Nigerian Journal of Theoretical and Environmental Physics (NJTEP)
ISSN Print: 3026-9601
DOI: https://doi.org/10.62292/njtep.v2i2.2024.53
Volume 2(2), June 2024

In-Depth Study of Climate Change and its Impact on Terrestrial Wireless Communications over North Western Nigeria

***Akinsanmi Akinbolati, Florence N. Ikechiamaka and Isaiah E. Igwe**

Department of Physics, Federal University Dutsin-Ma, Nigeria

*Corresponding author's email: aakinbolati@fudutsinma.edu.ng

ABSTRACT

In recent times, studies on climate change and the impact on wireless communications are gaining the attention of radio scientists and engineers for effective planning of radio link and equipment maintenance. Climate change variabilities and their implications on wireless communications over the cities of Kaduna, Katsina and Sokoto (north western Nigeria), were investigated using forty-two years' (1980-2021) atmospheric data. Results reveal substantial degree of climate change with increase in temperature profiles for all the locations. Minimum climatic mean temperature of 27.01, 29.30 and 30.70 °C were determined in Kaduna, Katsina and Sokoto respectively. Similarly, highest mean values of 30.20, 31.80 and 32.10 °C were obtained respectively in that order. The months with the least and highest temperatures in Kaduna are December and April with 23.91 and 33.06 °C respectively. For Katsina; 25.23 and 35.76 °C were obtained, while 26.28 and 36.05 °C were obtained in Sokoto in January and April respectively; and the hottest month in the studied region is April. For precipitation, minimum mean values of 2.02, 1.19 and 1.30 mm and maximum of 5.24, 2.53 and 2.39 mm were obtained in Kaduna, Katsina and Sokoto respectively. The month with the highest amount of rainfall in all the cities is August with mean values of 8.97**,** 6.45 and 6.52 mm in Kaduna, Katsina and Sokoto cities. The implications of these findings on terrestrial communications are that; installed out-door communication hardware such as the transmitting tower and antenna, transmitter modules and wave guides could be subjected to perturbations that will affect their optimal performances and durability during the months of excessive temperature and rainfall. Radio scientists and engineers should incorporate climate change impacts on equipment design and employ major preventive maintenance on outdoor hardware in the months of April and August over the studied areas to ensure reliability and safe cost.

Keywords:
Climate Change,
Wireless communications,
Preventive maintenance,
Outdoor hardware,
North Western Nigeria.

INTRODUCTION

Climate change, has been a global challenge that affects most of the socio-economic activities of the citizenry. Based on this, mitigating its effects on human endeavours has been listed in the United Nations Sustainable Development Goals (UN-SDGs, 2024). Climate change is the long-term changes in the average weather patterns observed over several decades in a particular region. These changes are attributed to human activities such as burning fossil fuels, deforestation, and other activities that release greenhouse gases into the atmosphere (Sanou et al., 2018; Boulahya, 2005). The effects of climate change are experienced differently in various regions, but they generally include rising temperatures, changes in precipitation patterns, and an increase in extreme weather events such as floods, droughts, and heat waves (IPCC, 2013). Climate change is a significant global issue that has far-reaching impacts on various aspects of human life and the natural environment. One of the ways in which climate change affects wireless communications is through changes in radio climatic factors (Akinbolati *et al.*, 2018) and by extension changes in the radio refractivity, a secondary radio climatic factor whose variation affects the quality of radio communication's signal (Mmahi *et al.*, 2021). Excessive temperature rise, high precipitation, moisture and thunderstorm have negative economic impact on communication system (Ajewole *et al.,* 2014, Ayantunji, 2018), Adewunmi et al., 2018, Ayegba et al., 2022). They effect Transmitting Base Station (TBS) equipment such as; transmitting antennas, wave guides, transmitting mast and towers. On the other hand, radio refractivity and refractivity gradient are parameters that influence the propagation behaviour of the wireless signal in the atmosphere (Sabiru et al., 2024; Iheanyichukwu et al., 2020) which could lead to anomalous propagation (signal losses and interference). Surveillance and forecasting of weather phenomena have improved over the centuries; as a result, the immense knowledge and information gathered helps to comprehend and predict climate change, which has a huge impact on atmospheric parameters research all over the world (Camberlin and Diop, 2003; Aweda et al., 2021).

As scientists, it is worrisome to observe the collapse of communication towers/masts and other outdoor hardwire causing economic loss and down time. This forms the curiosity to investigate climate change as one of the possible factors in the degradation of these hardwire. In recent years, Nigeria, has witnessed discernible shifts in its climate patterns, attributed to the broader phenomenon of global climate change. The Country experiences variations in temperature, precipitation, and humidity; factors known to influence the efficiency of radio communication systems (Akinbolati *et al.*, 2018; Sheu, 2021). As climate change becomes increasingly pronounced, understanding its specific repercussions on radio communication is crucial for maintaining effective and reliable communication networks. Communication systems serve vital functions in the socio-economic lives of any nation (Akinbolati and Ajewole, 2020. The interplay between climate characteristics and the reliability of radio communication systems necessitates an in-depth investigation to unravel potential challenges and devise strategic solutions in the study region.

Radio communication simply means ‘wireless’ communication. It is the type of communication (sending of signals or information from one point to the other) that does not require connecting wires directly from the transmitter to the receiver (Akinbolati et al., 2016). Rather, it is the transmission of radio_signal or radio wave from the transmitter through space (atmosphere) to the receiver. The signal of interest (data, voice, visual/picture, audio etc) is generated at the source, processed (filtered, amplified, modulated) and transmitted through the transmitter via the transmitting antenna in the case of terrestrial transmission (Akinbolati et al., 2018). In the case of satellite communication, the signal is processed at the source and transmitted using the uplink satellite earth station which beams the signal to the space craft/space station. The space station beams the signal back to the earth with its coverage area equals to the foot print of the transmitting satellite. Examples of radio communications are: radio and television broadcasting, telephone, walkie-talkie, internet, data transmission, microwave link etc. Most terrestrial communications are transmitted in the troposphere. The features of the troposphere are terrain (topography, natural and artificial structures, vegetations) hydrometeors (rain, fog, ice, and precipitation), primary radio climatic factors (temperature, pressure, humidity, wind speed and amount of rainfall) and secondary radio climatic factors (surface radio refractivity, refractivity gradient). All these factors have either positive or negative effect on transmitted tropospheric radio signal and outdoor hardware system (Akinbolati et al., 2016).

Several studies have investigated the impact of climate change on communication technologies worldwide. They highlighted the potential risks posed by climate change on various aspects of communication technologies such as signal propagation, frequency interference, antenna performance, energy consumption, and infrastructure resilience, but none has carried out a study similar to this current work in North Western Nigeria.

MATERIALS AND METHODS

Study Location

This study was carried out over the cities of Kaduna, Katsina and Sokoto, North western Nigeria. Their geographic Coordinates and climate classification are as presented in Table 1. The digital map indicating the study areas are as presented in Figure 1

Table 1: Geographic Coordinates and climate classification of the study locations

Location	**Lati.** ° N	**Long.** ° E	**Altitude (m)**	**Climatic Zone**
Kaduna	10.5167° N	7.4333° E	650.50	Guinea Savanna
Katsina	12.9908° N	7.6014° E	525.20	Sahel Savanna
Sokoto	13.0483° N	5.2582° E	494.85	Sahel Savanna

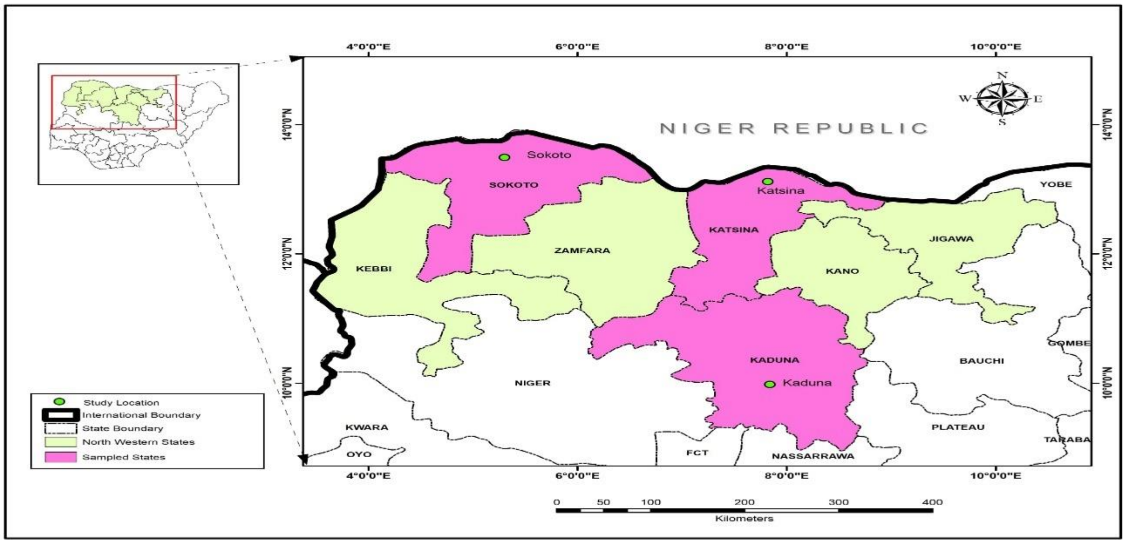

Figure 1: The digital map indicating the study areas over north west, Nigeria

The Atmospheric Parameters Deployed for the study

Forty-two years (1980 – 2021) monthly Satellite data of weather parameters; temperature, humidity and amount of rainfall at the surface were deployed in this study. The temperature and humidity data were obtained from European Center for Medium-Range Weather Forecast (ECMRWF-ERA 5), and the precipitation/rainfall were obtained from National Oceanic and Atmospheric Administration (NOAA, 2024). The data are of high resolution and reliable (Ojo *et al*, 2017) and approved for use by the ITU-R (Sabiru *et al*, 2024). The data were sorted into monthly, yearly, dry and wet seasons for easy analysis. Microsoft excel and Statistical Package for the Social Sciences (SPSS) and other statistical formula were used to analyse the climate change profile and the degree of climate change over the study locations as well as their influence on radio communication. Table 2 presents samples of the raw data used for Kaduna for 1980 and 2020.

Table 2: Typical Sample of the Mean Monthly Raw Data for the Years 1980 and 2020 in Kaduna

Year	Temp_(K)	Humidity(%RH)	Rainfall (mm)	Year	Temp_(K)	Humidity(%RH)	Rainfall (mm)
198001	302.38	22.72	0.01	202001	299.39	26.58	0.00
198002	303.63	18.69	0.02	202002	301.5	19.56	0.03
198003	305.78	28.18	0.07	202003	306.74	28.48	0.30
198004	306.21	44.66	0.88	202004	306.52	46.67	2.13
198005	302.20	77.00	4.85	202005	304.15	66.36	2.64
198006	300.61	83.34	3.79	202006	302.01	74.55	5.91
198007	299.19	86.30	8.30	202007	299.86	84.24	10.28
198008	299.12	86.69	9.24	202008	299.44	84.75	8.31
198009	300.29	85.69	5.09	202009	300.14	84.34	10.42
198010	301.05	80.88	1.82	202010	302.65	70.44	3.04
198011	302.66	47.69	0.06	202011	302.95	38.54	0.04
198012	300.65	27.77	0.01	202012	303.22	31.65	0.00

(ECMRWF-ERA 5, 2024; NOAA. 2024)

Data Sorting and Techniques

After the data were retrieved, sorting techniques were applied to organize and analyse the information effectively. The data sorting techniques used in this research work includes;

i. Time-based sorting: Data organized based on chronological order to identify trends and patterns over time

ii. Variable-based sorting: Sorting the data based on specific variables such as, temperature, rainfall, wind speed, or the degree of correlation.

iii. Categorization: Grouping the data into categories based on relevant factors such as, climate patterns.

iv. Data Visualization: Utilizing graphs, charts, tables, and maps to present the findings visually.

Empirical and Statistical Tools

Some common tools such as Microsoft excel and Correlation Coefficient for assessing the degree of relationship between atmospheric variables, and their variability to the climatology were used. Karl Pearson's Product Moment Correlation Coefficient for continuous data, presented in (1), was used to determine the degree of relationship between the variables and the climate, where x and y are the variables of interest.

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 (\sum y)2]}} = \frac{cov\,XY}{\sqrt{var\,X.var\,Y}} \qquad (1)$$

Time Series Analysis: Identifying trends and patterns in climatic change and correlation data over time. Furthermore, the forty-one years set of data were grouped into seven consecutive groups (of years) with the last being six years. The mean values were determined and analysed for proper observation of the climate change variability; this we called the seven year-mean group analysis in this study.

RESULTS AND DISCUSSION

Climatic Data and Variability over Kaduna, Katsina and Sokoto Cities

The average value for the twelve months for each of the forty-two years were determined and sorted out. Table 3 presents typical climatic data indicating annual mean for Kaduna as example for the years under study. The overall mean values for the forty-two years for temperature, rainfall and humidity are 302.25 K (29 ºC), 3.11 mm and 55.18 %RH respectively. In Katsina, the overall mean values for the forty-two years for temperature, amount of rainfall and humidity are 303.12 K (30.12 ºC), 1.76 mm and 41.49 %RH respectively. In addition, the overall mean values for temperature, rainfall and humidity, are 303.72 K (30.7 ºC), 1.87 mm and 38.74 %RH respectively In Sokoto.

Table 3: Typical derived annual mean value of the atmospheric parameters for the years 1980-2021 over the city of Kaduna

Year	Temp_sfc(K)	RH_sfc(%RH)	Rainfall(mm)
1980	301.98	57.47	2.85
1981	301.70	55.47	2.71
1982	301.52	58.79	2.75
1983	302.06	51.28	2.25
1984	301.93	56.83	2.46
1985	301.95	54.08	2.65
1986	301.99	56.93	2.75
1987	302.85	51.68	2.45
1988	302.11	54.85	3.22
1989	301.37	52.79	3.09
1990	302.47	54.45	2.93
1991	301.93	58.41	3.43
1992	301.30	57.11	3.18
1993	302.04	55.95	3.15
1994	301.56	57.13	3.63
1995	301.93	56.78	2.86
1996	302.38	54.95	3.36
1997	301.72	59.21	3.03
1998	302.40	54.77	3.48
1999	302.24	55.97	3.41
2000	301.94	52.59	3.02
2001	302.02	51.90	3.15
2002	302.08	55.02	3.17
2003	302.64	53.75	3.55
2004	302.41	54.13	3.12
2005	303.09	52.53	2.89
2006	302.89	52.12	3.22
2007	302.28	53.94	2.98
2008	302.10	53.05	3.53
2009	302.67	56.06	3.36
2010	302.83	55.70	3.63
2011	302.45	53.36	2.96
2012	302.18	57.04	3.64

2013	302.66	58.50	2.89
2014	302.42	57.73	3.24
2015	302.36	52.16	2.49
2016	302.65	56.79	3.33
2017	302.89	52.45	3.18
2018	302.45	56.57	3.57
2019	302.60	58.53	3.64
2020	302.38	54.68	3.59
2021	303.16	54.03	2.75
Overall climatic mean	**302.25**	**55.18**	**3.11**

Climatic variation of atmospheric parameters with the years under study in Kaduna

Figures 2, 3, and 4 illustrate the variability of temperature, amount of rainfall and relative humidity for the period of forty-two years (1980-2021) over the city of Kaduna. From figure 2, more fallings/reductions in about 23 points/years of temperature values compared to preceding years were observed in Kaduna. The minimum mean value of temperature was **300.01 K (27.01 ºC*)*** which was recorded in the year 2007. Similarly, rising in temperature was observed in about 18 points/years of temperature values compared to preceding years with the maximum value of **303.16 K (30.2 ºC)** in the year 2021. Six points were observed to maintain the same values in the years 1984-1986, and 2000-2002. This result clearly indicates climate change over the study areas with increases in the ambient temperature along the trend. The impact of this on wireless communication is the tendency to affect the radiation pattern of transmitting antennas leading to interference in signals. This is because some literatures have established negative impact of high temperatures on antenna performance (Kennedy and Bernard, 1992; Boithias, 1987)

Figure 2: Annual mean climatic variation of Temperature (K) over the years 1980-2021

Figure 3 presents the annual mean climatic variation of amount of rainfall for the years 1980-2021 over the city of Kaduna. This figure indicates that, highest amount of rainfall was recorded in the year 2007 with annual mean value of **5.24 mm**, and minimum value in the year 1982 with the value of **2.02 mm.** From the figure, there are fallings/reductions in twenty- two years (22 points) and rises in twenty years (20 points) under the studied periods. This clearly shows climate change in the rainfall weather pattern. This does not only have impact on wireless communications but on other socio-economic life of the people especially agriculture. The impact on wireless communication, is the rain induced-attenuation of signals especially during the high rainfall months and years. Stakeholders in wireless communications such as radio, television and GSM should make deliberate efforts at mitigating against losses during these periods.

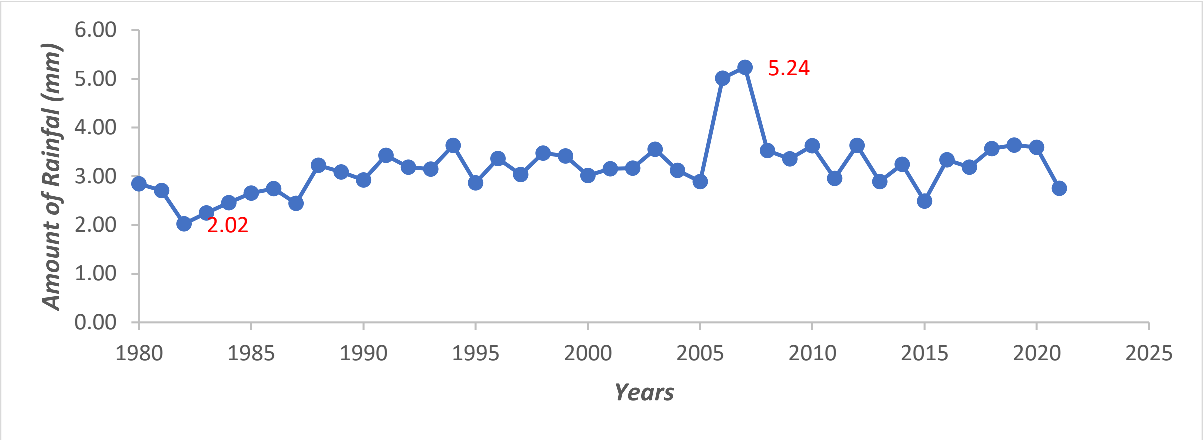

Figure 3: Annual mean climatic Variation of Amount of Rainfall over the years 1980-2021 in the city of Kaduna

Figure 4 presents the annual mean climatic variation in the relative humidity (amount of moisture in the atmosphere) over Kaduna City. From the figure, more fallings/reductions were observed in twenty years (of about 20 points) with the minimum value of **39.98 % RH** recorded in 2015, and rising of 22 points with the mean maximum value of **66.06 % RH** recorded in the year 2021. The implications of the findings are in tandem with those presented for temperature and rainfall.

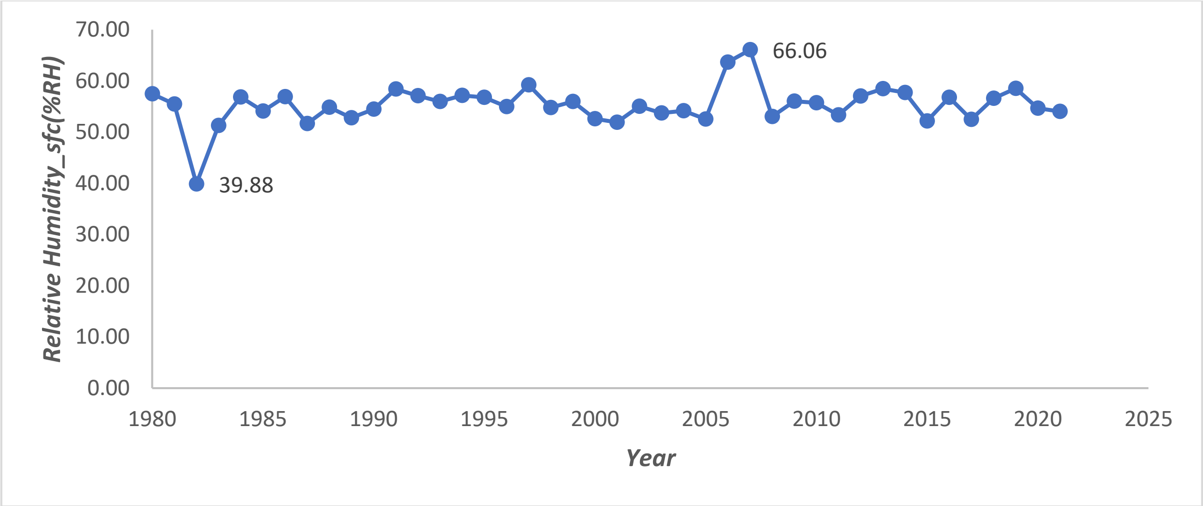

Figure 4: Annual mean climatic variation of Relative Humidity over the years 1980-2021

Climatic variations of atmospheric parameters over the years under study in Katsina

Figures 5, 6 and 7 illustrate the variability of temperature, amount of rainfall and relative humidity over the city of Katsina. From figure 5, it established that, more rising of about 22 points excluding the starting year were recorded, the maximum average value of ***304.82 K (31.8 ºC)*** in the year 2021, was recorded in the trend compared to falling points, which constituted about 19 points with the minimum value of ***302.30 K (29.3 ºC)*** in the year 1988. Meaning that, within the study period climate change was established in the temperature pattern with extreme increases in the ambient temperature along the trend. This will in no doubt have a negative impact on outdoor installed communications hardwires; such as towers and antennas.

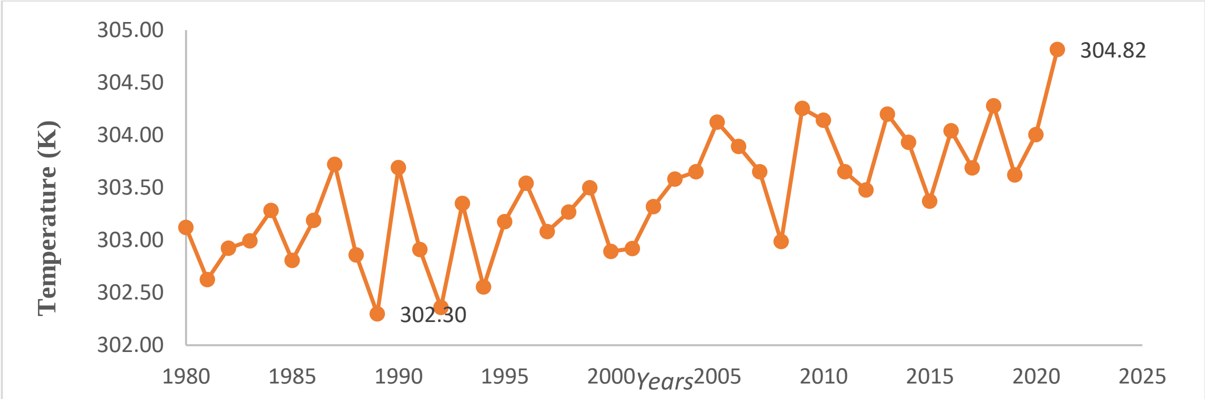

Figure 5: Annual mean climatic variation of Temperature (K) over the years 1980-2021in Katsina

Figure 6 presents the annual mean variation of rainfall for the years 1980-2021 over the city of Katsina. This figure indicates highest amount of rainfall in the year 2020 with the value of **2.53 mm**, and minimum value in the year 1984 with the value of **1.19 mm,** from the figure, there are fallings of 22 points and rises of about 20 points under the studied periods. In Figure7, reduction of about 17 points with the minimum value of ***36.91 %RH*** in 2007, and rising of 25 points with the maximum value of ***43.52 %RH*** were recorded in the years 2018, and 2019 respectively.

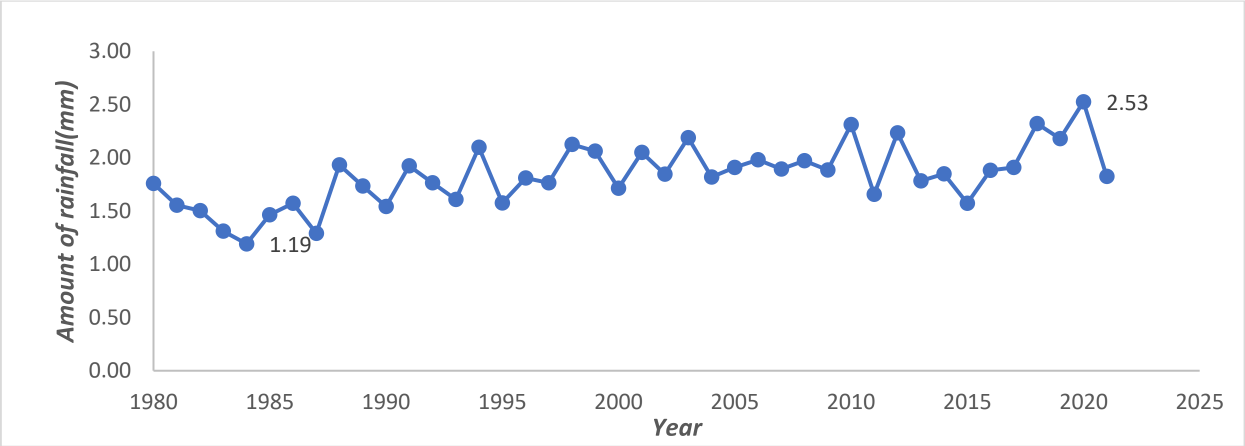

Figure 6: Annual mean climatic variation of Rainfall over the years 1980-2021in Katsina

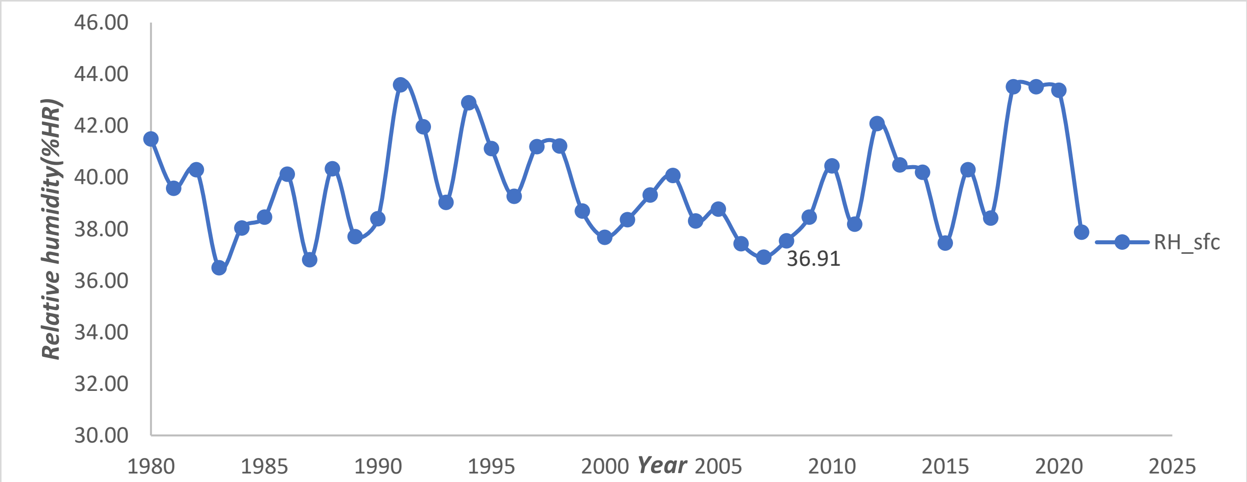

Figure 7: Climatic variation of Relative Humidity over the years 1980-2021in Katsina

Climatic variations of atmospheric parameters over the years under study in Sokoto

Figures 8, 9, and 10 depict the variability of temperature, amount of rainfall and relative humidity for the period of forty-two years (1980-2021) over the city of Sokoto. For the temperature profile, more fallings of about 22 points with the minimum average value of ***302.66 K (30.7 ºC)*** in the year 1989 recorded in the trend compared to raising, which constitute about 20 points with the maximum value of ***305.05 K (32.1 ºC)*** in the year 2021. Meaning that, within the study period there is change in weather pattern coupled with extreme increases in the ambient temperature along the trend.

Figure 9 presents the variation of annual mean of rainfall for the year 1980-2021 over the city of Sokoto. This figure indicates that, there is highest amount of rainfall recorded in the year 2020 with the value **2.39 mm**, and minimum value in the year 1987 with the value **1.30 mm,** from the figure, there are falling of 22 points and rises of about 20 points under the studied periods.

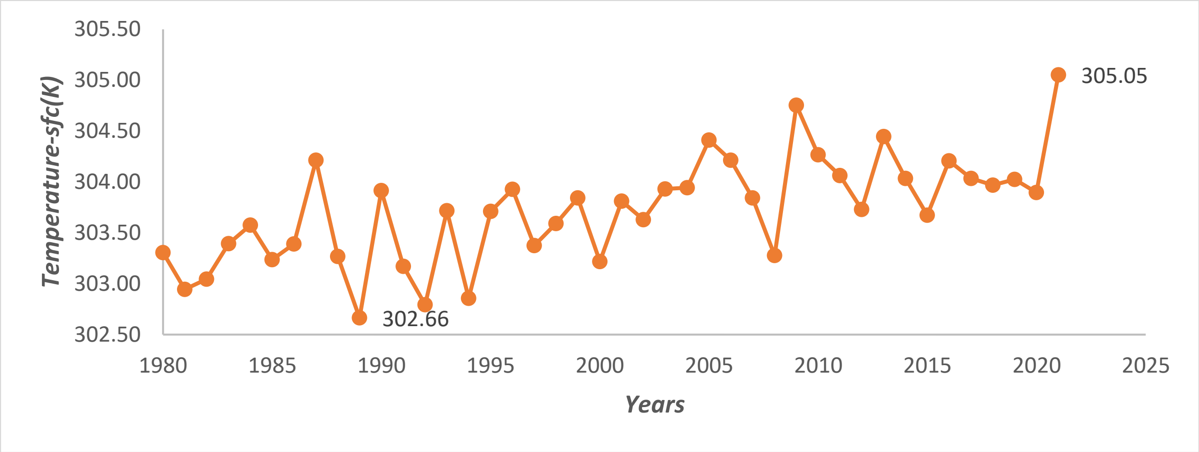

Figure 8: Climatic Variation of Temperature (k) for the years 1980-2021 over the city of Sokoto

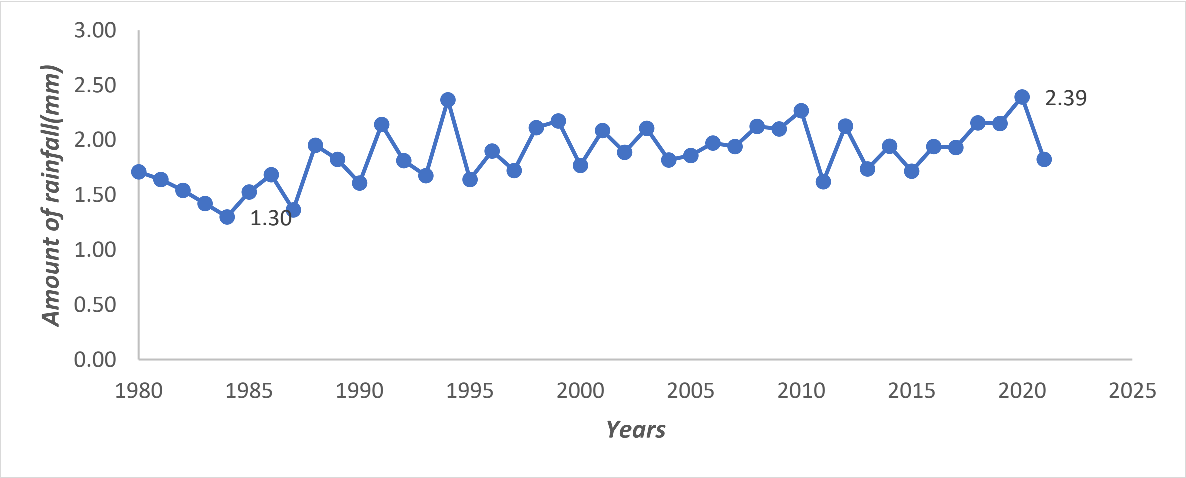

Figure 9: Climatic Variation of Annual Mean Amount of Rainfall over the year 1980-2021over the city of Sokoto

From figure 10, more fallings of about 23 points with the minimum value of ***35.99 %RH*** in 2006, and rising of 19 points with the maximum value of ***42.77 % RH*** in the year 1991 recorded.

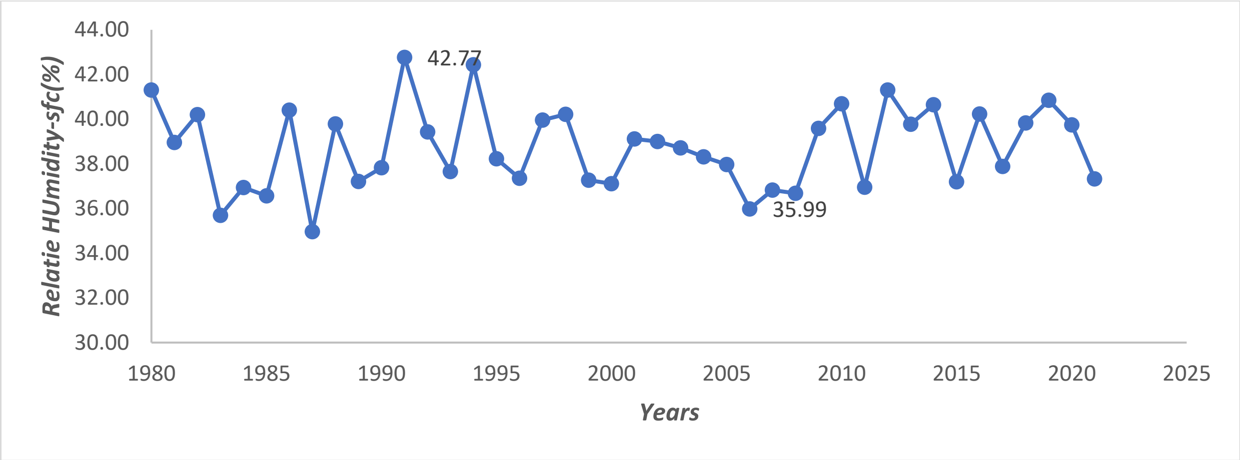

Figure 10: Climatic variation of Relative Humidity over the years 1980-2021 in Sokoto

In-depth Analysis of atmospheric parameters for the overall 42years monthly mean over Kaduna

In addition, the overall monthly mean for the forty-two years for the parameters were determined and plotted against the corresponding months. They are as presented in figures 11, 12 and 13

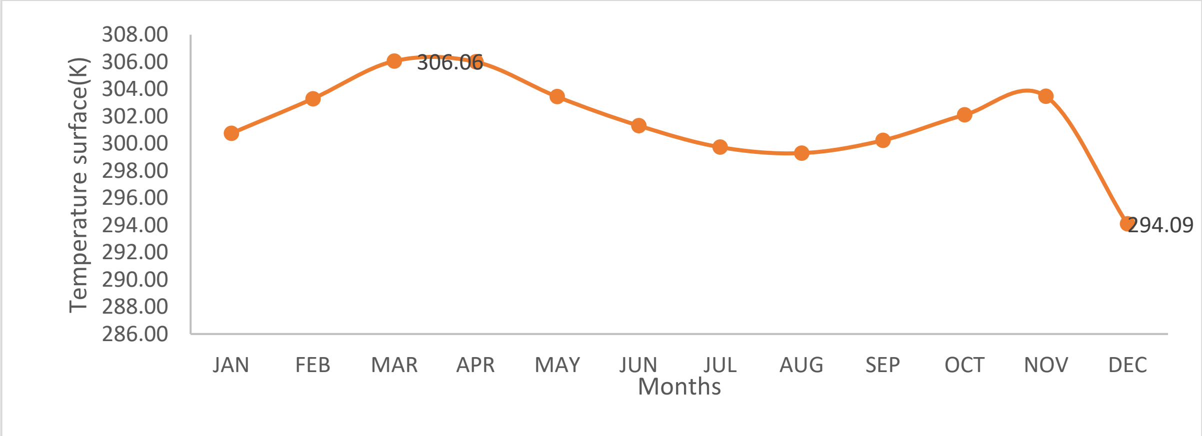

Figure 11: Monthly mean of forty-two years climatic variation of the ambient temperature over the years 1980-2021 in Kaduna

From figure 11, it is observed that; for the forty-two years, the months of March and April experienced the maximum temperatures followed by November with the average value of **306.06 K (33.06** ℃). Meanwhile, the month of December (the peak month of harmattan in Kaduna) always experienced the lowest temperature value of **249.09 K (23.91** ℃ **)** within the study period. Meaning that months of March and April were the hottest months in Kaduna. In addition, it is established that, there is always sharp decrease in values of temperature from the month of April down to the month of August (the wet season months) and rising from August up to the month of September every year. The implications of these findings on communications are that; installed out-door communication hardware such as the transmitting tower and antenna, transmitter modules and wave guides could be subjected to perturbations that will affect their optimal performances and durability during the months of excessive heats. For the month of December, transmitted radio signals are prone to experience tropospheric scattering if they are trapped in the ducts during harmattan.

The climatic variation for rainfall in Kaduna is as presented in figure 12. From the figure, it is clear that there is extremely high rate of amount of rainfall in the months of July, August and September with August being the peak of raining season in Kaduna with the average value of **8.97 mm.** The findings also show that the months of January, February, November and December every year recorded little or no rains with the least average value of **0.01 mm** recorded in the month of December for the whole forty-two years.

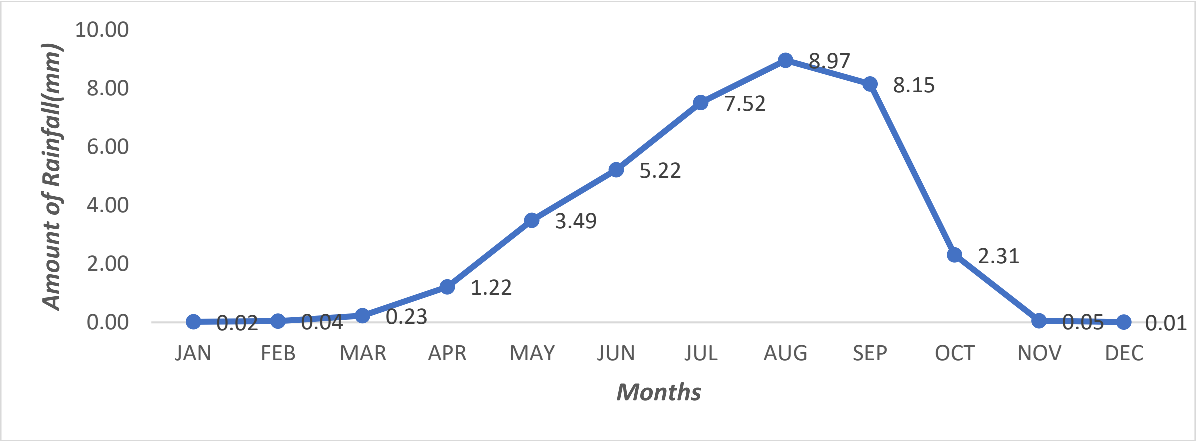

Figure 12: Monthly mean of forty-two years climatic variation of the amount of Rainfall over the years 1980-2021

The climatic variation for relative humidity in Kaduna is as presented in figure 13. From the figure, it is clear that higher values of relative humidity were recorded in the wet season months of May to October over the forty-two years under study. The highest and the lowest values of **86.47** and **19.69 %RH** were obtained in the months of **August** and **February** respectively. Radio communication operators may need to increase their transmitter power or take other necessary protocols to maintain quality of service during the months of high values, especially June-October, every year.

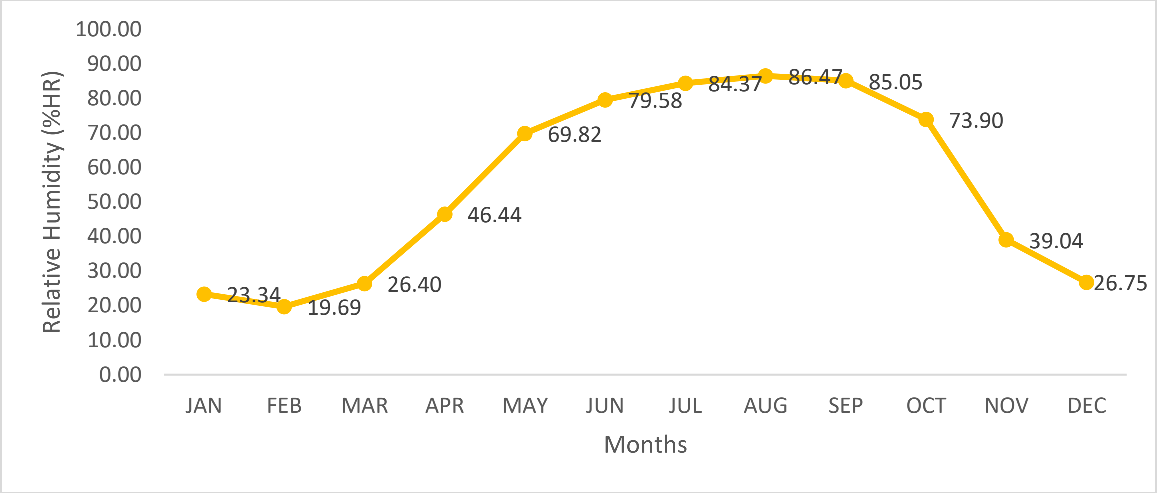

Figure 13: Monthly mean of forty-two years climatic variation of Relative Humidity over the years 1980-2021

In-depth Analysis of atmospheric parameters for the overall 42years monthly mean over Katsina

The overall monthly mean for the forty-two years for the parameters of temperature, rainfall and humidity were determined and plotted against the months. They are as presented in figures 14, 15 and 16. From figure 14, it is shown that, for the whole forty-two years, the month of April always experienced the maximum temperature with the overall average value of **308.76 K (35.76 *°C*)**. Meanwhile, the month of January and December always experienced the lowest temperature values of **298.23 K (25.23 *°C*)** and **299.24 K (26.24 *°C*)** respectively every year within the study period. The implication of this to radio communications; is that routine-checking on transmitting antennas is encouraged in the month of April to ensure a preset radiation pattern.

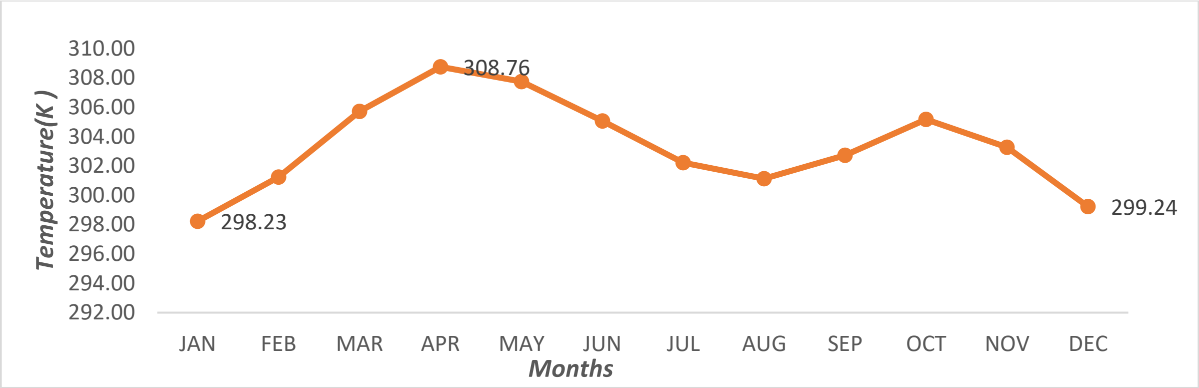

Figure 14: Monthly Mean Climatic Variation of the temperature over the years 1980-2021 in Katsina

For the rainfall pattern as depicted in figure 15, it is clear that there is extremely high rate of amount of rainfall in every month of August with the average value of **6.45 mm** and from the trend, it shown that the month of January and December had the same rate of amount of rainfall with the values of 0.01 mm, likewise the months of February and November also had the same values of 0.02 mm every year. Meaning that, the minimum values of the amount of rainfall were recorded in the month of November down to February every year for the whole forty-two years under study.

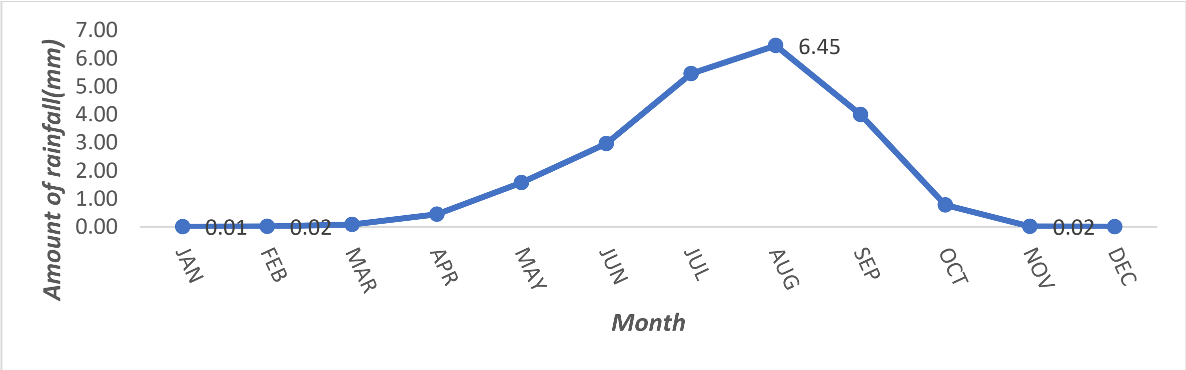

Figure 15: Monthly Average Means climatic variation of the Amount of Rainfall over the year 1980-2021 Katsina

From figure 16 shown that, for the whole forty-two years, the month of August always experienced the maximum relative humidity with the average value of **77.78 %RH**. Meanwhile, the month of March always experienced the minimum relative humidity value of **13.24 %RH** every year within the study period. And it followed that, there is always rise in relative humidity between the month of April ranges to August, and sharp decreasing along the trend from the month of August down to March every year within the studied period.

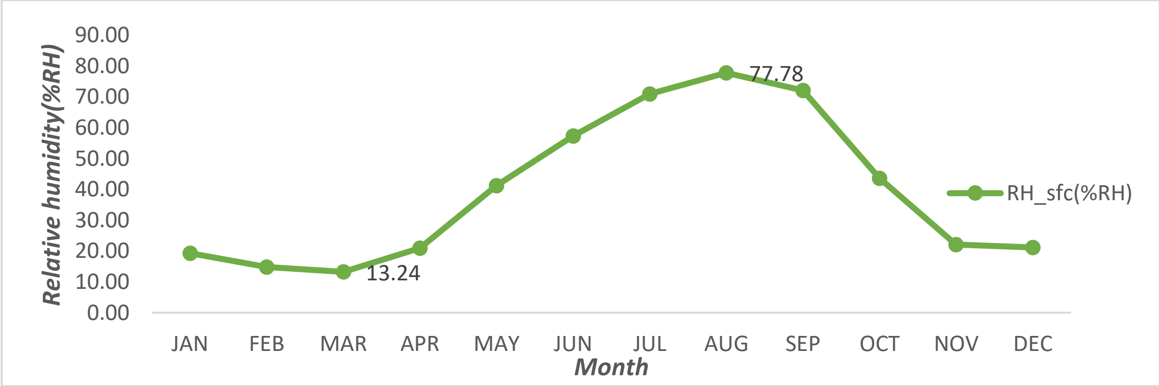

Figure 16: Monthly Mean climatic variation of the Relative Humidity over the year 1980-2021 in Katsina

In-depth Analysis of atmospheric parameters for the overall 42years monthly mean over Sokoto

In addition, the overall monthly mean for the forty-two years for the parameters were determined and plotted against the months. They are as presented in figures 17, 18 and 19 for temperature, rainfall and humidity respectively.

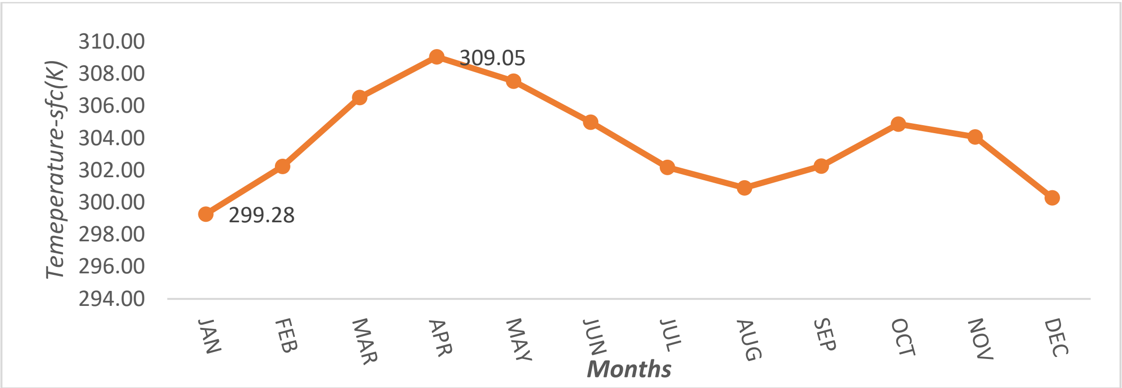

Figure 17: Monthly Mean Climatic Variation of the temperature over the years 1980-2021 in Sokoto

From figure 17, it was observed that, for the whole forty-two years, the month of April always experienced the maximum temperature with the average value of **309.05 K**. (**36.05 *ºC*).** Meanwhile, the month of January always experienced the lowest temperature value of **299.28 K (26.28 *ºC***) every year within the study period. Meaning that, for the studied years, the month of April was the hottest month all through the studied period in Sokoto**.** For rainfall as presented in figure 18, it is clear that there is extremely high rate of amount of rainfall in every month of August with the average value of **6.52 mm,** the minimum value was recorded in the month of November down to March every year with the average value of **0.00 mm** recorded in the month of December for the whole forty-two years.

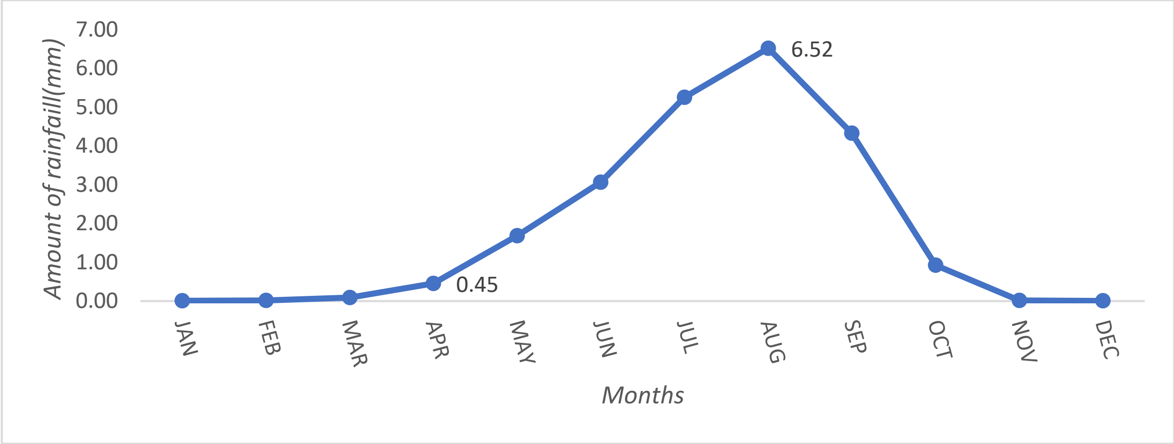

Figure 18: Monthly Average Mean climatic variation of the Amount of Rainfall over the years 1980-2021 in Sokoto

From figure 19, it is shown that, for the whole forty-two years, the month of August always experienced the maximum relative humidity with the average value of **76.68 %RH**, this is consistent with the result of rainfall. Meanwhile, the month of February always experienced the minimum relative humidity value of **15.82 %RH** every year within the study period. And it followed that, there is always rise in relative humidity between the month of February ranges to August, and sharp decreasing along the trend from the month of August down to February every year within the studied period.

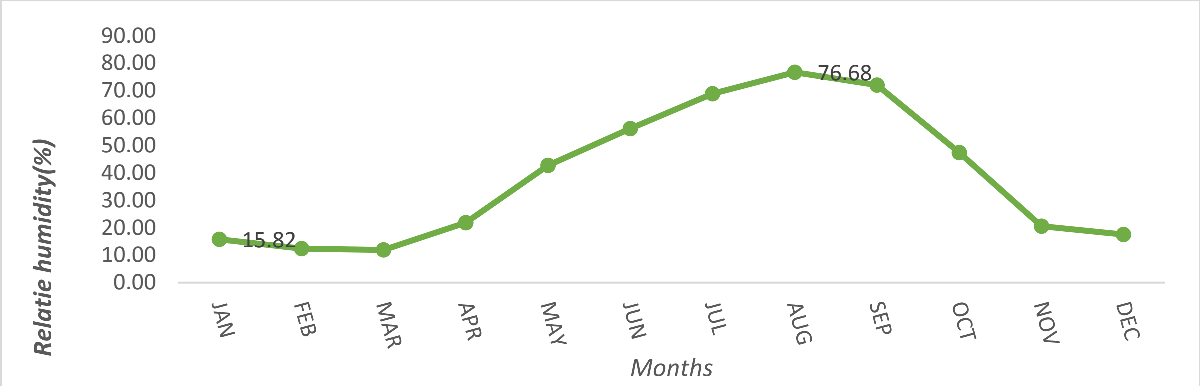

Figure 19: Monthly Average Mean climatic variation of Relative Humidity over the years 1980-2021 in Sokoto

Analysis of the seven years mean interval

Analysis of the seven years mean interval and comparison with the climatology in Kaduna

For the ease of observation and analysis, that will enhance reliability of results. The 42-years set of data were grouped into six groups of consecutive 7 years. The mean values were determined and analysed. The results of the overall seven years average interval for the forty-two years over the study areas are as presented in figures 20, 21 and 22 for temperature, rainfall and humidity respectively.

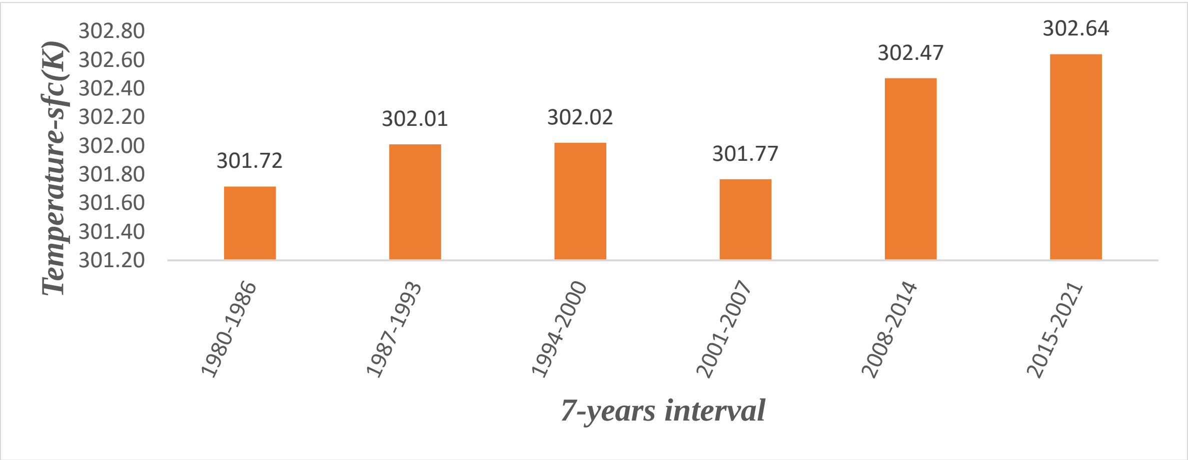

Figure 20: 7 Years-Interval Average value of Climatic Variation of Temperature over Kaduna

Figure 20 clearly shows the climatic variations of increase in temperature as the year increases, which indicates climate change pattern. The first seven years recorded the least with mean values of 301.72 K (28.72 ºC). that, the seven years period interval temperature has it maximum means value between the year 2015-2021 and its minimum means value within the year 1980-1986, respectively, 302.64 K (29.6 ºC), 301.72 K (28.7 ºC). This figure shows clearly that; there was climate change. There were rising in the temperature values especially in the last fourteen years. By implication, the rise in temperature will have a negative impact on the outside installed communication hardware such as the mast, towers and antenna. Excessive temperature has the tendency to introduce perturbation to antennas radiation capabilities. Communications' scientists and engineers should factor the effect of climate change in equipment design to ensure reliability and safe cost.

Figures 21 and 22 present the seven-year mean analysis for rainfall and relative humidity respectively. For the rainfall, the first seven years (1980-1986) recorded lower values compared to the next 21 years. However, there was a reduction in the amount of rainfall in the last 14 years of study covering (2008-2021). This means there have been higher temperatures and lower rainfall in the last one and half decades in Kaduna with various impacts on the socio-economic activities of the people. The humidity profiles in figure 22, follows the same trend with the rainfall pattern.

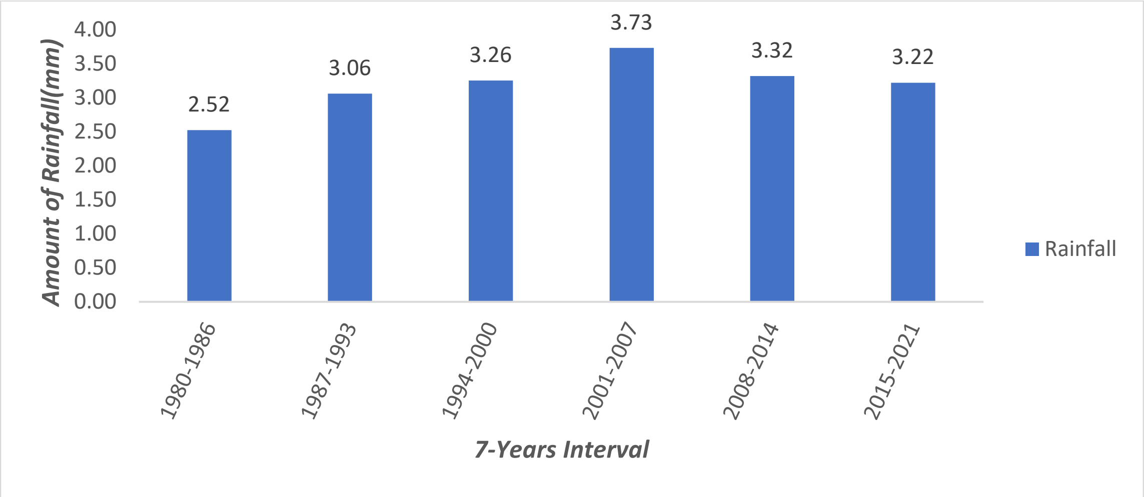

Figure 21: 7 Years-Interval Average value of Climatic Variation of Amount of rainfall over Kaduna

From figure 21, the amount of rainfall reached its minimum average value of 2.52 (mm), within the year 1980-1986, and reached it maximum average value of 3.73 (mm) between the years 2001-2007.

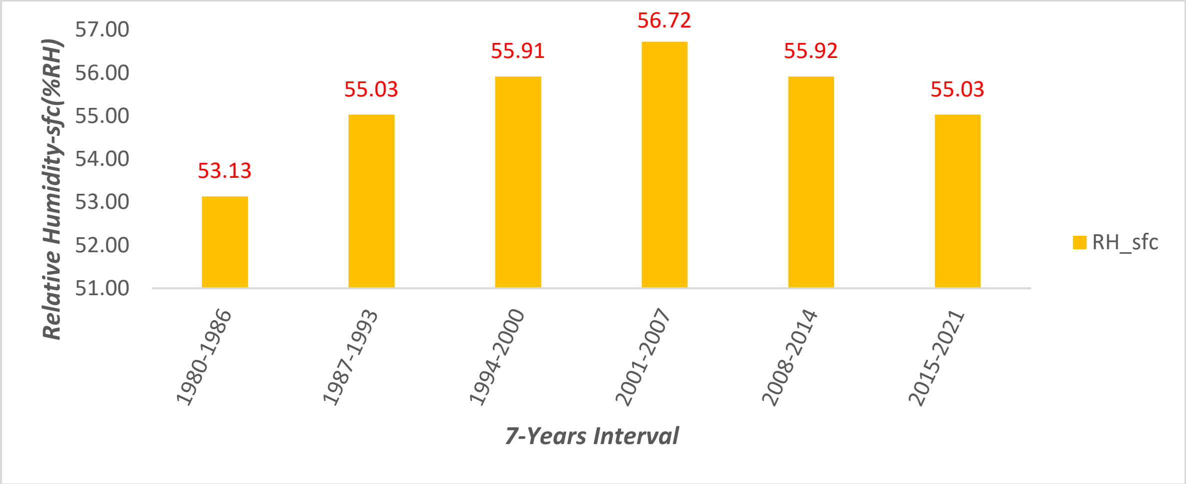

Figure 22: 7 Years-Interval Average value of Climatic Variation of Relative humidity over Kaduna

From figure 22, it is observed that, relative humidity reached its maximum average value of 56.72 %RH between the year 2001-2007 and its minimum average means of 53.13 %RH within the year 1980-1986.

Analysis of the seven years mean interval and comparison with the climatology in Katsina

These are the results of the overall seven years average interval for the forty-two years and compared with the climatology of the study area. And average values of the atmospheric parameters were determined and plotted against seven years interval. They are as presented in figure 23, 24 and 25 respectively.

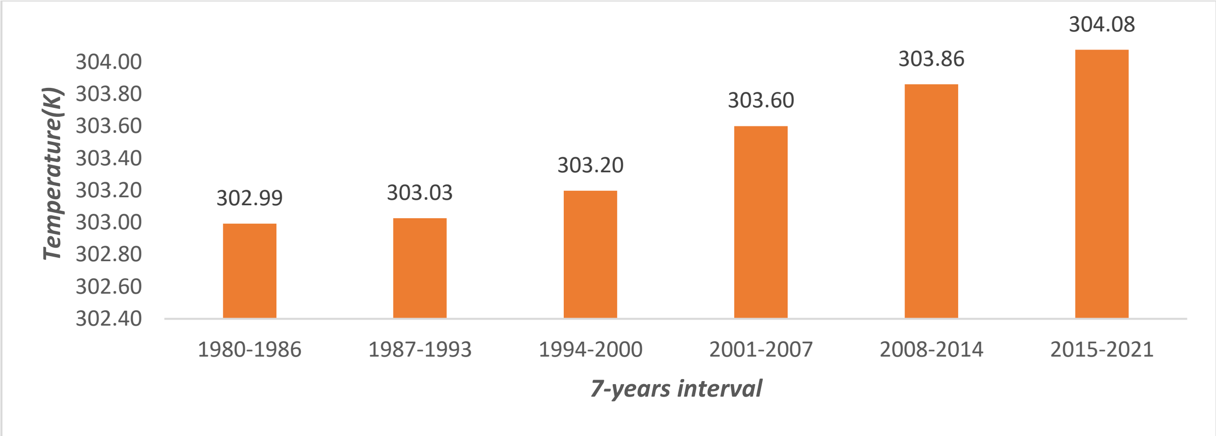

Figure 23: 7 Years-Interval Average value of Climatic Variation of Annual Temperature average means

From Figure 23, it is clearly shown that temperature increases in the seven years period interval. A clear attestation to climate change over the study areas with maximum mean value of 304.08K (31.1 ºC), between the year 2015-2021 and its minimum mean value within the year 1980-1986, with the value of 302.99 K (29.0 ºC). Figure 24 presents the variation of the amount of rainfall for seven years interval within the studied periods of 1980-2021 in the city of Katsina.

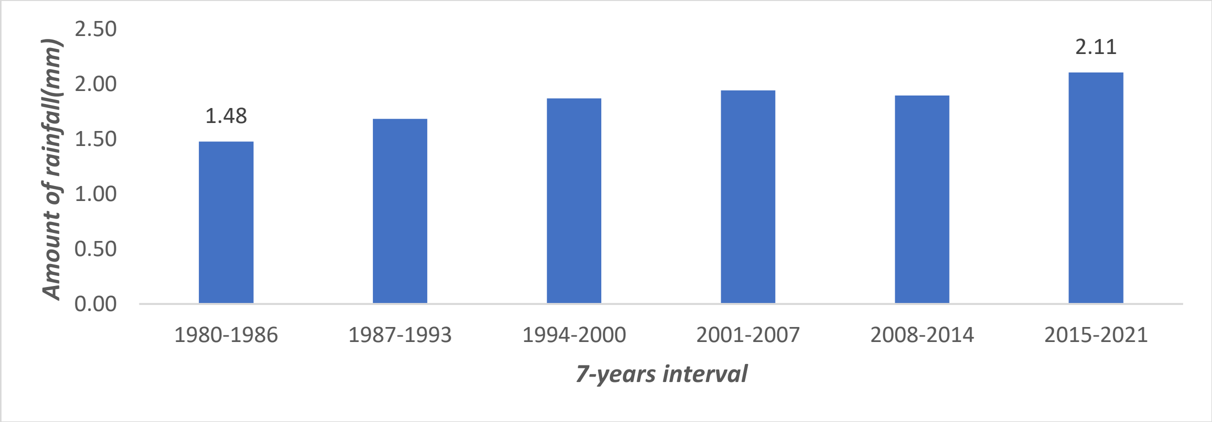

Figure 24: 7 Years-Interval Average value of Climatic Variation of Amount of Annual rainfall

From the figure, amount of rainfall reached its minimum average value of 1.48 (mm), within the years 1980-1986, and its maximum average value of 2.11(mm) between the years 2015-2021.

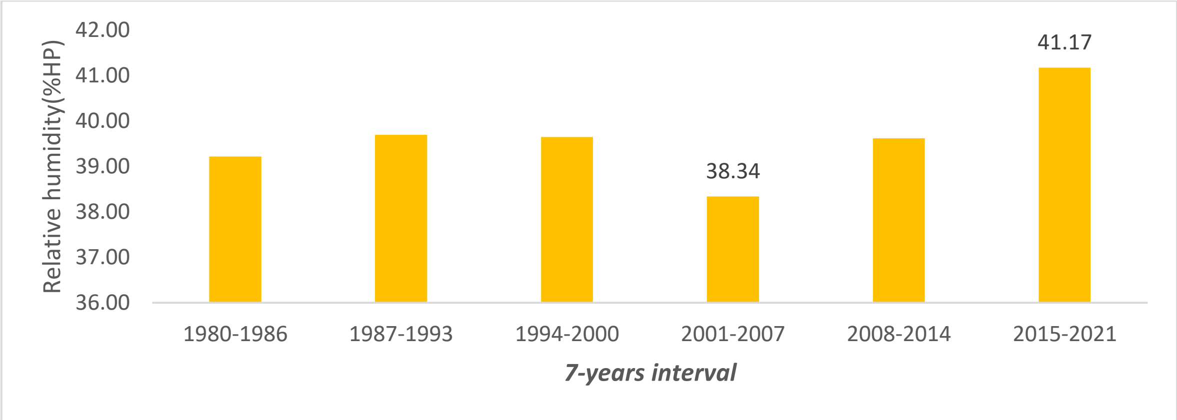

Figure 25: 7 Years-Interval Average value of Climatic Variation of Annual Relative humidity in Katsina

From figure 25, this shown that, relative humidity reached it maximum average value of 41.17% RH between the year 2015-2021 and its minimum average means of 38.34% RH within the year 2001-2007.

Analysis of the seven years mean interval and comparison with the climatology in Sokoto

These are the results of the overall seven years average interval for the forty-two years and compared with the climatology of the study area. They are as presented in figures 26, 27, and 28 for temperature, rainfall and humidity respectively. From Figure 26, it is clearly shown that, the temperature profile increases with the years especially in the last 21years. The seven years period interval has its maximum mean value of 304.12K (31.1 ºC), between the years 2015-2021 and its minimum mean value of 303.27 K (30.3 ºC). within the years 1980-1986, respectively.

From figure 27, the amount of rainfall reached its minimum average value of 1.55 (mm), within the years 1980-1986, and its maximum value of 2.03(mm) between the years 2015-2020. Slight reductions in values were observed in the last twenty-one years.

For the relative humidity in figure 28, it reached its maximum average value of 39.37 %RH between the years 2008-2014 and its minimum average value of 37.99 %RH within the year 2001-2007.

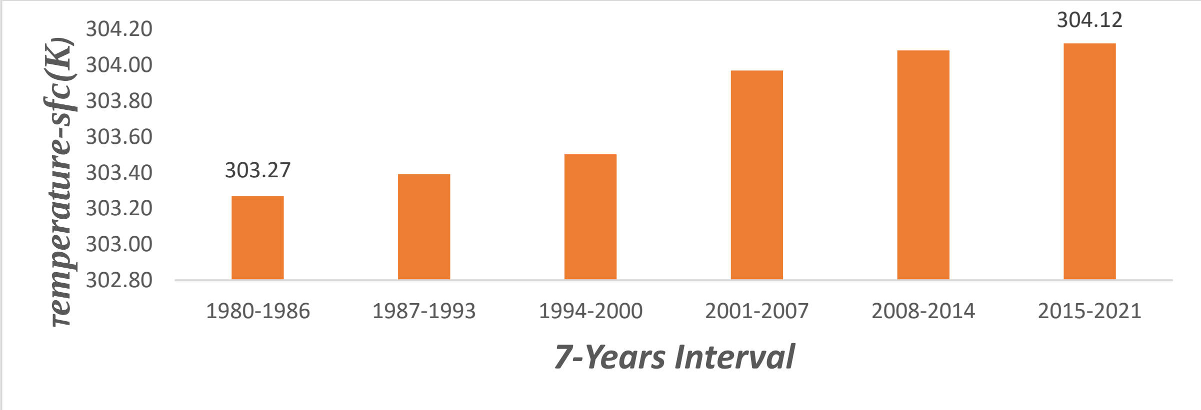

Figure 26: Seven (7) Years-Interval of Average value of Climatic Variation of Temperature

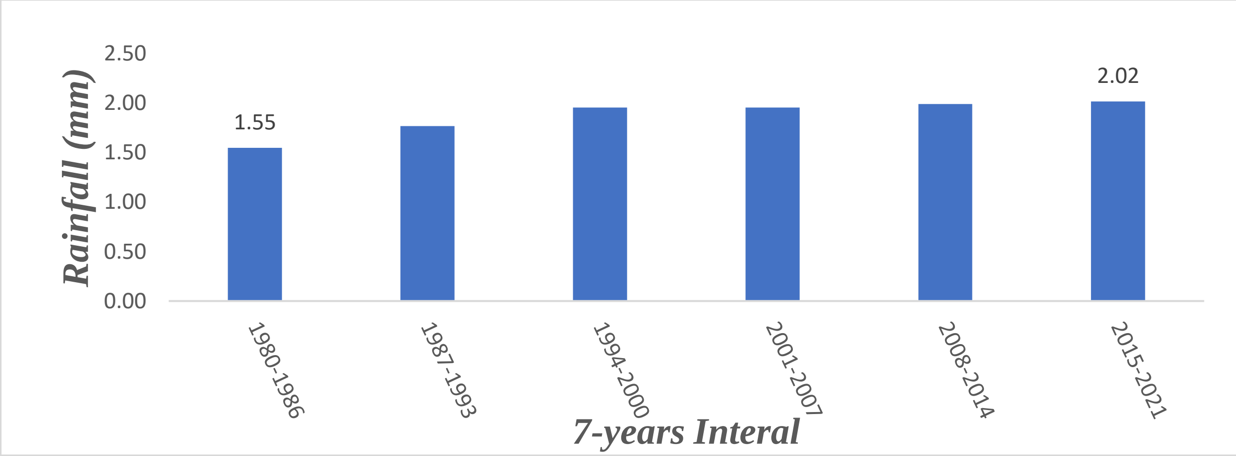

Figure 27: Seven (7) years Climatic Variation of Amount of Annual rainfall average means

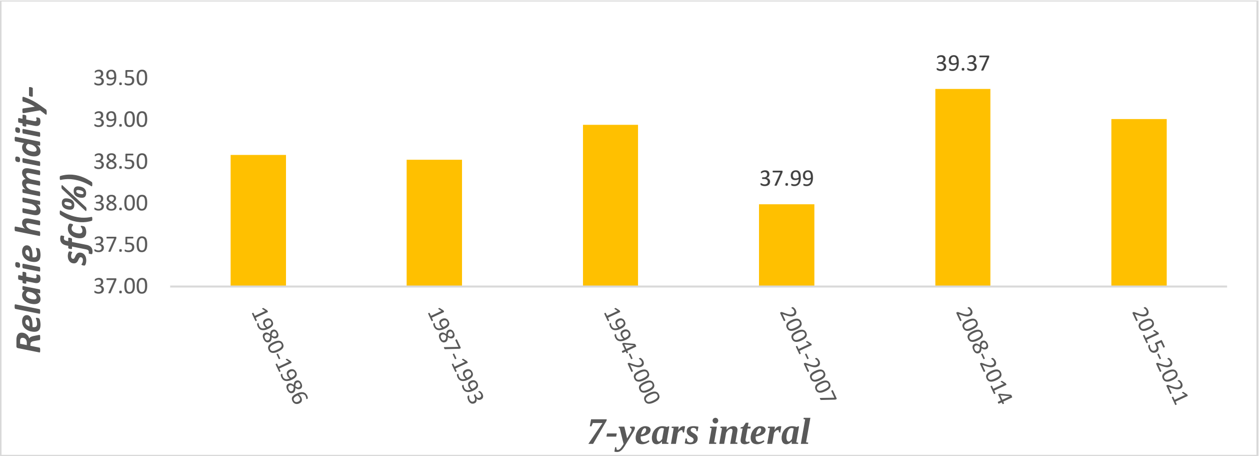

Figure 28: Seven (7) years Climatic Variation of Annual Relative humidity average means

Analysis of Degree of Relationship between Weather Parameters and years over the studied cities

This section discusses the degree of relationship between the atmospheric variables with the increase in the years from 1980-2021 using correlation coefficient (R) as presented in Tables 4, 5 and 6 for Kaduna, Katsina and Sokoto respectively. For the three locations, positive corelation coefficients of **0.59, 0.71 and 0.66** were established between temperature and the increase in years in Kaduna, Katsina and Sokoto respectively. This finding shows clearly an increase in temperature over the 42 years under study. The rate of increase is highest in Katsina followed by Sokoto and least in Kaduna. With this result, it is clear that there would be increase in temperature profiles in subsequent years in the North Western parts of Nigeria. Stake holders in the Climate action group should take proactive steps at mitigating the socio-economic effects of climate change over the region. Similarly, low positive corelation coefficients exist between rainfall/precipitation and the years. The degree is lower compared to those of the temperature profiles.

Table 4: Correlation Coefficient (R), between the Yearly mean of forty-two years and the atmospheric Variables over the city of Kaduna

	Year	Temp(K)	RH (%RH)	Rainfall(mm)
Year	1.00			
Temp(K)	0.59	1.00		
RH (%RH)	0.22	-0.20	1.00	
Rainfall (mm)	0.43	-0.36	0.71	1.00

Table 5: Degree of Correlation Coefficient (R), between the Yearly mean for forty-two years and the atmospheric Variables over the city of Katsina

	Year	Temp_sfc(K)	RH_sfc(%HR)	Rainfall(mm)
Year	1.00			
Temp_sfc(K)	0.71	1.00		
RH_sfc(%HR)	0.13	-0.05	1.00	
Rainfall(mm)	0.42	0.31	0.55	1.00

Table 6: Degree of Correlation Coefficient (R), between the Yearly mean for forty-two years and the atmospheric Variables over the city of Sokoto

	Date	Temp_sfc(K)	RH_sfc(%)	Rainfall(mm)
Date	1			
Temp_sfcK)	0.66	1		
RH_sfc(%)	0.09	-0.17	1	
Rainfall(mm)	0.45	0.14	0.52	1

As the years increase, temperature increased by 59, 71 and 66 % in Kaduna, Katsina and Sokoto cities respectively. On the other hand, rainfall increases by 43, 42, and 45 % respectively.

CONCLUSION

An in-depth study of climate change variabilities and the implications on wireless communication systems over north western Nigeria, using forty-two years (1980-2021) of atmospheric data was conducted. Results reveal substantial degree of climate change with increase in temperature profiles with the increase in the years for all the locations. Minimum mean temperature values of 27.01, 29.30 and 30.70 ºC were obtained in Kaduna, Katsina and Sokoto respectively. Similarly, highest mean values of 30.20, 31.80 and 32.10 ºC were obtained respectively in that order. The months with the least and highest temperatures in Kaduna are December and April with 23.91 and 33.06 ºC. For Katsina, the least and highest temperatures were recorded in months of January and April with 25.23 and 35.76 ºC respectively. In Sokoto, the least and highest temperatures were recorded in the months of January and April with 26.28 and 36.05 ºC respectively. The hottest month in the studied region is April. For the rainfall/precipitation, the minimum mean values of **2.02, 1.19 and 1.30 mm** were obtained in Kaduna, Katsina and Sokoto respectively, while the maximum values of **5.24, 2,53 and 2.39 mm** were obtained respectively. The month with the highest amount of rainfall in all the cities is August. **8.97, 6.45 and 6.52 mm** highest values of precipitation were recorded in Kaduna, Katsina and Sokoto cities respectively. The implications of these findings on communications are that; installed out-door communication hardware such as the transmitting tower and antenna, transmitter modules and wave guides could be subjected to perturbations that will affect their optimal performances and durability during the months of excessive temperature and rainfall. For the month of December, transmitted radio signals are prone to experience tropospheric scattering if they are trapped in the ducts during the harmattan seasons over the study areas. In addition, there were high rising in the temperature values especially in the last fourteen years. Communications' scientists and engineers should factor the effect of climate change in equipment design to ensure reliability and safe cost while special preventive maintenance be carried out in the months of April and August over the studied areas

ACKNOWLEDGEMENTS

We would like to acknowledge the Nigerian Tertiary Education Trust Fund (TETFUND) for sponsoring this research project under the TETFUND Institutionally Based Research (IBR) Projects. Special appreciation goes to the management of Federal University Dutsin-Ma, for approving and facilitating the award.

REFERENCES

Adewunmi,A. S., Alade, M. O., and Adewumi H. K. (2018), Influence of Air Temperature, Relative Humidity and Atmospheric Moisture on UHF radio Propagation in South Western, Nigeria, *International Journal of Science and Research vol. 4(8), 1-5*

Ayantunji, B.G. (2018), *Atmospheric humidity and its implication on UHF signal over Gusau*, North west, Nigeria Int. J. of Sc. & Eng. Research., 9 pp. 41-53

Ajewole, M. O., Akinbolati, A., Adediji, A.T. and Ojo J.S. (2014), *Precipitation effect on the coverage areas of terrestrial UHF television stations in ondo state, Nigeria,* Int'l J. of Eng'g and Tech., 4 pp. 525-535

Akinbolati, A., and M. O. Ajewole (2020) "Investigation of Path Loss and Modeling for Digital Terrestrial Television over Nigeria," *Elsevier Heliyon, e04101*,, https://doi.org/10.1016/j.heliyon.2020.e04101

Akinbolati, A., Ajewole, M.O. and Adediji, A. T. (2018), Path Loss Prediction Modeling for Digital Terrestrial Television (DTTV) in the Tropical Rain Forest Zone of Nigeria, *FUDMA Journal of Sciences*, 2 (3), 2-8

Akinbolati, A., Akinsanmi, O., Ekundayo, K. R. (2016). Signal Strength Variation and Propagation Profiles of UHF Radio Wave Channel in Ondo State, Nigeria, *I.J. Wireless and Microwave Technologies, 2016, 4, 12-28,* https://doi.org/10.5815/ijwmt.2016.04.02

Aweda, F. O.; Agbolade, J. O., Oyewole, J.A. and Sanni, M. (2021). *Seasonal Variation of Some Atmospheric Parameters in Fresh Water Swamp and Sudan Savanna areas of Nigeria. Nigerian Journal of Technology (NIJOTECH)*, 40(4): 740 –750.

Ayegba, A., Ojo, J.S. and Adediji, A.T (2022), *Statistical Analysis of Atmospheric parameters, noise temperature and digital terrestrial television signal strength over Jos Metropolis, Plateau State, Nigeria*, Heliyon, 8 (2022), Article 12345, https://doi.org/10.1016/j.heliyon.2022.e09988

Boulahya, M., Cerda, M. S., Pratt, M., & Sponberg, K. (2005). Climate, communications, and innovative technologies: potential impacts and sustainability of new radio and internet linkages in rural African communities. In *Increasing Climate Variability and Change: Reducing the Vulnerability of Agriculture and Forestry* (pp. 299-310). Dordrecht: Springer Netherlands.

Bothias, L (1987), Radio Wave Propagation, McGraw-Hill Inc. New York St. Louis San Francisca Montreal Toronto. Pp. 1-50

Camberlin, P., & Diop, M. (2003). *Application of daily rainfall principal component analysis to the assessment of the rainy season Characteristics in Senagal. Climate Research*, *23*, 159–169. http://doi.org/10.3354/cr023159

Charles L. Sanou, Daniel N. Tsado, André Kiema, Julia O. Eichie, Gildas L.M. Guidigan (2018); Diagnostic study of climate change and variability for the period 1981-2016 in South-eastern Burkina Faso, West Africa, *Conference paper at Unlocking Sub-Sahara African Potentials for Sustainable Development in the 21st Century, Nassarawa State University, Keffi (NSUK),* Nigeria

Ale, F., Olufemi, A. A., Ibrahim, H.D., Ayegba, A., Olu J. J., Fonyuy, W. D., Victor, A., (2017). *Investigation on Influence of Atmospheric Temperature and Relative Humidity on FM Radio Signal Strength: A Case Study of FM Abuja. International Journal of Scientific and Technology Research 6(11).*

The European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5, 2024.

IPCC, (2013). Summary for Policymakers. In: Climate Change 2013: *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. *CEUR Workshop Proceedings*, *1542*, 33–36. http://doi.org/10.1017/CBO9781107415324.004

Iheanyichukwu, A. C., Ike, A.O. and Chukwuemeka, P.C. (2020), *Investigating the impact of weather parameters on signal strength of satellite Dish in Enugu metropolis*, Int'l J. of Astrophysics and Space Sc, 8 (2). pp. 11-15, https://doi.org/10.11648/j.ijass.20200802.11

Kenedy, G. and Bernard, D (1992), Electronic Communication System, McGraw-Hill/ Macmillan, Singapore, Pp 80-85.

Mmahi, N. O., Akinbolati, A., Nkechiamaka, F. N., Akpaneno, A. F., Joseph, E. and Ekundayo, K. R. (2021): Studies on Surface Radio Refractivity Over Some Selected Cities in North Central, Nigeria, FUDMA Journal of Sciences, 5 (4), https://doi.org/10.33003/fjs- 2021-0504-774

National Oceanic and Atmospheric Administration (NOAA, 2024).

Ojo, O. L., J. S. Ojo and P. Akinyemi, 2017. "Characterization of Secondary radio climatic variables for microwave and millimeter wave link design in Nigeria", *Indian Journal of Radio and Space Physics*, vol.46, pp.83-9

Sheu, A.L. (2021), *The impact of atmospheric conditions on satellite signals between (10GHz – 14 GHz) at ku band in low latitude region of Oyo, South Western, Nigeria FJPAS*, pp. 85-93

Sabiru , A. Y., Akinbolati, A.,. Ikechiamaka, F. N. and Abe, B.T. (2024) "Characterization of some Secondary Radio-Climatic Factors for Reliable Radio Wave Propagation and Link's Design over North Western Nigeria" *Advances in Space Research (Elsevier),* vol.74(2) , pp.890-898. , https://doi.org/10.1016/j.asr.2024.04.038

United Nations Sustainaible Development Goals (2024), Reports of UN-SDGs.