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Spatio-Temporal Variation of Rainfall, Temperature and Vegetation on Maiduguri and Environs

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ABSTRACT

This study examines in detail the 10-year spatio-temporal variation in rainfall, temperature, and vegetation in Maiduguri and its environs. These include determining trends in rainfall, temperature, and vegetation over the 10-year period; examining the relationships among temperature, rainfall, and vegetation; and examining the relationship between surface temperature and rainfall. A simple linear regression analysis was deployed to analyse the data. The result shows that the regression coefficient (R2) of rainfall and vegetation is said to be R2=0.494, which indicates that there is a strong relationship between rainfall and vegetation, whereby the vegetation strongly depends on the rainfall. The regression coefficient (R2) for the relationship between temperature and vegetation in Maiduguri is 0.054, indicating a weak association and suggesting that vegetation in Maiduguri is not dependent on surface temperature. The final result concerns the relationship between temperature and rainfall, with an R2 of 0.006, indicating a weak association between the variables. This suggests that rainfall in Maiduguri is independent of local temperature.

Keywords: Rainfall, Temperature, Maiduguri and Vegetation

INTRODUCTION

The temperature of a body is determined by the balance between incoming and outgoing radiation and by the conversion of this energy into sensible and latent heat. Therefore, the temperature of a body is the degree of hotness or coldness of a body or place as measured by a thermometer (Animashaun *et al.*, 2020). The seasonal variation in temperature results mainly from the seasonal variations in the amount of insulation (Incoming Solar Radiation) received at any given location on the globe. Temperature tends to increase during summer when insulation receipts are lowest. The global climate has changed rapidly, with global mean temperature increasing by 0.7 °C over the last century (IPCC, 2007). However, the rates of change differ significantly across regions. This is primarily due to the varied land surfaces, with different surface albedo, evapotranspiration, and carbon cycle characteristics, which affect the climate in different ways (Ugonabo *et al.*, 2023).

Rainfall has been of primary importance in most studies on climate science, with its variability exerting a significant impact on society (Binbin *et al.,* 2020). Rainfall is liquid water in the form of droplets that have condensed from atmospheric water vapour and then precipitated. Rainfall is a significant component of the water cycle and is responsible for depositing most of the fresh water on the earth. Rainfall in Northeastern Nigeria is controlled by the West African Monsoon (WAM) (Itiowe et al., 2019). Each year, during the boreal summer, an air mass dominates the region in response to a low-pressure belt developing over North Africa, with a parallel high-pressure belt off the Gulf of Guinea. Once the monsoon has commenced, rainfall is primarily driven by instability and by convection cells developing in the lower atmosphere, with the land surface influencing their characteristics (Nouaceur, 2016).

Vegetation is the primary producer of any ecosystem. Therefore, natural vegetation is one of the most important components of Earth, as it supports all forms of life. They provide food, oxygen, fertility, and, finally, the life of all living beings on Earth. The growth and vigour of the vegetation cover are controlled by factors such as climate, soil and topography (Yelwa *et al.*, 2019). In general, climate factors are the most influential of the three factors. Climatic factors, such as rainfall and surface temperature, determine the availability of moisture for physical, biological, and chemical processes in plants, ultimately supporting plant health (Akinbobola *et al.*, 2023). Hence, with seasonal variations in rainfall and temperature, vegetation growth can change. This depends on the level of water and heat stress to which the vegetation is exposed.

However, by integrating these climatic variables (temperature, rainfall, and vegetation), research will be conducted to determine a 10-year relationship among them, using spatial and temporal data from 2002 to 2012. Global warming, changing weather patterns, and rising sea levels are linked to climate change, which increases the risk of extreme temperatures and low rainfall and ultimately affects agricultural production. The effects of climate change are unprecedented in scope and scale and are felt globally. The northern region of Nigeria, particularly Maiduguri, is highly susceptible to adverse environmental changes driven by climate change, including changes in temperature and precipitation (Akinbobola *et al.*, 2023). Therefore, there is a need to investigate the spatio-temporal variation in temperature, rainfall, and vegetation in Maiduguri. The primary aim of this study is to evaluate the spatio-temporal variations in temperature, rainfall, and vegetation over ten years (2002–2012) in Maiduguri. Specifically, the study seeks to (i) determine the trends in temperature, rainfall, and vegetation within the study period; (ii) examine the relationship between temperature and rainfall; (iii) assess the relationship between temperature and vegetation; and (iv) analyse the relationship between rainfall and vegetation dynamics in the area.

In line with these objectives, the study is guided by the following research questions: What are the temporal trends in temperature, rainfall and vegetation during the period under review? What is the nature of the relationship between temperature and precipitation in Maiduguri between 2002 and 2012? How does temperature variation relate to changes in vegetation cover within the study area? Furthermore, finally, what is the relationship between rainfall patterns and vegetation dynamics over the ten years? The relationship between changes in climatic variables and vegetation cover is used as an indicator of crop production status under changing climatic conditions. Analysis of vegetation dynamics in relation to climatic variables over long periods helps forecast future climatic conditions for agricultural management. The pattern and availability of precipitation in the environment are characterised by pronounced seasonal variation and are strongly influenced by topographic features. Among these factors, location appears to strongly influence the spatial and temporal variation in rainfall and other climatic parameters.

Several studies have examined the spatio-temporal variation in temperature, rainfall, and vegetation in Maiduguri. Research conducted by Bibi et al. (2004) on spatial-temporal variation and prediction of rainfall in Northern Nigeria from 1980 to 2006. The prediction throughout the study area shows a slight underestimation of precipitation in the drier months and an overestimation in the wetter months and the variation is consistently underestimated. The agreement between the prediction and the reference data increases as the wet season progresses, reaching a peak in September, after the peak of the wet season.

In Akinsonola and Oginjobi's 2014 study on the analysis of rainfall and temperature variability over Nigeria, a statistical approach was used to determine the confidence limits, coefficient of kurtosis, and coefficient of variation for rainfall and temperature over three decades (1971-2010). Their results revealed a significant increase (positive trend) in the country's temperature at the 95% confidence level. Additionally, rainfall has increased over the year under consideration. The rainfall anomaly across all stations exhibited a composite pattern, with some dry years alternating with wet years across all seasons. More recently, Abatcha et al. (2024) examined 31 years of rainfall data (1992–2023) in Maiduguri and found moderate variability (CV = 28.3%) and a significant upward rainfall trend ($z = 2.773$, $p = 0.005$). The study identified rainfall peaks in August and increasing intensities in June and August, suggesting changing rainfall dynamics and implications for agriculture and water management. Complementing this, Bukar et al. (2024) investigated the seasonal variability of vegetation using Landsat-derived NDVI data (2002–2023). Their findings indicated slight but positive trends in vegetation recovery during both rainy and dry seasons, influenced by climatic fluctuations and human factors such as insurgency and the influx of internally displaced persons (IDPs). They concluded that population pressure, fuelwood extraction, and disrupted farming activities contributed to vegetation stress, while localised greening and conservation initiatives fostered partial ecological recovery. Building on these insights, Umar et al. (2025) assessed the 2024 flood in Maiduguri and found a significant upward rainfall trend

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(Sen’s Slope = 10.27 mm/year; $p < 0.01$) and a high Rainfall Anomaly Index (RAI = 3.07), indicating intensifying precipitation. The authors reported severe human and infrastructural impacts, attributing the crisis to weak governance, poor drainage systems, and limited early-warning mechanisms, and emphasised the need for climate-informed urban planning and adaptive resilience strategies.

Study Area

The study area is located within Maiduguri, the capital of Borno State, northeastern Nigeria. Maiduguri covers an estimated land area of approximately 543 km² (Jimme et al., 2020), making it the largest urban centre in the North-Eastern region of Nigeria. Geographically, the city lies between latitudes 11°48′N and 11°55′N and longitudes 13°04′E and 13°14′E (Fig. 3.1), at an average elevation of about 355 m above mean sea level (Mukhtar et al., 2019). Maiduguri is situated within the Lake Chad Basin geological formation, which formed due to tectonic downwarping during the Pleistocene epoch (Waziri, 2007). Climatically, the area is characterised by a semi-arid Sudan–Sahelian climate, with distinct wet and dry seasons. Recent analysis of long-term rainfall records (1992–2023) indicates that Maiduguri experiences a mean annual rainfall of approximately 519.34 mm, with annual totals ranging from 292.7 mm to 838.2 mm, reflecting considerable interannual variability (Abatcha et al., 2024). The rainy season typically peaks in August, with the highest mean monthly rainfall of approximately 196.66 mm (Abatcha et al., 2024). According to the 2006 National Population Census, Maiduguri had an estimated population of about 1.275 million, predominantly comprising Kanuri, Shuwa, Babur-Bura, and other indigenous and non-indigenous ethnic groups, distributed across approximately 10,334 households (NPC, 2007).

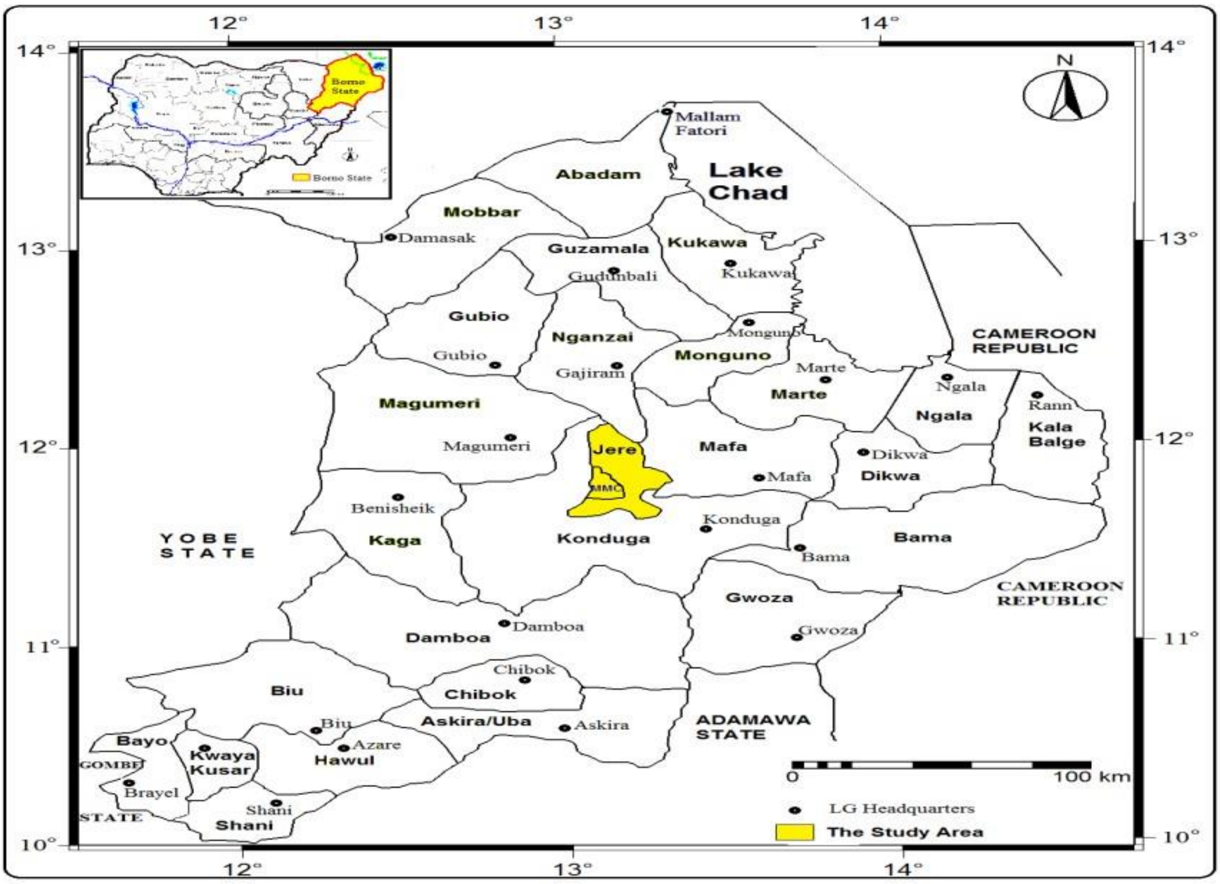

Fig.1: A map showing the study area.

In carrying out this research work, a ten (10) year monthly data set of rainfall, temperature and vegetation is required, where raw monthly data is obtained and later converted using descriptive statistics. The data required for this study were primarily secondary climatic data obtained from the Nigerian Meteorological Agency and the Maiduguri International Airport station. Vegetation data, in the form of the normalised difference vegetation index (NDVI, 2002-2012), were collected from the Department of Geography, University of Maiduguri. Various instruments were used to collect data for each variable in this study. To collect temperature

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data, a thermometer was used. A Rain gauge was used in obtaining rainfall Data. For vegetation data, the S10 spot-vegetation instrument was used.

RESULTS AND DISCUSSION

The trends in temperature, rainfall, and vegetation observed during the 10-year period 2002-2012 are presented in figures. 4.1a-c respectively. Fig. 4.1a shows a 10-year temperature trend. The graph was plotted using 10-year minimum and maximum temperature data extracted from the monthly instrumental record. The highest temperature was recorded in May and June, while the lowest was recorded in November and February. Over the 10-year period, the highest temperatures were recorded in 2002, 2010, and 2012, whereas the lowest was in 2008. Similarly, Fig. 4.1b shows the trend in rainfall pattern of ten years in Maiduguri, the graph was plotted using the data being obtained from instrumental record, the graph shows the trend in rainfall which shows that the highest monthly rainfall was primarily recorded in the month of July-August while the lowest values were recorded in the months of march and November, at the beginning and extreme end. Throughout the ten years, the highest rainfall was recorded in 2006 and the lowest was in 2005, as observed from the results in the figure. 4.1b. However, Fig. 4.1c shows a 10-year dataset of vegetation being obtained from NDVI using S10; the graph shows that the vegetation of Maiduguri is dense in August and September, and it gets sparse in the months of March-May. The vegetation was denser in 2011 and sparser in 2005.

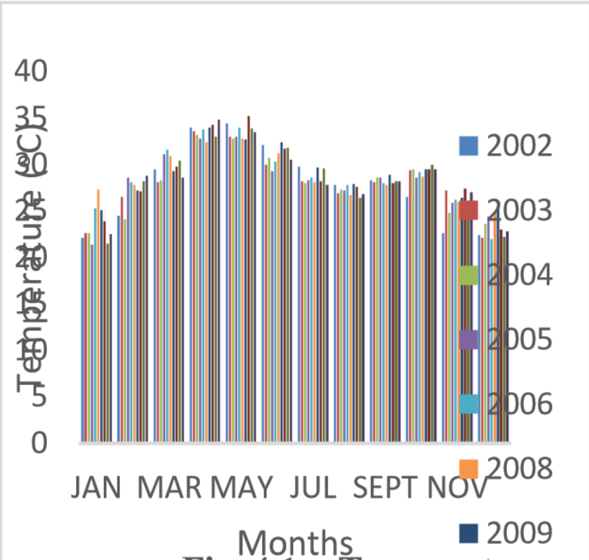

Fig. 4.1a: Temperature

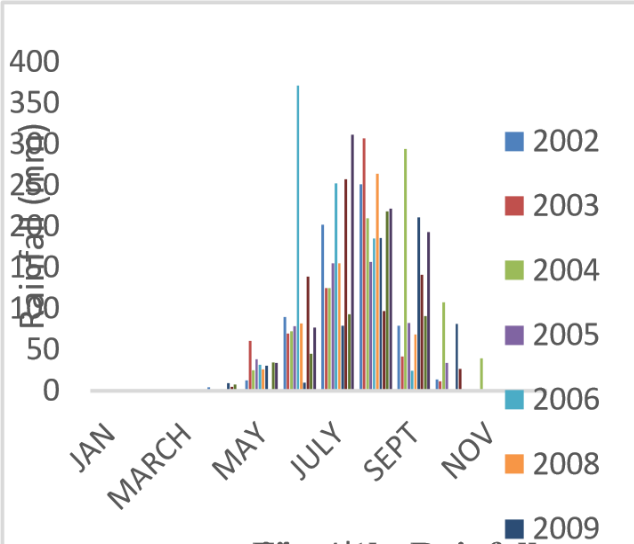

Fig. 4.1b: Rainfall

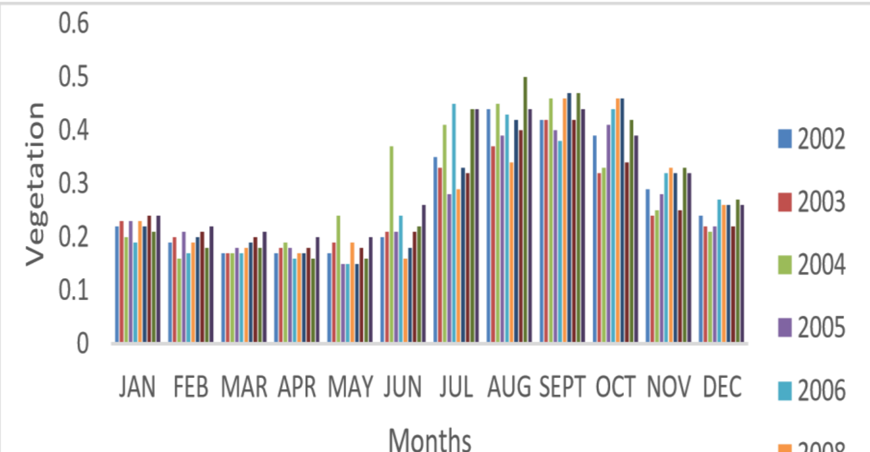

Fig. 4.1c: Vegetation

Fig. 4.2 shows the relationship between surface temperature and rainfall trend in Maiduguri and environs. The graph shows that there is a strong relationship between surface temperature and rainfall of Maiduguri, whereby high rainfall was recorded when the temperature is also high, while lower rainfall was recorded when the temperature is low.

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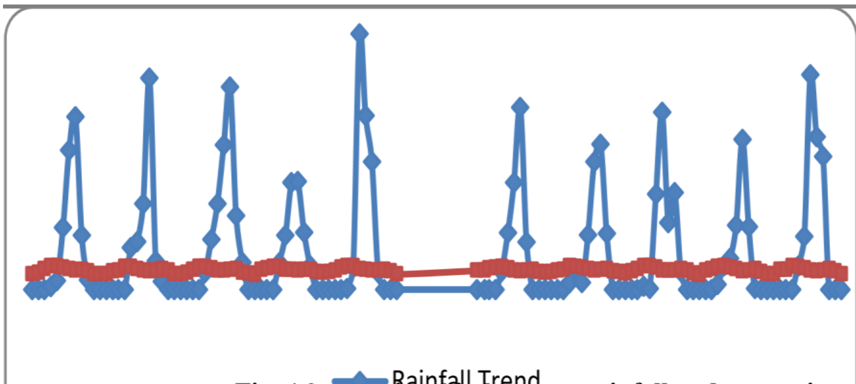

Fig. 4.2: Relationship between rainfall and vegetation

Fig. 4.3 shows the relationship between surface temperature and vegetation cover of Maiduguri and environs. The graph was plotted using 10 10-year of data on temperature and vegetation. It is well documented that vegetation cover strongly depends on surface temperature. The graph shows that vegetation in Maiduguri is dense where the highest temperatures are recorded and sparse when temperatures are low.

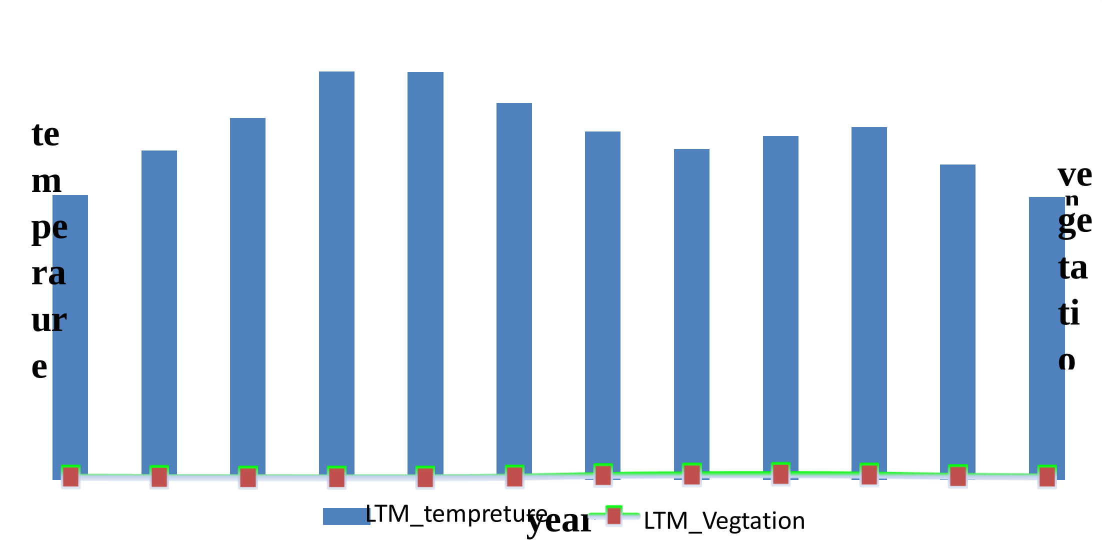

Fig. 4.3:temperature and vegetation

Fig. 4.4 shows the relationship between rainfall and vegetation trends of Maiduguri and environs. The graph was plotted using 10 10-year of data on vegetation and rainfall. The vegetation of a given area usually depends on the amount of rainfall being recorded in that area. The vegetation of Maiduguri gets dense in August and September when high amount of rainfall is reported.

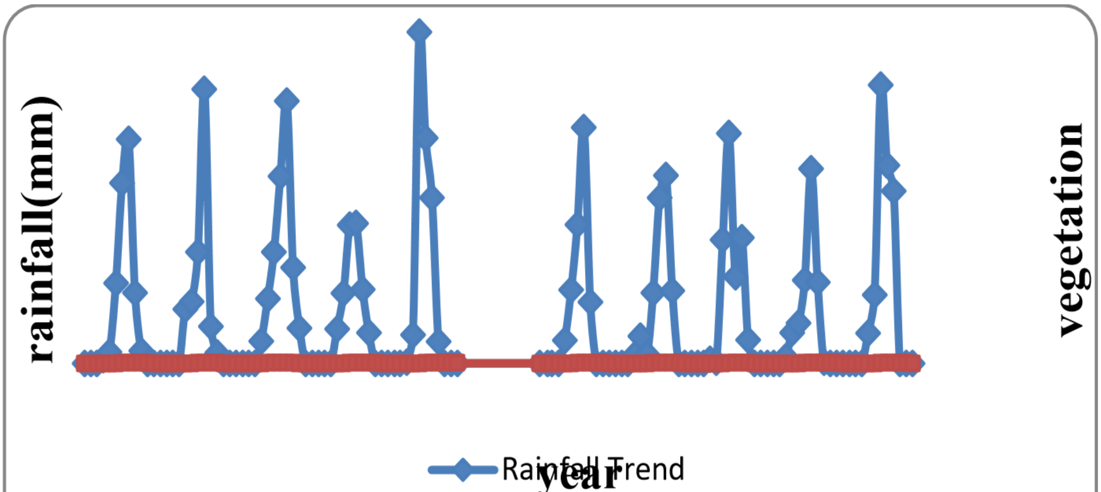

Fig. 4.4: Relationship between rainfall and temperature

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Vegetation cover in most environments is generally dominated by perennial vegetation, such as natural forests, home gardens, and agricultural and forest plantations. Therefore, the vegetation values observed in the present study reflect the dynamics of this natural vegetation. In this study, a simple linear regression analysis was performed to identify the relationship between vegetation and rainfall and vegetation and temperature in Maiduguri and environs the regression coefficient (R^2) was reported to be R^2=0.494 (Fig. 4.5) which indicates that there is strong relationship between the vegetation and amount of rainfall in the study area which means the availability of water is one of the significant factors that determines the density of vegetation. However, a weak correlation was reported between temperature and vegetation in Maiduguri and its environs, compared with the relationship with rainfall; the regression coefficient (R2) was 0.054 (Fig. 4.6), indicating a weak relationship between temperature and vegetation.

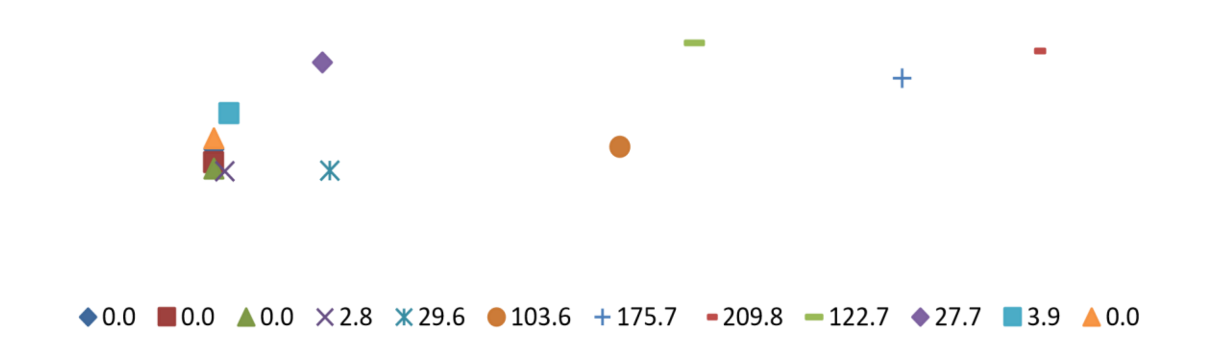

Fig.4.5 showing the relationship between LTM_ rainfall and vegetation

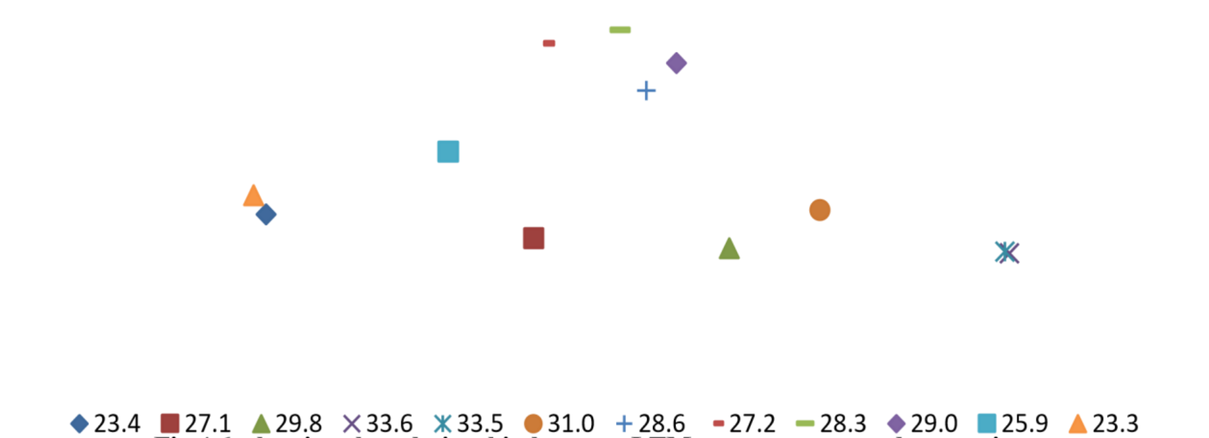

Fig.4.6: showing the relationship between LTM_ temperature and vegetation

CONCLUSION

This study has examined the spatio-temporal variation in temperature, rainfall, and vegetation in Maiduguri over 10 years (2002–2012) using empirical climatic and remote-sensing data. The findings demonstrate a dynamic interaction among these climatic variables, each exerting a measurable influence on the others. Temperature and rainfall exhibited clear seasonal patterns, with the highest temperatures recorded in May and June and peak rainfall observed in July and August. Vegetation cover, as measured by the NDVI, responded positively to these fluctuations, showing greater density during the wet months of August and September and sparse cover during the dry months of March to May. The analysis revealed a strong positive relationship between rainfall and vegetation ($R^2 = 0.494$), underscoring the critical role of precipitation in determining vegetation vigour and distribution in semi-arid environments such as Maiduguri. Conversely, the weak relationship between temperature and vegetation ($R^2 = 0.054$) indicates that vegetation dynamics in the area are more sensitive to rainfall variability than to temperature fluctuations. These findings corroborate the broader climatological understanding that precipitation remains the dominant control on vegetation productivity in the Sahelian ecological zone.

Overall, the study provides empirical evidence that Maiduguri's climatic system is undergoing subtle but perceptible changes consistent with broader regional climate trends reported in previous works (e.g., Abatcha et al., 2024; Bukar et al., 2024; Umar et al., 2025). The increasing rainfall trends observed in recent decades, alongside moderate vegetation recovery, indicate evolving climatic conditions that may affect agricultural productivity, water availability, and ecosystem stability. However, these shifts also highlight the vulnerability of local livelihoods to climatic extremes, particularly given the city's exposure to erratic rainfall, land degradation and human-induced pressures. It is therefore recommended that local and regional authorities integrate climate data and vegetation monitoring into urban and agricultural planning frameworks to strengthen adaptive capacity. Sustainable water management, afforestation programmes and community-based land rehabilitation initiatives should be prioritised to enhance ecological resilience. Future research should extend this temporal analysis beyond 2012 and incorporate additional climatic and socio-environmental variables, such as soil moisture and land-use change, to deepen understanding of the ongoing climatic transitions in Maiduguri and the broader northeastern Nigerian landscape.

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