. This upsurge has been determined to be considerably dependent on the increase in CO_2 emissions accounted for over 90% events of urban warming experienced in Nigerian cities. It was documented that ambient temperature for Jos during the study periods for the 0600Hr, 1200Hr and 1800Hr recorded 27.3ºC, 30ºC and 29.6ºC respectively. That of Port Harcourt for the same hours was 25ºC, 29ºC and 28ºC. The increase in CO_2 has been attributed to anthropogenic activities of man's quest for survival. The most vital significance of air temperature as related to atmospheric stability feature is associated with the interplanetary heating requirements and its attendant modification of the atmospheric layers. These temperature alterations generate forces that initiate the continuous circulation in the atmosphere. Through the progression of the day, cooling and heating effects of the earth's surface emanates triggering diverse stratification. This continuous heating and cooling pattern lead to a surface net heat flux including the sensible heat transfer between the earth surface and the overlaying air. The atmospheric boundary layer is the main driving force or centre that initiates the cycle of events in the lower atmosphere. The spreading of temperatures within the boundary layer has a momentous influence on the stability of the lower troposphere. The temperature profile of the lower troposphere is regulated by a number of aspects, including radiation instability, heat exchange, frictional imbalance, dry and moist convection etc. The tropospheric stratification of temperature is branded by its reduction in relation to altitude and this depends on time and space.

3.3. Insolation Profile Across Study Areas

The intensity of sunlight drives the atmospheric regime of any location. Trend analysis for this study revealed that the magnitude of solar radiation especially during noon time increases from the coastal area of Port Harcourt to the extreme north of Kano and Maiduguri from 0600 to 1200 hours (Figure 6 and 7). Average solar radiation was highest at 1200H with values 508 W/m^2, 639 W/m^2, 830 W/m^2, 905 W/m^2, 832 W/m^2 in Port Harcourt, Enugu, Jos, Kano and Maiduguri respectively (see Figure 7). Figure 6 shows the trend of solar insolation hours received across climate zones in Nigeria.

The reason for the shorter solar insolation hours at the coast is due to the longer season of rainfall and the prevalent cloud cover which lessen massive amount of solar insolation the earth surface receives [1]. The high solar insolation amount and increasing trend from the coast for 1200 hour shows that a progressively strong latitudinal zone characterizes the Nigerian climate. Ayoade [7] and Adaramola [15] noted that for any specified location, the solar insolation is firmly reliant on the latitude, time of the day and the season. Kano maintained the highest stake during the hour mark due to a higher latitudinal position as well as solar intensity ahead of the rest areas. Elevation and duration of sunshine insolation could have increased the amount of insolation in Jos almost similar to Maiduguri (Figure 8). As revealed by result analysis, solar insolation peaks at noon because at that time incoming solar radiation exceeds heat loss from the earth's surface. Therefore, surface temperature is still increasing. Maximum temperature occurs when the rate of heat loss from the earth's surface is the same as rate of heat gained from solar insolation. This occurs later in the afternoon usually (1400H-1600H).

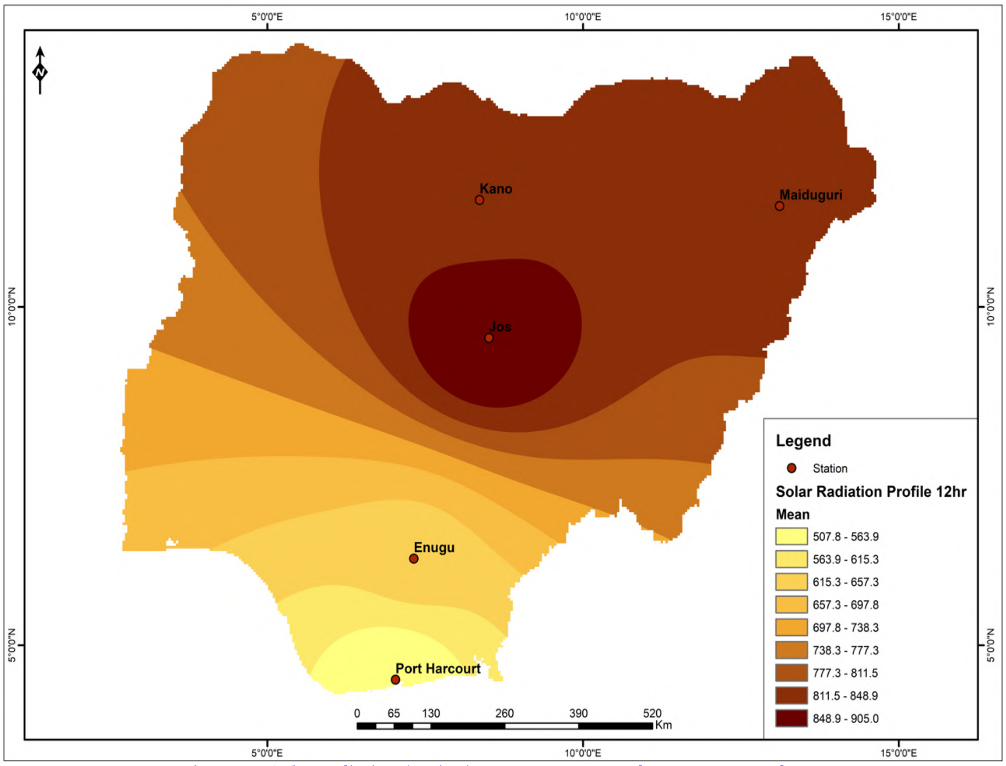


Figure 6. Solar radiation (W/m²) pattern across study areas at 1200 hour.

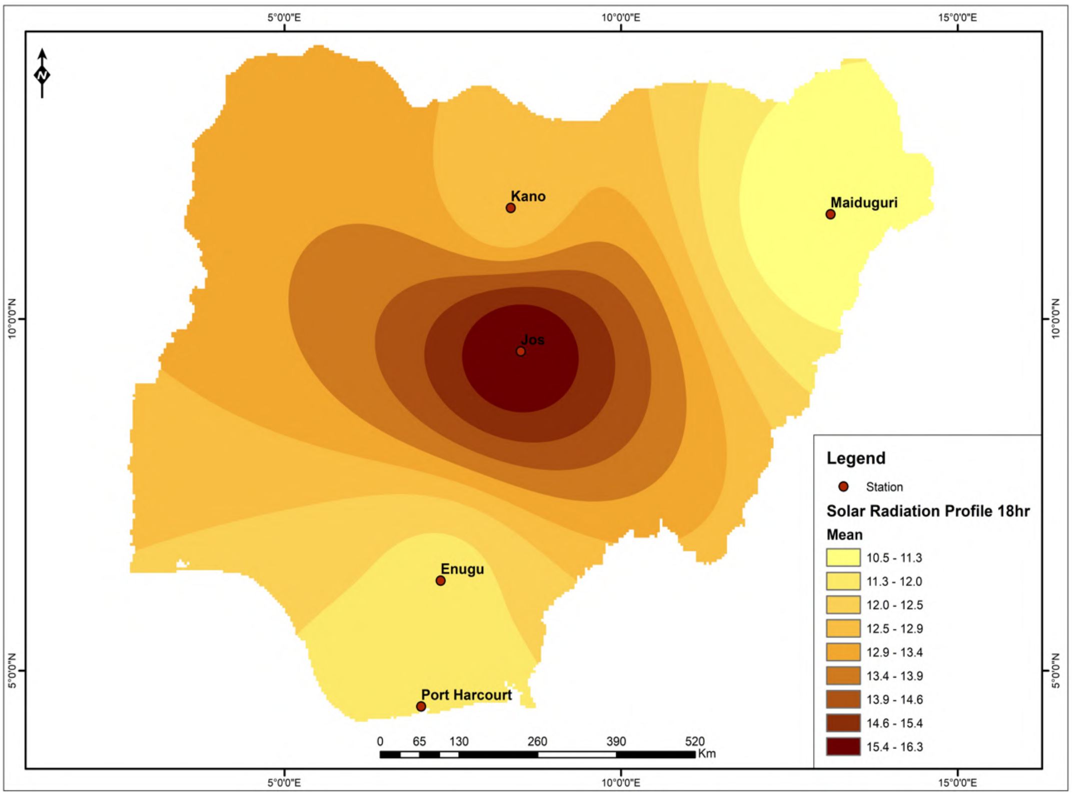


Figure 7. Solar radiation (W/m²) pattern across study areas at 1800 hour.

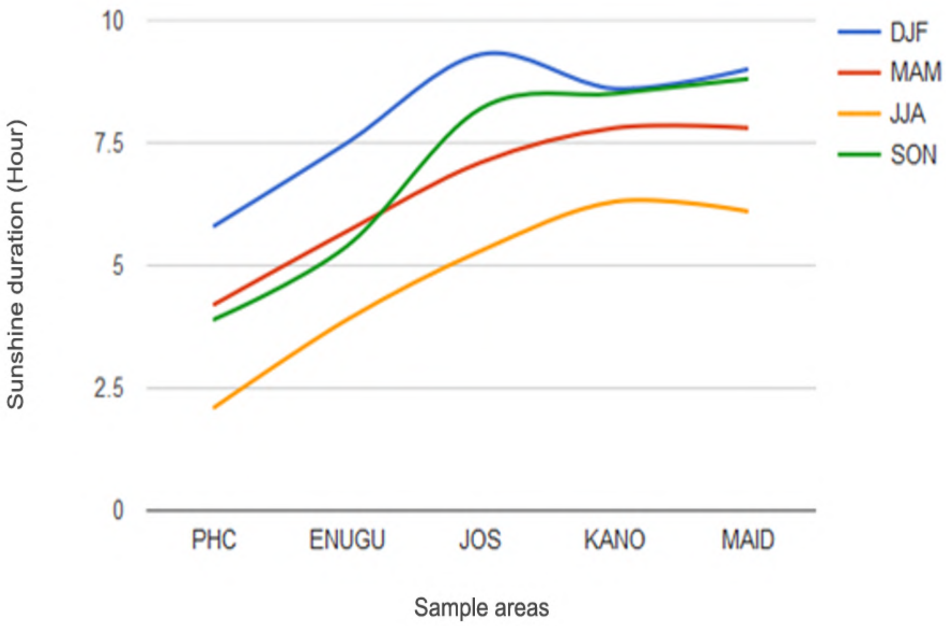


Figure 8. Mean daily duration of solar radiation across study areas.

At 1800H, infrared exceeds insolation and this can continue till 2300H-0000H. All the areas maintained a slightly uniform trend i.e. 11-16 W/m² (Figure 7). The trend (most especially between July and October) indicates the period of reasonable distribution of rainfall across the entire country at the return of the ICTZ when it stretches far north and also due to the lesser intensity of solar insolation at the hour.

3.4. Wind Speed/Direction Profile Across Sampled Areas

Analysed mean seasonal diurnal wind speeds trend across the sample area are shown on Figures 9-12. Result reveals that wind speed increases from the tropical rainforest zone to the arid region. Kano and Maiduguri maintained a higher trend across the hours than the rest domain.

Port Harcourt area had the lowest wind speed all through the mean diurnal seasons with range from 0.9-1.3m/s (Figures 4-7). This trend could be as a result of surface friction, prevalence of large vegetation covers and the humid environment which acts to depress wind speed. Wind speed is swayed not just by pressure gradient but similarly by the degree of surface unevenness which makes it change direction frequently as well as the stability condition of the air.

Amadi and Udo [16] disclosed that atmospheric circulation form as well as surface characteristics pattern is mostly responsible for wind speed alterations at any given location.

Enugu and Jos are within the extremes of the lower wind trend at the coastal tips and higher wind trend at the northern ends. The surface wind speed range for Enugu throughout the diurnal season is within 2.0-2.5 m/s while for Jos is 2.1-2.5m/s.

The dominance of the local horizontal pressure gradients due to differential heating of the topographical surfaces would have given Enugu and Jos an edge over Port Harcourt.

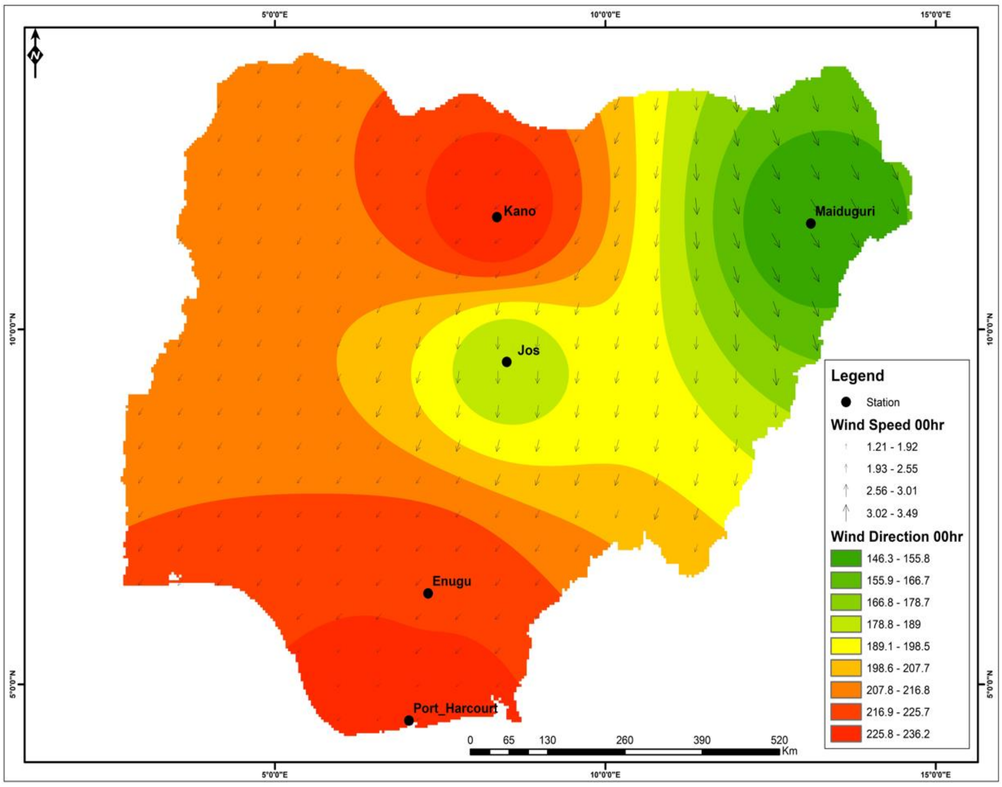
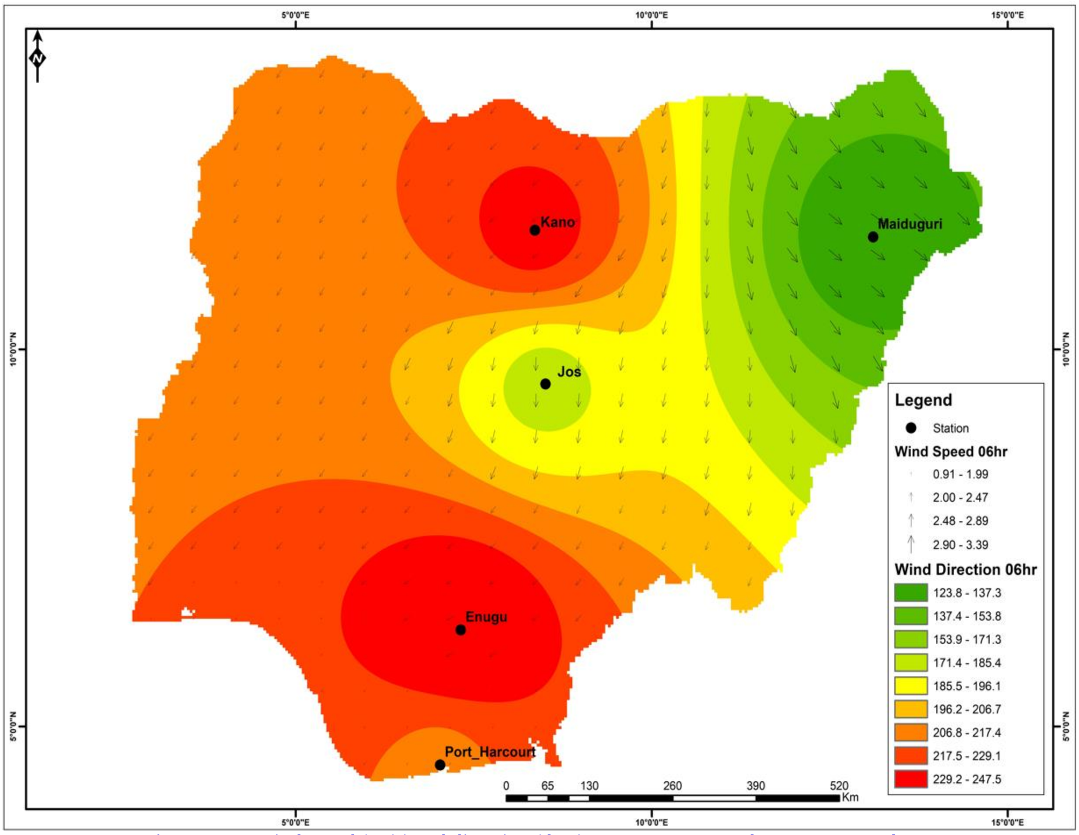
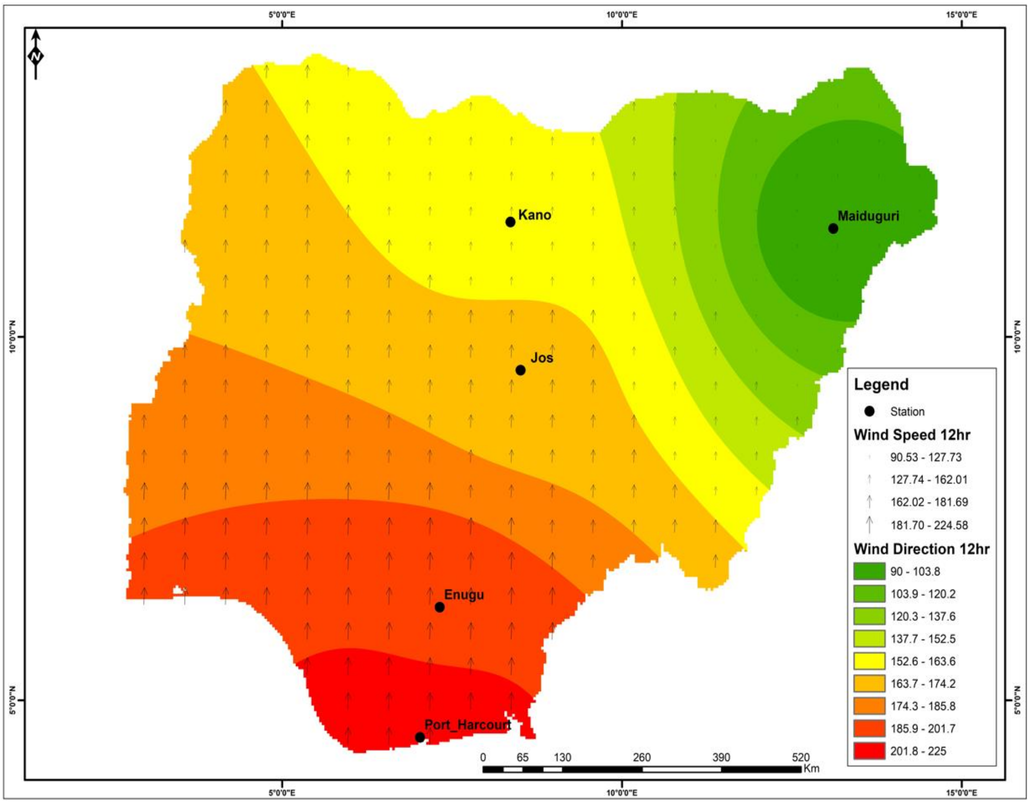


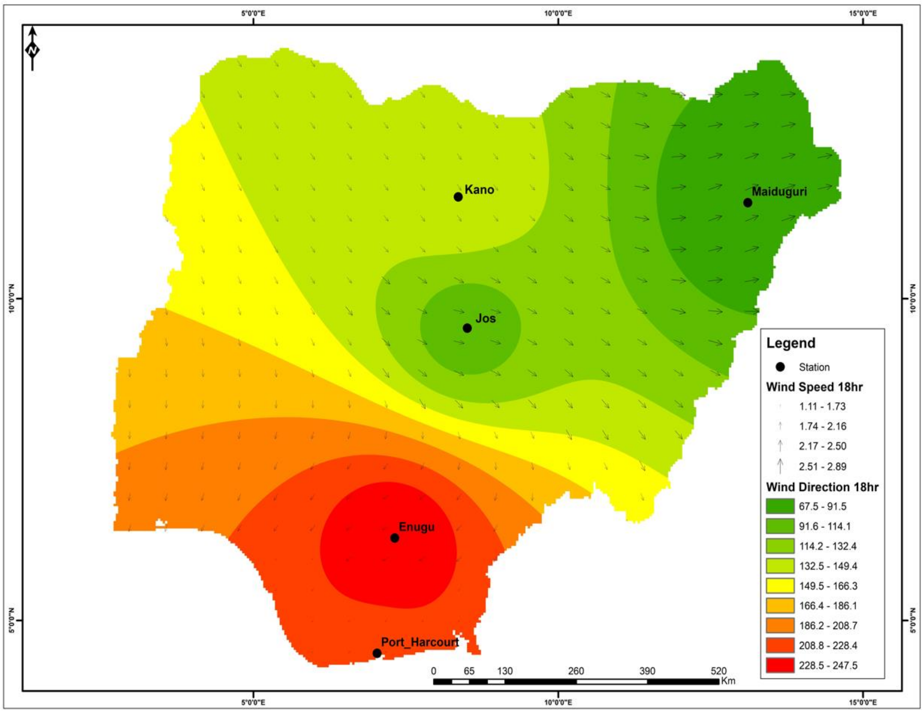
Figure 9. Wind speed (m/s) and direction (deg.) pattern across study areas at 0000 hour.



Figures 10. Wind speed (m/s) and direction (deg.) pattern across study areas at 0600 hour.



Figures 11. Wind speed (m/s) and direction (deg.) pattern across study areas at 1200 hour.



Figures 12. Wind speed (m/s) and direction (deg.) pattern across study areas at 1800 hour.

The high surface wind speed trend observed in Kano and Maiduguri (2.4-3.5m/s) could be due to the nearly uniform terrain and vast land mass prevalent in the northern axis of the sampled stations as well as the non-prevalence of substantial vegetation settings to retard wind velocity. Ngene, et al. [17] have observed that most cities in the extreme north have better and higher wind velocity, hence could be applicable in the generation of wind energy. Amadi and Udo [16] in their study of wind trend over Nigeria posited that wind speed variation tend to be higher at well exposed locations than places of forest, vegetation, hills, mountains and other intervening structure.

This environmental peculiarity between the northern end and the southern coast goes to show the difference in wind speed amount analysed in this study. Wind in any specific area carry out key functions which includes; bringing moisture to the land or removes it, subject to the placement of the land to the direction of wind. Aiyelabegan [18] noted that higher winds are allied with low relative humidity while light winds are usually allied with high relative humidity.

The wind direction system as shown from Figures 9-12 revealed that the areas exhibited wind pattern with respect to their geographical positions or locations. The coastal shows a dominant south-westerly (SW) while the far inland northern end, a south-easterly (SE), easterly (E) and north-easterly directions prevalent across the hours. The wind direction pattern shows the orientation of Jos location relative to the placement of other study areas. It should be noted that the tropical maritime air mass across the Atlantic Ocean is associated with the south-western winds referred to as the south-west monsoons. On the other hand, tropical continental air mass across the Sahara Desert is associated with the north-easterly winds commonly referred to as the north-eastern Harmattan winds.

3.5. Relative Humidity Profile Across Study Areas

The pattern of relative humidity across the sampled stations for the years under review is shown on Figures 13-16 for the various diurnal hours. The average diurnal pattern within the period under study discloses that relative humidity is higher at the coastal ends of Port Harcourt throughout the seasons i.e. above 70% (see Figures 13-16) and decreases towards the northern axis of the country. In the central part of Nigeria (Jos) and extreme north (Kano and Maiduguri) of the country, humidity values are below 40% at 1200H except during 00-0600 period when it ranges from 41-71% (Figures 13-16). This trend shows that prevailing atmospheric conditions at any given time are stronger at the areas close to the sources of influence and the position of the humidity enhancement/discontinuity zone (ITCZ). Musari, et al. [19] have noted the month of February in Jos where relative humidity reduces to 36% and could be high at other months. The report posited that inhabitants are partially comfortable with the mixed weather pattern that is observed in Jos.

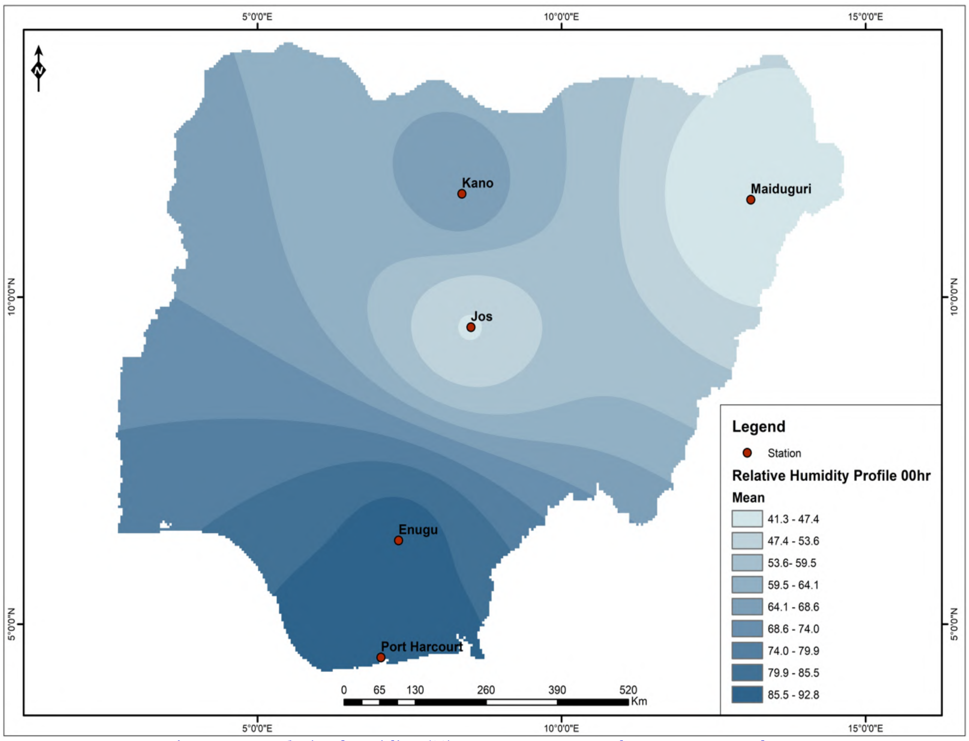


Figure 13. Relative humidity (%) pattern across study areas at 0000 hour.

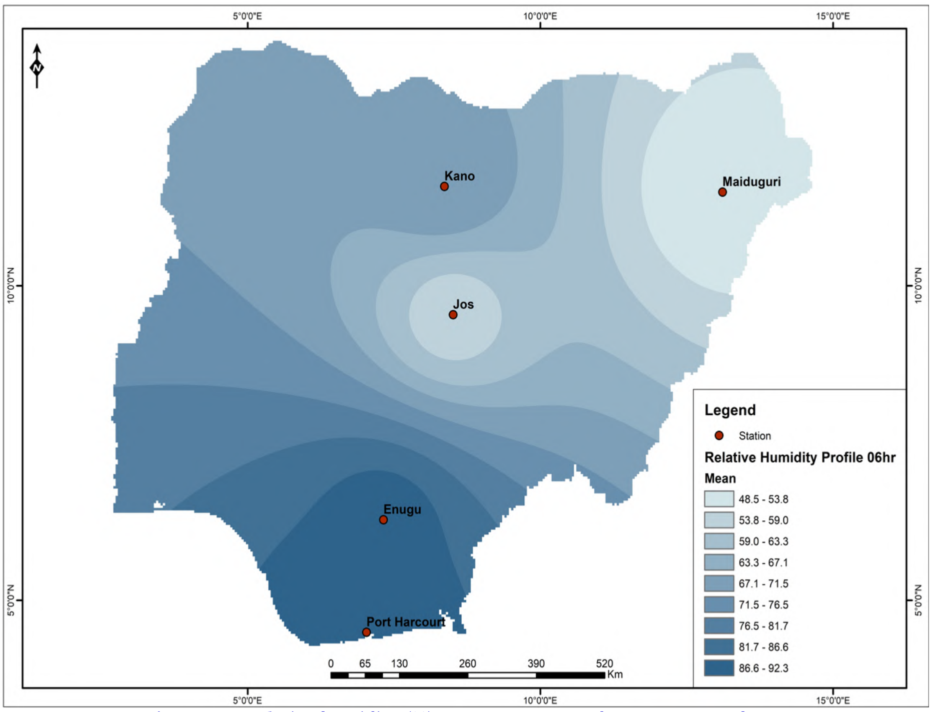


Figure 14. Relative humidity (%) pattern across study areas at 0600 hour.

Ajileye, et al. [20] as well as Oyewole, et al. [21] emphasized that the average percentage relative humidity for the northern zone of Nigeria throughout the year range between 40-70%. This influence results from the dominant extent of dry season which embarks from October to mid-May as against the short duration of rainy season. An important fact that could have led to the high amount of relative humidity at the coastal areas is the dynamic exchange of the ocean-land relationship [22] through the continentality effects as well as the dominance of cloud cover.

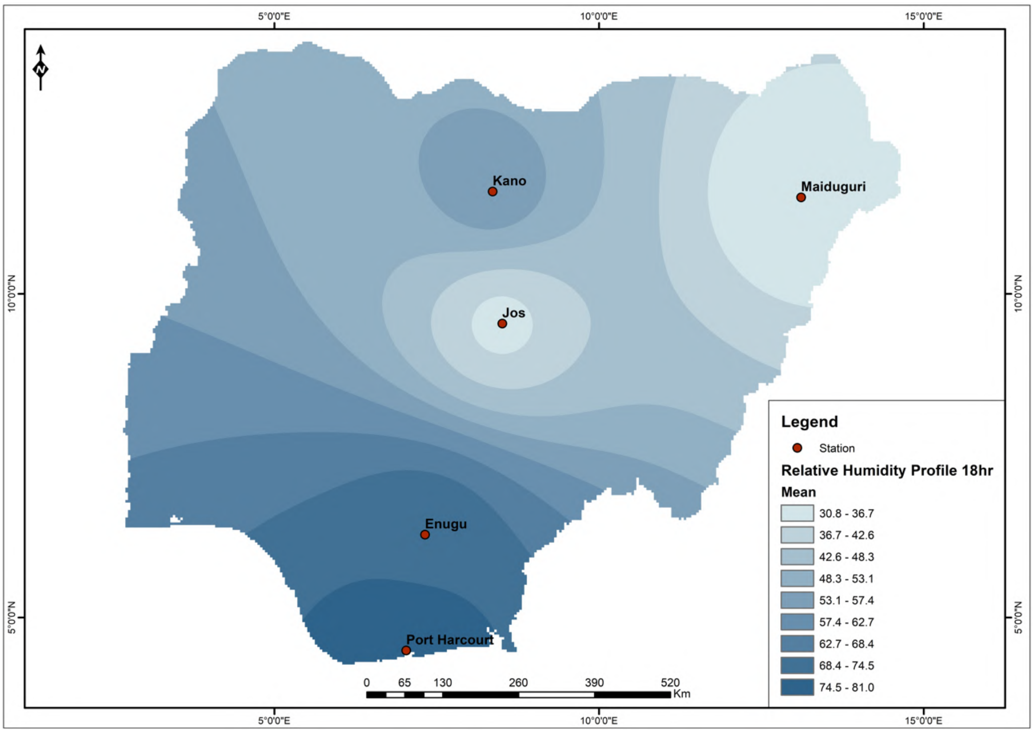


Figure 15. Relative humidity (%) pattern across study areas at 1200 hour.

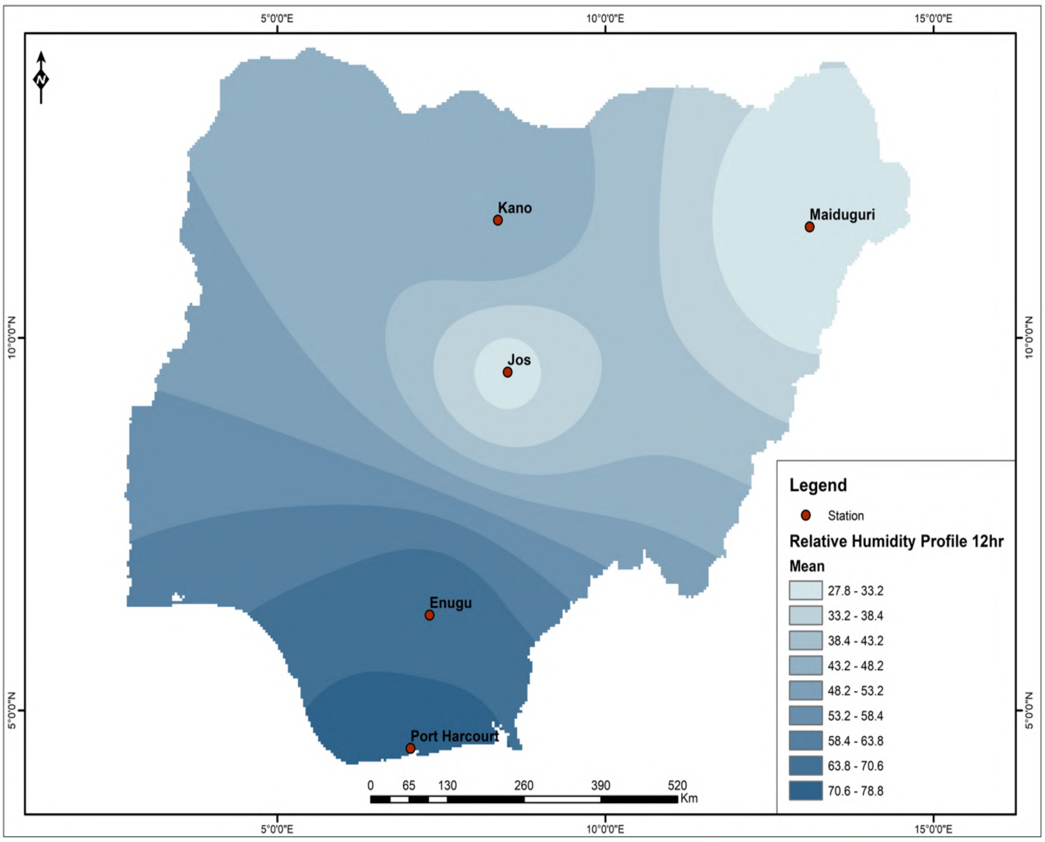


Figure 16. Relative humidity (%) pattern across study areas at 1800 hour.

Salau [22] has revealed that the all-round period of high relative humidity at the coastal fringes of Nigeria when coincided with warm atmospheric conditions could result in heat stress at the areas thereby increasing the threshold of discomfort and energy consumption of people. At this instance, Sanusi, et al. [23] posited that the tendency for humans to discharge heat through evaporation from the skin is constrained by the high level of humidity in the atmosphere. Ayoade [7] and Eludoyin [24] have disclosed that there is commonly a steady shrinkage of the moisture content with increasing altitude and latitudinal position of locations. This means, the higher the altitude, the lower the humidity and this is due to the decrease in pressure level. This fact could have contributed to the lower trend of relative humidity for areas with higher altitudes than the coastal locations. Diurnal temperature range enhances the difference in the percentage humidity between the early hours and noon. When air temperatures are high, humidity reduces and vice versa. However, this circumstance also depends on prevailing air mass across the country which modifies the ambient atmospheric environment. Umoh, et al. [25] noted that the density difference in air temperature and moisture level from any location to another determines the prevalent localised weather pattern. An analysis of mean relative humidity across Nigeria from 1950-2012 conducted by Amadi, et al. [26] revealed that high level of relative humidity occurs in the months of June-October with a peak in August, while the lowest level are noted from November to March. Amadi, et al. [26] also noted that relative humidity ranges between 60-80% and 20-80% over most southern and northern areas of Nigeria respectively.

3.6. Cloud Cover Pattern Across Study Areas

The pattern of cloud cover examined within the periods under review over the climate areas show that the extent of cloud cover over Nigeria decreases sharply from the coastal environs to the far north (Figures 17-20). Analysed data reveals a steady decrease from Port Harcourt to Enugu for the 0000, 1200 and 1800 hours except at 0600 hours where there is a slight increase from Port Harcourt to Enugu. This slight increase could be due to elevation difference between the areas as well as the impact of high air temperature values due to a higher solar intensity prevalent in Enugu than in Port Harcourt. The massive release of sensible heat during the night leading to more water vapour couple with orographic clouds which is enhanced due to lifting force by Elevation Mountains could have impacted at Enugu during the early morning time (0600 hour).

Sato, et al. [27] have observed that topography has enormous influences on cloud development. It emphasised that cloud advances often over topographic platform as a result of the unstable vertical stratification across topographic environment due to higher altitudinal surface. From result analysis, it was observed that sampled domain of close proximity to the ocean exhibited high cloud mass thereby receiving limited solar radiation than low cloud areas up north. For any given place, solar radiation received on the earth surface decreases with an increase in Cloud cover. The trend anomaly noticed between Kano and Maiduguri could be linked to the slight latitudinal difference which affects temperature as well as Lake Chad River close to Maiduguri that tends to increase the water vapour content of the atmospheric environment. The mean cloud cover noted from the evaluated data for the various sample areas was between 5.0-7.0 oktas for the southern domain and 2.3-4.3 oktas for the northern zone (Figures 17-20).

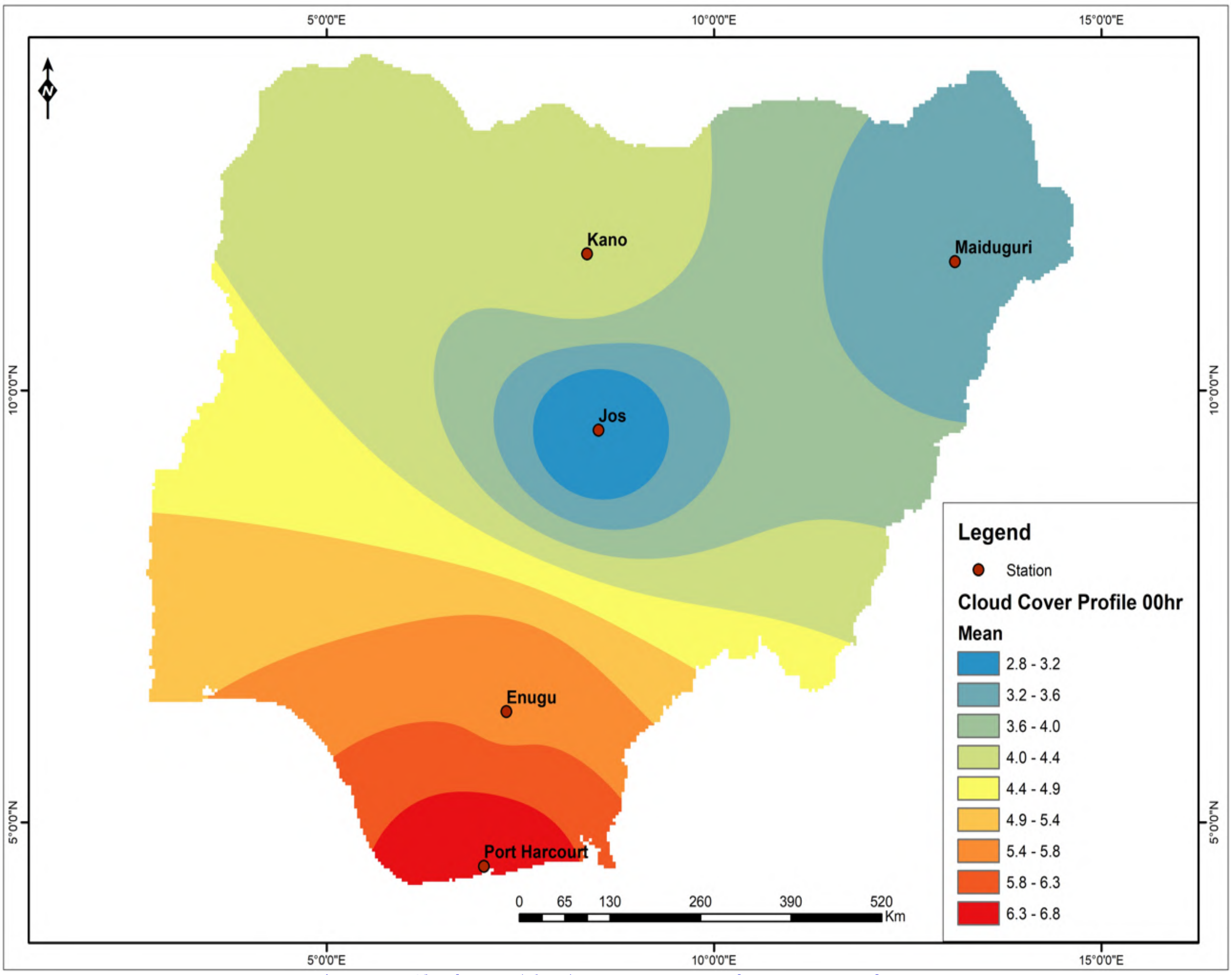


Figure 17. Cloud cover (oktas) pattern across study areas at 0000 hour.

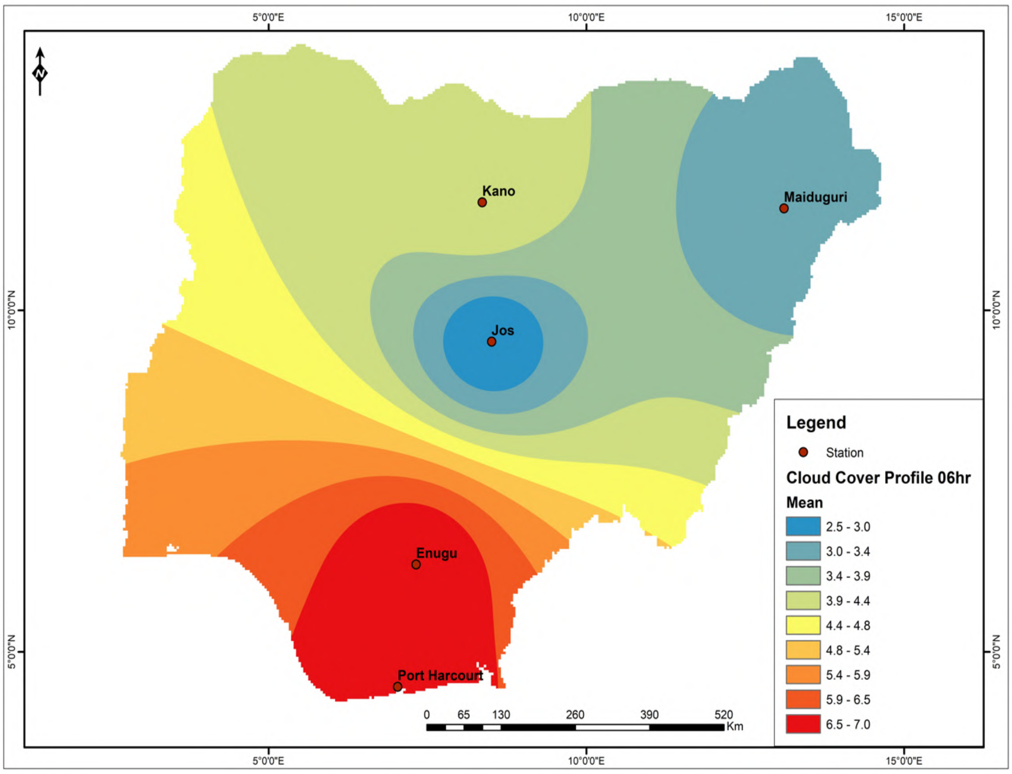


Figure 18. Cloud cover (oktas) pattern across study areas at 0600 hour.

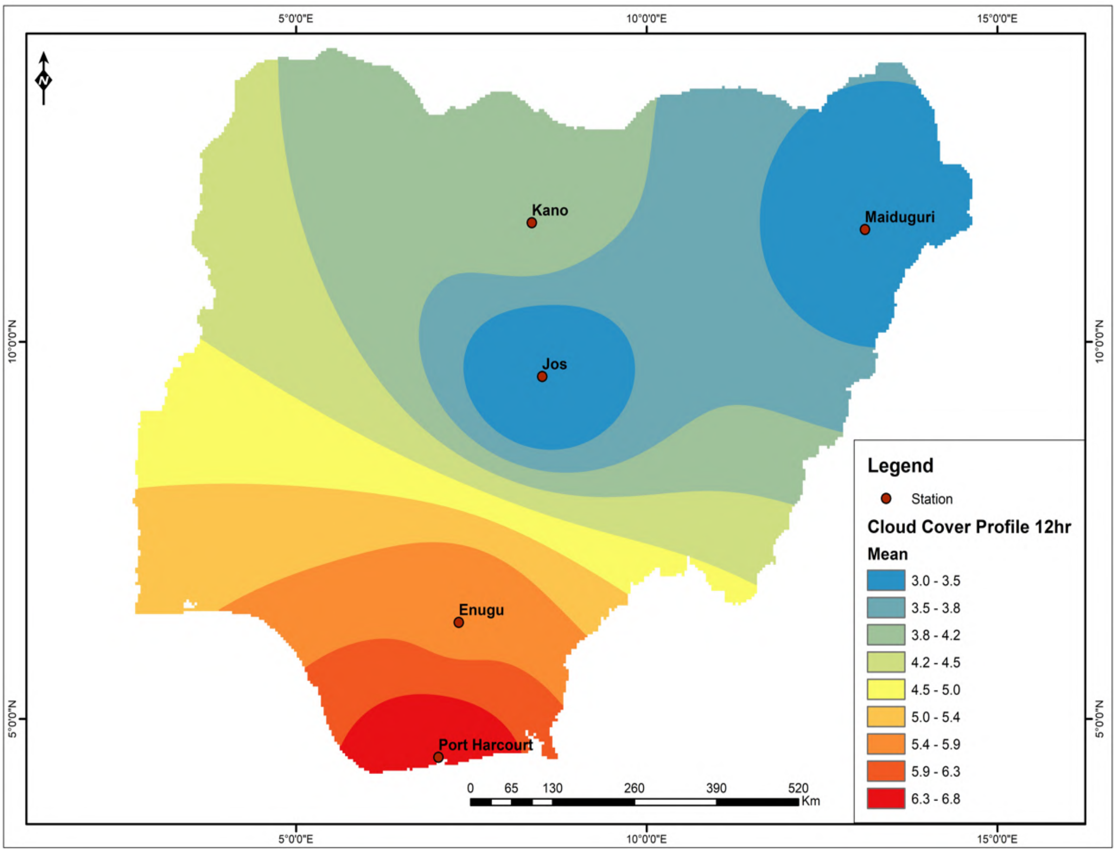


Figure 19. Cloud cover (oktas) pattern across study areas at 1200 hour.

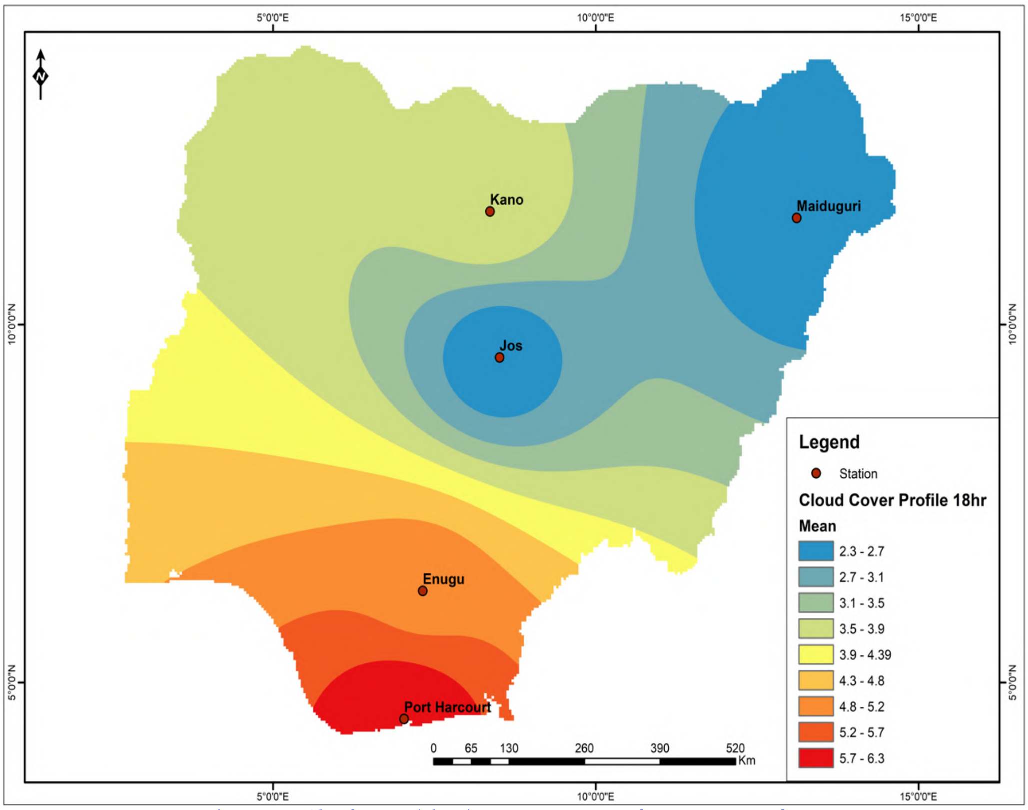


Figure 20. Cloud cover (oktas) pattern across study areas at 1800 hour.

Generally, cloud was maximum at night and minimum during mid-day. However, this trend depends on the peculiarity of factors that either enhances of diminishes cloud cover amount at the sampled areas. The significance of more cloud cover at nights at the southern ends is that it traps terrestrial radiation from the earth surface, hence, emitting heat back to the surface. This trend modifies the ambient temperature creating slightly warm nights. This drift is the opposite during less cloudy night which is more frequent at the northern ends. It has been disclosed in a study conducted by Ohunakin, et al. [28] that the highest amount of cloud cover over Nigeria within the periods (1981-2010) occurs during the months of July, August and September. This is with a mean rate of 65%, 80% and 95% for the northern, central and southern suburbs of Nigeria respectively. It is observed that these months correspond with the time of peak wet season across the Country.

3.7. Rainfall Pattern Across Study Areas

Rainfall pattern across the areas revealed that rainfall amount reduces as one moves away from the coast towards the northern region. The ITCZ, a zone of moisture discontinuity and rain bearing system oscillates from across the ocean crossing southern Nigeria towards the far north. Its nature is such that any location overshadowed by it responds to the unstable pattern as a result of its associated moist warm air moving over the dry, cold and stable continental air mass from across the Sahara Desert. It is observed that the JJA season mark the periods of peak rainfall across the sample areas (Figure 21). Adakayi [29] disclosed that as a result of the highly deficient moisture flux in the atmospheric layers of Sudan and Guinea Savannah of the northern region, rainfall is minimal when compared to the coastal region. Owolabi [30] affirmed that rainfall pattern is significantly influenced by the position of any area relative to unique geographical features. These features include closeness to massive water bodies, proximity to Sahara Desert, effects of mountainous barriers as well as latitudinal position. This unique geographical arrangement would have impacted on the rainfall anomaly across sample areas. The highest average rainfall value was in Port Harcourt i.e. 200 mm as well as Enugu and this is due to the bi-modal rainfall nature of the areas. That of the far northern axis with lower average rainfall pattern (46-59 mm) is due to the mono-modal rainfall nature of the areas. It was observed that rainfall in Jos was closer to that obtained in Enugu. This could be due to the influence of mountainous barriers that forces air mass upwards creating unstable conditions and hence generating orographic type of rainfall.

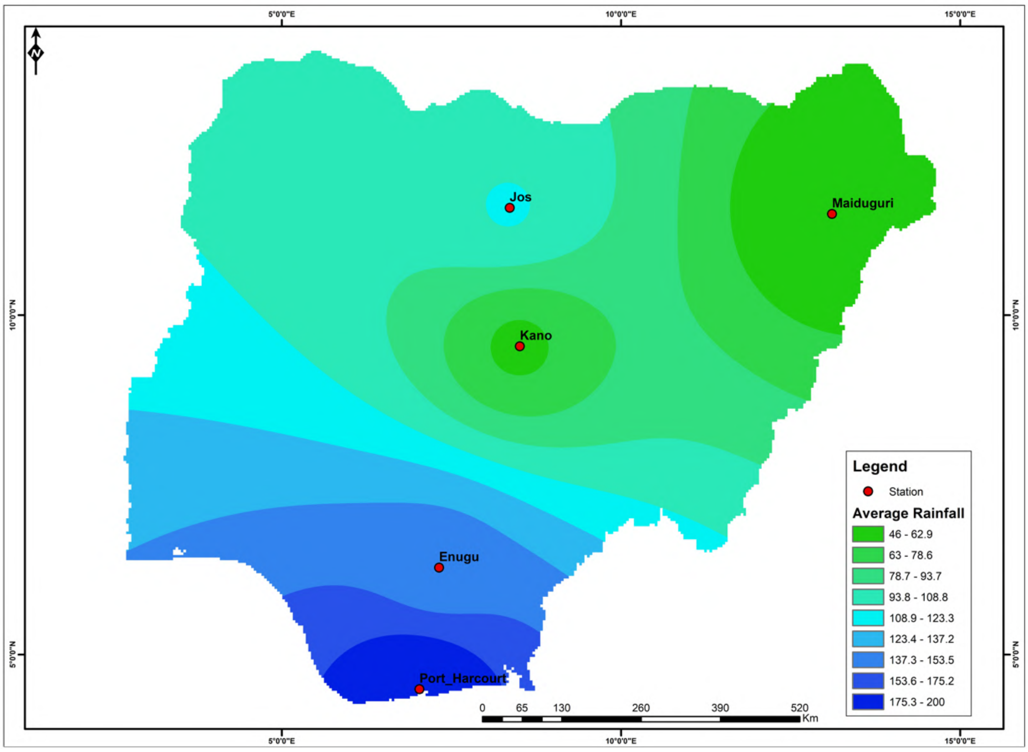


Figure 21. Rainfall (mm) pattern across the study areas.

4. FACTORS THAT INFLUENCES THE WEATHER PATTERN OF THE CLIMATIC ZONES

The important aspect about the weather conditions of any location is to understand the prevailing circumstances that either strongly enhance or moderate it.

4.1. Closeness to the Oceans

It is observed that the monsoonal flow from the ocean considerably contributed to stable nature of Port Harcourt during the night and early morning periods. The oceans can transport warm and cold currents into land thereby altering the weather of areas in the channel of these flows. As one drifts towards the northern axis, the variations in the flow field decreases the moisture content of current prevalent within areas close to the ocean. A natural current such as sea breeze consists of stably stratified air that could moderate thermal gradients along coastal locations [31]. Climates of Marine tropical locations usually have abundant rainfall and lesser range of diurnal and seasonal air temperature values than climates in the continental tropical belt. Due to the areas position close to the equator, the climate is branded by high temperature and profuse rainfall. As a result of the high temperature, there is a high rate of evaporation and transpiration. The major disadvantage for the northern position is their location in far continental hubs which constrains the constant impact of the tropical maritime air mass. This makes the diurnal and annual temperature range large due to the dry nature of the air.

4.2. Latitudinal Positions of Study Areas

The intensity of sunlight drives the weather and climate regime of any locality. Olusegun, et al. [32] specified that Nigeria's climate follow a strong latitudinal belt becoming drier and warmer from the southern coastal ends towards the northern Sahara tips. It is noted that high solar insolation activity escalates temperature values, a significant indicator of atmospheric stability. It has been found that solar radiation impacts on latitudinal location of any place. Ayoade [7] noted that the higher the latitudinal location of a place the lower the solar altitude becomes during the day. Oke [33] noted that solar insolation activity determines the depth of the boundary layer during the day which generates either deep convective, shallow convective or laminar system. It determines the radiation regime as well as the length and severity of cold or warm periods. It is found that net radiation is lowest in coastal areas due to lesser solar radiation hours. However, the net radiation in the core north is slightly higher than the coastal environment due to the high terrestrial radiation at night time. This lowest net radiation trend in the coastal areas could have enhanced the moderating effects of the ocean currents creating a very stable condition during night time. Oke [33] also disclosed that energy of significance to climate science occur in the atmosphere-earth relationship in four diverse dimensions i.e. radiation, thermal, kinetic and potential. It is noted that the contributory energy is always the radiant heat while the output is through one or mixture of all of them. This energy fluxes are being changed constantly from one system to another. From stability pattern across the sampled areas, more thermal energy led to unstable conditions during the day while a combination of terrestrial radiation and kinetic energy led to stable conditions during the night.

4.3. Period of Season/Cloud Cover

Every season have its own strategic pattern along latitudinal zone. This includes the location of ITCZ or ITD as it navigates the south-northern bands ushering rains to various areas, the periods for the prevalence of cloud cover and humidity variations, seasons of high and low temperatures etc. [1]. The ITD over land navigates along with moist warm air across areas bringing unstable conditions when moving over the cool dry north-easterly air mass from the Sahara Desert. Periods of rainfall across the areas witnessed strongly unstable conditions most especially the northern areas. The reverse is the case during the *Hamattan* period where the stably stratified air mass from across the Saharan desert sweeps the entire country. This generates limited instability due to the much-restricted solar intensity mostly at the northern ends than in the southern tips. Seasons influences cloud cover (e.g. JJA season of peak rainfall) which enhances or reduces heat effect at any location. There are clouds that develop immediately after solar intensity and traps outgoing terrestrial radiation making the surface warmer hence increasing instability. There are high clouds that also trap outgoing terrestrial radiation and reflect back to earth surface thereby enhancing energy fluxes of both surface heat flux and sensible heat flux. Cloud cover could also trap solar radiation thereby reducing heat effect on the surface.

The atmosphere in the extreme north remains almost cloudless as a result of the subsidence air of foremost high pressure ensuing in massive amounts of insolation. This cloud-free sky during the day allows insolation in, but also lets abundant sensible heat out at night. For this reason, far north exhibit extreme temperature variations. Temperature could be high during the day and very low at nights. Also, periods of highest atmospheric humidity such as from MAM-SON season in the coastal area of Port Harcourt reduces the amount of solar intensity that touches the ground surface and also limits the terrestrial energy lost to the atmosphere. This is because humid environment absorbs heat thereby stagnating buoyancy. This atmospheric pattern could disrupt instability and create near stable conditions as heat could be transferred horizontally (advection) to other locations. This could have contributed to low periods of instability both in Port Harcourt and Enugu which exhibited high humidity values over the years considered.

4.4. Topography/Elevation and Nature of Surface

The nature of land surface is a dynamic section of the environmental system. While solar radiation is the definitive heat source for the boundary layer, about two thirds of immediate heat transfer to the atmosphere emanates from the earth surface [34]. Massive scale deviations in ground surface characteristics such as topography, roughness, soil, vegetation cover etc. have prime significances to atmospheric stability pattern of any area. The dry and loose nature of the soil surface at the northern extreme of Kano and Maiduguri influences the diurnal variation of temperature when compared to the moist compacted soil type of coastal Port Harcourt. The rate of both surface and sensible heat fluxes remains high with dry soils and low where moist soil prevails. Under moist soil condition, atmospheric stability changes will be slower with time and vice versa under dry soil condition.

According to Thomsen, et al. [35] atmospheric stability is intensely prompted by geological settings, particularly hilly areas where temperature exhibits intense fluctuations during the day. This is why areas like Jos and Enugu could experience extreme instability during day at 1200H as high solar intensity impacts high elevation areas and after few hours' exhibit lower instability or stable conditions due to pressure differences across terrains. This occurrence is also due to the greater losses of heat energy from high elevations areas as temperature tends to drop faster with increasing altitude. Topography also affects the wind field through the intermediary of pressure field created due to thermal effects in high land areas. That is why areas such as Enugu and Jos could experience stability pattern both at the extreme and minimal levels.

Topographic and elevation factor influences temperature and precipitation which impacts stability pattern. According to Ayoade [7] highland climates differ from place to place with respect to latitude and elevation. They also display enormous dissimilarities across limited horizontal stretches due to variations in local topography. Sampled areas like Jos far away from oceans could exhibit extremes of low and high surface air temperature during certain periods due to the duration of solar radiation, limited cloud cover and the thin nature of air mass as a result of decreasing pressure with increase in altitude. Locations of high elevations tend to be cooler than areas of low elevations which are hot and humid due to increased pressure. This high altitudinal position of the northern areas most especially Jos, contributed to the stable nature observed during night time. The higher the altitude, the cooler air becomes.

5. CONCLUSION

This study has been able to examine the variant weather pattern of climate zones in the lower atmosphere in Nigeria using the 6-hourly Era-Interim data from 2010-2015. Findings from this study have shown that atmospheric conditions for the areas vary with time and scale. Findings revealed that air temperature trend across the areas indicate strong latitudinal positions with drier and hotter weather pattern from the coast northwards. Air temperature across the diurnal periods was within 23-34 ^{o}C. Mean solar radiation peaked at 1200 hour for all climate zones and ranged from 508-905 W/m^2. Wind speed increases northwards and ranged from, i.e. 0.9-3.5m/s with higher and lower wind speeds at the northern and coastal zones of Nigeria respectively. The wind variation is due to the surface characteristics across the areas. Southwesterly winds dominated coastal zone while southeaster/northeasterly winds dominated the arid zone except during periods of rainy season. Average cloud cover for the areas in oktas ranged from: 2.3-7.0 with highest values at the coast and lowest values near the desert. Relative humidity values ranged from: 31-93% and rainfall pattern across the climate of Nigeria showed that it reduces from the coastal domain's northwards. The main features that altered the climate of Nigeria across spatial domains include nearness to massive water bodies, closeness to Sahara Desert, topography, effects of mountainous barriers as well as latitudinal position.

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Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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