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Historical trends and impacts of climate change on temperature, rainfall and humidity in Nigeria: A century-long analysis

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Abstract:
The alarming rate of the increase in global greenhouse gas (GHG) emissions and the resulting climate change can cause increases in average national temperatures, leading to increase in evapotranspiration and uncertainty in the intensity and frequency of weather parameters. Based on reliable data and information from literature, this paper provides comprehensive analysis of historical trends in global GHG increase, local atmospheric temperature, relative humidity (RH) and precipitation changes. The results of the study provide valuable insights on the effects of global warming on variations in local weather parameters (temperature and precipitation) in Nigeria over the past decades. The paper shows that there is direct correlation between global GHG emissions/concentration and national average temperatures, with no clear relationship between the average national temperature with RH and amount of rainfall. Thus, it is essential to continue monitoring and reporting climatic data to better understand the impacts of climate change on Nigeria's weather, and to develop effective strategies for mitigation and adaptation efforts. This is expected to broaden and deepen both short-term and long-term risk management in Nigeria and support national climate planning process.

Keywords: *Emissions, Greenhouse gas, Precipitation, Temperature rise, Weather*

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) demonstrates the unequivocal link between human-induced greenhouse gas emissions and the occurrence of climate-related extreme events. Climate change is a complex environmental problem because of its long-term uncertain timeframe, scales of occurrence, differential impacts and vulnerabilities. Nigeria, like many parts of the world, is experiencing climate change. In particular, the country is becoming warmer. Various studies show that annual and seasonal timescales indicate a significant positive increase in temperatures in Nigeria. The mean temperatures have been consistently increasing throughout the country in the last five decades and have been rising significantly since the 1980s, with a change of 1.01°C in the linear warming for the period 1951 - 2005. The linear warming for the same period for 30-year averages on a decadal slice further revealed positive changes in temperature by an average of 0.2°C/decade. The mean annual variability and trend of rainfall over Nigeria in the last few decades depict the existence of a number of inter-annual fluctuations that have been responsible for dry and wet years or extreme climate events such as droughts and floods in many parts of the country and at different times [1, 2, 3].

The extreme weather events with unusual rains and persistent record breaking floods in many parts of the country also threaten good harvest. More worrisome is the increasing knowledge that the country will be subject to consistent changes in rainfall and temperature conditions, particularly towards the end of the century. Recent analysis of anticipated future climatic trends for the country, as captured in the Third National Communication, indicates that for 2050 and 2070, the minimum temperature increase could range from 1.48°C to 1.78°C and the maximum temperature increase of about +3.08°C to +3.48°C compared to the baseline of 1990. A general increase in the number of days of rain and days with extreme rainfall events that may generate floods are projected over most ecological zones of the country except in the northeast Sahel zone, where the scenario analysis suggests fewer extreme events related to rainfall and flooding [1, 4, 2].

Thus, it is evident that Nigeria's climate has been changing, due to increases in global average greenhouse

gas (GHG) emissions, concentration and temperature [3]. The duration, frequency and intensity of rainfall have increased in some places in Nigeria, producing large runoffs and flooding [5]. Climate and disaster risk assessment are crucial for national or sectoral planning processes, and this requires up-to-date and relevant information and data related to climate change and development. The scope of the work cover past, current and possible future observations and analysis of data on global GHG emissions and concentrations, national temperature, humidity and precipitation. The research questions include:

a. What are the primary drivers of climate variability (temperature/precipitation/humidity patterns) in Nigeria?
b. How has climate variability in Nigeria changed over the past century?
c. What are the projected future changes in climate variability for Nigeria?

The aim of the paper is to identify the impact of climate change and global warming on the Nigeria's weather, specifically national atmospheric temperature, humidity and precipitation.

The objectives of the paper are:

a. To use reliable data from literature to identify climate change impacts on Nigeria.
b. To use graphical presentation to indicate the influence of climate change on Nigeria.
c. To suggest effective management plan and adaptation measures to manage climate change effects.

There are a number of studies that provide useful evidence and discussion of the various impacts of climate change on Nigeria's weather. The vast majority of the literature that provides evidence of climate change impacts, however, either focused on different weather parameters or limited geographic extent, or on specific sectors or regions of the country. However, discussion on the literature often takes the form of mitigation and adaptation recommendations, rather than discussing the actual mechanism of the impacts.

The World Bank Group [6] provides country profile of the impact of climate change in Nigeria, and gave important observation, and Climate and climate-related information is largely drawn from the Climate Change Knowledge Portal (CCKP), a World Bank Group online platform with available climate data and analysis based on the latest Intergovernmental Panel on Climate Change (IPCC) reports and datasets. Data sources under this study are limited to the CCKP, and precipitation analysis did not look into the actual cause of rainfall variability.

Rufai and Mansur [7] in "A Review on Sectoral Impact of Climate Change in Nigeria", looked at the difference between the terms climate change and global warming, identify the causes of climate change, and highlight the impact of climate change on various sectors in Nigeria. This is aimed at providing a useful starting point for developing more effective forms of Climate Change Communication to help bridge the gap between the scientific community and the public, with the hope of fostering effective mitigation and adaptation measures.

Odjugo [8], on "The impact of climate change on water resources; global and Nigerian Analysis", investigated the impact of climate change on global and regional water resources. The study found that rainfall has decreased by 92 mm, and temperature increased by 0.8^{o}C since 1960. However, the paper was limited to atmospheric temperature and rainfall only (without detailed observation of global GHG trends), and historical data for temperature and rainfall were limited to a short range of 1960-2004.

Oyewole, *et al.* [9] used a 30-year period (1979-2010) to analyse annual rainfall and relative humidity for eight scattered stations (Sokoto, Kano, Minna, Maiduguri, Lagos, Port-harcourt, Calabar, and Ilorin) across Nigeria. The result shows that there was an increase in rainfall of about 18%, and relative humidity shows no significant change within the study period. Here, the study was limited to a relatively short period of time.

Animashaun, *et al.* [10] studied the spatiotemporal variability of rainfall at 33 sub-basins of the Niger Central Hydrological Area (NCHA), Nigeria, for a data length of 105 years (1911-2015). The results showed that except for sub-basins 21 and 22 (which are positive), all other sub- basins have a negative trend signifying a decrease in trends of rainfalls. This implies that a decreasing trend (at varying levels of significance) was recorded across the sub-basins except for sub-basins 21 and 22. Here, their study was limited to only Niger central and does not represent Nigeria as a country.

Efeizomor [11] aimed at analyzing the historical data on temperature and precipitation extremes in Nigeria from 1900-2020. The study focused on identifying the trends and patterns of temperature and precipitation extremes in Nigeria over the last century, as well as the spatial and temporal variability of these extremes. The analysis provided valuable insights into the impacts of temperature and precipitation extremes on various sectors of the Nigerian economy, and the implications of these impacts for policy makers, stakeholders, and the general public. However, the study did not clearly relate global historical changes in GHG concentrations to the variations in the temperature and precipitation in Nigeria and hence, does not indicate the actual nexus between changes in global climate parameters with local changes.

Audu, *et al.* [12] examined the trends of rainfall over the North-Eastern part of Nigeria from 1985 and 2020 (36 years). The data used were the annual empirical rainfall records for Yola, Gombe, Maiduguri, Jalingo, Bauchi and Potiskum obtained from the Nigerian Meteorological Agency (NiMet), Abuja. Mann-Kendall (M-K) tests together with Sen's Slope estimator were employed for the analysis. The results indicated substantial increases in the annual rainfall over Maiduguri (10.6); Bauchi (21.9966); Gombe (1.6754); Jalingo (8.7904) and Potiskum (1.0971); while Yola (-1.0062) had a negative magnitude. The results therefore established that the annual rainfall over a greater part of North-eastern Nigeria (5/6 stations) consistently increased over time. However, the scope of the study was limited to a particular region.

Idowu, *et al.* [13] presented the Impact of Climate Change in Nigeria, without any historical data and an extensive focus on Nigeria's weather. Abaje and Oladipo

[14] looked at changes in the Temperature and Rainfall Conditions Over Kaduna State, Nigeria. This has limited the geographical extent of the study. Other works such as Aich, *et al.* [15], Durodola [16], Olaniyi, *et al.* [17], Okon, *et al.* [18] and Aneni and Aisagbonhi [19], examined the impact of climate change in Nigeria on a single sector/area such as flood, Agriculture and Food Security, ecosystem, sustainable development.

Summarily, while existing literature offers valuable insights into climate change's effects on Nigeria, there is a notable gap in studies that correlate global GHG trends with local weather parameter changes over extended periods. Addressing this gap is essential for developing a comprehensive understanding of how global climate dynamics influence local weather patterns, thereby informing more effective mitigation and adaptation strategies.

1.1 Climate change

Climate change is a broad term used to refer to changes in the Earth's climates, at local, regional, or global scales, and can also refer to the effects of these changes. In recent decades, the term 'climate change' is most often used to describe changes in the Earth's climate driven primarily by human activity since the pre-Industrial period (beginning from 1850 onwards), particularly the burning of fossil fuels and deforestation, resulting in a relatively rapid increase in carbon dioxide (CO_2) concentration in the Earth's atmosphere [20, 21]. Climate change has been defined by Intergovernmental Panel on Climate Change [22] as a change in the state of the climate that can be identified statistically by changes in the mean and/or the variability of its properties and that persists for an extended period typically decades or longer.

Global warming is a term often used interchangeably with climate change, as it is one of the most important measures of global changes. Global warming refers to the rise in average global temperatures, which is linked to significant impacts on humans, wildlife, and ecosystems around the world. Because there are more factors and impacts than only rising surface temperatures, the term climate change is used to include these additional impacts. There is strong consensus among active climate scientists, representing 97%, that human influence has been the dominant cause of observed warming trends since the 20th century [3, 23]. This change in global average temperature seemingly small but consequential and rising, leading to increasingly sweltering heat waves, causing weather-related fatalities across the world [24].

Over the last two centuries, humans have significantly influenced the atmosphere, responsible for constantly increasing CO_2 emissions due to demographic and economic growth. The levels of CO_2 between 1860 and 1970 have almost remained constant at 285 ppm, with an increase of less than 2%. From 1970 to 2021, the level of GHG has accelerated by almost 70%, reaching a concentration of 475 ppm. This has resulted in a corresponding increase in global average temperature to 27.3^{o}C (about 1.07^{o}C) in 2021. The CO_2 concentration, mainly due to combustion of fossil fuels in various sectors (energy, transport, industry, agriculture) is unprecedented in recorded history. Scientists have reported that the world needs to return to a 'safe' concentration of 350 ppm (equivalent to a temperature increase of 1.5^{o}C above pre-industrial level) by 2100 in order to stabilize global warming [25 - 33]. Figure 1 shows the global historical trends in CO_2 emissions ($mtCO_2$), average CO_2 concentration (ppm) and average temperature rise above the pre-industrial level (Degree Celsius, ^{o}C).

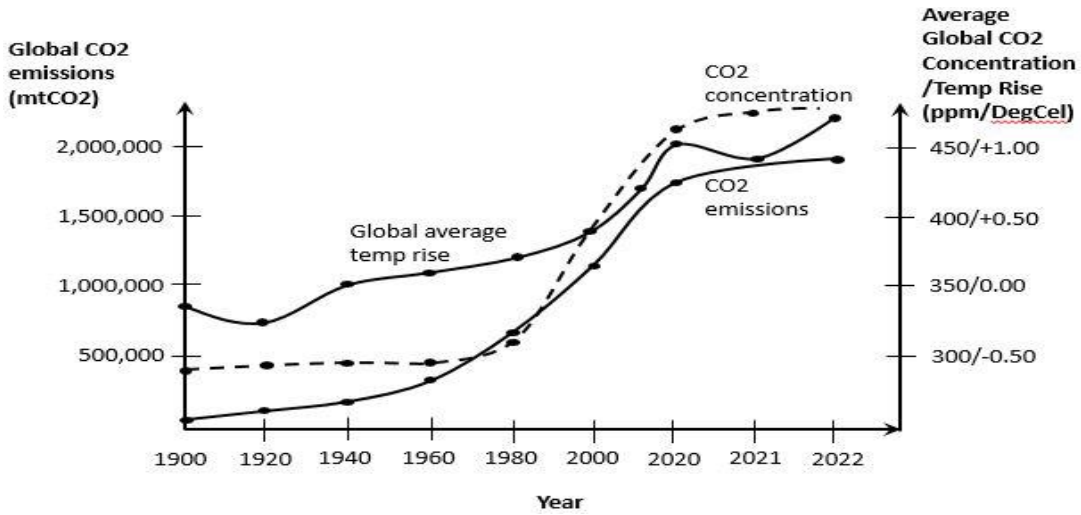

Figure 1: Historical Global CO_2 emissions and average concentrations and temperature rise [25, 34, 32]

In 2018, GHG emissions in Nigeria were estimated at 347 $MtCO_2e$. The energy sector represented the largest source of GHG emissions in the country (60% of total emissions), followed by the Agriculture, Forestry and Other Land Use (AFOLU) (approximately 25%); the waste (9%) and the Industrial Processes and Other Product Use (IPPU) (5%) sectors. With this level of emissions, Nigeria contributes less than 1% of global carbon emissions [35]. However, as the Nigerian economy is expected to grow rapidly to meet the demands of its large population which is expected to reach 402 million by 2050 [36], the country is expected to emit more GHGs in the future. Nigeria's GHG

emissions in 2030 are expected to reach 435 million tonnes of CO_2 equivalent, representing a 31% increase in total emissions between 2018 and 2030 [37]. This projected rise in GHG emissions calls for more ambitious future mitigation efforts in line with the country's international climate commitments and to address the challenges that climate change poses to Nigeria's development.

Climate change has significant effects on weather, environment, agriculture, humans, as well as animals [24]. According to the European Commission [38], climate change consequences have effects on the natural world (High temperatures, Drought and wildfires, Availability of fresh water, Floods, Sea-level rise and coastal areas, Biodiversity, Soils, Inland water, Marine environment), on social threat (Health, Vulnerable population, Employment, Education), to business (Infrastructure and buildings, Energy, Agriculture and forestry, Insurance, Tourism and Cross-cutting issues for businesses), threats to territories (The Arctic, Northern Europe, North-western Europe, Central and eastern Europe, Mediterranean region, Cities and urban areas, Mountain areas). These concerns necessitated series of international discuss that issued urgent calls for a global treaty for a feasible solution.

The changes in global greenhouse gases are projected to change local, regional and global climate and climate-related parameters such as temperature, humidity, precipitation, soil moisture and sea level [51]. The effects of climate change on weather are highlighted below.

1.2 Higher average temperatures

Human activities, including the burning of fossil fuels, land-use change and agriculture, are increasing the atmospheric concentrations of greenhouse gases, thereby increasing the heat trapping ability of the air, which tend to warm the atmosphere. Global mean surface temperature has increased in the range 0.3-0.6°C since the late 19th century, and by 1.1°C in the 21st century, a change that is unlikely to be entirely natural in origin. This change in global average temperature (seemingly small but consequential and climbing) means that, each summer, we are likely to experience increasingly sweltering heat waves. Currently, strings of record-breaking days are being connected to new long-term trends, which are especially problematic in regions where infrastructure and housing have not been built with intensifying heat in mind. Some models project an increase in global mean surface temperature relative to 1990 of about 2°C by 2100 [3, 39, 24].

1.3 Changes in humidity

Humidity denotes the amount of water vapor in the air. Humidity determines whether the air is wet enough to form clouds that create rain. Relative humidity provides a percentage, giving an idea of how close the air is to being saturated. Relative humidity also depends on the temperature of the air. A warmer air can hold more water (relative humidity drops), because it absorbs more moisture. Thus, atmospheric air can hold more moisture as the atmosphere becomes warmer due to climate change. This can lead to rising absolute humidity levels, which can make spaces uncomfortable. Humidity governs the increasing likelihood of heavier rainfall and more dangerous heatwaves. Working together, humidity and temperature can be thought of as the twin pillars of climate change [40, 41].

1.4 Changes in rainfall pattern

Climate change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources. Current climate models indicate that rising temperatures will intensify the Earth's water cycle, increasing evaporation. Increased evaporation will result in more frequent and intense storms, but will also contribute to drying over some land areas. As a result, storm-affected areas are likely to experience increases in precipitation and increased risk of flooding, while areas located far away from storm tracks are likely to experience less precipitation and increased risk of drought. However, the water holding capacity of air increases by about 7% per 1°C warming, which leads to increased water vapor in the atmosphere. Hence, storms, whether individual thunderstorms, extratropical rain or snow storms, or tropical cyclones, supplied with increased moisture, produce more intense precipitation events. Therefore, warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events [3, 42, 43].

2. Methodology and Data

The fundamental approach to the study is the analysis of historical data over a relatively long period of time. The study area, data collection and analysis methods are discussed in the following sections.

2.1 The study area

Nigeria has a total land mass area of about 923,768 km^2 and is situated between latitudes 4^{o}N and 14^{o}N, and between longitudes 3^{o}N and 14^{o}E (Figure 2). Nigeria has only two distinct seasons (dry and wet) because it is a tropical country. The dry season is marked by low relative humidity and higher temperatures than during the wet season due to strong winds from the Sahara Desert. Nigeria's mean annual temperature ranges between 17°C to 37°C in the south to 12°C to 45°C in the north. The highest temperatures in Nigeria occur during the dry season, and vary little from the coast to inland the country's areas. For Nigeria, temperature increases of 0.03°C per decade were observed between 1901–2016, with stronger increases occurring over the last 30 years of 0.19°C per decade. Rainfall magnitude and frequency in Nigeria relies primarily on the latitude. The southern region generally sees convectional rains because of the region's closeness to the equatorial belt. Rainfall for the country varies from a very wet coastal area with annual rainfall greater than 3,500 mm to the Sahel region in the northwest and north-eastern parts, which receive an annual rainfall less than 600 mm. The annual variation of rainfall, particularly in the northern parts, is large [4, 44, 45, 46].

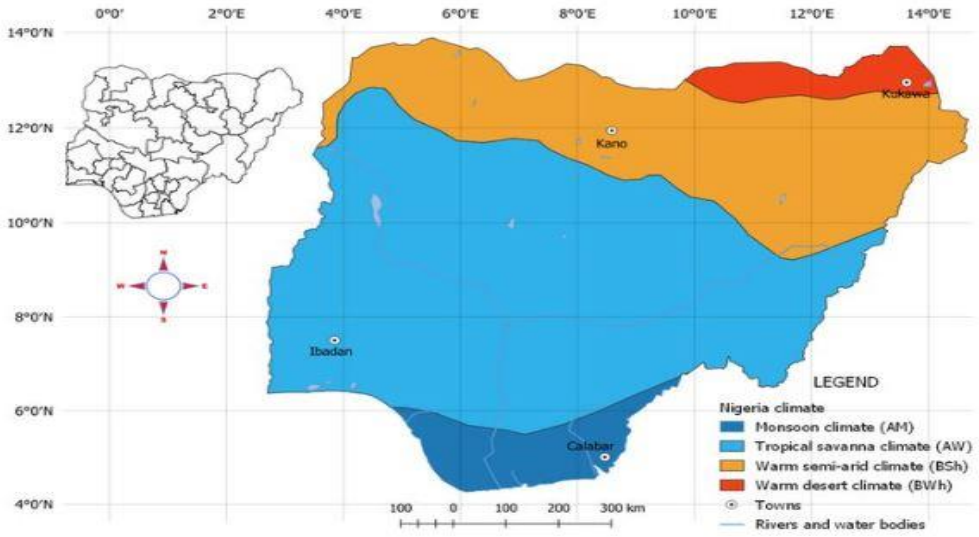

Figure 2: Map of Nigeria showing location and weather conditions [44]

2.2 Data sourcing and analysis

Historical datasets (1900-2020) on global CO_2 emissions, Nigerian national temperatures, humidity and rainfall were collected from literature for descriptive analysis (Sections 1.1 and 3). The secondary climatic data of Nigeria were collected from various reliable sources, particularly the World Bank's Climate Change Knowledge Portal (CCKP) and the European Environmental Agency. Changes in the climate parameter trends were presented on graphical figures, which were observed and analysed for proper discussion.

3. Results and discussion

Due to a combination of political, geographic, and social factors, Nigeria is recognized as highly vulnerable to the impacts of climate change. Nigeria is at risk to numerous natural hazards and prone to various climate change impact [47, 48]. Changes in rainfall patterns are predicted, with increasing drought, floods or intense storms in many regions [49]. Nigeria is classified as one of the ten most vulnerable countries to the impacts of climate change and natural hazards [50]. However, not every place will experience the same effects: Climate change may cause severe drought in one region while making floods more likely in another. Thus, the discussion is based on the average impact of climate change on Nigeria.

3.1 Global CO_2 concentration trends

Figure 3 shows the historical trend relationship between global average GHG concentration and average temperature, against the average national temperature for Nigeria. The global GHG concentration has been roughly constant up till 1970s where a significant increase started until around year 2020, where the rate of increase began to reduce. However, average global temperature changes keep rising since the 1920s, meanwhile average national temperatures has been roughly constant between 1900 and 2000, where it began to respond to the global GHG concentration up till year 2020. From year 2020, both global and national temperatures began to drop again, probably due to global and local climate change mitigation actions.

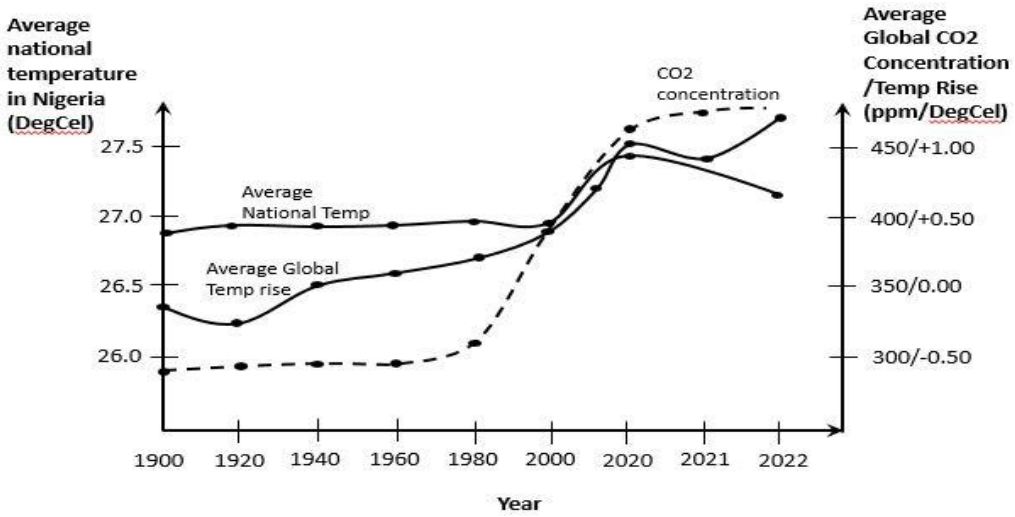

Figure 3: Historical Average Global CO_2 concentration/Temperature Rise, and Average Local Temp in Nigeria [25, 34, 51]

3.2 Trends in Local weather parameters

Between 1900 and 2022, Nigeria experienced a temperature increase of between 0.52-1.2°C in its average annual temperature, with a significant increase occurring around the 1990s and the greatest increase occurring in the northern region (Figure 4). The mean annual temperature is projected to increase by 1.1 to 2.5°C by 2060, with an extreme increase expected in the north of Nigeria. Precipitation intensities showed fluctuating patterns before the national average temperature began to rise. Around the 1990s, precipitation levels started trending upward, seemingly responding to the overall increase in national temperatures [6, 51, 52].

In Nigeria, precipitation trends suggest a high degree of variability/uncertainty, and the last several decades have seen a decrease in the predictability for seasonal rains across Nigeria. Although the rainfall trend is showing a fluctuation in intensity from the 1930s, rainfall on the overall has decreased across the country. Between 1950 and 1990, the country experienced an overall decrease in precipitation of 18mm, or 4.5 mm per decade. Between 1901 and 2015, rainfall amount in Nigeria dropped by 81mm, while temperature increase was significant, precisely, 1.2°C. Nigeria is projected to experience increased rainfall variability and extreme rainfall events across most regions, with southern areas expecting continued variations. Additionally, sea levels are anticipated to rise by 0.4 to 1.0 meters by 2100, exacerbating flooding in coastal regions. These changes indicate that Nigeria's climate will continue to be significantly impacted by climate change [5, 8, 9, 11, 53, 51].

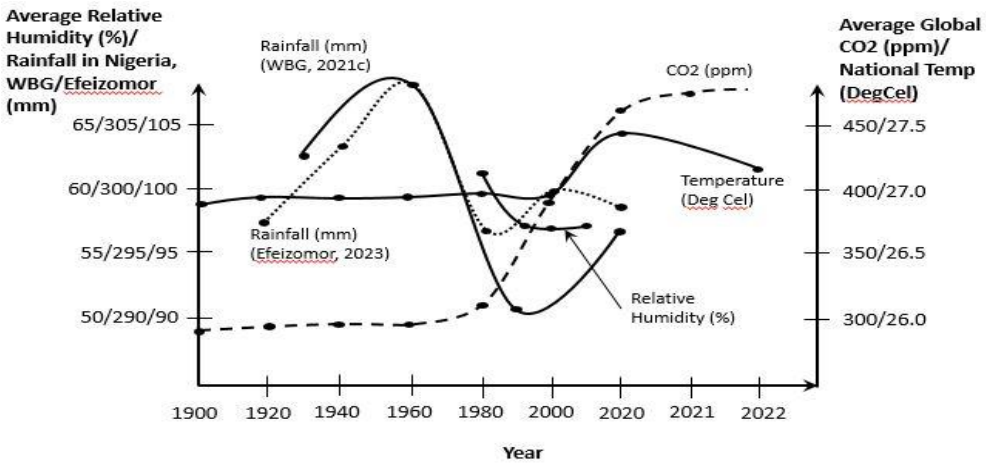

Figure 4: Historical data of Global GHG concentration, Local average atmospheric Temperature, Humidity and Rainfall in Nigeria [25, 51, 52, 11, 9].

Although the amount of atmospheric moisture will theoretically increase as expected, the average relative humidity (based on data from eight stations across the country) actually decreased between 1980 and 2010 [9]. This is due to the fact that, although a warmer world causes more evaporation, a warmer atmosphere can hold more water vapor, widening the gap between the saturation point and the absolute humidity. Although there is a decrease in relative humidity, specific humidity should theoretically increase, since a warmer air can hold more water vapor. Since land usually warms faster than ocean, relative humidity over land decreases compared to over ocean (where most evaporation happens). Also due to the warming over the ocean, specific humidity will also increase over the oceans.

4. Conclusion

Although local average atmospheric temperatures increase significantly in Nigeria (from the late 1990s) as a result of GHG emissions and global warming, there is obviously no corresponding increase in precipitation as expected. However, there is rising concern in reduced predictability (increased uncertainty) of rainfall patterns, implying the impact of climate change on rainfall patterns within the country. Rainfall for the country is highly variable and analysis indicates no clear trend in precipitation. Climate projections for the coming decades reveal a significant increase in temperature over all the ecological zones, along with higher degree of uncertainty around future rainfall amount and frequency, and variability. To reduce the risk of climate change to Nigeria, both policy and technology mechanisms must be given special consideration and proper implementation in the context of sustainable development.

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