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The Effects of Climate-Related Factors on the Incidences of Malaria Cases in the Braced States, Nigeria

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Abstract

Nigeria accounts for around 25% of all malaria cases worldwide, making it a severe nationwide public concern. The study examines the effects of temperature, vapour pressure, diurnal temperature range (DTR), and rainfall on the number of instances of malaria in the BRACED States, Nigeria. The climatic data employed in this research were generated from Climate Research Unit (CRU) TS v 4.07 with high-resolution grids of 5° x 5° latitudes and longitudes time series data from January 1962 – December 2021, while the number of malaria cases was generated from the Ministry of Health offices. The climatic data and the number of malaria cases obtained were analysed with descriptive and inferential statistical techniques. The results of fixed effect (FE) and random effects (RE) regression showed that malaria had a weak positive relationship with temperature (0.3614) and Vapour pressure (0.3015), while a weak negative relationship was found between malaria and rainfall (-0.4155) and DTR (-0.1697). Therefore, for effective malaria control and elimination strategies, the study recommends that insecticide-treated bed nets (ITNs) should be distributed in large quantities to homes, giving priority to high-transmission areas and to those who are most susceptible, such as pregnant women and children.

Keywords: Climate-Related Factors; Diurnal Temperature Range (DTR), Malaria; Rainfall, Temperature; Vapour Pressure.

1. Introduction

Malaria has held a distinctive role in the development of humanity since the beginning of time. Over thousands of years, its casualties ranged from Neolithic inhabitants, Greeks, paupers, princes, and primitive Chinese (Institute of Medicine (US) Committee on the Economics of Antimalarial Drugs, 2004).

The United Nations Children's Fund [UNICEF] (2024) estimates that bites from malaria-transmitting mosquitoes resulted in approximately 249 million incidents in 2022, resulting in approximately 608,000 mortalities owing to the disease caused by mosquitoes. Although an innocent child less than five years old succumbs to death daily owing to malaria, the majority of these fatalities are easily avoidable through treatment. Pregnant women and

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young children are especially vulnerable to the sickness, particularly in Africa, where 95% of cases and 96% of fatalities from malaria occur (UNICEF, 2024). According to the Institute of Medicine (US) Committee on the Economics of Antimalarial Drugs (2004), those who reside in underprivileged dwellings in Africa's subcontinent, Asia, the Amazon basin, along other tropical nations currently constitute the most frequent casualties of diseases such as malaria, 40% of the proportion of people worldwide continues to dwell in locations within which the spreading is propagated.

The World Health have certified 15 countries since 2015 as free from malaria cases in 2023, these countries include Georgia (2025), Egypt (2024), Cabo Verde (2024), Belize (2023), Tajikistan (2023), Azerbaijan (2023), EL Salvador (2021), China (2021), Algeria (2019), Argentina (2019), Uzbekistan (2018), Paraguay (2018), Kyrgyzstan (2016), Sri Lanka (2016), and Maldives (2015). Out of the one hundred ninety-five (195) countries in the world (WHO, 2025), Nigeria is missing from the list.

In Nigeria, malaria constitutes a severe general health problem, where about 68 million instances of malaria and 194,000 deaths are predicted for 2021 (WHO, 2023). However, research has shown that malaria remains most common in the northeastern parts of Nigeria (WHO, 2023). Since 2010, there has been a decline of malaria cases in thirteen (13) states, while an increase in cases has been observed in 24 states. Among these, the Federal Capital Territory (FCT), the States of Kano and Lagos, and the State of Lagos were among the top three where the predicted incidence of malaria increased the greatest (WHO, 2023).

Antiques and documents from the past attest to the widespread prevalence of malaria. For example, in Mesopotamian ceramic tablets that were printed in cuneiform, life-threatening chronic high fevers like malaria are shown. Just lately, antigenic substances for malaria have been identified in Egyptian antiquities from 3200–1304 BC. (Miller et al., 1994). In Indian literature, in the Vedic era (1500–800 BC), malaria was called the "King of Diseases."

Multiple investigations have demonstrated the long-standing relationship between climate and health. Hippocrates (~460 to 377 B.C.) noted in the 5th century B.C. that natural events, not gods or devils, were linked to outbreaks of diseases (National Research Council [NRC], 2001). The NRC (2001) states that disease agents such as bacterial, viral infections and different kinds of microorganisms as well as their host organisms like mosquitoes or mice and rats are susceptible because of the modification of relative humidity, temperature, along with other various physical variables. It stands to reason that climate has the potential to influence viral infection trends. They noted that the distinctive geographic distribution and seasonal variability in numerous illnesses provide the strongest evidence for this sensitivity. Different diseases are impacted differently by the weather and climate. For instance, warm weather is linked to yellow fever, malaria, and meningitis, which are diseases spread by mosquitoes; cool weather is linked to influenza epidemics; dry conditions are linked to meningitis; and heavy rainfall is linked to cryptosporidiosis outbreaks.

This study is based on the theories of vector-borne disease, temperature-dependent disease transmission, and humidity-dependent survival theory.

1.1 Vector-borne Disease Theory

Vector-borne disease was first reported in 1897 by Ronald Ross while studying in India. He made a significant contribution to the subject by proving how mosquitoes carry malaria parasites. Vector-borne diseases include numerous infectious ailments arising from the passing on of infectious diseases through bacteria and viruses referred to as vectors, which are transmissible illnesses that are capable of being spread within humans, such as dengue and malaria (See Fig. 1). Countless of these transmitting agents comprise blood-sucking insects, with mosquitoes being among the most well-known (World Organisation of Animal Health [WOAH], 2019; World Health Organisation [WHO], 2020). Since vectors are ectothermic, changes in the climate and weather, such as temperature, rainfall and relative humidity (See Fig.1), can have a great impact on how well they can reproduce, survive, and spread diseases. De Souza et al. (2024) averred that since these vectors are ectothermic, changes in rainfall DTR, vapour pressure, temperature, and relative humidity (See Fig.1) can have an impact on how well they can reproduce, survive, and spread diseases.

1.2 Temperature-dependent Disease Transmission

Temperature has a significant effect on how disease vectors behave, for example, slight increases in temperature (28°C) encourage an increased number of bites from vectors, which raises the likelihood of disease transmission (Mikery Pacheco et al., 2023; Gastelbondo-Pastrana et al., 2024). The situation is especially true for Anopheles mosquitoes since both high and low temperatures can interfere with their ability to thrive and survive (Agyekum et al., 2021). In contrast, rainfall enhanced the longevity of adult mosquitoes and the quantity of vector reproductive sites. Consequently, stagnant "waters" become a perfect ground for mosquito larvae formation (Reiter, 2001; Gastelbondo-Pastrana et al., 2024). The fundamental reproduction rate, which is an indicator of an illness's propensity to spread, is strongly influenced by temperature for vector-borne illnesses (Van Wyk et al., 2023). Thermal biology has shown that the spread of vector-borne diseases decreases at hot and cold temperatures and increases at mid-temperatures (Shocket et al. 2018).

1.3 Humidity-dependent Survival Theory

For certain contagious infections to spread, bacteria must be able to live (i.e., continue to spread) irrespective of their host in the atmosphere. The ability of certain bacteria to survive within the atmosphere is believed to be impacted by the moisture content (Lin & Marr, 2020). Also, Bose (2022) has shown that humidity affects how viruses spread. In this respect, modelling and experimental research have demonstrated that low relative humidity (RH) is important for the survival and spread of viruses.

Employing the theories of temperature-dependent disease transmission, vector-borne disease, and humidity-dependent survival can be beneficial in offering an overall structure for comprehending the numerous ways in which climate conditions affect the spread of malaria. With the help of these theories, we can determine which particular climate elements, such as temperature, humidity, vapour pressure, DTR and rainfall, are responsible for the spread of malaria in the BRACED States.

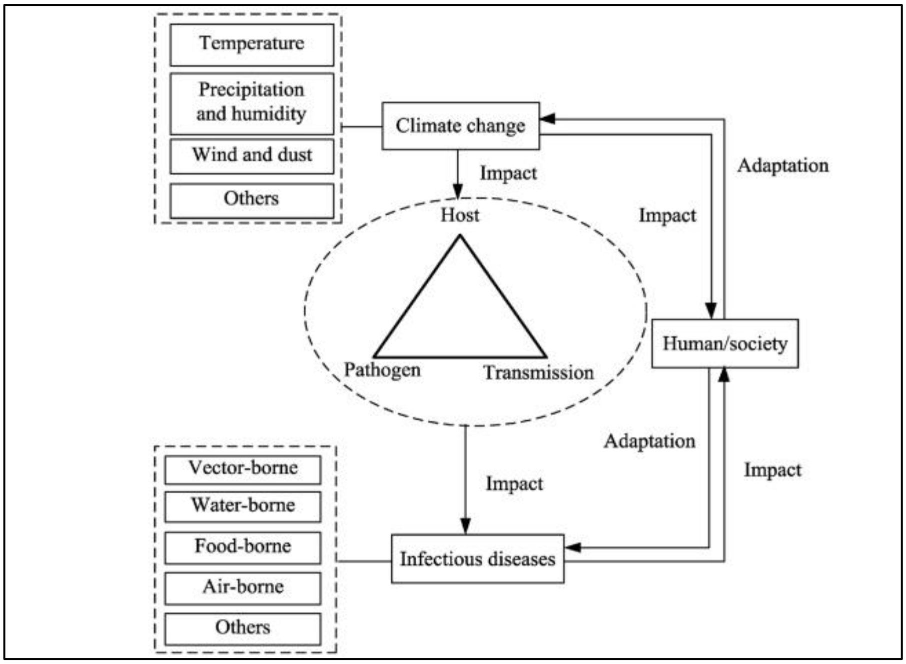

Figure 1: Climate Change, Human Infectious Diseases, and Human Society

Source: Adopted from WU et al. (2016).

1.4 Aim and Objectives

The study aims to examine the effects of climate-related factors on malaria incidence in the BRACED States, Nigeria. To achieve this aim, the following specific objectives are stated:

1. To analyse the relationship between malaria cases and climate-related factors such as temperature, humidity, vapour pressure, and rainfall in the BRACED States.

2. To determine the spatial pattern of malaria cases as related to temperature, vapour pressure, and rainfall in the BRACED States.

Numerous global investigations have shown that there are links between climatic parameters and malaria transmission. For instance, Liu et al. (2024) revealed that the incidence of malaria in Asian countries was found to be positively correlated with temperature and rainfall. Mafwele and Lee (2022) found a link between the spread of malaria and rainfall and temperature in African nations.

In Rwanda and Uganda, Colón-González et al. (2016) discovered a significant relationship between rainfall, temperature and malaria incidence.

Kurup et al. (2017) found links between the frequency of malaria in some areas and weather patterns in Guyana, South Africa. A study carried out within the Sidama region of Boricha district, Ethiopia, by Dabaro et al. (2021) found that temperature, topography, and rainfall are the main factors promoting malaria.

Sena et al. (2015) discovered that rainfall and malaria incidence are correlated with different lag effects. Sadiq and Kinang (2023) discovered that malaria cases and rainfall were found to be strongly and positively correlated.

Employing artificial intelligence and variations in the climate, Nkiruka et al. (2021) discovered that a significant contributing factor to malaria epidemics is non-seasonal changes in temperature in six sub-Saharan African countries. Akinbobola and Hamisu (2022) found that malaria in Jos and Kano, Nigeria, is influenced by the regional climate. In Southwest Nigeria, Owolabi et al. (2024) discovered differences in the patterns of malaria transmission between states. In Lapai LGA, Niger State, Apegba et al. (2019) found a negative relationship between temperature and malaria. In Ondo State, Nigeria, Omonijo et al. (2011) discovered correlations between the prevalence of malaria and weather-related and climatic parameters. Weli and Efe (2015) found a strong correlation between the frequency of malaria and increasing temperatures and rainfall in Port Harcourt, Nigeria.

From the foregoing, we observe that a larger proportion of the studies, for example, Weli and Efe (2015), Colón-González et al. (2016), Mafwele and Lee (2022), and Liu et al. (2024), found a positive relationship with climatic parameters such as rainfall, temperature, and malaria prevalence. When considering the geographical location, studies carried out in Africa, South America and Asia countries appear to show a similar trend, indicating that climatic parameters have a significant impact on the transmission of malaria parasites. On the other hand, an investigation by Nkiuka et al. (2021) employed inferential statistics and artificial intelligence (AI) to better analyse non-seasonal change in temperature by highlighting the importance of advanced technology in epidemiology modelling. Furthermore, Studies carried out by Sena et al. (2015), Dabaro et al. (2021), and Sadiq and Kinang (2023) pointed out that rainfall is frequently cited as a crucial element associated with the lag effect. However, an investigation undertaken by Apegba et al. (2019) found a negative relationship between temperature and malaria, even though numerous studies found a positive relationship with an increase in rainfall, temperature and an increase in malaria cases. Owolabi et al. (2024) findings indicate that socioeconomic factors, local environment, and health facilities can modify the association between climate and malaria. In addition to temperature and rainfall, Dabaro et al. (2021) incorporate topography, highlighting the importance of landscape elements. The above findings underline the necessity of more investigation into the intricate relationships between climate-related variables and the spread of malaria cases. Research carried out globally has revealed that climatic variables are the major factors regarding the spread of instances of malaria and transmission, which continues to be a serious concern for public safety. The distribution, behaviour, and variability in malaria vector populations, together with the growth and survival of the parasite, can all be impacted by humidity, temperature, rainfall variability and other environmental conditions. The effective forecasting models and focused control tactics are hampered by the incomplete comprehension of the intricate interactions that exist between climatic conditions and malaria transmission.

Regardless of the robust discussion and empirical studies on the interactions among climate-related factors and the instances of malaria at the international, national, regional and local levels, there existed a relatively small amount of research that evaluated how climate-related factors like temperature, DTR, vapour pressure and rainfall which serve as catalysts in propelling incidences of malaria in the Braced States; to this end, a different approach to investigating incidences of malaria in the BRACED states was employed to offer a cross-level investigation of climate-related factors on the effects of malaria instances and in developing a unique framework for efficient prevention and treatment of malaria in BRACED states and on a global scale; these appear to be the scientific knowledge gaps which this study seeks to satisfy.

2. Materials and Methods

2.1 Study Area

The geographic coordinates of the BRACED States are 4o50'N and 7o10'N to the north, and 6o40'E and 8o30'E to the east (See Figure 2). The BRACED States make up roughly 8.5 per cent of Nigeria's total land area, with a total size of 86,344 km2 (33,337 sq mi). It is responsible for 30,853,979 individuals living in the country. With a general mean annual rainfall of 1,193.0mm, the area's mean annual rainfall varies from 152.6mm in Edo State to 216.8mm in Cross River State. The region's mean yearly diurnal temperature range (DTR) is 8.5oC, with variations from 7.8oC in Bayelsa State to 9.2oC in Cross River. The region's average yearly temperature is 26.3oC, with variations from 26.9oC in Delta, 27.0oC in Edo States, 25.9oC in Akwa Ibom, Bayelsa (26.1oC), Cross River (26.0oC), and Rivers States (25.6oC). With a typical vapour pressure of 27.5 hPa, the region's mean annual vapour pressure varies from 26.4 hPa in Cross River State to 28.8 hPa in Delta State.

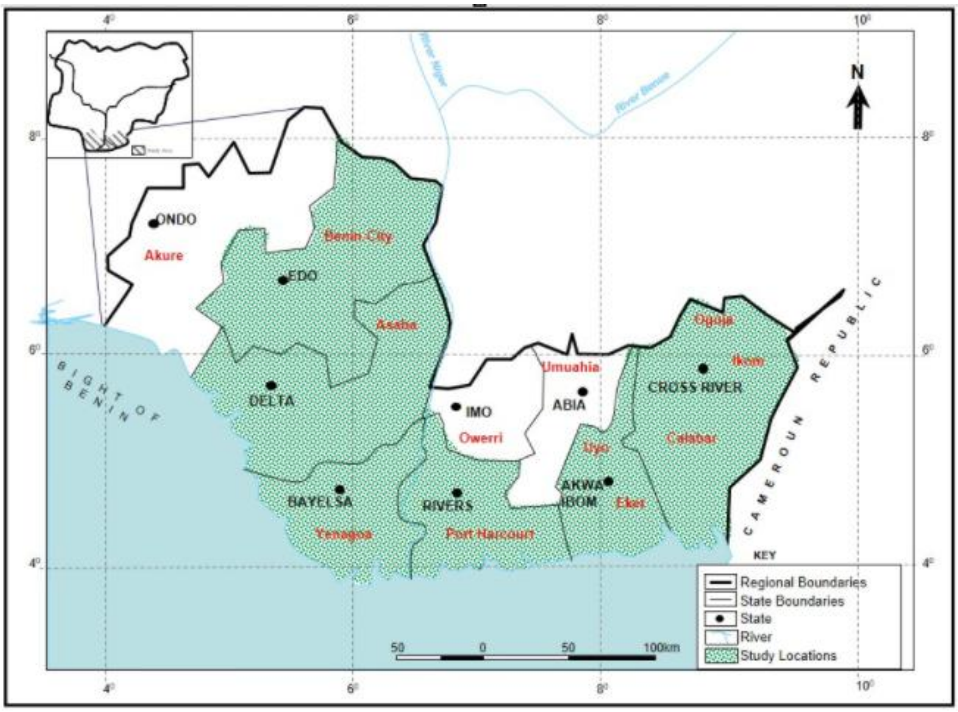

Figure 2: Niger Delta, Nigeria Showing the BRACED States Employed in the study

The study is based on six states, which include Bayelsa, Rivers, Akwa Ibom, Cross River, Edo, and Delta States, which make up the BRACED States. These six states are found along the Atlantic coast between the Bonny and Benin coasts in the east and west, respectively. The zone is geographically divided into the coastline extreme south's Central African mangroves, and the primary inland ecoregions that are the Nigerian lowland forests, the BRACED States swamp forests, the Cross–Sanaga–Bioko coastal forests, and the Cross–Niger transition forests, which are arranged east-west (Ojugbele 2024).

2.2 Data Collection

Ex-post facto research design, which deals with historical data on climate characteristics (e.g. temperature, DTR, vapour pressure and rainfall) and malaria cases in the BRACED States, Nigeria, was used in this study. The historical data entailed secondary data on climatic variables and malaria cases that are currently available. The major limitations with secondary data are data availability, where the data might not be accessible for specific periods or some geographic locations, and the data might not be collected in the desired geographical area of interest of the researcher. To overcome this, the climatic data were obtained from the CRU station, which covered all land areas except for Antarctica. On the other hand, data on malaria were based on the years of availability in the BRACED States. In this study, the temperature, DTR, vapour pressure, and rainfall data were obtained from CRU TS v 4.07 via Google Earth for the period January 1962 – December 2021, high-resolution 0.5 x 0.5-degree gridded data (University of East Anglia Climatic Research Unit et al., 2024). Malaria records were obtained directly from the various ministries of health in the BRACED States.

2.3 Data Analysis

The annual climatic and malaria data obtained were analysed with the help of descriptive statistics (such as tables, linear graphs, mean, standard deviation, and Pearson correlation), diagnostics tests (Variance Inflation Factor [VIF], Breusch-Pagan/Cook-Weisberg Heteroscedasticity Test, Ramsey REST Test, and Cameron and Trivedi's Decomposition of Information Matrix-Test) and inferential statistical techniques (FE and RE regression analysis). The regression model is given as follows:

$$MAL\ it = \alpha 0 + \alpha 1TEMPit + \alpha 2VAPit + \alpha 3DTR\ it + \alpha 4RAINit + €it$$

Where: MAL is malaria; TEMP is temperature; VAP = vapour pressure; DTR = diurnal temperature range; RAIN = rainfall.

Furthermore, descriptive statistics were used in describing the nature of the variables in terms of their measure of central tendencies and dispersion, while the diagnostic tests were used in evaluating the presence or absence of multicollinearity and heteroskedasticity. On the other hand, FE and RE regression analyses were employed in ascertaining the relative impact of the climatic variables (temperature, vapour pressure, DTR and rainfall) on the number of instances of malaria in the affected BRACED States, Nigeria. However, the descriptive, diagnostic and inferential statistics were analysed using STATA Software Version 14.2. A priori expectation is that the climatic variables will impact the cases of malaria in the BRACED States.

3. Results and Discussion

This section discusses the overall trends, summary of descriptive results and analytical results of the weather parameters and incidences of malaria cases in the BRACED states. Figure 3 displays the general patterns of rainfall, temperature, diurnal temperature range (DTR), vapour pressure (VAP), and prevalence of malaria cases in the BRACED States from 1962 to 2021. The outcomes of the research revealed that malaria had 8149.4 cases, vapour pressure (27.7 hPa), rainfall (1165.3mm), DTR (8.6 °C), and temperature (26.3 °C). The outcomes of the study also revealed that Bayelsa had a 202.3mm mean temperature, with Rivers having 25.6 °C, Akwa Ibom (25.9^{o}C). Cross River (26.0 °C), Edo (27.0 °C), and Delta (26.9^{o}C). On the other hand, Bayelsa had 202.3mm of rainfall, Rivers (202.5mm), and Akwa Ibom (206.9mm). Cross River (208.6mm), Edo (152.5mm), and Delta (192.5mm). The results of DTR revealed that Bayelsa had 7.8^{o}C, Akwa Ibom (8.9^{o}C), Rivers (8.3^{o}C), Cross River (9.2^{o}C), Edo (8.9^{o}C), and Delta (8.4 °C). The outcomes of the vapour pressure indicate that Bayelsa had 28.4 hPa, Rivers (27.3 hPa), Akwa Ibom (26.9 hPa), Cross River (26.5 hPa), Edo (28.0 hPa), and Delta (29.0 hPa), Figure 3 indicates that the lowest vapour pressure was recorded in Rivers State and the highest vapour pressure was observed in Delta State.

The outcomes of the research findings indicate that 1988 recorded the lowest temperature of 25.3 °C, while 2021 recorded the highest temperature of 26.9 °C. The lowest rainfall of 434.2mm was recorded in 1988, and the highest rainfall of 1377.2mm was in 1969. The study shows that the lowest DTR of 8.0 °C was recorded in 1976, and the highest DTR of 9.2 °C was recorded in 1993. The study also indicates that the lowest vapour pressure of 25.0 hPa was recorded in 1988, and the highest vapour pressure of 28.8 hPa was recorded in 2010. Additionally, the lowest malaria incidence of 3474.8

was recorded in 1989, and the highest malaria incidence of 14090.3 was recorded in 2016 (See Fig.3).

Figure 3 revealed that temperature fluctuates at all times, with some states exhibiting more variation than others. For instance, Delta had the lowest temperature of 26.1oC in 1975, 1976, and 1988 and the highest temperature of 27.7oC in 2016. Edo had the lowest temperature of 26.1oC in 1975 and 1976, with the highest temperature of 27.7oC in 2010, 2016, and 2021. Bayelsa had the lowest temperature of 25.3oC in 1975 and 1976 and the highest temperature of 26.8oC in 2016 and 2021. Rivers had the lowest temperature of 24.7oC in 1988 and the highest temperature of 26.3oC in 2016 and 2021. Akwa Ibom had the lowest temperature of 24.7oC in 1988 and the highest temperature of 26.6oC in 2021.

The amount of rainfall appears to vary from state to state, with considerable upward or downward swings, which may indicate regional climatic patterns. Figure 3 shows that Cross River had the lowest rainfall of 55.7mm in 1988 and the highest rainfall of 260.2mm in 1969. Delta had the maximum rainfall of 229.7mm in 1968, followed by 69.7 mm in 1988. Rainfall in Edo was at its peak in 1963 at 189.8 mm and fell as low as 38.1 mm in 1988. Rainfall in Bayelsa ranged from the lowest in 1988 (127.8mm) to the greatest in 1995 (236.1mm). Rainfall on rivers was at its maximum in 1969 (247.8 mm) and lowest in 1988 (81.0 mm). Rainfall in Akwa Ibom was at its peak in 1969 at 260.9 mm and fell as low as 61.8 mm in 1988.

Diurnal Temperature Range (DTR) shows that there are significant differences in temperature between day and night, with some states showing more pronounced oscillations. According to the result, in 1979, Bayelsa State DTR was at its lowest of 7.2°C, while in 1993, it reached its peak of 8.5°C. In 1976, Rivers State DTR was at its lowest, 7.7°C, while in 1993, it reached its peak, 8.9°C. DTR in Cross River was at its lowest in 1976 (8.5°C) and its highest in 1993 and 1989 (9.7°C). In 1976 and 1979, respectively, Edo State DTR was the lowest at 8.3°C, while in 1993, it was the highest at 9.7°C, and in 1979, Delta State DTR was at its lowest of 7.8 °C, while in 1993, it reached its maximum of 9.2^{o}C.

The state-by-state variations in the Vapour Pressure (VAP) trends could be partly attributed to additional climate phenomena, such as rainfall. This was demonstrated in 1988 when the lowest vapour pressure of 26.6hPa was observed in Bayelsa State, with Rivers State having 25.3hPa in 1988, Cross River State (23.8 hPa) in 1988, Edo State (24.5hPa) in 1988, and Delta State (26.1 hPa) in 1988, Figure 3 also indicates that the highest vapour of 27.5 hPa was recorded in Cross River in 2017, 30.4 hPa was recorded in Delta in 2010, 29.6 hPa was recorded in Edo in 2010, 29.6 hPa was recorded in Bayelsa in 2010, 28.3 hPa in Rivers in 2017 and 27.8 hPa in 2017 in Akwa Ibom. Figure 3 shows that Delta, Edo and Bayelsa states had their highest vapour pressure in 2010, while Cross River, Rivers and Akwa Ibom states had their highest vapour pressure in 2017, respectively.

Along with other external factors, Figure 3 shows how the prevalence of malaria cases fluctuates over time and can be attributed to temperature, rainfall, vapour pressure (VAP), and diurnal temperature range (DTR). This is noticeable in states like Cross River, which had the least amount of 60 instances of malaria in 1984, with a maximum malaria instance of 1878 recorded in 1995. Delta had the least amount of malaria instances of 50 in 2007, and the maximum malaria instances of 1328 in 2018. Edo had the least amount of malaria instances, 13522 in 1981 and the maximum instances of malaria 36192 in 2002. Bayelsa had the least amount of malaria instances, 1002 in 2016 and the maximum number of instances of malaria of 47186 in 2016. Rivers had the least amount of malaria instances, 955 in 2010 and the maximum instances of malaria of 2827 in 1987. Finally, Akwa Ibom had the least amount of malaria instances, 3 in 1967 and the maximum instances of 4683 in 2013.

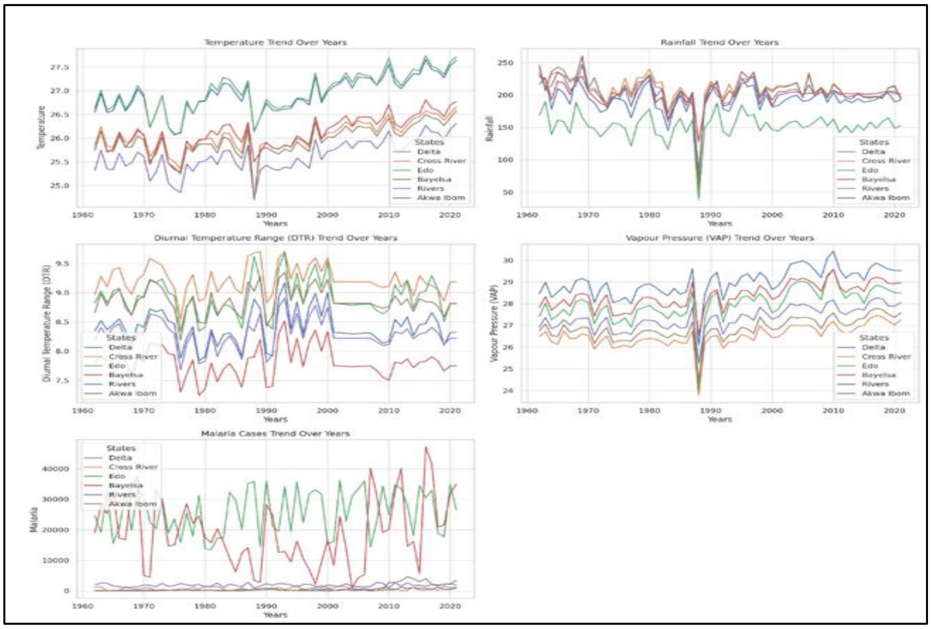

Figure 3: Overall Trends in Temperature, Rainfall, Diurnal Temperature Range (DTR), Vapour Pressure (VAP), and Malaria in The BRACED States From 1962 – 2021

Table 1: Summary of Descriptive Results for Temperature, Rainfall, Diurnal Temperature Range (DTR), Vapour Pressure (VAP), and Malaria Incidences in BRACED States, Nigeria

Variables	Mean	Median	Std	Min	Max
Temperature	26.2706	26.1883	0.6204	24.7	27.7403
Rainfall	194.2706	198.5342	29.5698	38.1	260.8833
Diurnal Temperature Range (DTR)	8.5817	8.6262	0.5362	7.2433	9.7083
Vapour Pressure (VAP)	27.6812	27.5788	1.0558	23.78	30.4146
Malaria	8149.4417	1478.5	11739.6538	3	47186

Source: Researcher's Computation via STATA 14.2

Table 1 provides a summary of the descriptive outcomes for temperature, rainfall, vapour pressure (VAP), diurnal temperature range (DTR), and malaria occurrences in the BRACED States, Nigeria. Table 1 shows that temperature had a Std (0.62^{o}C) and a Mean (26.3^{o}C), indicating that the temperature is still comparatively stable. This points to uniform climate conditions with a mean temperature of 26°C throughout the BRACED States. Rainfall had a Mean (194.22mm) and Std (29.57mm), which implies that rainfall varies significantly with temperature. Significant variation in the amount of rainfall is shown by the broad spectrum and higher standard deviation recorded, which shows that certain states in the BRACED States or at certain times of the year may significantly receive more rainfall than others. DTR shows a moderate range, with a Mean (8.6 °C) and a Std (0.54^{o}C). The lower Std recorded suggests that daily temperature variations follow a regular pattern, typically falling between 8 and 9°C. Vapour pressure had a Mean (27.7hPa) and a standard deviation (1.06hPa). The result of the vapour pressure reveals that the slight fluctuation in vapour pressure indicates significant variations in humidity levels. The rather small range in vapour pressure recorded suggests stable levels of air moisture. Malaria had a Mean (8,149) cases and a much lower median of 1,478 malaria cases. Table 1 shows that the prevalence of malaria varies and is extremely skewed. The Std is exceptionally high, and the mean is substantially greater compared with the median, indicating that even though incidents of malaria are comparatively low in certain parts of the BRACED States, they are exceedingly prevalent in areas of the BRACED States. This may imply that there are hot areas with strong malaria distribution.

Table 2: Pearson Correlation Matrix

	Malaria	**Temperature**	**Rainfall**	**DTR**	**Vapour Pressure**
Malaria	1.0000				
Temperature	0.3614	1.0000			
Rainfall	-0.4155	- 0.3340	1.0000		
DTR	-0.1697	0.0840	-0.1952	1.0000	
Vapour Pressure	0.3015	0.7099	-0.0067	-0.5013	1.0000

Source: Researcher's Computation via STATA 14.2

The results of the Pearson Correlation Matrix in Table 2 show the degree and the trends of the dependent (malaria) and independent (temperature, rainfall, DTR, and vapour pressure) variables in the BRACED States. The correlation coefficients showed, a weak negative relationship between malaria and rainfall (-0.4155) and DTR (-0.1697); these results imply that decreases in malaria cases can be attributed to an increase in the amount of rainfall in the area. Although rainfall normally causes stagnant water that can assist Anopheles mosquito reproduction, on the other hand, too much rain might destroy mosquito larvae or interfere with breeding grounds. This relationship illustrates the nonlinear effects of rainfall on mosquito habitat, which supports the idea that although a small amount of water is required, too much water might hinder mosquitoes' habitat (See Karp et al., 2023; Palagi et al., 2022). Also, this weak negative association can be attributed to the reflection of seasonal or geographical trends associated with the region being studied, when enhanced spreading of malaria may not occur during rainfall peak periods of the year, while geographical location and human characteristics influence this development. Furthermore, increased daily temperature variations might hinder the spread of malaria due to the negative correlation with DTR. This supports the scientific proof that consistent temperature ranges encourage the growth of parasites and the continued existence of mosquitoes. Higher daylight variation might decrease the effectiveness of vectors by putting mosquitoes under stressful conditions and perhaps disrupting the external gestation time of Plasmodium parasites. Table 2 showed that malaria had a weak positive relationship with temperature (0.3614) and vapour pressure (0.3015). The results show that temperature has a significant impact on mosquitoes' ability to transmit diseases since it affects the parasitic organism's growth and frequency of bites. This result is consonant with temperature-dependent disease transmission, which states that slight temperature increases encourage an increased number of bites from the vector, which raises the likelihood of disease transmission. The weak positive correlation suggests that although temperatures in the BRACED states are favourable for the spread of malaria, they might not always meet the ideal parameters for the quicker growth of parasites. In the same way, mosquito lifespan and productivity are supported by vapour pressure, which is a stand-in for relative humidity. The reproductive cycle of mosquitoes is prolonged by excessive moisture, which raises the risk of infection spreading. According to the humidity-dependent survival theory, mosquitoes need conditions that are adequately moist for them to continue being productive and contagious (See Lin & Marr, 2020; Niazi et al., 2021). Thus, the findings are consistent with the theory that climate has a complicated, occasionally contrasting, impact on the spread of malaria. Temperature, rainfall, DTR, and humidity are examples of climate factors that influence malaria's distribution across countries. Long-term spreading is particularly probable in areas experiencing continually excessive moisture and temperature values. However, because of ecological restrictions on mosquito survival, spreading could be reduced in drought-prone or high-altitude regions of the world.

The results of this study are consistent with the early results of Liu et al. (2024), who discovered that temperature had the greatest impact on the prevalence of malaria in Asian nations, and rainfall had a significant influence on malaria cases (P0.05). Additionally, Mafwele and Lee (2022) discovered that temperature variations could potentially hasten or decrease the spread of malaria. Although other factors also seem to be important, Colón-González et al. (2016) discovered a significant relationship between rainfall, temperature and malaria incidence. According to Stopard et al. (2021), higher temperatures and DTR have a major impact on mosquito mortality rates, infection distribution, and infectious magnitude, all of which reduce the two mosquito species' overall vectorial ability. As observed by Omonijo et al. (2011) and Siraj et al. (2014), the presence of water is crucial to mosquitoes' development in the early stages of their life cycle. Nevertheless, Akinbobola and Omotosho (2013) found that excessive rainfall might reduce the number of mosquito larvae and eggs inside their places of breeding, which impede the growth, their continued existence, and the spread of mosquitoes.

In a related finding, Sadiq and Kinang (2023) discovered that the anopheles mosquito's abundance and distribution have been impacted by the six-year rise in rainfall and temperature. Akinbobola and Hamisu (2022) demonstrated that the number of instances of malaria in Jos and Kano was correlated with local meteorological parameters, albeit with varying lag times and orientations. The findings show that malaria instances are significantly higher in Jos than in Kano due to local meteorological conditions. The results are in tandem with the theory of vector-borne disease, which states that since vectors are ectothermic, changes in the climate and weather, such as temperature, rainfall, vapour pressure, and relative humidity, can have a great impact on how well they can reproduce, survive, and spread diseases.

Table 3: Variance Inflation Factor

Variable	VIF	1/VIF
Vapour Pressure	6.34	0.157670
Temperature	5.27	0.189920
DTR	2.88	0.347450
Rainfall	1.32	0.757167
Mean VIF	3.95	

Source: Researcher's Computation via STATA 14.2

Table 3 shows the VIF result, which was used to test the presence or absence of multicollinearity among the pairs of independent variables of the study (VAP, Temperature, DTR, and Rainfall). The mean VIF is 3.95, which is less than the accepted mean VIF of 10.0; this demonstrates that multicollinearity does not exist in the malaria model, VAP, Temperature, DTR and Rainfall. The VIF result further suggests that the result obtained in this study can be relied upon.

Table 4: Breusch-Pagan/Cook-Weisberg Heteroscedasticity Test

Ho: Constant variance		
Variables: fitted values of malaria		
Chi2 (1)	**=**	**87.32**
Prob > chi2	**=**	**0.0000**

Source: Researcher's Computation via STATA 14.2

Table 4 shows the Breusch-Pagan/Cook-Weisberg test for heteroskedasticity; the table indicates that Chi2(1): 87.32; probability Chi2: 0.0000, which is lower than 0.05%. This indicates that there is no heteroskedasticity in the study's variables. There is evidence that the results would be valid because the result suggests that the sample used does not contain unequal variance.

Table 5: Ramsey REST Test

Ho: the model has no omitted variables		
F (3, 352)	**=**	**3.27**
Prob > F	**=**	**0.0213**

Source: Researcher's Computation via STATA 14.2

Table 5 displays the results of the Ramsey regression specification-error test (RESET) for the responses to the factors (dependent variable: malaria) and the variables that were not included. The result revealed that F (3, 352) is 3.27 with a probability of F of 0.0213, which is less than 5%, an indication that the null hypothesis has been accepted and the alternative hypothesis was rejected, indicating that the model does not suffer from functional misspecification.

Table 6: Cameron and Trivedi's Decomposition of Information Matrix-Test

Source	**chi2**	**df**	**P**
Heteroskedasticity	105.69	14	0.0000
Skewness	46.21	4	0.0000
Kurtosis	5.79	1	0.0161
Total	157.68	19	0.0000

Source: Researcher's Computation via STATA 14.2

Cameron and Trivedi's decomposition of the information matrix (IM) test was conducted to check if the empirical models do not violate any axioms of the regression model to create excellent judgements regarding the information being studied. Heteroskedasticity result Chi2 = 105.69 with a probability value of 0.0000 which is less than 5%, skewness Chi2 = 46.21 with a probability value of 0.0000 which is less than 5%; and kurtosis Chi2 = 5.79 with probability value of 0.0161 which is less than 5%, which suggest that they the results are highly significant, rejecting the null hypothesis and accepting the alternative hypothesis that the models do not break any axioms of regression.

Table 7 shows the FE and RE regression results. The FE and RE were used to look at how temperature, diurnal temperature range (DTR), rainfall, and vapour pressure (VAP) affect malaria incidence in the BRACED States. The Hausman test (Prob>Chi2= 0.0000 < 0.05) shows that FE is significantly more consistent and effective than RE.

Table 7: Fixed and Random Effects Regression Results

Dependent Variable: Malaria				
Estimator(s)	***Fixed Effect (FE)***		***Random Effect (RE)***	
Variable(s)	***Coefficient***	***Probability***	***Coefficient***	***Probability***
Temperature	22161.3 (6.95)	0.000	6407.56 (3.33)	0.001
Rainfall	-314.078 (-10.26)	0.000	-145.133 (-7.15)	0.000
DTR	-29208.5 (-9.80)	0.000	-6995.02 (-4.26)	0.000
VAP	-16657.5 (-7.83)	0.000	-1146.43 (-0.92)	0.357
F-value	(4, 296) =93.86			
F-Probability	0.0000			
R-Squared (Overall)	0.1918		0.2981	
Wald Ch2(6)			150.76	
Prob. Ch2			0.0000	
Hausman Test	Chi2(2) = 51.55		Prob > Chi2 = 0.0000	

Source: Researcher's Computation via STATA 14.2

Based on the Hausman test, FE results were used in validating our proposition, hence, the results indicated that all the parameters (VAP, DTR, rainfall, and temperature) statistically significantly influence Malaria. Analysing the result for temperature, FE had a coefficient of 6,407.56 (p = 0.001), and RE had a coefficient of 22,161.3 (p = 0.000). The results of the two models revealed that temperature had statistically significant and positive effects on the incidence of malaria in the BRACED States. The result suggests that warmer temperatures have been linked to a rise in malaria incidence, which is probable because they provide healthier environments for mosquitoes to breed and pathogen growth. Rainfall results indicate that FE had a coefficient of -314.078 (p = 0.000) and RE had a coefficient of -145.133 (p = 0.000). The outcomes show that rainfall has a strong negative link with malaria incidence. Thus, unlike widespread beliefs that increased rainfall enhances the development of mosquito breeding sites, this finding implies that heavy rainfall can carry away the breeding sites or that other environmental factors inhibit the spread of malaria during increased rainfall frequencies.

DTR results show that FE had a coefficient of -29,208.5 (p = 0.000) and RE had a coefficient of -6,995.02 (p = 0.000). The results show that DTR has a considerable detrimental impact on malaria incidence. A broader variation in temperature might result in fewer favourable circumstances for mosquitoes' continued existence or infection growth, and thus lower malaria prevalence in the BRACED States. The result of the VAP shows that FE had a coefficient of -16,657.5 ($p = 0.000$) and RE had a coefficient of -1,146.43 ($p = 0.357$). The outcome of the study revealed that only the FE model shows a statistically significant result for VAP. Thus, the negative coefficient result demonstrates that increased humidity could decrease malaria prevalence, yet the absence of relevance in the RE model demonstrates that there is unexplained individual variation influencing this association. Nevertheless, Table 7 shows that the FE had an F-statistic (93.86) with $p = 0.0000$, demonstrating the generalisation of the model's effectiveness and significance. The RE model reveals a Wald Chi^2 (150.76) with $p = 0.0000$, indicating significance. The RE overall R^2 is 0.2981 which is higher than the overall R^2 for FE (0.1918). This implies that all the variables (temperature, rainfall, DTR and VAP) jointly explained about 29.8 per cent variation in Malaria while the unexplained variation is about 70.2 per cent, which account for other variables such as income levels, medical systems, mosquito prevention initiatives, land utilization, and immunity to infection not included in the regression model, are probably going to assume significant parts in determining malaria distributions across the BRACED State. The result of the study reveals that temperature, rainfall, vapour pressure, and DTR have a major impact on malaria occurrence. DTR and temperature exhibit substantial and constant consequences, whereas vapour pressure and rainfall show intricate interactions that require additional research. The findings of the current study do not support those of Apegba et al. (2019), who discovered a 41% negative correlation between malaria and temperature. The findings of Nkiruka et al. (2021) in the Democratic Republic of the Congo, Niger, Mali, Cameroon, Nigeria, and Burkina Faso, however, indicate that the prevalence of malaria has a negative linear correlation with vapour pressure and a favourable linear correlation between rainfall and the ambient temperature.

4. Conclusion and Recommendations

The literature documents evidence of robust studies on the effects of climate-related factors on the instances of malaria in Nigeria. Additionally, scholars' research papers have shown that climate-related factors like rainfall, relative humidity, DTR, Vapour pressure, and temperature significantly affect how malaria cases spread. Notably, a thorough grasp of the precise impacts of these factors on the instances of malaria in the BRACED States is limited. However, there is a need to incorporate non-climatic factors such as the type of vector, the parasitic organism, ecological change and urban growth, population density and movement of people, the degree of antibody responses to malaria among individuals, the resistance to insecticides in mosquitoes, and drug resistance in parasites to enable a precise, data-fuelled technique for detecting malaria in high-risk areas, focusing on preventative measures, and appropriately distributing resources. Therefore, to close the gap in the literature, the research employed the panel regression model to evaluate whether climatic variables affect the incidence of malaria cases. The findings of the FE and RE regression models showed that malaria had a weak positive correlation with temperature (0.3614) and vapour (0.3015), but a weak negative correlation with rainfall (-0.4155) and DTR (-0.1697). In summary, the regression analysis provided strong proof that climate variables significantly affect the incidence of malaria. This can help us understand how climate change may affect the prevalence and transmission of malaria.

Based on the study results, the researcher recommends that insecticide-treated bed nets (ITNs) should be distributed in large quantities to homes, giving priority to high-transmission areas and to those that are most susceptible, such as pregnant women and children.

There is also a need to administer antimalarial drugs to pregnant women in high-transmission areas to avoid complications for both the mother and the foetus in the womb.

The government of the six states should implement malaria vaccines like RTS and S in high-transmission areas.

The government in the six states should develop a sanitation programme that will lower the number of breeding grounds for mosquitoes, clear blocked drainage systems to remove stagnant water, and improve the drainage systems.

The government should improve the gathering and dissemination of data to better understand how malaria is transmitted and response efficacy.

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