Journal of the Egyptian Society of Parasitology, Vol. 55, No. 2, August 2025
J. Egypt. Soc. Parasitol. (JESP), 55(2), 2025: 169 - 174
Online: 2090-2549

IMPACT OF CLIMATE VARIATION ON MALARIA INCIDENCE RATES IN SUB-SAHARAN AFRICA: A REGIONAL ANALYSIS

By

MUDASIRU OLAMIDE ROKEEB, AMUSA AISHA ADEBOLA, OLOYEDE HALEEMAH and MUDASIRU OLAMIDE ROKEEB*

Department of Medical Laboratory Science, Ladoke Akintola University of Technology, Ibadan, Oyo State, Nigeria (*Correspondence: olamiderokeeb2004@gmail.com, Mobile: 09151866018)

Abstract

Malaria remains a major public health concern in the sub-Saharan Africa The climate variability, especially rainfall, influences malaria transmission via mosquito breeding habitats with regional variations. This study evaluated the correlation between malaria incidence rates and rainfall patterns from 2020 to 2022 in Nigeria, Mozambique, and the Democratic Republic of Congo countries, alongside a descriptive epidemiological review of national control policies.

The results showed that malaria incidence in Nigeria declined from 313.76 to 305, in Mozambique from 234 to 223, and the Democratic Republic of Congo from 330 to 310. Correlation analysis showed a strong negative relationship between rainfall and malaria incidence in Nigeria (r= -0.765) and Mozambique (r= -0.991), but a strong positive correlation in the Democratic Republic of Congo (r= 0.895). Nigeria showed the effective control measures, followed by Mozambique.

Keywords: Malaria, Rainfalls, Sub-Saharan Africa, Epidemiology, Variations, Coefficient.

Introduction

Malaria remains a significant global public health problem, especially in the tropical and sub-tropical regions, with a disproportionate burden in sub-Saharan Africa (WHO, 2020). It is a preventable and treatable disease caused by *Plasmodium* spp. transmitted by 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 (O'Meara *et al,* 2004).

This study examined the correlation between malaria incidence rates and climate variations, specifically rainfall patterns, by focusing on three sub-Saharan African countries, 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 indicated that stagnant water, resulting from heavy rainfall, serves as a breeding ground for malaria vectors, mainly during eggs, larvae and pupae developments (Smith *et al,* 2007). Also, 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 the current intervention strategies.

While numerous studies have explored the epidemiology of malaria in sub-Saharan Africa, relatively few have specifically examined how climate variability, especially rainfall pattern, directly influences on regional incidence over time. The majority of literatures concentrated on the impact of climatic factors without referring malaria vectors. Also, studies tend to overlook analyzing the national malaria control policies across different sub-Saharan African countries, which could have feasible strategies for reducing malaria in other regions.

No doubt, malaria epidemiology, role of climatic factors as rainfall, mosquito breeding habitats, and national control policies in sub-Saharan Africa are critical. To cover this gap this study focused on Nigeria, Mozambique and the Democratic Republic of Congo.

According to the 2022 report, the Sub-Saharan Africa accounted for 233 million out of 249 million malaria cases reported globally and approximately 594,000/619,000 malaria-related deaths over 94% (Venkatesan, 2024). About 50% of world malaria cases were due to (27%) in Nigeria, (12%) in the Democratic Republic of the Congo and (4%) in Mozambique (Li *et al*, 2024).

Climatic influences on malaria transmission: Rainfall and temperature play a critical role in malaria transmission by creating favorable co-nditions for *Anopheles* breeding places and parasitic development (Gubler, 1996). 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.

Ecology of *Anopheles* spp., mainly *An. gambiae*, is closely related to rainfall-driven breeding habitats (Takken and Knols, 1999). Fuller *et al*. (2012) found that *An. arabiensis* is an opportunistic feeder and efficient vector of *P. falciparum* in Africa and may invade areas outside its normal range, separated by expanses of barren desert. WHO (2023) added that A*n. stephensi* an alarming resistance to insecticides, such as DDT & pyreth roids, spreading is a major potential threat to African malaria control by tolerating pollution, and different climatic and environmental conditions and detected in Ethiopia, Sudan, Somalia, and now in Nigeria and Kenya. Other African *Anopheles* bite usually at night indoors, but *An. stephensi* bites at dusk when outsides air is still warm, limiting the effectiveness of insecticidal nets.

Temporary water bodies formed during rainy seasons favor the development of larvae to emerging adults; yet regional habitat suitability variations is still under explored. For instance, southern Nigeria's high rainfall supports more breeding sites, but Mozambique's coastal ecology presents unique challenges. The existing studies showed that the climatic impacts without focusing on how specific breeding habitats influence transmission dynamics; a limitation study seeks to address via targeted correlation analyses.

Effective malaria control relies on interventions as insecticide treated nets (ITNs), indoor residual spraying (IRS), and Artemisinin® (ACTs) based on the combined therapies (NMEP, 2014). Nevertheless, studies on the malaria transmission were insignificantly related to ITN coverage, although much could be achieved in attempts to curtail malaria transmission through enhanced ITN coverage (Okunlola *et al,* 2021). Mozambique has implemented the seasonal malaria chemoprevention, and IRS, but with less comprehensive coverage. The control measures in the Democratic Republic of Congo were hampered by logistical challenges and conflict, resulted in the higher incidence and variability (Ntuku *et al,* 2016).

This study aimed to evaluate the relation between rates of malaria incidence and rainfall from 2020 to 2022years in Nigeria, Mozambique, and the Democratic Republic of Congo.

Material and Methods

Malaria incidence data in Nigeria, Mozambique, and the Democratic Republic of Congo were cited from WHO reports of years 2020 to 2022, and annual rainfall data were sourced online on World Meteorological Organization website. Pearson's correlation coefficient assessed the relations between rainfall, and malaria incidence. The variation coefficient 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 individual malaria control policies.

In respect to background of this study, statistical data were collected on three sub-Saharan African countries, focused on malaria incidences from 2020 to 2022 (WHO, 2023). The countries were selected based on the fact that they have higher malaria incidence rates, according to the current data that can help to solve malaria problem before 2020th years.

In this study, malaria incidence rate was defined by annual number cases/1,000 population at risk. To know the correlation between climate changes and malaria incidence rates, the annual rainfall patterns selected sub-Saharan African countries were from the World Meteorological Organization website. For Nigeria, the southern region was selected for analysis, with its higher rainfall compared to the northern region. But, the malaria incidence rate in the Democratic Republic of Congo for 2022 year was not yet published by the WHO, and, the malaria incidence rate was predicted for the year 2022 based on the available data, in order to avoid errors in calculations.

After data collection, statistical analysis was done using appropriate formulas like the coefficient of variation formula (V= Standard deviation/Mean×100) to determine the coefficient of in the malaria incidence variations from 2020 to 2022, and for the rainfall patterns. Besides, correlation analysis was carried out to examine relationship between malaria incidence rates and rainfall patterns from 2020 to 2022 using the Pearson's correlation coefficient (r). Microsoft excel was used to visually to represent the graphical representation of the line charts of both malaria incidence rates and rainfall patterns, and to know the feasible control measures, to be recommended to country with a high positive malaria and rainfall to minimize errors.

Results

In 2021, Nigeria had a malaria incidence rate of 306, Mozambique recorded 229, and the Democratic Republic of Congo had a rate of 320. In 2022, Nigeria had a malaria inrate of 305; Mozambique showed 223, but for the Democratic Republic of Congo were 310.

Rainfall patterns for these countries from 2020 to 2022 are as follows: Nigeria recorded 1,800mm, 1,850mm, & 2,000mm; Mozambique had 950mm, 1,00mm, & 1,10mm, and the Democratic Republic of Congo recorded 1,545mm, 1,534mm, & 1,386.10 mm.

Statistically showed Nigeria had a coefficient of variation of 1.27% for malaria incidence rate and 4.51% for rainfall patterns, with a co-rrelation coefficient (r) of -0.765 between malaria incidence and rainfall. Mozambique had a coefficient of variation of 1.97 % for malaria incidence rate and 6.13% for rainfall patterns, with r=-0.991. The Democratic Republic of Congo had a coefficient of variation of 2.55% for malaria incidence rate and 4.87% for rainfall patterns, with a (r) of 0.895. Nigeria has nearly the best effective control measures for eradicating malaria, followed by Moza-mbique and the Democratic Republic of Congo.

Details were given in tables (1, 2, & 3), and figures (1, 2, & 3).

Table 1: Annual malaria rate per 1000populations

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

Table 2: Annual rainfall in mm

Variations	2020	2021	2022
Nigeria	1800	1850	2000
Mozambique	950	1000	1100
Congo (DRC)	1545	1534	1386.1

Table 3: Coefficient variations of MIR% & RPs% & between MIR & RPS

Variations	Malaria Incidence	Rainfall pattern	Coefficient r
Nigeria	1.27	4.5	-0.765
Mozambique	1.97	6.13	-0.991
Congo (DRC)	2.55	4.87	0.895

Discussion

Analysis of the malaria incidence rates and rainfall patterns from 2020 to 2022 in the three dealt with countries showed specific variations in malaria burden, environmental-factors, and effectiveness control strategies.

Nigeria showed a slight but marked decrease in malaria incidence, from 313.76 per 1,000 populations in 2020 to 305 in 2022, due to stable malaria control landscape, underpinned by sustained interventions such as insecticide treated nets, indoor residual spraying, and improved antimalarial treatments (Okorosobo *et al*, 2020). But, slow reduction pace indicated that room for enhanced programmatic efficiency and coverage is a must.

Mozambique reported a more pronounced decline from 234 in 2020 to 223 in 2022. The steady downward trajectory reflected moderately effective control measures. But, the country didn't exhibit the same policy robustness as Nigeria; its malaria control efforts were adequately structured to drive consistent reductions in incidence. The Democratic Republic of Congo showed a decline from 330 in 2020 to a rate of 310 in 2022, with the slowest rate of improvement among the three countries. The World Bank (2024) is helping to fight poverty and improve the living standards for the people of the Democratic Republic of Congo, via education, energy, health and other vital social services

In this study, as to variability in malaria and rainfall, Nigeria exhibited the low malaria variability incidence (V=1.27%), with a highly stable epidemiological profile, with moderate rainfall variability (V=4.51%), and minimal apparent influence on incidence rates, due to effective intervention coverage buffering the environmental fluctuations effects (Amadi *et al*, 2021).

Mozambique recorded a moderately low variability in malaria incidence (V= 1.97%) with highest rainfall variability (V= 6.13%). Despite the greater fluctuation in precipitation, malaria incidence continued to decline, suggested that interventions remain effective even under varying climatic conditions. The Democratic Republic of Congo showed highest incidence variability (V= 2.55%), reflected inconsistent malaria control efforts. Rainfall variability (V= 4.87%) was similar to that of Nigeria, yet the Democratic Republic of Congo epidemiological instability pointed to systemic weaknesses in the intervention consistency and coverage. Deutsch-Feldman *et al.* (2021) reported that despite evidence that older children and adolescents bear the highest burden of malaria, large malaria surveys focus only on younger children. They concluded that 5-14-year-old accounted for a large proportion of malaria infections in the DRC, and that attempt to assess malaria burden in highly endemic countries like the DRC need to include this age stratum in malaria surveys.

In the present study, as to the relation between malaria incidence and rainfall patterns showed diversity. In Nigeria, the highly negative relation between rainfall and malaria incidence showed that increased rainfall may disrupt vectors breeding habitats by flooding and/or intensified control activities in rain season mitigate transmission risk, & urbanization, infrastructure improvements, and socio-economy have their marked input (Keating *et al*, 2010).

In Mozambique, the more or less negative correlation showed that higher rainfall was associated with low malaria incidence, with the continuous environmental control strategies and/or the natural impact of rainfall on the vectors habitats (Chaves *et al*, 2012).

However, the Democratic Republic of Congo displayed a strong positive correlation, with declining rainfall corresponding to reduced malaria incidence, with conventional malaria models of transmission, where rainfall creates conducive breeding environments for mosquitoes (Panzi *et al*, 2022).

Al-Agroudi *et al.* (2018) in a retrospective study over three years among 99 Peace Keeping Forces in Africa back to Egypt found that they were malaria patients from Central Africa (41), Darfur (38), DR Congo (11), Nigeria (3), Chad (2) and 1 from to each of Djibouti, Kenya, Rwanda, or Tanzania, and the *Plasmodium* species were *P. falciparum* (83), *P. vivax* (9), *P. ovale* (1) & mixed species (5).

The present study covered only three years

(2020 to 2022), the predicted malaria incidence for the Democratic Republic of Congo in 2022, based on available data, introduced potential uncertainty, but actual data would add more facts. Generally, malaria incidence and prevalence depends depend on climatic changes, with have input mainly the vectors and insecticides is a must in malaria eradication (Hemingway *et al*, 2016).

Conclusion

The study highlighted that the rainfall's influence on malaria incidence was moderated by the effectiveness of national control strategies. Strengthening region-specific interventions is the key for malaria eradication or even reduction in the sub-Saharan Africa.

Authors' interest: Authors declared that neither has competing of interests nor received any funds.

Authors' contribution: Authors equally shared in data collection, writing, revising manuscript and approved its publication.

References

Al-Agroudi, MA, Ahmad, GMS, Kondo, MK, Morsy, TA, 2018: Malaria situation in Egypt the last three years: Retrospective study in an Egyptian Fever Hospital. JESP 48, 3:635-644.

Amadi, M, Shcherbacheva, A, Haario, H, 2021: Agent-based modeling of complex factors impacting malaria prevalence. Malar J. 2021 Apr 15; 20(1):185. doi: 10.1186/s12936-021-03721-2.

Chaves, LF, Satake, A, Hashizume, M, Minakawa, N, 2012: Indian Ocean dipole and rainfall drive a Moran effect in East Africa malaria transmission. J. Infect Dis. 205, 12:1885-91.

Deutsch-Feldman, M, Parr, JB, Keeler, C, Brazeau, NF, Goel, V, *et al*, 2021: The burden of malaria in the Democratic Republic of the Congo. J. Infect. Dis. 223, 11:1948-52.

Fuller, DO, Parenti, MS, Hassan, AN, Beier, J C, 2012: Linking land cover and species distribution models to project potential ranges of malaria vectors: An example using *Anopheles arabiensis* in Sudan and Upper Egypt. Malar. J. 11: 264-72.

Gubler DJ, 1996: The global emergence/resurgence of arboviral diseases. Arch. Virol. 11:S61-71.

Hemingway, J, Ranson, HA, Magill, A, *et al*, 2016: Averting a malaria disaster: Will insecticide resistance derail malaria control? Lancet 387, 10029:1785-8.

Keating, J, Miller, JM, Bennett, A, Lindsay, S W, 2010: Urbanization and malaria in sub-Sahraan Africa: A systematic review. Malar. J. 9: 276-382.

Li, J, Docile, HJ, Fisher, D, Pronyuk, K, Zhao, L, 2024: Current status of malaria control and elimination in Africa: Epidemiology, diagnosis, treatment, progress and challenges. J. Epidemiol. Glob. Hlth. 14, 3:561-79.

NMEP, 2014: National Malaria Elimination Programme: National malaria strategic plan 2014-2020. Abuja, Nigeria: Federal Ministry of Health.

Ntuku, HM, Mafuta, EM, Kayembe, PK, *et al*, 2016: Malaria control in the Democratic Republic of Congo: Achievements and challenges. Malar. J. 15:582-90.

O'Meara, WP, Smith, DL, Milman, J, McKenzie, FE, 2004: The global burden of *Plasmodium falciparum* malaria in 2000. Malar. J. 3:4-10.

Okorosobo, T, Nwokoro, C, Azuike, EC, *et al*, 2020: Impact of insecticide-treated nets on malaria prevalence in children less than five years in Nigeria: A systematic review. Malar. J. 19, 1: 407-14.

Okunlola OA, Oyeyemi, O, Lukman, AF, 2021: Modeling the relationship between malaria prevalence and insecticide-treated bed net coverage in Nigeria using a Bayesian spatial generalized linear mixed model with a Leroux prior. Epidemiol. Hlth. 43:e2021041.doi:10.4178/epih.e2021041

Panzi, EK, Okenge, LN, Kabali, EH, Tshimungu, F, *et al*, 2022: Geo-climatic factors of malaria morbidity in the Democratic Republic of Congo from 2001 to 2019. Int. J. Environ. Res. Pub. Hlth. Mar 23;19(7):3811. doi:10.3390/ijerph1907381

Smith, DL, McKenzie, FE, Snow, RW, 2007: Revisiting the basic reproductive number for malaria and its implications for elimination. Malar. J. 6:139-144.

Takken, W, Knols, BGJ, 1999: Ecology of *Anopheles* mosquitoes in relation to malaria transmission. Microbes Infect. 1, 15:1695-703.

Venkatesan, PW, 2024: The 2013 WHO World malaria report. Lancet Microbe 5:e214.

WHO, 2020: World Malaria Report 2020. Geneva, Switzerland.

WHO, 2023: Annual Report: Universal Health Coverage, Communicable and Noncommunicable Diseases (UCN) Cluster, WHO Regional Office for Africa.

World Bank, 2024: Democratic Republic of Congo Overview. https://www. worldbank. org/en/cou- ntry/drc/overview.

Explanation of figures

Fig. 1: Malaria incidence rate versus rainfall in Nigeria.
Fig. 2: Malaria incidence rate versus rainfall in Mozambique.
Fig. 3: Malaria incidence rate versus rainfall in Congo (DRC).