Variance of atmospheric radio wave refractivities across Nigeria – from the Savannah to the mangrove

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Abstract— The variance of atmospheric radio wave refractivities across the different vegetative climatic belts in Nigeria has been examined. Data abstracted from Weather API (Weather2), Yr. no and NIMET (Nigeria meteorological agency) websites has been analyzed. Generally, there was an increase in the average atmospheric radio wave refractivities as one confronts the coastline of the Atlantic Ocean and in the reverse, there was a decrease in the average atmospheric radio wave refractivities as one travels towards the borderline of the Sahara desert. This indicates that, gradually radio wave propagation worsens towards the Atlantic Ocean and reversely; step by step, the radio wave propagation betters towards the Sahara desert. The correlation between the average atmospheric radio wave refractivities and the perpendicular distances away from the coastline of the Atlantic Ocean was 0.84 with an approximate model of y = -0.125x + 388.9. Similarly, the correlation between the average atmospheric radio wave refractivities and the perpendicular distances away from the Sahara desert was 0.84 with an approximate model of y = 0.122x + 267.2. The correlations were not absolute because of the non-uniformity of the weather or climate patterns across the country. Reliefs and rivers account for some of the anomalies in the non-uniform trends. In addition, isotherms and isohyets in the weather map are non-linear and can cut across the vegetative climatic zones. By and large, results registered that the Sahel savannah will favour radio signal propagation through the troposphere better than any other belt and the mangrove was the least, but on the contrary, the mangrove will record better signal stability than any other belt and the Sahel savannah will register the least due to high variance in the weather pattern in the former than the latter belt. Finally, the dry will favour radio signal propagation through the troposphere better than the wet due to reduction in mean monthly relative humidities.

Keywords— Variance, Atmospheric radio wave refractivity, Vegetative climatic belts, Savannah, Rainforest, Mangrove and Radio signal strength.

INTRODUCTION

Radio wave is a member of the electromagnetic wave. It is an essential element required for communications. The range of their frequencies is from 300GHz to as low as 3Hz and their proportionate wave lengths span 1 millimeter to 100 kilometers [11]. The atmosphere is an indispensable channel for the propagation of radio waves, most especially communications that employ tropospheric propagation mode [9]. The condition of the atmosphere has a force on propagating radio waves through it.

Refractivity or refraction is the bending of electromagnetic waves away from a particular path due to difference in the composition of the medium(s) which they travel through [7]. The difference in medium(s) is observed as an obstacle, especially if the composition of the new medium(s) is denser. It alters the speed and direction of propagation of the radio wave.

In the atmosphere, radio wave refractivity is the variation of radio waves from a straight path as it propagates through the atmosphere due to variation in the density of air as a function of altitude [1] [5]. Radio wave refractivity in the atmosphere is due to the velocity of radio waves through air decreasing (or increasing) with increasing (or decreasing) density (this is, increasing or decreasing index of refraction) [6]. The afore-mentioned is true, since the index of atmospheric radio wave refractivity is the ratio of the speed of radio wave in free space to that of the radio wave in the atmosphere. The speed of the radio wave is a function of the density of the medium which it is travelling through [10].

Without atmospheric radio wave refractivity, it will be near impossible for radio waves or signals to travel round the globe [9]. The atmosphere as a channel bends the radio wave back to the earth after being transmitted into space from an earth station. However, study has shown that refractivity has a negative force on radio waves together with the weather components [1].

The weather of a place is the state of its atmosphere at a particular time [2], while the climate of a place is the general weather conditions prevailing in a place over a very long period [3]. Weather components, atmospheric pressure, temperature, humidity bear negatively on radio waves, invariably radio signals [1]. Also depending on the direction of wind, the atmosphere has an impact on radio waves. Mathematically, radio wave refractivity is a function of atmospheric pressure and temperature and relative humidity.

Nigeria is divided into several climatic belts depending on their vegetations. The vegetation of a place is a mirror of the state of the atmosphere of that place and invariably the weather or climate of that place. The different vegetative climatic belts in Nigeria are: Sahel savannah, Sudan savannah, Guinea savannah, Rainforest, Mangrove (freshwater and saltwater types) and Montane [4].

Nigeria falls on the tropical plate of Africa and lies between longitudes 4^0 00′ 00″ E and 14^0 00′ 00″ E and latitudes 3^0 00′ 00″ N and 14^0 00′ 00″ N respectively [4]: a location slightly above the equator.

The focus of this research narrows on the variance of the atmospheric radio wave refractivities across Nigeria; from the savannah belts to the rainforest belt, through to the mangrove belt and the relatively striking montane belts. Also, the relevance of the work is to establish the best belt(s) suitable for radio wave propagation and the worse. More so, it intends to probe and draw a verdict on which atmospheric or climatic conditions are favourable for radio wave propagation, since Nigeria has predominantly two seasons: the wet and the dry and both have characteristic different atmospheric conditions.

A REVIEW OF THE CLIMATE OF SELECTED CITIES ON THE DIFFERENT VEGETATIVE CLIMATIC BELTS

In this research, data from eighteen cities (18) in Nigeria was analyzed. The cities are situated on different belts. The cities captured are: Kano, Maiduguri, Minna, Akure, Aba, Onitsha, Makurdi Abuja, Enugu, Calabar, Lagos, Jos, Sokoto, Obudu, Lokoja, Warri, Kaduna and Ibadan. Below is a review of the climates of the different cities.

Kano – This is a city formerly in the Sudan savannah but presently in the Sahel savannah in view of the Nigerian satellite images and global climatic changes due to undue warming of the globe. It is situated in longitude and latitude 8^0 31′ 0.12″ E and 12^0 00′ 00″ N respectively in Northern Nigeria [50]. Kano shows monthly average minimum and maximum humidities of 25.00 % in August and 80.00 % in March respectively and an overall monthly mean humidity of 51.42 % [47]. Also, it shows monthly mean minimum and maximum temperatures of 71.60 ^{0}F in February and March and 89.60 ^{0}F in April with a gross monthly mean temperature of 79.40 ^{0}F [28].

Maiduguri – This is a city in the Sahel savannah. It is situated in longitude and latitude 13^0 9′ 35″ E and 11^0 50′ 42″ N respectively [48]. It is in the northern segment of Nigeria. It records monthly average minimum and maximum humidities of 28.00 % in March and 82.00 % in August respectively and an overall monthly mean humidity of 53 % [46]. Also, it records monthly mean minimum and maximum temperatures of 71.60 ^{0}F in December and January and 90.50 ^{0}F in May with a gross monthly mean temperature of 81.05 ^{0}F [27].

Abuja – It is situated in the heart of Nigeria. It sits on the Guinea savannah belt with a longitude and latitude of 7^0 10′ 50″ E and 9^0 10′ 32″ N in that order [51]. It shows monthly mean minimum and maximum humidities of 30.00 % in December and 84.00 % in July respectively and an overall monthly mean humidity of 60.50 % [41]. Also, it shows monthly mean minimum and maximum temperatures of 77.18 ^{0}F in July and 86.36 ^{0}F in March with a gross monthly mean temperature of 87.14 ^{0}F [13].

Enugu – It is situated in the east of the southern segment of Nigeria. The longitude and latitude of the city is 6^0 26′ 24.71″ E and 7^0 29′ 39.47″ N in that order [62]. It is in the rainforest belt with a derived savannah and it is located on an escarpment in-between the Cross River basin and Benue trough [12]. Enugu registers monthly mean minimum and maximum humidities of 83.00 % in February and March and 92.00 % in August respectively and an overall monthly mean humidity of 86.75 % [31]. Also, it registers monthly mean minimum and maximum temperatures of 78.88 ^{0}F in August and 84.74 ^{0}F in March with a gross monthly mean temperature of 81.20 ^{0}F [16].

Calabar – This is a city in the shadow of the Atlantic Ocean. It is planted in the southern-most region of Nigeria with longitude and latitude of 8^0 20′ 49.92″ E and 4^0 58′ 33.67″ N in the sequence [60]. It is in the saltwater Mangrove belt. It shows monthly mean minimum and maximum humidities of 83.00 % in February and March and 92.00 % in August respectively and an overall monthly mean humidity of 86.75 % [32]. Also, it shows monthly mean minimum and maximum temperatures of 76.10 ^{0}F in August and 83.30 ^{0}F in February and with a gross monthly mean temperature of 80.27 ^{0}F [17].

Lagos – This is a city whose outstretched arm hugs the Atlantic Ocean. It stands on the west of southern Nigeria. Its longitude is 3^0 23′ 44.98″ E with a latitude of 6^0 27′ 11.01″ N. It shares the saltwater Mangrove belt with other cities in the neighbourhood of the Atlantic Ocean [57]. It records monthly mean minimum and maximum humidities of 81.00 % in February and April and 88.00 % in June through October respectively and an overall monthly mean humidity of 84.83 % [37]. Also, it records monthly mean minimum and maximum temperatures of 77.18 ^{0}F in August and 83.30 ^{0}F in February and March with a gross monthly mean temperature of 80.25 ^{0}F [18].

Jos – It is a city in the Northern half of Nigeria. Even though it is located in the Guinea savannah area with a longitude of 8^0 53′ 31″ E and a latitude of 9^0 55′ 42″ N, it sits on the montane belt. It is embraced by mountains [61]. It registers monthly mean minimum and maximum humidities of 26.00 % in April and 72.00 % in August respectively and an overall monthly mean humidity of 40.80 % [43]. Also, it registers monthly mean minimum and maximum temperatures of 68.00 ^{0}F in January and 75.74 ^{0}F in April with a gross monthly mean temperature of 71.11 ^{0}F [14].

Sokoto – This is a city situated at the northern-most axis of Nigeria with a longitude of 5^0 13′ 53″ E and a latitude of 13^0 3′ 5″ N [49]. It is in the region just after the borderline of the Sahara desert and lies in the Sahel savannah belt. Sokoto shows monthly mean minimum and maximum humidities of 18.00 % in March and 69.00 % in September respectively and an overall monthly mean humidity of 40.67 % [45]. Also, it shows monthly mean minimum and maximum temperatures of 23.60 ^{0}F in January and 92.66 ^{0}F in May with a gross monthly mean temperature of 83.87 ^{0}F [29].

Obudu – She strikingly sits in the borderland of the Guinea savannah and Rainforest belts and stands on a montane belt. Her longitude and latitude are 9^0 10′ 0″ E and 6^0 40′ 0″ N in sequence [55]. It is located in the south-eastern region of Nigeria. Obudu records monthly mean minimum and maximum humidities of 57.00 % in February and 90.00 % in August respectively and an overall monthly mean humidity of 72.82 %. Also, it records monthly mean minimum and maximum temperatures of 77.72 ^{0}F in August and 82.20 ^{0}F in March with a gross monthly average temperature of 79.52 ^{0}F [23].

Lokoja – This city shores the confluence of the rivers Niger and Benue in the borderland of the North and South halves of Nigeria. It is in the Guinea savannah belt with longitude and latitude of 6^0 44′ 0″ E and 7^0 48′ 0″ N in that order. [53]. Lagos registers monthly mean minimum and maximum humidities of 49.00 % in January and 84.00 % in August and September respectively and an overall monthly mean humidity of 71.08 % [40]. Also, it registers monthly mean minimum and maximum temperatures of 78.62 ^{0}F in July and 84.74 ^{0}F in March with a gross monthly mean temperature of 81.02 ^{0}F [25].

Warri – This is a deltaic city, deep down south of Nigeria. Its longitude and latitude are respectively 5^0 45′ 0″ E and 5^0 31′ 0″ N. As a deltaic city, it shores so many freshwater rivers: hence it is classified as a Freshwater mangrove [59]. It shows monthly mean minimum and maximum humidities of 78.00 % in January and 86.00 % July through September respectively and an overall monthly mean humidity of 82.67 % [36]. Also, it shows monthly mean minimum and maximum temperatures of 77.90 ^{0}F in July and 83.30 in April and May ^{0}F with a gross monthly mean temperature of 80.42 ^{0}F [24].

Kaduna – The city is located in the Sudan savannah belt in the north west of Nigeria. Its geographical coordinates are 7^0 26′ 25″ E and 10^0 31′ 23″ N [63]. Kaduna is located on the southern end of the high plains of Northern Nigeria [68]. It is made up of undulating plateau and hills [69]. Kaduna records monthly mean minimum and maximum humidities of 19.00 % in March and 72.00 % in August respectively and an overall monthly mean humidity of 40.08 % [44]. Also, it records monthly mean minimum and maximum temperatures of 76.82 ^{0}F in September and 86.36 ^{0}F in March with a gross monthly mean temperature of 40.08 ^{0}F [15].

Ibadan – It is a city in the western region of southern Nigeria with geographical coordinates of 3^0 53′ 48.9″ E and 7^0 23′ 16″ N [64]. It has a rainforest vegetation. It registers monthly mean minimum and maximum humidities of 70.00 % in February and 90.00 % in August respectively and an overall monthly mean humidity of 82.00 % [38]. Also, it registers monthly mean minimum and maximum temperatures of 75.00 ^{0}F in August and September and 80.00 ^{0}F in December and April with a gross monthly mean temperature of 78.42 ^{0}F [20].

Minna – It is situated in the northern segment of Nigeria. It is located on the Guinea savannah belt with longitude and latitude of 6^0 33′ 25″ E and 9^0 36′ 50″ N in that order [65]. It shows monthly mean minimum and maximum humidities of 15.00 % in February and 82.00 % in August respectively and an overall monthly mean humidity of 46.00 % [42]. Also, it shows monthly mean minimum and maximum temperatures of 82.00 ^{0}F in August and 88.00 ^{0}F in March with a gross monthly mean temperature of 82.37 ^{0}F [26].

Aba – This is a city positioned in the south eastern sector of Nigeria. It is has longitude and latitude of 8^0 10′ 0″ E and 7^0 21′ 0″ N in the sequence [56]. It is in the rainforest belt. Aba records monthly mean minimum and maximum humidities of 83.00 % in February and March and 92.00 % in August respectively and an overall monthly mean humidity of 86.75 % similar to her neighbouring city, Calabar [33]. Also, it records monthly mean minimum and maximum temperatures of 77.90 ^{0}F in July and 82.40 ^{0}F in March and with a gross monthly mean temperature of 86.75 ^{0}F [21].

Akure – It is a city in the western segment of southern Nigeria with geographical coordinates of 5^0 12′ 00″ E and 7^0 15′ 00″ N [58]. It has rainforest vegetation. Akure registers monthly mean minimum and maximum humidities of 84.00 % in August and September and 49.00 % in January respectively and an overall monthly mean humidity of 70.50 % [35]. Also, it registers monthly mean minimum and maximum temperatures of 84.00 ^{0}F in August and 85.00 ^{0}F in March with a gross monthly mean temperature of 80.42 ^{0}F [19].

Makurdi – This city embraces the river Benue and it is in the neighbourhood of the Northern and Southern borderline of Nigeria. It is in the Guinea savannah belt with longitude and latitude of 8^0 32′ 00″ E and 7^0 44′ 00″ N [52]. Makurdi shows monthly mean minimum and maximum humidities of 83.00 % in February and March and 92.00 % in August respectively and an overall monthly mean humidity of 86.75 % [39]. Also, it shows monthly mean minimum and maximum temperatures of 78.44 ^{0}F in December and 89.80 ^{0}F in March with a gross monthly mean temperature of 81.97 ^{0}F [30].

Onitsha – It is situated in the east of the southern sphere of Nigeria. The longitude and latitude of the city are 6^0 47′ 00″ E and 6^0 10′ 00″ N in that order [54]. It is in the rainforest belt. Onitsha records monthly mean minimum and maximum humidities of 83.00 % in February and March and 92.00 % in August respectively and an overall monthly mean humidity of 86.75 % [34]. Also, it records monthly average minimum and maximum temperatures of 78.62 ^{0}F in July and 84.74 ^{0}F in March with a gross monthly mean temperature of 80.98 ^{0}F [22].

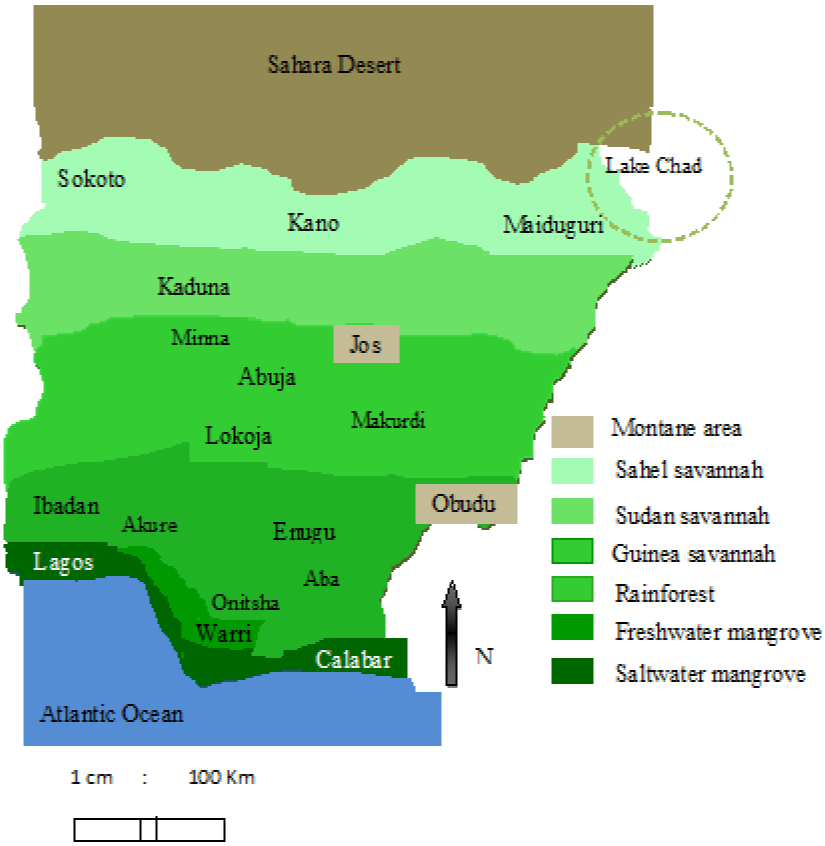

Fig. 1 The locations of the various cities on their respective vegetative climatic belts.

MATERIALS AND METHODS

Relevant data for mean monthly weather parameters was accessed from Yr. no, Weather2 and NIMET (Nigeria Meteorological Agency) websites. The atmospheric radio wave refractivity was computed using the Eqn. 1 below [1].

$$N = K \times P^2 \times \sqrt{T} \times \sqrt[3]{H} \qquad (1)$$

Where K = Constant = 0.01064097915

P = Atmospheric pressure in inHg

T = Atmospheric temperature in ^{0}F

H = Relative humidity in %

N = Radio refractivity [$(\text{inHg})^{2}\,{}^{0}\text{F}^{1/2}\,\%^{1/3}$]

The above formulation has an accuracy of $^{+}_{-}5$ in comparison with the existing International Telecommunication Union (ITU) expression for calculating Radio refractivity. The ITU expression may be used for all radio frequencies: for frequencies up to 100 GHz, the error is less than 0.5 % [8].

RESULTS AND ANALYSIS

The Figs. 2, 3, 4, 5, 6, 7, 8, 9, 10 show the comparison between the average monthly atmospheric radio wave refractivities of all cities; comparison between average monthly atmospheric radio wave refractivities of the cities in the wet; comparison between the average monthly atmospheric radio wave refractivities of the cities in the dry; comparison between the average monthly atmospheric radio wave refractivities of the savannah cities; comparison between the average monthly atmospheric radio wave refractivities of the rainforest and mangrove cities; relationship between perpendicular distances away from the Atlantic Ocean and average atmospheric radio wave refractivities; line of best fit between perpendicular distances away from the Atlantic Ocean and average atmospheric radio wave refractivities; relationship between perpendicular distances away from the Sahara desert and average atmospheric radio wave refractivities and line of best fit between perpendicular distances away from the Sahara desert and average atmospheric radio wave refractivities respectively. The legend series of the cities in the figure below is in order of increasing magnitude of average atmospheric radio wave refractivity.

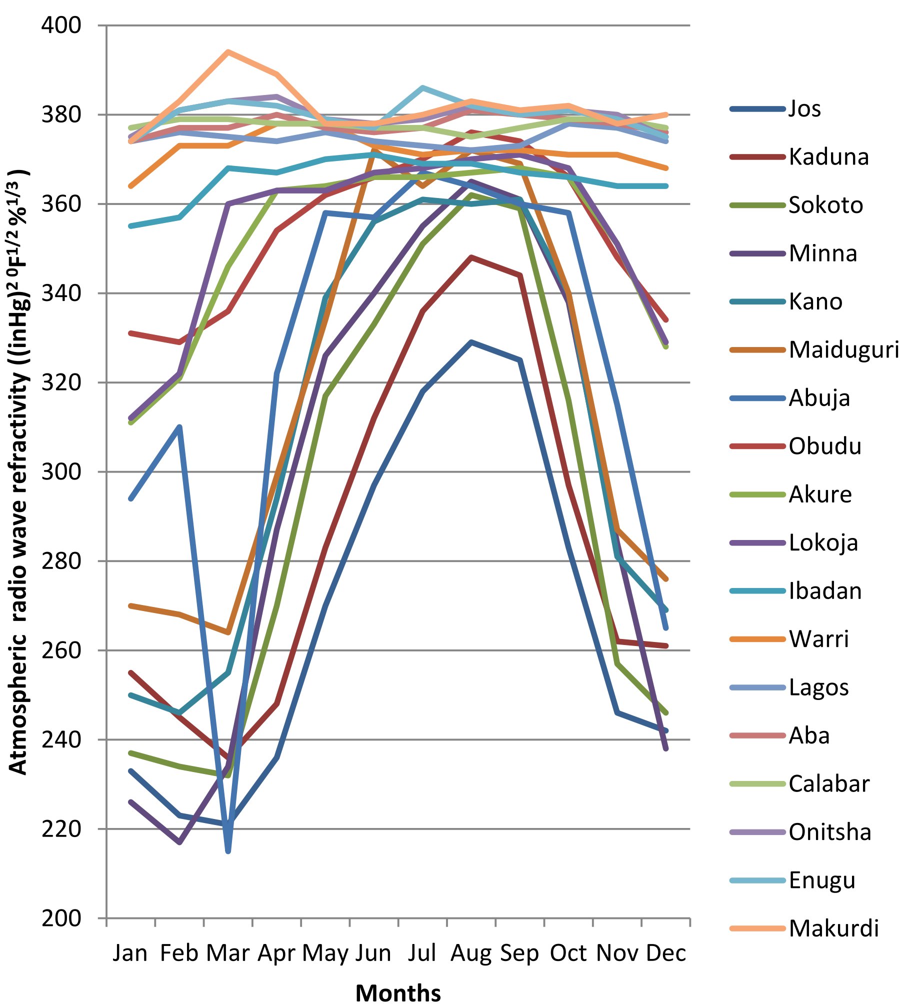

Fig. 2: Comparison between the average monthly atmospheric radio wave refractivities of all cities

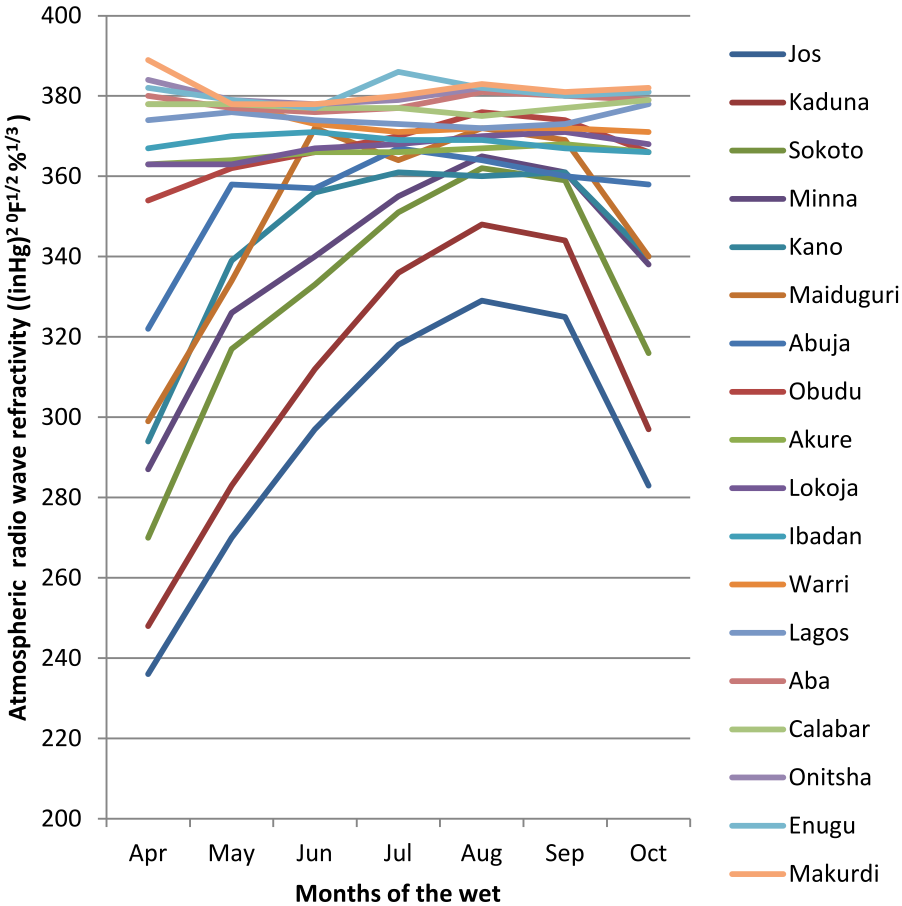

Fig. 3: Comparison between average monthly atmospheric radio wave refractivities of the cities in the wet

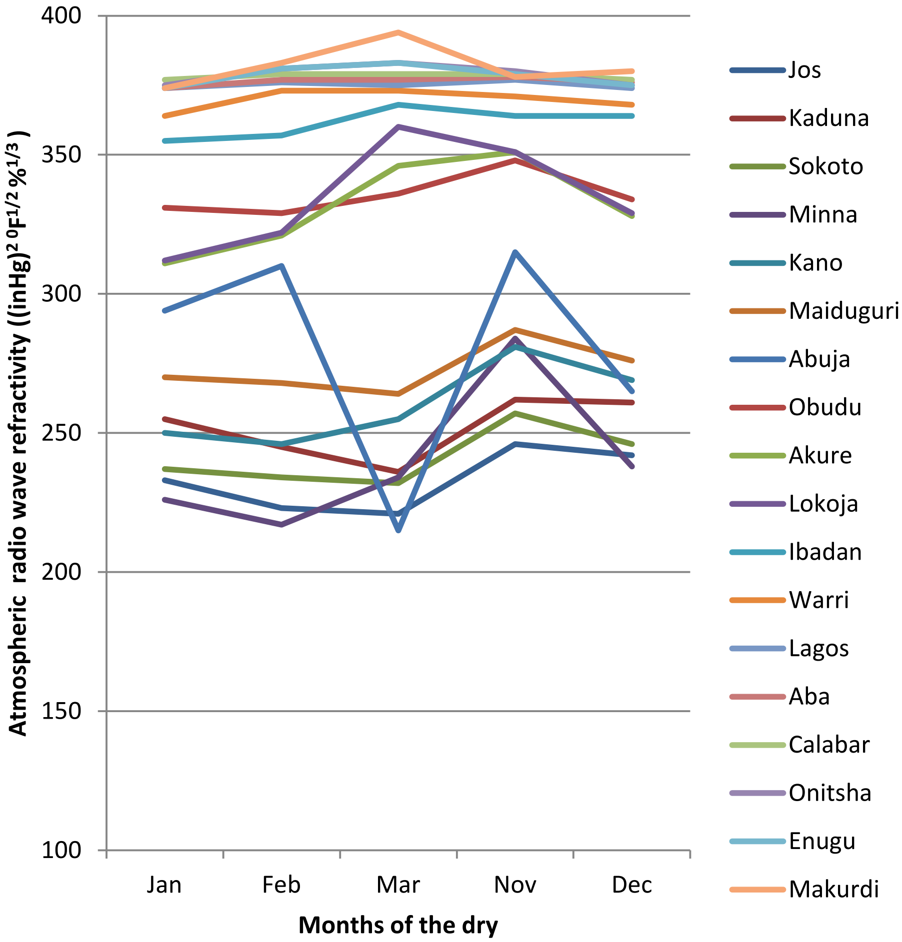

Fig. 4: Comparison between the average monthly atmospheric radio wave refractivities of the cities in the dry

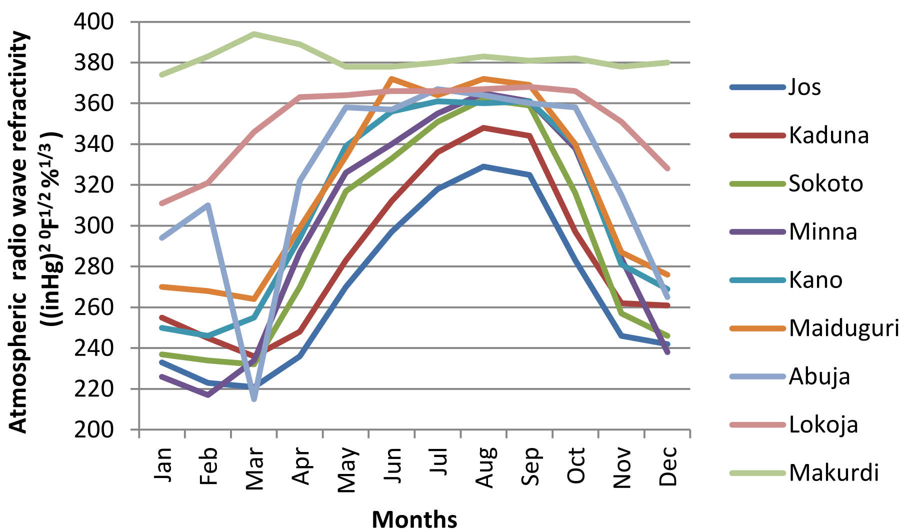

Fig. 5: Comparison between the average monthly atmospheric radio wave refractivities of the savannah cities

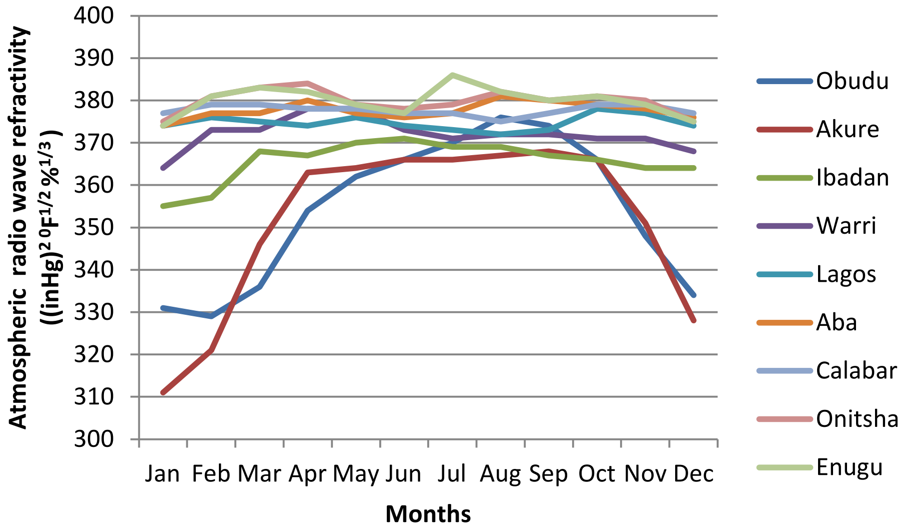

Fig. 6: Comparison between average monthly atmospheric radio wave refractivities of the rainforest and mangrove cities

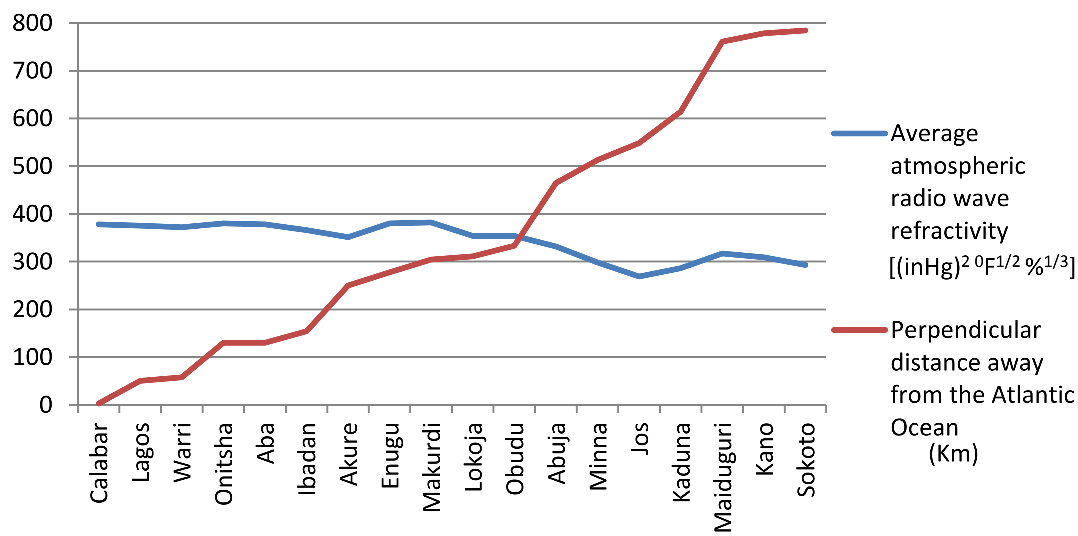

Fig. 7: Relationship between perpendicular distances away from the Atlantic Ocean and average atmospheric radio wave refractivities

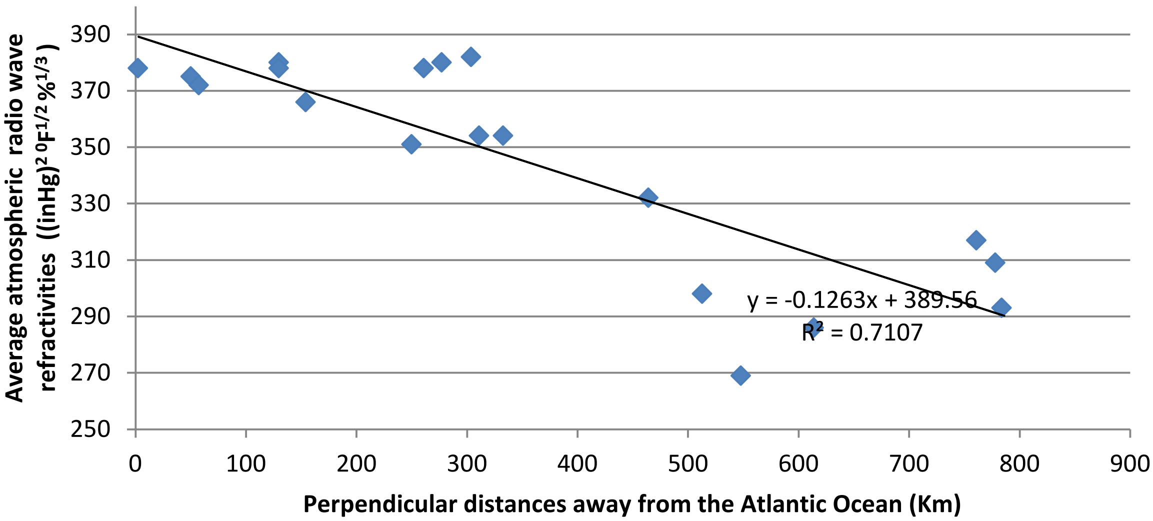

Fig. 8: Line of best fit between perpendicular distances away from the Atlantic Ocean and average atmospheric radio wave refractivities

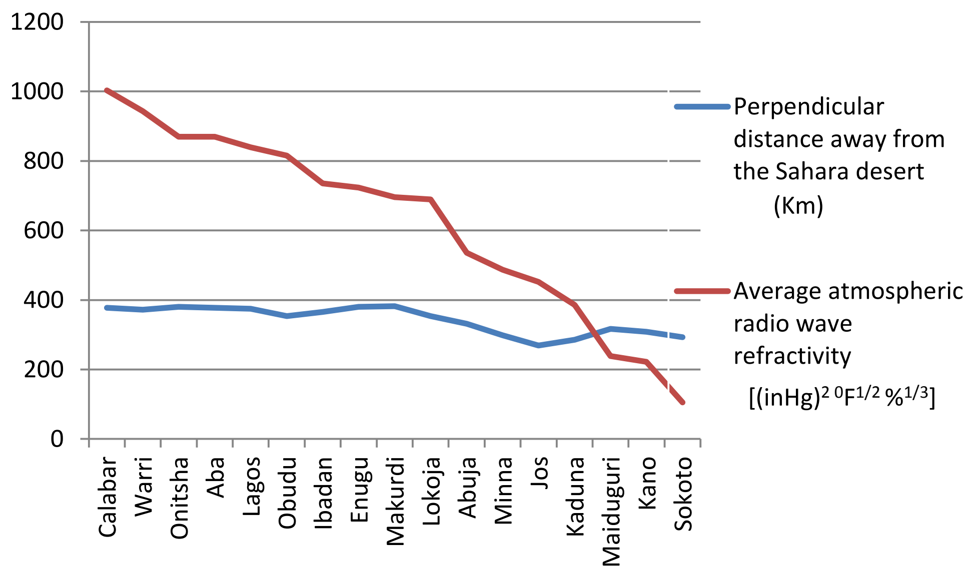

Fig. 9: Relationship between perpendicular distances away from the Sahara desert and average atmospheric radio wave refractivities

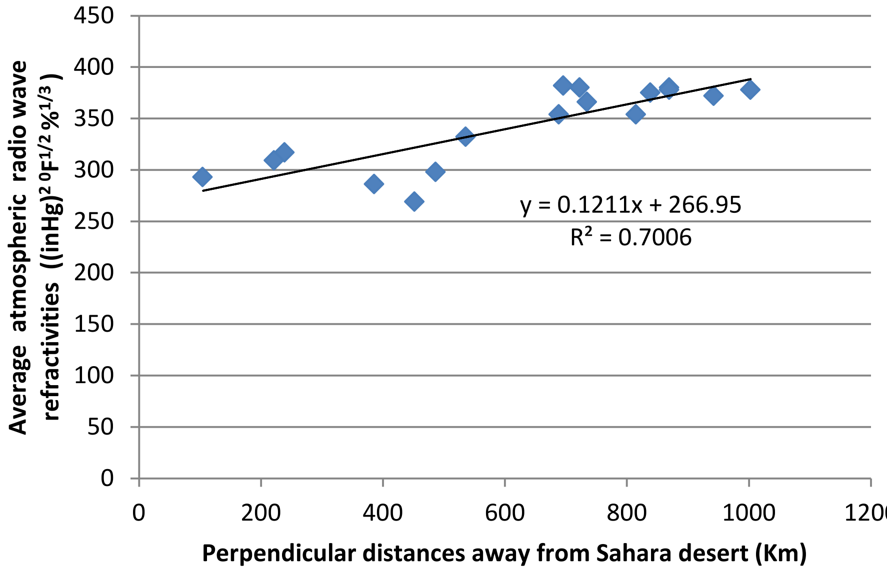

Fig. 10: Line of best fit between perpendicular distances away from the Sahara desert and average atmospheric radio wave refractivities

In a peck order of increasing magnitude of average atmospheric radio wave refractivities, the cities are arranged thus: Jos, Kaduna, Sokoto, Minna, Kano, Maiduguri, Abuja, Obudu, Akure, Lokoja, Ibadan, Warri, Lagos, Aba, Calabar, Onitsha, Enugu and Makurdi.

In fig. 1, observe that the refractivities of the rainforest and mangrove cities are higher than those of the savannah cities with the exception of Makurdi. This is owing to the fact that the relative humidities of the former cities are very high compared to that of the latter cities. Even though the highest temperatures are registered in the savannah cities, it is counterbalanced by the lowest temperatures also registered there, since the monthly mean temperatures were considered. More so, relative humidity has a higher weight in deciding the magnitude of refractivity than the other two atmospheric parameters: temperature and pressure. Generally, the mean monthly atmospheric pressure on the average throughout the country was near even. Hence the atmospheric pressure contributed near negligible number in the differences read in the atmospheric radio wave refractivities above. The exception shown in Makurdi results from the fact that the city hugs the river Benue and in consequence, accounts for the near steady and high mean monthly relative humidities. Also, the city is in the Guinea Savannah, which accounts for high mean monthly temperatures that is brought to bear in radio wave refractivity. To buttress this, Lokoja also in the Guinea savannah has very high average atmospheric radio wave refractivity, consequent upon the fact that it is a town lying next to the confluence of the Benue and Niger rivers with higher mean monthly relative humidities than its counterpart cities in the Guinea savannah. However, Makurdi is further down south than Lokoja and is closer to the rainforest and Atlantic Ocean; in regard to their coordinates. This suggests the higher average atmospheric radio wave refractivity in the former than the latter, since its mean monthly relative humidities are higher.

In figs. 3 and 4, the refractivities of the rainforest and mangrove cities were to a vast degree stable, this due to fact that the mean monthly humidities and temperatures are relatively stable, unlike the savannah cities where high mean monthly humidities and temperatures are registered during the wet and in the contrary, very low mean monthly humidities and temperatures are recorded in the dry. Even though, the highest temperatures are registered in the savannah during the dry, on the average it is low because of the very low night temperatures.

Study has shown that atmospheric radio wave refractivity has a negative bearing on signals [1]. Hence, to a very large extent, propagations of signals are better in the northern sphere of Nigeria than the southern sphere for communications that employ the tropospheric propagation mode, since low refractivity favours propagation of radio waves through the atmosphere.

Also in figs. 3 and 4, notice that Jos recorded the least mean monthly atmospheric radio wave refractivity, both in the wet and dry in Nigeria. This entails that for tropospheric propagation mode, the best quality of signal propagation will be recorded here. Even though it sits in the Sudan savannah belt, its montane climates strikingly differentiates it from other cities on the selfsame belt. Throughout Nigeria, it records the lowest mean monthly temperatures and comparatively low mean monthly relative humidities: since on the average; the atmospheric pressure that has a minimal effect on atmospheric radio wave refractivity is near uniform in Nigeria.

More so in figs. 3 and 4, Makurdi registered the highest mean monthly atmospheric radio wave refractivity throughout the year followed by Enugu, this is both in the wet and dry. As earlier highlighted, Makurdi hugs the river Benue. This accounts for its high mean monthly humidities in comparison with other Guinea savannah cities but shows similar mean monthly temperatures with these sister cities in the Guinea savannah: hence the very higher mean monthly radio wave refractivities relative to its sisters. This city's higher average refractivity than those of the coastal cities of Atlanta is in regard to the comparable high mean monthly relative humidities with these Atlantic coastal cities, but distinctly higher mean monthly temperatures. Similarly Enugu shares similar mean monthly relative humidities as her twin rainforest cities – Ibadan and Akure, but differs in higher mean temperatures, since from its coordinates it is farther away from the Atlantic Ocean. Its climate is a hybrid of the rainforest and mangrove in view of mean monthly temperatures and mean monthly relative humidities respectively. This is true because, Calabar and Lagos that are in the shadow of the Atlantic Ocean, share similar mean monthly relative humidities as Enugu, but Enugu records a higher mean temperature than the aforementioned twin: Calabar and Lagos which equates to higher average atmospheric radio wave refractivity. The above weather pattern may be attributed to the fact that Enugu has a derived savannah, even though it is located in the rainforest and it lies at the foot of an escarpment of the Udi hill with a lake (Nike Lake) [12]. In communications wordings, this spells that Makurdi followed by Enugu will have the least propagation quality of signals for communication that utilize tropospheric propagation mode because a high refractivity bears negatively on radio wave propagation and invariably radio signals.

Strikingly, in fig. 5, Kaduna has the second lowest average atmospheric radio wave refractivity. This is because it is located in the borderland between the Sahel and Guinea savannah: that is in the Sudan savannah. Here, there is a characteristic lower mean monthly temperatures than the cities in the Sahel savannah, but shears similar temperatures with the Guinea savannah cities like Abuja. In other words, Kaduna has lower mean monthly relative humidities than that of its brothers in the Sudan savannah, but comparable to that of the Sahel savannah. In short words, its weather is a hybrid of the Sahel and Guinea savannah. This may be owed to the fact that Kaduna stands on the southern end of the high plains of northern Nigeria with a quasi-montane climate. It shares similar mean monthly relative humidities with Jos that posses a montane climate. That is, Kaduna and Jos sit on the same isohyets.

In fig. 5, Sokoto has the lowest average atmospheric radio wave refractivity and invariably the lowest mean monthly relative humidities and highest mean monthly temperatures in Nigeria. Even though, Sokoto, Kano and Maidugari are located on the same belt, the coordinates of Kano and Maiduguri show that these cities are farther away from the Sahara desert than Sokoto. Similarly the coordinates of Maiduguri show it is farther away from the Sahara desert than that of Kano. This is responsible for the higher average atmospheric radio wave refractivity registered in Maiduguri relative to its counterparts in the Sahel savannah, since there is a gradual decrease in mean monthly temperatures and relative humidities as one drifts away from the Sahara desert. Also, the Maiduguri is close to the Lake Chad. This has a significant effect in the comparatively higher average relative humidities and consequently average atmospheric radio wave refractivity. This entails in communication that in the Sahel savannah, radio signals will propagate better as we move towards the Sahara desert due to decrease in humidity which favours radio wave propagation through the troposphere, even though there is are slight variations in temperatures. Recapitulating, relative humidity has a higher force in determining the weight of atmospheric radio wave refractivity.

Also, in fig. 5, Lokoja amongst the cities in the Savannah has the highest atmospheric radio wave refractivity because it is located close to a confluence. This accounts for its high mean monthly relative humidities and invariably high average atmospheric radio wave refractivity compared to the other cities in the savannah belt. It also has a stable refractivity to a very huge extent, unlike the other savannah cities which have varying refractivities with relatively very low refractivities during the dry and higher refractivities during the wet. Hence radio signal propagation quality will be worse where there is a huge water body since it has a bearing on its refractivity. Lokoja will impede radio signal through the atmosphere more than any other savannah city. Also notice that amongst the Sahel savannah cities, Maiduguri has higher mean monthly relative humidities in view of the fact that it sits close to the Lake chad as earlier accentuated.

In fig. 6, Lagos and Calabar have the highest atmospheric radio wave refractivities than Ibadan and Warri in the southern segment of Nigeria (that is, in the rainforest and mangrove). Calabar's average refractivity is higher than that of Lagos by virtue of the fact that Calabar is further down the south into the Atlantic Ocean and in a sequel has a higher relative humidity than Lagos even though they shear similar mean monthly temperatures. Warri trails the twin cities mentioned above (Calabar and Lagos) because it is farther from the Atlantic Ocean, even though it is a deltaic city with many fresh waters, it has a lower mean relative humidity compared to the above duo: Lagos and Calabar. Ibadan trails Warri in the increasing peck order of average atmospheric radio wave refractivity because it is farther away from the Atlantic Ocean with lower mean monthly relative humidities, but with similar mean monthly temperatures compared to the cities in the rainforest and mangrove. In few words, there was a gradual increase in the refractivity of the cities in the rainforest and mangrove belts as one heads down the Atlantic Ocean with the exception of Enugu that has a higher temperature than the coastal cities but shares similar relative humidity with these coastal cities. In communications tune, signal will propagate better as you move away from the Atlantic Ocean in the rainforest and mangrove, because of the decrease in relative humidity as one heads away from the Ocean, even though there are slight variances in temperatures.

Also, in fig. 6, notice that Obudu has the least average atmospheric radio wave refractivity compared to the other cities in Southern Nigeria. Even though she stands in the Guinea savannah, she lies on a montane belt with strikingly low mean monthly temperatures compared to the other cities in the south but has comparative mean monthly relative humidities in the wet. Consequently in the southern cities (that is, cities in the rainforest and mangrove), signals will propagate far better than any other in Obudu through the atmosphere.

In fig. 7, generally; there is a gradual increase in the average atmospheric radio wave refractivity down the Atlantic Ocean coast. This means, there will be worse propagation of radio wave or signal through the atmosphere as one heads towards the Atlantic Ocean.

In fig. 8, the correlation between the perpendicular distances away from the coastline of the Atlantic Ocean and the average atmospheric radio wave refractivities is 0.84. The approximate model of average atmospheric radio wave refractivity away from the Atlantic Ocean coast is $y = -0.125x + 388.9$. The above correlation was not absolute because of the non-uniformity of the weather patterns across the country. The relief (mountains and hills) and rivers (very large water bodies) mainly is responsible for some of these anomalies: for example; Jos recorded the least average atmospheric radio wave refractivity in the North, while Obudu registered the least in the South, by virtue of their montane climate. Also Lokoja and Makurdi registered the highest average radio wave refractivity in the Savannah by virtue of the large river bodies embracing them. Strikingly there was a shift in the pattern of the atmospheric radio wave refractivity in Kaduna and Enugu. Both cities are located in the Sudan savannah and Rainforest belts respectively. Kaduna shares similar mean monthly temperatures with cities in the Guinea savannah but has common relative humidity with Jos on a montane area in the Guinea savannah. Similarly Enugu shares the same monthly average temperatures with cities in the mangrove but records higher mean temperatures than those cities. Here also: isotherm and isohyets but not isobars (since mean monthly air pressure was near uniform in the country) were brought into consideration for the anomalies, because these lines are non-linear and can cut across the vegetative climatic zones. This accounts as well for the deviation of the correlation from absoluteness.

In fig. 9, mostly; there was a gradual decrease in average atmospheric radio wave refractivities up the Sahara desert border. This entails that there will be better propagation of radio wave or signal through the atmosphere as one moves towards the Sahara desert.

In fig. 10, the correlation between the perpendicular distances away from the borderline of the Sahara desert and the average atmospheric radio wave refractivities is 0.83. The approximate model of average atmospheric radio wave refractivity away from the Sahara desert borderline is y = 0.122x + 267.2. The above correlation was not absolute because of the non-uniformity of the weather patterns across the country as earlier captured.

CONCLUSION

Generally, there was an increase in the average atmospheric radio wave refractivities as one confronts the coastline of the Atlantic Ocean and in the reverse, there was a decrease in the average atmospheric radio wave refractivities as one heads towards the borderline of the Sahara desert. Hence radio wave propagation through the troposphere gradually worsens towards the Atlantic Ocean and reversely the radio wave propagation via the troposphere step by step, betters towards the Sahara desert.

The correlation between the perpendicular distances away from the coastline of the Atlantic Ocean and the average atmospheric radio wave refractivities is 0.84. The approximate model of average atmospheric radio wave refractivity away from the Atlantic Ocean coastline is y = -0.125x + 388.9: where y is the average atmospheric radio wave refractivity and x is the perpendicular distance away from the Atlantic Ocean coastline. Similarly, the correlation between the perpendicular distances away from the borderline of the Sahara desert and the average atmospheric radio wave refractivities is 0.84. Also, the approximate model of average atmospheric radio wave refractivity away from the Sahara desert borderline is y = 0.122x + 267.2: where y is the average atmospheric radio wave refractivity and x is the perpendicular distance away from the Sahara desert borderline. The above correlations were not absolute because of the non-uniformity of the weather or climate patterns across the country. The reliefs and rivers account for some of the anomalies in the non-uniform trend down the ocean coastline or up the desert borderline. In addition, isotherm and isohyets but not isobars were brought into consideration because these lines are non-linear and can cut across the vegetative climatic zones, for example is Enugu that sits in the rainforests, shares similar mean monthly temperatures as other cities in this belt; but has common mean monthly humidities with cities in the mangrove. Also, Kaduna shares similar mean monthly temperatures with cities in the Sudan savannah but has common mean monthly humidities as Jos in the Guinea savannah and a montane climate.

By and large, the most favourable belt for radio signal propagation through the troposphere is the Sahel savannah belt with low mean monthly relative humidities, while the least favourable belt for radio signal propagation through the troposphere is the Mangrove belt with very high mean monthly relative humidities, in view of the fact that, the variance in mean monthly temperatures between the two belts is not comparable to their relative humidities and the variance in the mean monthly atmospheric pressure is near uniform. A point of note is that: relative humidity bears more weight in the expression for calculating radio wave refractivity, seconded by atmospheric temperature and the least is the atmospheric pressure [1]. This is due to their ranges of variations.

With the exception of winds and may be rainfall that affect communications [66] [67], radio signal propagation through the troposphere in the Savanna will be less stable than the rainforest and mangrove owing to the fact that there is less variance in the atmospheric parameters, that is atmospheric temperature, pressure and humidity in the latter belts than the former belt.

Finally, radio signal propagation will generally propagate better throughout the country in the troposphere during the dry than the wet. This is on the account that the mean monthly relative humidities generally falls during the dry, but rises in the wet.

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