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The Impact of Climate Variation on Malaria Incidence Rates in Sub Saharan Africa

Nimah Adeoye*

Nigeria

***Corresponding author:** Nimah Adeoye, Nigeria.

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Abstract

Background: *Malaria remains a major public health concern in sub-Saharan Africa, with Nigeria, Mozambique, and the Democratic Republic of Congo among the most affected [1]. While climate variability, particularly rainfall, influences malaria transmission through mosquito breeding habitats, the extent of its impact varies by region [2, 3]. This study investigates the correlation between malaria incidence rates and rainfall patterns from 2020 to 2022 in the three selected countries, alongside a descriptive epidemiological review of national control policies.*

Methodology: *Malaria incidence data were collected from WHO reports for the years 2020 to 2022, while annual rainfall data were sourced online. Pearson's correlation coefficient was used to assess the relationship between rainfall and malaria incidence. The coefficient of variation was also calculated for both variables to evaluate data stability. Microsoft Excel was used for graphical representation. A descriptive epidemiological review was conducted to assess the effectiveness of malaria control policies in each country.*

Results: *Nigeria recorded a malaria incidence decline from 313.76 to 305, Mozambique from 234 to 223, and the Democratic Republic of Congo from 330 to an estimated 310. Correlation analysis showed a strong negative relationship between rainfall and malaria incidence in Nigeria (r = - 0.7651) and Mozambique (r = -0.99), but a strong positive correlation in the Democratic Republic of Congo (r = 0.895). Nigeria demonstrated the most effective control measures, followed by Mozambique.*

Conclusion: *The study highlights that rainfall's influence on malaria incidence is moderated by the effectiveness of national control strategies. Strengthening region-specific interventions remains key to sustained malaria reduction in sub-Saharan Africa.*

Keywords: Malaria Incidence Rate, Rainfall Patterns, Sub Saharan Africa, Descriptive Epidemiology, Coefficient of Variation, Correlation Coefficient.

Introduction

Malaria remains a significant global public health challenge, particularly in tropical and subtropical regions, with a disproportionate burden in sub-Saharan Africa [1]. It is a preventable and treatable disease caused by parasites transmitted through the bites of infected mosquitoes. Although effective control and prevention strategies exist, challenges such as drug and insecticide resistance, limited access to healthcare, and inadequate funding continue to hinder progress [4].

This research aims to examine the correlation between malaria incidence rates and climate variations, specifically rainfall patterns, by focusing on three sub-Saharan African countries which include Nigeria, Mozambique, and the Democratic Republic of

Congo. Data from 2020 to 2022 were collected and analyzed. Rainfall was selected as a key variable due to evidence from previous studies indicating that stagnant water, resulting from heavy rainfall, serves as a breeding ground for malaria vectors, especially during the larval and pupal stages [2-5].

Additionally, descriptive epidemiological analysis was conducted to assess the policies and control measures implemented in the selected countries to combat malaria. This approach provides insight into regional efforts and helps identify gaps and strengths in current intervention strategies. While numerous studies have explored the epidemiology of malaria in sub-Saharan Africa, relatively few have specifically examined how climate variability, particularly rainfall patterns, directly influences its regional incidence over time. Existing literature often generalizes the impact of climatic factors without writing on the breeding habitats of malaria vectors. Additionally, previous research tends to overlook the analysis of national malaria control policies implemented across different sub-Saharan African countries, insights that could inform effective strategies for reducing malaria incidence in other regions. This literature review synthesizes existing studies on malaria epidemiology, the role of climatic factors (particularly rainfall), mosquito breeding habitats, and national control policies in sub- Saharan Africa. It identifies gaps in the literature and justifies the current study's focus on Nigeria, Mozambique, and the Democratic Republic of Congo.

Malaria Epidemiology in Sub-Saharan Africa

Sub-Saharan Africa accounts for approximately 94 percent of global malaria cases, with Nigeria and the Democratic Republic of Congo contributing 27 percent and 12 percent of the total burden respectively [1]. High incidence rates in these countries reflect systemic challenges, including weak healthcare infrastructure and socio-political instability, particularly in the Democratic Republic of Congo [6]. Mozambique, while less burdened than Nigeria and the Democratic Republic of Congo, still reports significant malaria prevalence, driven by its tropical climate and limited intervention coverage. These country-specific trends underscore the need for tailored epidemiological analyses to inform targeted control strategies.

Climatic Influences on Malaria Transmission

Climatic factors, particularly rainfall and temperature, play a critical role in malaria transmission by creating favorable conditions for Anopheles mosquito breeding and parasite development [2-3]. Heavy rainfall leads to stagnant water pools which serve as breeding sites, increasing vector populations and transmission risk. However, few studies have disaggregated these effects for West and Central African countries like Nigeria and the Democratic Republic of Congo, where ecological and socio-economic contexts differ significantly. This gap highlights the need for country-specific analyses of rainfall and malaria relationships.

Mosquito Breeding Habitats

The ecology of *Anopheles* mosquitoes, particularly *Anopheles gambiae*, is closely tied to rainfall-driven breeding habitats [5]. Temporary water bodies formed during rainy seasons are ideal for larval development, yet regional variations in habitat suitability remain underexplored. For instance, southern Nigeria's high rainfall supports extensive breeding sites, while Mozambique's coastal ecology presents unique challenges. Existing studies often generalize climatic impacts without focusing on how specific breeding habitats influence transmission dynamics, a limitation this study seeks to address through targeted correlation analyses.

Malaria Control Policies

Effective malaria control relies on interventions such as insecticide treated nets (ITNs), indoor residual spraying (IRS), and artemisinin-based combination therapies (ACTs) [7]. Nigeria's National Malaria Strategic Plan (2014 to 2020) has achieved significant ITN coverage, contributing to a stable decline in incidence [8]. Mozambique has implemented seasonal malaria chemoprevention and IRS, though with less comprehensive coverage. In contrast, the Democratic Republic of Congo's control efforts are hampered by logistical challenges and conflict, resulting in higher incidence and variability [6].

Methodology

In respect to the background of this research, statistical data were collected on three sub-Saharan African countries which include Nigeria, Mozambique, and the Democratic Republic of Congo, focusing on malaria incidence rates from 2020 to 2022, as reported by the WHO [1]. These countries were selected based on the fact that they have high malaria incidence rates in sub-Saharan Africa, according to the WHO. Also, 2020 to 2022 was selected so as to work with current data which can help solve the problem of malaria burden compared to the years before 2020. In this context, the malaria incidence rate is defined as the number of malaria cases per 1,000 population at risk, annually. To understand the correlation between climate variability and malaria incidence rates, the annual rainfall patterns of the selected sub-Saharan African countries were collected using search engines like Google. For Nigeria, the southern region was selected for analysis, as it experiences higher rainfall compared to the northern region.

The malaria incidence rate for the Democratic Republic of Congo for the year 2022 has not yet been published by the WHO. However, the malaria incidence rate was predicted for the year 2022 based on previously available data, in order to avoid errors in calculations. After data collection, statistical analysis was conducted using appropriate formulas like the coefficient of variation formula (CV = Standard deviation / Mean × 100) to determine the coefficient of variation in malaria incidence rates from 2020 to 2022, as well as for the rainfall patterns. Additionally, correlation analysis was carried out to examine the relationship between malaria incidence rates and rainfall patterns from 2020 to 2022 using Pearson's correlation coefficient (r). Microsoft Excel was used to visually represent the graphical representation of the line charts of both malaria incidence rates and rainfall patterns.

Furthermore, a descriptive epidemiological study was carried out on the selected sub-Saharan African countries to understand the policies and control measures implemented in different regions to combat malaria. This analysis aimed to identify the country with the most effective policies and control strategies, which could then be recommended to countries showing a strong positive correlation between malaria incidence rates and rainfall patterns. The descriptive epidemiology also served as a control for the statistical calculations, helping to minimize potential errors.

Results

According to the World Malaria Report released by WHO in 2020 [1], Nigeria had a malaria incidence rate of 313.76 per 1,000 population, Mozambique had a rate of 234, while the Democratic Republic of Congo recorded a rate of 330. In 2021, Nigeria had a malaria incidence rate of 306, Mozambique recorded 229, while the Democratic Republic of Congo had a rate of 320. In 2022, Nigeria had a malaria incidence rate of 305, Mozambique recorded 223, while the predicted rate for the Democratic Republic of Congo, using trend analysis, was 310.

The rainfall patterns for the selected sub-Saharan African countries from 2020 to 2022 are as follows: Nigeria recorded 1,800 mm, 1,850 mm, and 2,000 mm; Mozambique had 950 mm, 1,000 mm, and 1,100 mm; while the Democratic Republic of Congo recorded 1,545 mm, 1,534 mm, and 1,386.10 mm. Statistical analysis showed that Nigeria had a coefficient of variation of 1.27 percent for malaria incidence rate and 4.51 percent for rainfall patterns, with a correlation coefficient (r) of -0.7651 between malaria incidence and rainfall. Mozambique had a coefficient of variation of 1.97 percent for malaria incidence rate and 6.13 percent for rainfall patterns, with a correlation coefficient (r) of -0.99. The Democratic Republic of Congo had a coefficient of variation of 2.55 percent for malaria incidence rate and 4.87 percent for rainfall patterns, with a correlation coefficient (r) of 0.895.

Descriptive epidemiology indicates that Nigeria has the most effective policies and control measures for eradicating malaria among the three selected sub-Saharan African countries, followed by Mozambique and then the Democratic Republic of Congo.

Table Showing Malaria Incidence Rates Yearly (Per 1000 populations)

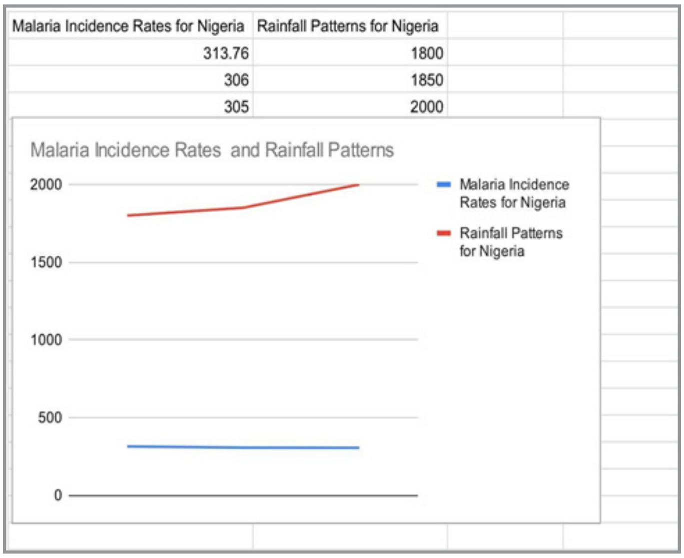
	2020	2021	2022
Nigeria	313.76	306	305
Mozambique	234	229	223
Congo(DRC)	330	320	310

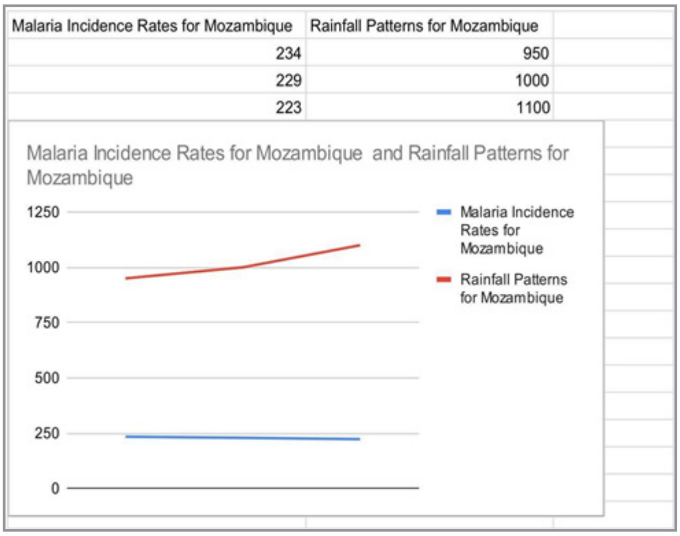
Table Showing Annual Rainfall Patterns (In millimetres (mm))

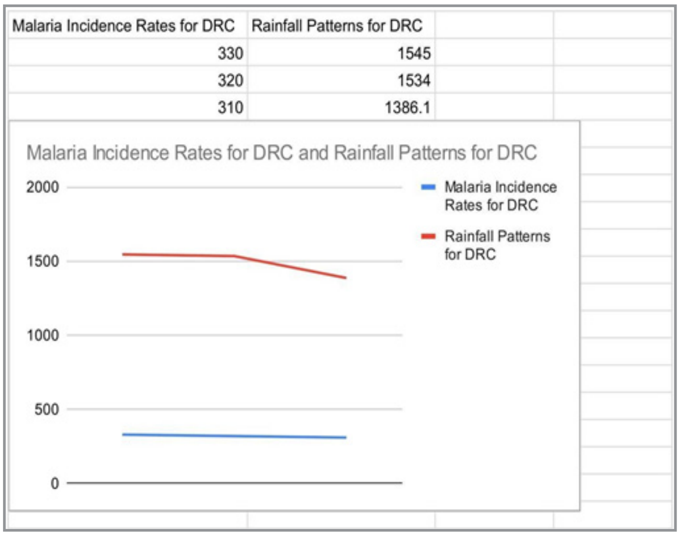
	2020	2021	2022
Nigeria	1800	1850	2000
Mozambique	950	1000	1100
Congo(DRC)	1545	1534	1386.10

Table Showing Coefficient of Variation of MIR(%) and RPs(%) and Correlation Coefficient between MIR and RPs

	Coefficient of Variation (Malaria Incidence Rates)	Coefficient of Variation (Rainfall Patterns)	Correlation Coefficient (r)
Nigeria	1.27	4.50	-0.765
Mozambique	1.97	6.13	-0.991
Congo(DRC)	2.55	4.87	0.895







Discussion / Interpretation

The analysis of malaria incidence rates, rainfall patterns, and their statistical interrelations from 2020 to 2022 in Nigeria, Mozambique, and the Democratic Republic of Congo provides critical insights into the epidemiology of malaria within these sub-Saharan African nations. The observed patterns highlight country-specific variations in malaria burden, environmental influences, and the effectiveness of national control strategies.

Trends in Malaria Incidence

From 2020 to 2022, all three countries experienced a gradual decline in malaria incidence, reflecting the positive impact of ongoing control efforts. Nigeria demonstrated a slight but consistent decrease in malaria incidence, from 313.76 per 1,000 population in 2020 to 305 in 2022. This suggests a stable malaria control landscape, underpinned by sustained interventions such as the use of insecticide treated nets, indoor residual spraying, and improved access to antimalarial treatments [7, 8]. The slow pace of reduction, however, indicates room for enhanced programmatic efficiency and coverage.

Mozambique reported a more pronounced decline from 234 in 2020 to 223 in 2022. The steady downward trajectory reflects moderately effective control measures. While Mozambique does not exhibit the same policy robustness as Nigeria, its malaria control efforts appear adequately structured to drive consistent reductions in incidence. The Democratic Republic of Congo showed a decline from 330 in 2020 to an estimated 310 in 2022, with the slowest rate of improvement among the three. The persistently high incidence underscores systemic challenges, including weak healthcare infrastructure, socio-political instability, and insufficient policy implementation, all of which hinder sustained malaria control [6].

These patterns suggest that while progress is evident, the extent and pace of malaria reduction are significantly influenced by the strength of national malaria control programs, healthcare system capacity, and socio-environmental conditions. Variability in Malaria Incidence and Rainfall Patterns.

The coefficient of variation (CV) was employed to assess the temporal stability of malaria incidence and rainfall across the study period; Nigeria exhibited the lowest variability in malaria incidence (CV = 1.27 percent), indicative of a highly stable epidemiological profile. The moderate variability in rainfall (CV = 4.51 percent) had minimal apparent influence on incidence rates, likely due to Nigeria's effective intervention coverage buffering the effects of environmental fluctuations [8].

Mozambique recorded a moderately low variability in malaria incidence (CV = 1.97 percent) and the highest variability in rainfall (CV = 6.13 percent). Despite the greater fluctuation in precipitation, malaria incidence continued to decline, suggesting that interventions remain effective even under varying climatic conditions. The Democratic Republic of Congo had the highest variability in malaria incidence (CV = 2.55 percent), reflecting inconsistent malaria control efforts. Rainfall variability (CV = 4.87 percent) was similar to that of Nigeria, yet the Democratic Republic of Congo's epidemiological instability points to systemic weaknesses in intervention consistency and coverage [6]. These findings affirm that while rainfall variability is present across all three countries, its influence on malaria transmission is modulated by the strength and consistency of national control measures.

Relationship Between Malaria Incidence and Rainfall Patterns

The correlation analysis reveals diverse relationships between malaria incidence and rainfall, underscoring the multifaceted role of environmental factors in malaria epidemiology [2, 3]. In Nigeria, the strong negative correlation (r = -0.7651) between rainfall and malaria incidence suggests that increased rainfall may disrupt mosquito breeding habitats through flooding or that intensified control activities during the rainy season mitigate transmission risk. Urbanization, infrastructure improvements, and other socioeconomic factors may also contribute to this inverse relationship [9].

In Mozambique, the near perfect negative correlation (r = -0.99) indicates that higher rainfall is associated with decreased malaria incidence. This could reflect the dominance of environmental management strategies or the natural impact of rainfall on vector habitats, such as dilution or flushing of breeding sites [5]. The consistency of this relationship suggests rainfall is a significant determinant of transmission dynamics in Mozambique.

Conversely, the Democratic Republic of Congo displayed a strong positive correlation (r = 0.895), with declining rainfall corresponding to reduced malaria incidence. This aligns with conventional models of malaria transmission, where rainfall creates conducive breeding environments for mosquitoes [2]. The Democratic Republic of Congo's weaker intervention systems may leave the population more vulnerable to environmental determinants of transmission [6]. While the analysis provides valuable insights, several limitations should be noted. The data cover only three years (2020 to 2022), limiting the ability to capture long term trends. The predicted malaria incidence for the Democratic Republic of Congo in 2022, based on previous data, introduces potential uncertainty, and actual data would strengthen the findings.

Additionally, the correlation analyses assume linear relationships, but non-linear or lagged effects of rainfall on malaria transmission may exist. Other factors such as temperature, humidity, socioeconomic conditions, and intervention coverage were not included in the analysis but likely influence malaria dynamics. Future research should incorporate longer time series, additional environmental and social variables, and non-linear modeling to better understand malaria transmission drivers. Also, the study of adaptive features of malaria vectors to insecticide will help in understanding the eradication of malaria [10].

Conclusion

This study examined the relationship between malaria incidence rates and rainfall patterns in Nigeria, Mozambique, and the Democratic Republic of Congo from 2020 to 2022. The findings revealed a general decline in malaria incidence across all three countries, with Nigeria and Mozambique showing more stable reductions compared to the Democratic Republic of Congo. Statistical analysis showed varying correlations between rainfall and malaria incidence, with negative correlations observed in Nigeria and Mozambique, and a strong positive correlation in the Democratic Republic of Congo. These results indicate that the impact of rainfall on malaria transmission is influenced by the effectiveness of national control measures and regional ecological conditions.

Descriptive epidemiology highlighted Nigeria as having the most effective malaria control policies among the three countries, followed by Mozambique and the Democratic Republic of Congo. The study emphasizes the importance of strengthening national control strategies and tailoring interventions to regional climatic and epidemiological contexts. Although limited by data availability and the short study period, the analysis provides valuable insights that can guide future research and policy development aimed at reducing malaria incidence in sub- Saharan Africa.

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