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Spatiotemporal Dynamics of Malaria Incidence and Climatic Variability Across the Six Area Councils of the Federal Capital Territory, Abuja: Implications for Defining the Malaria Transmission Season

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Abstract: Malaria remains a major public health challenge in Nigeria, and its transmission is strongly influenced by climatic and environmental conditions. Variations in temperature and rainfall can affect mosquito breeding, parasite development and the seasonal distribution of malaria. Understanding these relationships is important for improving malaria surveillance and determining the appropriate timing of control interventions. This study examined the relationship between climatic variables and malaria incidence in the Federal Capital Territory (FCT), Abuja.The study employed a retrospective ecological approach using monthly malaria incidence data obtained from one health facility in each of the six Area Councils of the FCT. Data covering the period 2020–2022 were examined to determine temporal and spatial patterns of malaria occurrence. Longer-term malaria incidence data were also examined using annual malaria incidence estimates and population projections. Climatic variables, particularly rainfall and temperature, were considered in assessing variations in malaria incidence. Malaria incidence was expressed in relation to population size to facilitate comparison among the Area Councils. The findings demonstrated considerable temporal and spatial variation in recorded malaria incidence across the FCT. Most Area Councils exhibited a recurring pattern of increased malaria incidence in February and August, followed by lower recorded incidence during November, December and January. The highest incidence occurred in August in 2020 and 2021, whereas the peak shifted to September in 2022, suggesting interannual variability in the timing of peak malaria transmission. Gwagwalada recorded an unusual pattern of relatively low malaria incidence in 2020, which may have been influenced by reduced healthcare utilization associated with the use of the University of Abuja Teaching Hospital as a major COVID-19 treatment centre. In 2021, the National Hospital in AMAC recorded substantially higher malaria cases than the other study facilities. The longer-term analysis also indicated an overall increase in malaria incidence, with AMAC showing a particularly pronounced increase. The observed seasonal patterns were broadly consistent with the established influence of climatic conditions, particularly rainfall and temperature, on malaria transmission. Climate-informed malaria early-warning systems, strengthened surveillance and Area Council-specific interventions are recommended to support more effective malaria prevention and control in the FCT.

Keywords: *Malaria Incidence; Climatic Variables; Rainfall; Temperature and Climate Variability*.

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I. INTRODUCTION

Malaria remains one of the most important public health challenges in tropical and subtropical regions of the world, particularly in sub-Saharan Africa. The disease is caused by Plasmodium parasites and transmitted predominantly through the bites of infected female Anopheles mosquitoes. Despite substantial progress in malaria prevention, diagnosis and treatment, the disease continues to impose a considerable health and socioeconomic burden. The World Health Organization (WHO) estimated that approximately 282 million malaria cases and 610,000 deaths occurred globally in 2024, with the WHO African Region accounting for the overwhelming majority of the global burden. Nigeria remains one of the countries with the highest malaria burden globally.

Malaria transmission is influenced by several interacting biological, environmental, socioeconomic and climatic factors. Among these factors, temperature and rainfall are particularly important because they directly affect the ecology and development of malaria vectors and parasites. Temperature influences mosquito survival, biting frequency and the rate at which Plasmodium develops inside the mosquito. Rainfall contributes to the formation and maintenance of temporary and permanent water bodies that serve as breeding habitats for Anopheles mosquitoes. Consequently, changes in temperature and rainfall can alter the intensity, timing and geographical distribution of malaria transmission. The relationship, however, is complex because the effect of a climatic variable depends on its magnitude, duration, seasonality and interaction with other environmental conditions.

The influence of climate on malaria transmission is particularly important in countries such as Nigeria, where malaria transmission occurs throughout the year but varies substantially according to ecological and climatic conditions. The WHO reports that malaria transmission risk exists throughout Nigeria, although the intensity of transmission varies geographically and seasonally. Nigeria has consequently adopted approaches that emphasize the use of subnational epidemiological and climatic information to improve malaria-control planning.

The Federal Capital Territory (FCT), Abuja, presents an important setting for examining the relationship between climate and malaria. Abuja has a tropical climate characterized principally by distinct wet and dry seasons. Seasonal variation in rainfall and temperature creates changing environmental conditions that can affect mosquito breeding and malaria transmission. The availability of breeding sites generally increases during the rainy season, potentially resulting in increased vector abundance and malaria transmission. However, the relationship between climatic variables and malaria incidence may involve time lags, whereby weather conditions in one month influence malaria incidence in subsequent months.

Evidence from Abuja supports the importance of these climatic influences. Sani et al. examined monthly malaria incidence and weather variables in Abuja from 2000 to 2013 and found that malaria incidence was higher during the months with the greatest rainfall, particularly June to August. Their analysis further demonstrated that rainfall had a significant positive effect on malaria incidence at a one-month lag, while temperature and humidity also demonstrated significant effects at longer lags. These findings indicate that climatic conditions can influence malaria occurrence not only contemporaneously but also after a period of delay.

Evidence at the national level also demonstrates significant associations between environmental and climatic conditions and malaria transmission. A spatiotemporal study of malaria in Nigeria found significant relationships between malaria incidence and environmental predictors including rainfall, temperature, aridity and proximity to water. The findings suggest that environmental conditions can help explain spatial differences in malaria transmission and may be useful in identifying areas and periods requiring intensified intervention.

Understanding the relationship between climatic variables and malaria incidence is therefore important for strengthening malaria surveillance and control. Conventional malaria interventions, including insecticide-treated nets, indoor residual spraying, environmental management, early diagnosis and effective treatment, can be more effectively deployed when the periods of increased transmission risk are known. Climate and malaria surveillance data can provide an opportunity to anticipate changes in transmission and support timely public health responses. WHO's current malaria surveillance guidance emphasizes the importance of high-quality surveillance and the integration of information to improve malaria prevention and response, including in the context of climate-related changes.

For the FCT, determining the relationship between rainfall, temperature and malaria incidence is particularly relevant because the territory is undergoing rapid population growth and urban development. Changes in land use, drainage, settlement patterns and environmental management may modify the availability of mosquito breeding sites and potentially influence how climatic conditions translate into malaria transmission. Thus, findings from other geographical areas cannot necessarily be applied directly to Abuja. Local empirical evidence is required to characterize the climatic conditions associated with increased malaria incidence in the territory.

Malaria continues to represent a significant public health problem in Nigeria despite the implementation of multiple control and prevention interventions. The continued burden of

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malaria is influenced by the interaction of climatic, environmental, demographic, socioeconomic and health-system factors. Nigeria's large malaria burden makes the development of locally appropriate and evidence-based approaches to prevention and control particularly important.

In the FCT, malaria transmission exhibits seasonal variability, with increased incidence generally associated with the rainy season. However, the precise relationship between climatic variables and malaria incidence may vary over time. Although previous research in Abuja has demonstrated significant associations between weather variables and malaria occurrence, much of the available evidence is based on historical datasets. For example, the study by Sani et al. used data from 2000–2013 and identified rainfall, temperature and humidity as important predictors at different time lags.

A major challenge is therefore the need for continuous assessment of the climate–malaria relationship using available epidemiological and meteorological data. Climatic conditions are not static, and variations in rainfall and temperature may influence the timing and magnitude of malaria transmission from one period to another. Furthermore, the existence of a statistical association does not necessarily imply that the same climatic thresholds or seasonal patterns will remain constant over time.

There is also an important operational gap in translating knowledge of climatic influences into malaria-control planning. If the period of increasing malaria transmission can be reliably identified from climatic and epidemiological patterns, malaria interventions can be intensified before or during periods of greatest risk. Conversely, interventions that are planned without adequate knowledge of local seasonal patterns may be implemented too early, too late, or for periods that do not correspond with the actual transmission dynamics. Consequently, there is a need for evidence that clearly characterizes how temperature and rainfall relate to malaria incidence in the FCT.

Addressing this problem is important for improving climate-informed malaria surveillance and strengthening the timing and allocation of malaria-control resources in Abuja. By examining the relationship between climatic variables and malaria incidence, the present study seeks to generate evidence that can contribute to a better understanding of malaria transmission dynamics in the FCT and support more effective, locally responsive malaria prevention and control strategies.

II. MATERIALS AND METHODS

- *Study Area*

According to Dawam (2000), the Federal Capital Territory Abuja is situated between latitude 8° 25" and 9° 25" North of the Equator and longitude 6° 45" and 7° 45" East of the Greenwich Meridian. The Federal Capital Territory Abuja covers an area of 8,000 square kilometers and occupies about 0.87% of Nigeria within the region generally referred to as the "Middle Belt" (Wikipedia retrieved 2023). Abuja is bordered on all sides by four states namely Niger, Nasarawa, Kogi and Kaduna. In 2022, the world bank estimated total population of the FCT to be about 3.65 million with a density of 703 persons per km2 (World Bank, 2022). However, according to the National Bureau of Statistics, Nigeria, the estimated population of the FCT Abuja in 2023 is 3,839,646 (NBS, 2023)

The territory is bounded by significant relief features, physiologic regions, a sufficiently unique Climatic, Vegetation and hydrological systems that have made it ideal for locating Nigeria's new Federal Capital. It is currently home to the three tiers of government as well as a local authority the Ministry of the Federal Capital and the Federal Capital Development Authority.

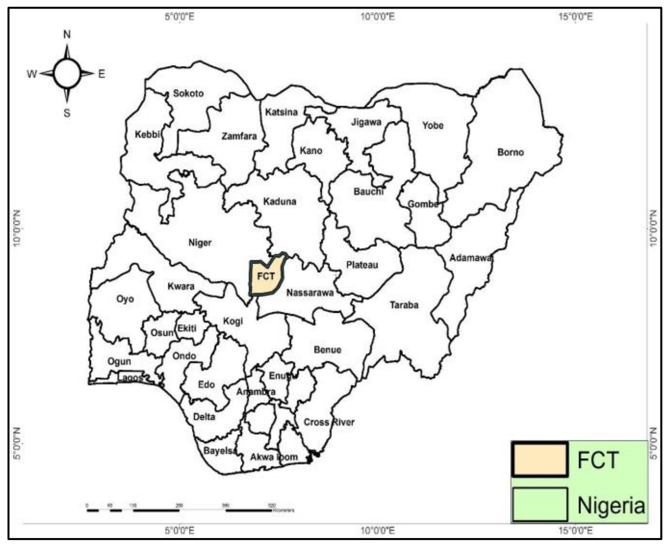

Fig 1: Map of Nigeria Showing FCT
Source: FCDA, Cartography Department.

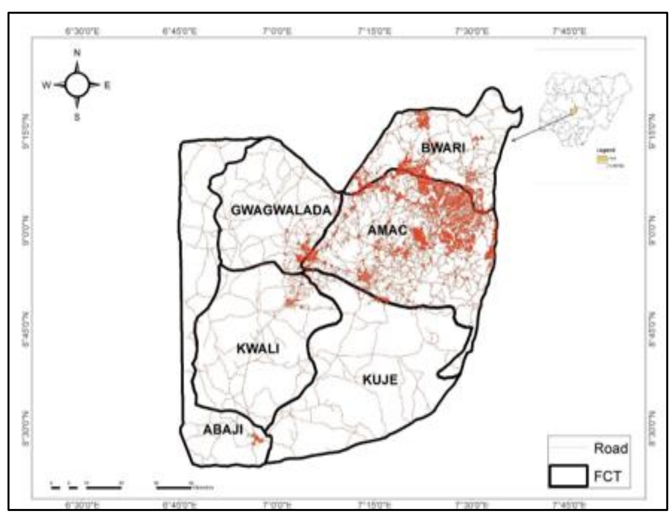

Fig 2: Study Area Map
Source: Agis, 2021.

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➢ *Sampling Procedure*

The data used in the study was mainly secondary in nature. Data was collected from (willing) hospitals within the FCT (Table 1), the Nigerian Meteorological Agency (NIMET), the Nigerian Population Commission, and The Nigerian Bureau of Statistics. Climate data was sourced from the year 2000 to 2021 via NASA/NOAA on the website https://power.larc.nasa.gov/data-access-viewer/ .

Annual malaria incidence data was obtained from the World Bank country archives on malaria incidence.

Table 1: Selected Health Centers in the Study Area

S/N	Area Council	Selected Health Centres
1	AMAC	National Hospital
2	Gwagwalada	University of Abuja Teaching hospital
3	Bwari	Bwari General Hospital
4	Kwali	Kwali General Hospital
5	Kuje	Kuje General Hospital
6	Abaji	Abaji General Hospital

Source: Reconnaissance/field survey 2023

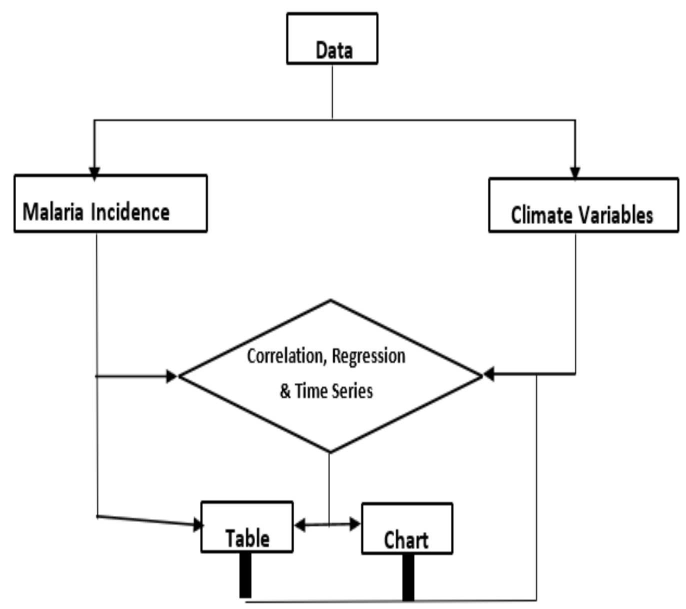

Fig 3: Flowchart Showing the Research Method. (Study.com, 2023).

The data collected were subjected to preprocessing to ascertain their validity and to also put them in a format suitable for analysis (Coll *et. al.*, 2020). For instance, climate data obtained from the National Oceanic and Atmospheric Administration (NOAA) was converted from its csv format to exl format suitable for analysis in Microsoft excel and SPSS statistical software Packages. The climate data was also subjected to other quality measures as recommended by Costas *et. al.*, (2021) including but not limited to A students T-test to ascertain the suitability of the data for regression analysis.

The analysis was driven by the duration of the climate data available, specifically annual incidence and monthly incidences. Monthly averages for rainfall and temperature obtained from NIMET (2021 to 2022) and Annual climate data from NOAA (2000 to 2018) to be precise.

III. RESULTS AND DISCUSSION

❖ *Ascertain The Relationship Between Climatic Variables, Specifically Temperature and Rainfall and the Incidence of Malaria Cases in the Federal Capital Territory, Abuja*

Monthly data over a three-year period (2000 to 2022) was obtained from available recorded incidences of malaria in one hospital in each area council (Figure 3). Annual data was obtained from the world banks calculated incidences of malaria per 1000 persons in Nigeria (see appendix III), while population data is based on the Nigerian Population Comissions'(NPC) 2022 projection figures.

Figure 4 presents the observed malaria incidence recorded in 2020 by the hospitals from which data was obtained. All the area councils with the exception of Gwagwalada follow a distinct pattern clearly indicating spiking incidences of malaria (in varying magnitudes) in February and August with noticeable dips in recorded cases in November, December and January. The University of Abuja teaching hospital Gwagwalada was the major treatment center for the COVID-19 Epidemic in the FCT. This perhaps could be a reason for the low incidence of cases since the populace would have avoided the hospital within that period. This raises the question of factors affecting hospital patronage and self-medication for ailments within the territory. It is notable that the malaria incidences recorded in 2020 were higher than subsequent years.

In 2021, (figure 5) malaria incidences recorded at the National Hospital in AMAC were significantly higher than any of the other hospitals polled for the study. The incidences of malaria recorded in the National Hospital AMAC showed spikes and dips similar to what was observed in 2020. However, because the number of recorded cases is significantly higher than that of the other area councils, recorded malaria incidences are far above the curve. The recorded cases in Gwagwalada area

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council did not deviate from the curve like can be observed in 2020.

In the year 2022, the highest recorded incidences of malaria within the FCT can be observed in the month of September. In the years 2020 and 2021, the highest recorded incidences of malaria were in August. This indicates some type reaction to variability which is discussed further in subsequent sections of this chapter. Figure 6, shows the total incidences of malaria based on population and incidences per 1000 persons for all area councils over a period of 22 years. A cursory glance showcases steady growth of malaria incidence overtime, Morealso there is an increase in Abuja Municipal Area Council than any other area council.

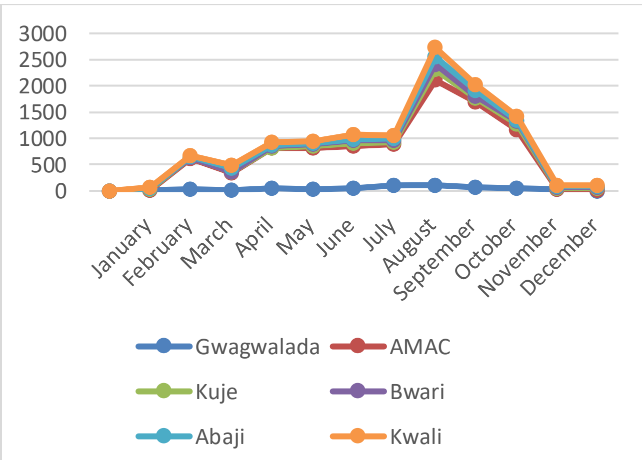

Fig 4: Malaria Incidence in the FCT From January to December 2020 (Field Surveys)

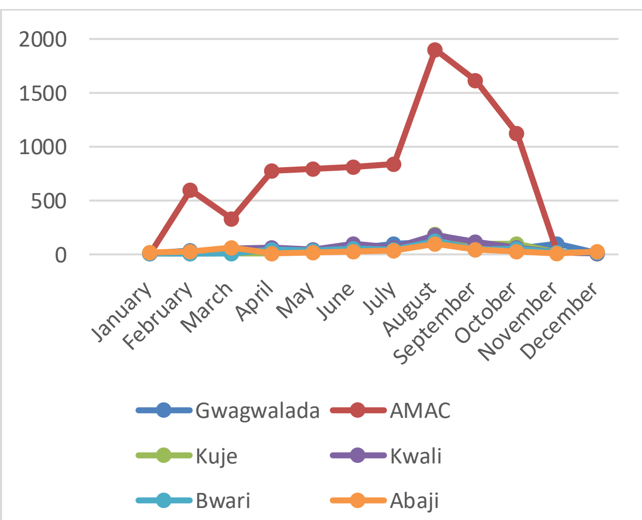

Fig 5: Malaria Incidence in the FCT From January to December 2021 (Field Surveys)

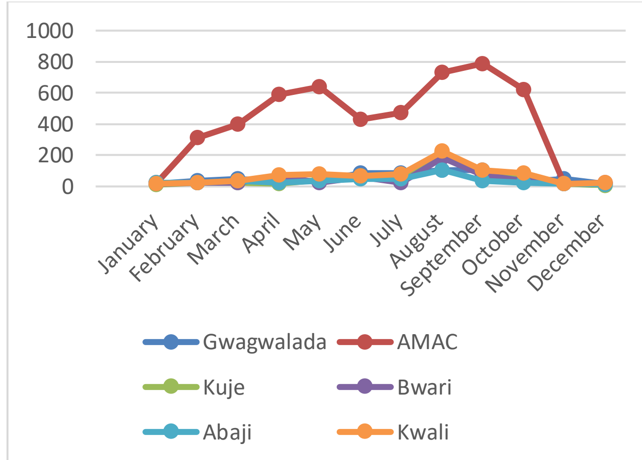

Fig 6: Malaria Incidence in the FCT from January to December 2022 (Field Surveys)

IV. DISCUSSION

The findings of this study demonstrate considerable temporal and spatial variation in malaria incidence across the six Area Councils of the Federal Capital Territory (FCT), Abuja, between 2020 and 2022, with evidence of longer-term increases in malaria incidence over the broader period examined. The observed patterns indicate that malaria transmission in the FCT is not evenly distributed across time or geographical areas. Rather, incidence appears to fluctuate according to seasonal conditions, population characteristics, healthcare utilization and other environmental and socioeconomic factors. The occurrence of pronounced peaks in February and August in several Area Councils, followed by relatively lower recorded incidence in November, December and January, suggests that malaria transmission in Abuja has a strong seasonal component.

A. Seasonal Pattern of Malaria Incidence

One of the most important findings is the recurrent pattern of increased malaria incidence during February and August, with reduced recorded cases during November, December and January. The August peak is consistent with the established relationship between malaria transmission and the rainy season in Abuja. During the rainy season, increased availability of stagnant water and temporary pools provides suitable breeding habitats for Anopheles mosquitoes. Increased mosquito abundance can subsequently increase malaria transmission, particularly where environmental conditions remain favourable for vector survival and parasite development.

The August peak observed in this study agrees with findings reported by Sani et al. (2020), who investigated the

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relationship between weather factors and malaria occurrence in Abuja. Their study found that malaria incidence was higher during the months with greater rainfall, particularly between June and August. They also demonstrated that rainfall had a significant positive association with malaria incidence at a lag of approximately one month. This lagged relationship is epidemiologically plausible because rainfall creates breeding sites, followed by mosquito development, parasite development and subsequent transmission to humans. The present study therefore provides additional evidence that August represents an important period of elevated malaria transmission in the FCT.

The findings are also broadly consistent with the wider literature on malaria seasonality. Craig et al. (1999) demonstrated that malaria transmission is strongly associated with rainfall and temperature, although the strength and timing of the association vary according to local ecological conditions. Similarly, Thomson et al. (2005) reported that rainfall and temperature are important determinants of the seasonal suitability of environmental conditions for malaria transmission in Africa. These studies support the interpretation that the observed seasonal fluctuations in malaria incidence in the FCT are likely to be partly associated with changes in climatic conditions.

However, the February peak observed in several Area Councils requires additional consideration because February generally falls within the dry season in Abuja. The occurrence of increased malaria incidence during this month suggests that malaria transmission in the FCT cannot be explained exclusively by contemporaneous rainfall. Several factors may contribute to this pattern. First, rainfall from the preceding wet season may create persistent breeding habitats that remain suitable for mosquito reproduction into the early dry season. Second, temperature during the dry season may remain within a range that permits mosquito survival and Plasmodium development. Third, malaria cases reported in February may reflect infections acquired several weeks earlier, thereby producing a delayed epidemiological response to climatic conditions.

The February increase may therefore represent a lagged effect of climatic conditions rather than an immediate response to rainfall during the same month. This interpretation is particularly relevant because previous research has demonstrated that climatic variables can influence malaria incidence after delays of several weeks. Sani et al. (2020), for example, identified significant lagged relationships between weather variables and malaria incidence in Abuja. Consequently, the identification of February as a period of elevated incidence emphasizes the importance of incorporating time-lag effects when examining climate malaria relationships.

B. Variation in the Timing of Peak Malaria Incidence

The findings further show a shift in the timing of the annual maximum malaria incidence from August in 2020 and 2021 to September in 2022. This change is important because it suggests that the malaria season may not have a fixed onset or peak from year to year. Rather, changes in climatic conditions, particularly rainfall distribution and temperature, may shift the timing of maximum transmission.

A one-month shift from August to September may reflect changes in the onset, intensity or persistence of rainfall. Where rainfall begins later or remains substantial later in the wet season, the development and persistence of mosquito breeding habitats may also be delayed. Such a delay can subsequently shift the peak in malaria cases. This interpretation is consistent with studies showing that malaria transmission responds not only to the total amount of rainfall but also to its timing, duration and temporal distribution.

A global observational study by Ryan et al. (2024) demonstrated significant associations between malaria incidence and temperature and precipitation across multiple countries and territories. Importantly, the study highlighted the complex nature of climatic influences on malaria, with relationships varying geographically and temporally. The shift in the peak malaria incidence observed in the FCT between 2020 and 2022 may therefore represent local evidence of the temporal variability of climate-sensitive disease transmission.

This finding has important implications for malaria-control programmes in the FCT. If malaria transmission peaks at different times in different years, interventions based strictly on fixed calendar periods may not always coincide with the period of maximum transmission. Climate-informed surveillance could therefore be used to identify changes in the onset and progression of the malaria season and support more timely deployment of preventive measures.

C. Differences Among Area Councils

The study also revealed substantial spatial differences in malaria incidence among the Area Councils. Abuja Municipal Area Council (AMAC) consistently recorded considerably higher incidences than other Area Councils, particularly in 2021. This finding may be associated with the demographic and socioeconomic characteristics of AMAC. AMAC contains the major urban centre of the FCT and has a much larger concentration of population, commercial activities, healthcare facilities and human movement than many other parts of the territory.

The higher number of recorded cases in AMAC may therefore reflect both a genuinely greater malaria burden and greater healthcare utilization. The National Hospital, which was the principal facility from which AMAC data were obtained, is a major referral institution. Patients presenting to such a facility may include referrals from locations outside the immediate catchment area. Consequently, hospital-based malaria counts should not automatically be interpreted as representing the incidence of malaria among residents of the Area Council without considering the population served by the facility.

This observation is particularly important because the study used data from one hospital in each Area Council. Hospital-based surveillance is valuable for identifying temporal trends but may be affected by healthcare-seeking behaviour, accessibility, referral patterns, diagnostic practices and the availability of alternative treatment sources. These factors can introduce differences between recorded incidence and the true community incidence of malaria.

The findings are consistent with the conclusions of Dalrymple et al. (2019), who demonstrated substantial spatial variation in malaria incidence across Nigeria and showed that environmental and geographical factors contribute to differences in transmission. Similarly, Alegana et al. (2016) emphasized the importance of spatial heterogeneity in malaria transmission and the need for geographically targeted malaria interventions.

D. The Unusual Pattern Observed in Gwagwalada

Gwagwalada exhibited a different pattern from most of the other Area Councils, particularly in 2020. The relatively low number of recorded malaria cases may be partly explained by the role of the University of Abuja Teaching Hospital as a major treatment centre for COVID-19 during the COVID-19 pandemic. The diversion of healthcare resources and the population's possible reluctance to attend a facility associated with COVID-19 treatment may have reduced hospital attendance for non-COVID conditions, including malaria.

This explanation should, however, be interpreted cautiously. A reduction in hospital-recorded malaria cases does not necessarily indicate a corresponding reduction in actual malaria transmission within Gwagwalada. During the COVID-19 pandemic, healthcare utilization was substantially disrupted in many countries. Fear of infection, movement restrictions, reduced access to healthcare facilities, changes in healthcare priorities and disruptions to routine services all affected the reporting and treatment of other diseases.

WHO reported that the COVID-19 pandemic disrupted essential malaria services in many malaria-endemic countries, including malaria diagnosis, treatment and prevention activities. Therefore, the unusually low malaria incidence recorded at the Gwagwalada facility in 2020 may reflect a surveillance or healthcare-utilization effect rather than an actual decline in malaria transmission.

This finding highlights an important limitation of relying exclusively on facility-based surveillance. Changes in the number of recorded cases may reflect changes in disease occurrence, but they may also result from changes in healthcare-seeking behaviour and accessibility. Self-medication is particularly relevant in the Nigerian context, where individuals may obtain antimalarial medicines directly from pharmacies or patent medicine vendors without attending hospitals. Consequently, facility-based malaria data should ideally be interpreted alongside community-based surveillance, pharmacy data and other sources of malaria information.

E. Higher Malaria Incidence Recorded in 2020

Another notable finding is that malaria incidence recorded in 2020 was higher than in subsequent years in several Area Councils. At first glance, this may appear inconsistent with the disruption to healthcare utilization associated with COVID-19. However, several explanations are possible. The high incidence may reflect particularly favourable climatic conditions during 2020, increased malaria transmission, differences in reporting, or variations in the number and characteristics of patients attending the participating hospitals.

The pandemic itself may also have altered malaria surveillance in complex ways. Although healthcare utilization decreased for some conditions, malaria remained a common febrile illness and could have continued to generate substantial demand for healthcare services. At the same time, COVID-19 symptoms overlap with malaria symptoms, potentially affecting diagnosis and treatment patterns.

The finding therefore emphasizes the need to distinguish between recorded malaria incidence and actual malaria transmission. Facility records represent malaria cases that reached the healthcare system and were diagnosed and recorded. They do not necessarily capture individuals who self-medicated, sought treatment elsewhere or did not seek treatment. Consequently, the observed decline after 2020 should not automatically be interpreted as a decline in the underlying malaria burden.

F. Long-term increase in malaria incidence

The analysis of malaria incidence over the longer period indicates a general increase in incidence over time, with AMAC showing a particularly pronounced increase. This trend is important because it suggests that malaria remains an important and potentially growing public health concern in the FCT despite ongoing control efforts.

Several factors could contribute to the observed increase. Rapid population growth and urban expansion in Abuja can increase the number of people exposed to malaria vectors. Unplanned settlements, inadequate drainage, construction activities and accumulation of stagnant water may create additional mosquito breeding habitats. Increased human mobility can also facilitate the movement of malaria parasites between areas with different levels of transmission.

Climate variability may further contribute to changing malaria transmission patterns. Increasing or fluctuating temperatures and changes in rainfall timing can modify mosquito breeding conditions and parasite development. However, the long-term increase observed in the present study should not be attributed to climate alone. Changes in population size, diagnostic practices, healthcare accessibility, surveillance

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coverage and reporting systems can also influence the number of recorded malaria cases.

The use of population projections in calculating incidence per 1,000 persons is therefore an important methodological consideration. Population growth in the FCT, particularly in AMAC, means that absolute numbers of malaria cases may increase partly because more people are exposed. Population-adjusted incidence provides a more meaningful measure of risk, although the accuracy of the estimate depends on the reliability of the population projections and hospital catchment assumptions.

The findings of this study are broadly consistent with previous research demonstrating that malaria incidence is associated with seasonal and climatic variability. The pronounced August peak agrees particularly well with the Abuja study of Sani *et al.* (2020), which reported increased malaria incidence during periods of higher rainfall and identified lagged effects of weather conditions.

The observed shift from August to September as the peak month in 2022 is also consistent with the wider understanding that malaria transmission responds to temporal variations in climatic conditions rather than following an entirely fixed seasonal pattern. Studies conducted across Africa have demonstrated that rainfall and temperature influence malaria transmission through their effects on mosquito abundance, parasite development and the availability of breeding habitats (Craig et al., 1999; Thomson *et al.,* 2005).

The spatial differences observed between Area Councils are likewise consistent with evidence of substantial geographical heterogeneity in malaria transmission in Nigeria. Dalrymple et al. (2019) demonstrated that malaria incidence in Nigeria is associated with environmental and spatial factors, indicating that malaria-control strategies should take local transmission patterns into account.

V. CONCLUSION

The findings demonstrate that malaria incidence in the FCT varies substantially by month, year and Area Council. The recurrent peaks observed in February and August, the shift of the annual maximum from August to September in 2022, the unusually low Gwagwalada records during the COVID-19 period, and the relatively high incidence recorded in AMAC all demonstrate the complex nature of malaria transmission and malaria surveillance in Abuja.

The overall pattern is broadly consistent with existing evidence linking malaria transmission to climatic and seasonal conditions, particularly rainfall and temperature. However, the findings also demonstrate that climatic variables alone cannot explain all variations in recorded malaria incidence. Healthcare-seeking behaviour, population growth, urbanization, referral patterns, surveillance practices and disruptions associated with COVID-19 are likely to contribute to the observed patterns.

Consequently, malaria-control programmes in the FCT would benefit from integrating routine malaria surveillance with meteorological information. Such an approach could improve prediction of periods of increased transmission and support earlier and more geographically targeted intervention. Further analysis using correlation, regression or time-series models, particularly models incorporating one- and two-month climatic lags, would be valuable for establishing the magnitude and statistical significance of the relationship between temperature, rainfall and malaria incidence in the FCT.

RECOMMENDATIONS

Based on the findings of this study on the relationship between climatic variables and malaria incidence in the Federal Capital Territory (FCT), Abuja, the following recommendations are proposed:

- The FCT health authorities should strengthen the integration of meteorological data, particularly rainfall and temperature, with routine malaria surveillance. Regular analysis of these variables can support early identification of periods of increased malaria risk.
- Malaria prevention and control programmes should be planned around the observed seasonal pattern of malaria incidence rather than relying solely on fixed calendar periods. Particular attention should be given to the period preceding the major increase in cases, especially around the beginning of the rainy season and the observed August/September peak.
- The FCT Administration, in collaboration with the Nigeria Centre for Disease Control and Prevention (NCDC), the National Malaria Elimination Programme (NMEP) and the Nigerian Meteorological Agency (NiMet), should develop or strengthen a climate-based malaria early-warning system. Such a system could use rainfall and temperature thresholds to alert health authorities to anticipated increases in malaria transmission.
- Distribution and effective use of insecticide-treated nets, indoor residual spraying where epidemiologically appropriate, environmental management and larval-source management should be intensified before periods of expected high malaria transmission. Early implementation would allow communities to be protected before malaria incidence reaches its seasonal peak.
- Malaria interventions should take account of differences among the six Area Councils. The relatively high incidence observed in AMAC suggests the need for intensified surveillance and targeted interventions in highly populated and rapidly urbanizing areas. At the same time, rural and peri-urban Area Councils should not be overlooked because malaria transmission may be sustained by environmental conditions that differ from those in the urban centre.

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- Local authorities should strengthen environmental sanitation, drainage maintenance and the elimination of stagnant water around residential areas, construction sites, markets and other potential mosquito breeding locations. Urban planning should incorporate measures that reduce the creation of permanent and temporary mosquito breeding habitats.
- Health facilities should improve the completeness, consistency and timeliness of malaria reporting. Standardized recording of malaria cases, diagnostic methods, patient residence, age, sex and date of diagnosis would improve the quality of data available for monitoring spatial and temporal trends.
- Because hospital records may underestimate the actual incidence of malaria due to self-medication, treatment at pharmacies and patent medicine vendors, or failure to seek healthcare, malaria surveillance should incorporate information from other sources. Community surveys, pharmacy and patent medicine vendor data, and other community-based surveillance approaches could complement hospital records.
- Future assessments of malaria incidence should use regularly updated population estimates and clearly defined hospital catchment populations. This is particularly important in AMAC and other rapidly growing parts of the FCT, where population growth may substantially influence the number of recorded malaria cases.
- Future studies should examine lagged relationships between rainfall, temperature and malaria incidence over one or more months. The occurrence of malaria peaks in February and August/September suggests that climatic conditions may influence malaria transmission after a delay. Time-series and distributed-lag statistical models could provide a more robust understanding of these relationships.
- The recurring February increase observed in several Area Councils warrants further investigation. Future research should determine whether this pattern is associated with residual breeding sites from the preceding rainy season, temperature conditions, delayed effects of rainfall, population movement, healthcare-seeking behaviour or other environmental and socioeconomic factors.
- The unusually low malaria records observed in Gwagwalada during 2020 demonstrate how disruptions to healthcare services can affect disease surveillance. During epidemics, pandemics or other health emergencies, alternative mechanisms for maintaining malaria surveillance should be established to ensure continuity of data collection and service delivery.
- Continuous malaria health education should be provided to communities, emphasizing the importance of sleeping under insecticide-treated nets, eliminating mosquito breeding sites, seeking early diagnosis and treatment, and avoiding inappropriate self-medication. Education campaigns should be intensified before anticipated periods of high transmission.
- Effective climate-sensitive malaria control requires collaboration between the health, environment, water, sanitation, urban planning and meteorological sectors. The FCT Administration should establish mechanisms for routine sharing and joint interpretation of climatic, environmental and epidemiological information.
- Future studies should use data from multiple health facilities within each Area Council and, where possible, incorporate community-level malaria data. Studies should also include additional variables such as relative humidity, vegetation, land use, mosquito abundance, socioeconomic conditions, population movement and malaria-control coverage. This would provide a more comprehensive explanation of the factors driving malaria incidence in the FCT.

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