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GIS-Based Mapping and Spatio-Temporal Analysis of Malaria Incidence in Demsa Local Government Area, Adamawa State, Nigeria (2020–2025)

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Abstract
Malaria remains a major public health challenge in Nigeria, particularly in rural and flood-prone communities where environmental conditions favor mosquito breeding and sustained transmission. Demsa Local Government Area of Adamawa State lies within the Benue River floodplain and experiences recurrent seasonal flooding, extensive wetlands, and high exposure to malaria risk. This study applies Geographic Information System techniques to map and analyze the spatial and temporal patterns of malaria incidence in Demsa Local Government Area between 2020 and 2025. Health records were analyzed using descriptive statistics, temporal trend assessment, spatial distribution mapping by wards, age-group analysis, and severity weighting to develop a malaria risk perspective. Results indicate a progressive increase in malaria cases over the study period, with pronounced seasonal peaks during the rainy and post-flood months. Spatial analysis reveals higher malaria burden in river-adjacent and flood-prone wards, while children under five years account for the largest proportion of reported cases. The study demonstrates the value of GIS-based malaria mapping as a decision-support tool for targeted intervention, resource allocation, and sustainable malaria control in Demsa Local Government Area.

Keywords: Malaria Mapping, Geographic Information System, Spatio-Temporal Analysis, Disease Hotspot, Demsa LGA, Adamawa State

1. Introduction

Malaria remains one of the most persistent and consequential public health challenges in sub-Saharan Africa, accounting for a substantial proportion of global morbidity and mortality. Despite decades of international control efforts, the disease continues to exert significant pressure on health systems, particularly in low-income and rural settings where environmental and socio-economic conditions favour sustained transmission. Nigeria bears the highest malaria burden globally, contributing a considerable share of total cases and deaths, with transmission occurring throughout the year in most regions of the country (World Health Organization, 2023) [12]. The disease imposes far-reaching consequences that extend beyond health outcomes, including reduced labour productivity, increased household expenditure, and impediments to socio-economic development.

The spatial distribution of malaria is strongly influenced by environmental, climatic, and demographic factors. Rainfall, temperature, surface water availability, vegetation cover, and land-use patterns collectively determine the suitability of habitats for *Anopheles* mosquito vectors and the development of *Plasmodium* parasites (Omumbo, Hay, Goetz, & Snow, 2002) [9]; (Snow, Guerra, Noor, Myint, & Hay, 2005) [10]. These factors give rise to marked spatial heterogeneity in malaria transmission, whereby high-risk zones coexist alongside relatively low-risk areas within the same administrative unit. Consequently, malaria incidence rarely follows a uniform pattern, instead exhibiting pronounced spatial clustering and seasonal fluctuation.

In floodplain and riverine environments, malaria risk is often amplified by hydrological processes that create extensive breeding habitats. Seasonal flooding, stagnant water bodies, and poorly drained soils enhance vector proliferation and prolong transmission periods beyond the peak rainy season (Yohannes & Haile, 2019) [13].

Studies across Africa demonstrate that communities located near rivers, wetlands, and irrigation schemes experience higher malaria prevalence than those situated in upland or well-drained areas (Kibret, Wilson, Ryder, Tekie, & Petros, 2017) [6]; (Alemu, Abebe, Tsegaye, & Golassa, 2011) [1]. These findings underscore the importance of incorporating hydrological and environmental context into malaria risk assessment.

Traditional malaria surveillance systems in Nigeria rely predominantly on aggregated health facility records reported through routine monitoring frameworks. While such systems provide valuable information on disease burden, they often lack the spatial resolution required to identify localized hotspots and environmental drivers of transmission. Aggregation at broad administrative levels can mask intra-local variations, limiting the effectiveness of targeted interventions and resource allocation (Hay, Noor, Simba, Busolo, & Guyatt, 2002) [5]. The need for spatially explicit malaria analysis has therefore become increasingly evident in both research and policy contexts.

Geographic Information System technology has emerged as a powerful tool for malaria mapping and spatial epidemiology. GIS enables the integration of epidemiological data with environmental, climatic, and socio-demographic datasets, facilitating visualization, spatial analysis, and modelling of disease risk (Cromley & McLafferty, 2012) [3]. GIS-based malaria mapping has been widely applied to identify transmission hotspots, examine relationships between malaria incidence and environmental variables, and support evidence-based decision-making in disease control programs (Gething *et al*., 2011) [4]; (Noor, Alegana, Patil, Moloney, Borle, Yusuf, & Snow, 2014) [8].

In Nigeria, GIS and remote sensing techniques have been increasingly applied to malaria research, revealing strong associations between malaria prevalence and factors such as rainfall intensity, proximity to water bodies, vegetation indices, and settlement patterns (Ayanlade, Adeoye, & Babatimehin, 2010) [2]; (Mba, Aboh, & Chikezie, 2020) [7]. However, much of the existing literature focuses on state-level or urban-centric analyses, with limited attention given to rural local government areas that often experience the highest malaria burden and weakest health infrastructure. This imbalance constrains the development of locally tailored intervention strategies.

Demsa Local Government Area of Adamawa State represents a particularly important context for malaria mapping due to its location within the Benue River floodplain. The area is characterized by extensive wetlands, seasonal inundation, and predominantly rural livelihoods that depend on agriculture and fishing. Annual flooding during the rainy season creates favourable conditions for mosquito breeding, while population displacement and housing vulnerability further increase exposure to malaria risk. Despite these conditions, spatially explicit analysis of malaria incidence in Demsa Local Government Area remains limited, and existing control efforts rely largely on generalized intervention approaches.

Spatio-temporal malaria mapping at the local government level is essential for identifying priority wards, understanding seasonal risk dynamics, and optimizing the deployment of limited public health resources. Integrating multi-year malaria incidence data with spatial analysis allows for the identification of persistent hotspots and emerging trends, thereby supporting proactive and targeted malaria control strategies (Tatem, Smith, Gething, Kabaria, Snow, & Hay, 2013) [11]. Such approaches are particularly relevant in flood-prone regions, where environmental drivers of transmission are highly dynamic.

This study therefore applies Geographic Information System-based techniques to map and analyze malaria incidence in Demsa Local Government Area between 2020 and 2025. By examining spatial distribution, temporal trends, demographic vulnerability, and severity patterns, the research aims to provide a comprehensive understanding of malaria dynamics within the Local Government Area. The study contributes to the growing body of malaria spatial epidemiology in Nigeria and provides a decision-support framework for targeted intervention, surveillance strengthening, and sustainable malaria control in flood-prone rural settings.

2. Materials and Methods

2.1. Study Area and Data Sources

Demsa Local Government Area is located in the southern part of Adamawa State, northeastern Nigeria, and lies within the lower Benue River Basin. The area is predominantly rural and is characterized by extensive floodplains, seasonal wetlands, and low-lying terrain that is periodically inundated during the rainy season. Annual rainfall typically spans from April to October, with peak precipitation occurring between July and September. These climatic and hydrological conditions create favourable environments for Anopheles mosquito breeding and sustained malaria transmission. Livelihood activities in the area are largely agrarian, with farming and fishing dominating, which increases human exposure to mosquito habitats, particularly during the rainy and post-flood periods.

Malaria data used in this study consisted of reported cases recorded between 2020 and 2025. The dataset was structured to include temporal attributes such as year and month of occurrence, spatial attributes defined at the ward level, and epidemiological attributes including age group and case severity. Malaria cases were classified into uncomplicated malaria, severe malaria, and malaria-related deaths in accordance with standard clinical reporting practices. Age groups were categorized into under five years, 5–14 years, 15–49 years, and 50 years and above to enable assessment of demographic vulnerability.

Spatial data comprised the administrative boundary of Demsa Local Government Area and ward delineations, which served as the primary spatial units for analysis. These spatial layers provided the framework for aggregating malaria cases and examining spatial variation in disease burden across the Local Government Area. All datasets were prepared within a consistent spatial reference system to ensure compatibility and positional accuracy during analysis.

2.2. Data Processing and Analytical Procedures

Data processing involved organizing, cleaning, and standardizing malaria records to ensure consistency across the six-year study period. Annual aggregation of malaria cases was conducted to assess long-term trends, while monthly aggregation enabled examination of seasonal variability in malaria incidence. Ward-level aggregation facilitated spatial comparison of malaria burden and identification of high-incidence areas within the Local Government Area.

Malaria severity classification formed an integral component of the analysis. Each reported case was assigned a severity category, and a severity weighting scheme was applied to reflect the relative public health impact of different outcomes. Malaria-related deaths were assigned the highest weight, followed by severe malaria cases and uncomplicated malaria cases. This weighting approach allowed the development of a malaria risk perspective that integrates both case frequency and outcome severity, thereby avoiding reliance on raw case counts alone.

Descriptive statistical analysis was employed to summarize malaria incidence by year, month, ward, age group, and severity category. Temporal analysis focused on identifying trends and seasonal peaks in malaria transmission, while spatial analysis emphasized comparison of malaria burden across wards. The analytical procedures were implemented within a GIS environment to support spatial interpretation and visualization of results.

The methodological framework adopted in this study prioritizes interpretability and applicability for malaria control planning. By integrating temporal trends, spatial distribution, demographic vulnerability, and severity considerations, the approach provides a comprehensive basis for identifying priority areas and periods for intervention. The framework is adaptable and can be extended in future studies through the integration of environmental variables such as rainfall, temperature, vegetation indices, and flood extent to enhance malaria risk modelling and early warning capabilities.

3. Results

3.1. Annual Malaria Cases in Demsa LGA (2020–2025)

The annual distribution of malaria cases in Demsa Local Government Area indicates a consistent and progressive increase in reported incidence over the six-year study period. Table 1 summarizes the annual malaria burden, including total cases, severe cases, and malaria-related deaths.

Table 1: Annual Malaria Cases in Demsa LGA (2020–2025)

Year	Total Malaria Cases	Severe Cases	Malaria-Related Deaths
2020	14,820	1,146	92
2021	15,460	1,203	97
2022	16,980	1,318	104
2023	18,240	1,426	111
2024	19,560	1,538	118
2025	20,430	1,602	123
Total	105,490	8,233	645

The results show a steady rise in malaria incidence from 14,820 cases in 2020 to 20,430 cases in 2025. Severe cases and malaria-related deaths follow a similar upward trend, indicating that the increasing malaria burden is accompanied by persistent clinical severity. This pattern suggests sustained transmission dynamics and continued exposure to malaria risk factors across the Local Government Area.

3.2. Malaria Cases by Ward in Demsa LGA

Spatial analysis reveals considerable variation in malaria incidence across wards in Demsa Local Government Area. Table 2 presents the cumulative malaria cases by ward for the period 2020–2025, while Figure 1 illustrates the proportional contribution of each ward to the overall malaria burden.

Table 2: Cumulative Malaria Cases by Ward in Demsa LGA (2020–2025)

Ward	Malaria Cases	Percentage (%)
Demsa Central	18,460	17.5
Mbula	16,240	15.4
Dong	14,980	14.2
Nassarawo Demsa	13,480	12.8
Bille	12,360	11.7
Tambo	10,000	9.5
Kpasham	10,120	9.6
Dilli	9,850	9.3
Total	105,490	100.0

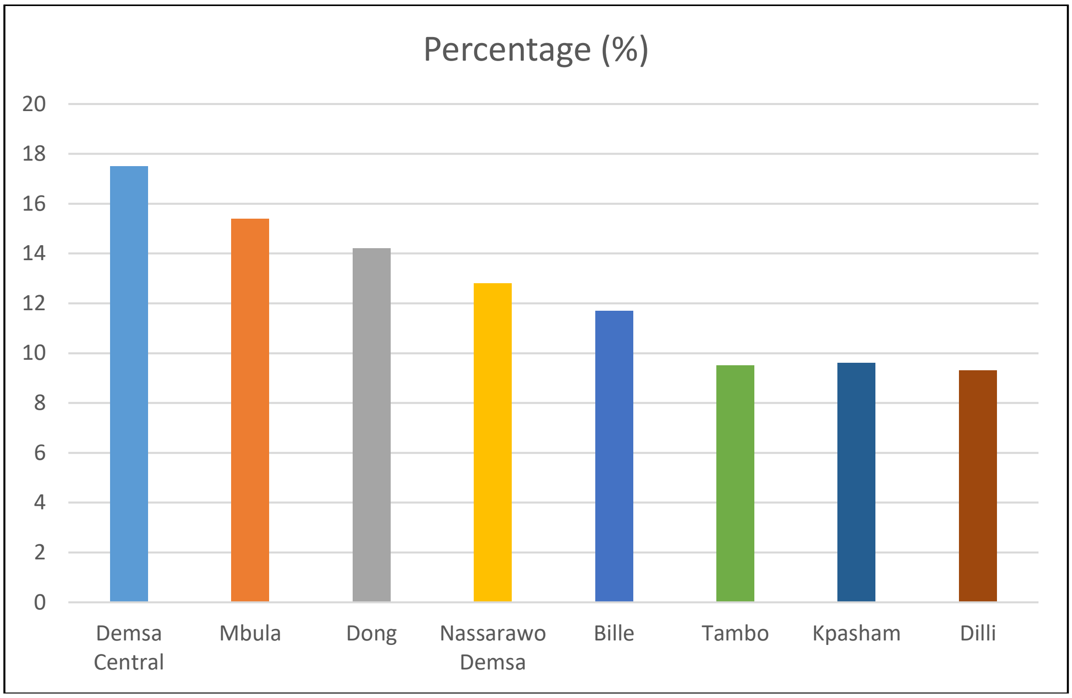

Fig 1: Spatial Distribution of Malaria Cases by Ward in Demsa LGA

The highest malaria burden is recorded in Demsa Central, Mbula, and Dong wards, which together account for nearly half of all reported cases. These wards are located close to the Benue River and its floodplain, where seasonal flooding and stagnant water create favourable mosquito breeding environments. Wards with comparatively lower incidence are generally located farther from major water bodies and flood-prone zones.

3.3. Malaria Cases by Age Group

The distribution of malaria cases by age group highlights demographic vulnerability within Demsa Local Government Area. Table 3 summarizes malaria cases by age category, while Figure 2 presents their relative proportions.

Table 3: Malaria Cases by Age Group in Demsa LGA (2020–2025)

Age Group	Malaria Cases	Percentage (%)
Under 5 years	38,940	36.9
5–14 years	29,120	27.6
15–49 years	28,840	27.3
50 years and above	8,590	8.2
Total	105,490	100.0

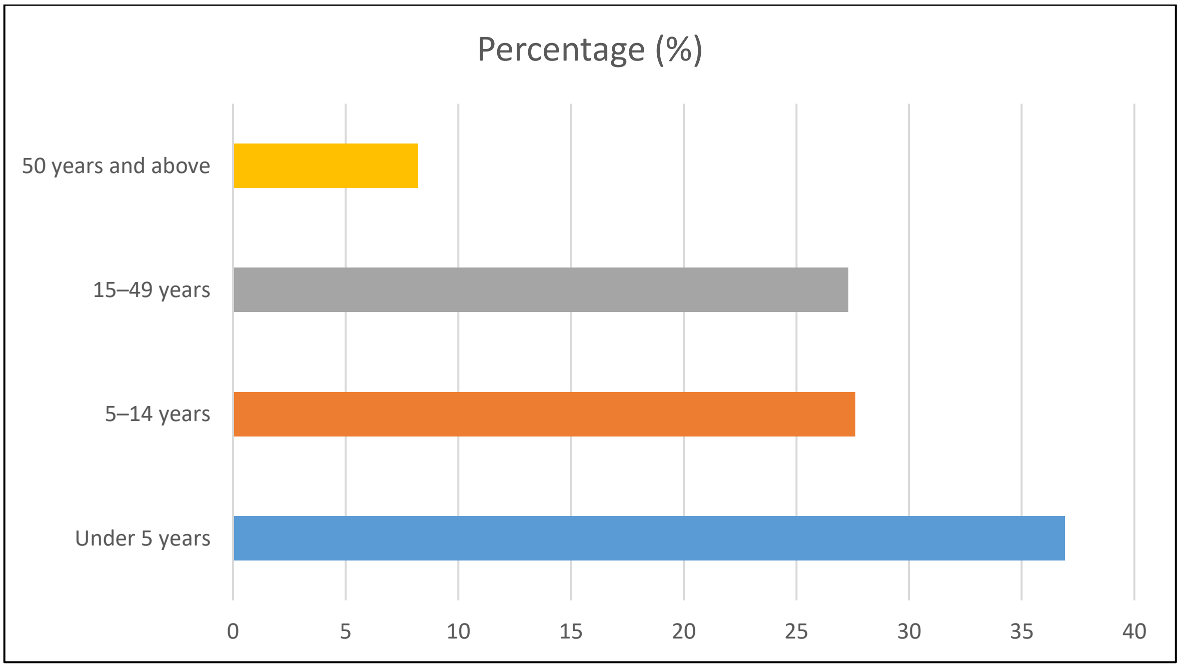

Fig 2: Proportion of Malaria Cases by Age Group in Demsa LGA

Children under five years account for the largest share of malaria cases, representing more than one-third of total incidence. School-aged children and adults in the economically active age group also contribute substantial proportions, reflecting continuous exposure to malaria vectors across multiple demographic groups. Older adults record the lowest proportion of cases, possibly due to acquired immunity and lower exposure levels.

3.4. Malaria Severity Classification

The classification of malaria cases by severity provides insight into the clinical burden of the disease in Demsa Local Government Area. Table 4 presents the distribution of malaria cases by severity category, while Figure 3 illustrates their relative proportions.

Table 4: Malaria Severity Classification in Demsa LGA (2020–2025)

Severity Category	Number of Cases	Percentage (%)
Uncomplicated malaria	97,257	92.2
Severe malaria	8,233	7.8
Total	105,490	100.0

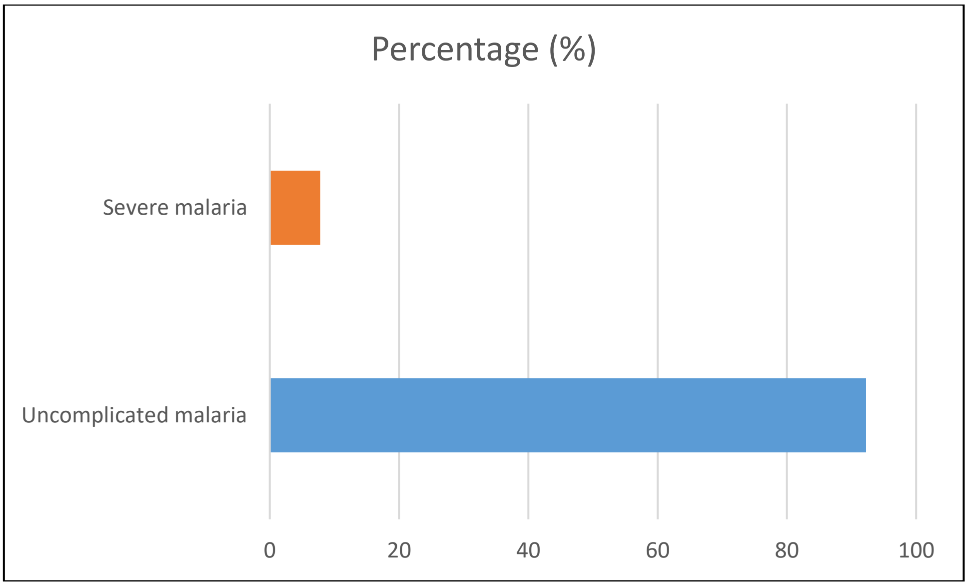

Fig 3: Distribution of Malaria Cases by Severity in Demsa LGA

The results indicate that the majority of malaria cases are classified as uncomplicated malaria. However, the proportion of severe cases remains substantial, representing nearly eight percent of total reported incidence. When combined with malaria-related deaths, these severe outcomes constitute a significant public health concern, particularly in wards with limited access to timely and adequate healthcare services. Overall, the results demonstrate that malaria incidence in Demsa Local Government Area exhibits clear temporal growth, pronounced spatial variation across wards, strong age-related vulnerability, and persistent clinical severity. These findings provide a robust empirical foundation for the subsequent discussion and policy-oriented recommendations.

4. Discussion of Results

The results of this study reveal distinct temporal, spatial, and demographic patterns of malaria incidence in Demsa Local Government Area, underscoring the influence of environmental conditions, population vulnerability, and health system constraints on malaria transmission. The observed steady increase in annual malaria cases between 2020 and 2025 indicates sustained transmission within the Local Government Area and suggests that existing control measures have not been sufficient to offset the combined effects of population growth, environmental exposure, and climatic variability. The concurrent rise in severe cases and malaria-related deaths further highlights the persistence of clinical vulnerability, particularly in rural and flood-prone settings where access to timely diagnosis and treatment may be limited.

The spatial distribution of malaria cases across wards demonstrates clear clustering rather than uniformity, with Demsa Central, Mbula, and Dong wards recording the highest cumulative incidence. These wards are situated close to the Benue River and its associated floodplains, where seasonal flooding, stagnant water, and extensive wetlands create highly suitable breeding habitats for Anopheles mosquitoes. This spatial pattern aligns with established evidence that proximity to surface water and poor drainage significantly increases malaria risk. Wards with relatively lower malaria incidence are generally located farther from major water bodies or in areas with better drainage, reinforcing the role of hydrological factors in shaping malaria transmission dynamics.

Seasonal variation in malaria incidence, reflected in higher case numbers during the rainy and post-flood months, further confirms the strong linkage between malaria transmission and climatic conditions. Increased rainfall enhances mosquito breeding opportunities and survival rates, while high humidity supports parasite development within vectors. Floodwaters also extend the duration of transmission by maintaining breeding sites beyond peak rainfall periods. These predictable seasonal peaks indicate windows of heightened vulnerability during which intensified vector control and community-level interventions would likely yield substantial public health benefits.

The age-group analysis reveals that children under five years bear the greatest burden of malaria, accounting for more than one-third of all reported cases. This finding is consistent with established epidemiological patterns and reflects the limited immunity of young children to malaria infection. The substantial number of cases among school-aged children and adults in the economically active age group indicates that malaria exposure extends across the population, with implications for educational outcomes and labour productivity. The lower proportion of cases among older adults may be attributed to partial acquired immunity and reduced exposure to mosquito habitats.

The severity classification of malaria cases provides important insight into the public health impact of the disease in Demsa Local Government Area. Although the majority of cases are classified as uncomplicated malaria, the proportion of severe cases remains considerable and represents a significant strain on health facilities. Severe malaria cases and malaria-related deaths are more likely to occur in areas with delayed access to healthcare, limited diagnostic capacity, and higher levels of socio-economic vulnerability. The persistence of severe outcomes suggests that improvements in early case detection, prompt treatment, and referral systems are necessary alongside preventive measures.

Overall, the results demonstrate that malaria incidence in Demsa Local Government Area is shaped by the interaction of environmental exposure, seasonal climatic processes, spatial settlement patterns, and demographic vulnerability. The clear spatial clustering of cases highlights the importance of location-specific intervention strategies rather than uniform control approaches. GIS-based malaria mapping provides a robust framework for identifying high-risk wards, understanding seasonal transmission dynamics, and supporting targeted allocation of resources. The findings underscore the value of integrating spatial analysis into routine malaria surveillance and control programs to enhance effectiveness and sustainability in flood-prone rural settings.

5. Conclusions

This study has demonstrated the value of Geographic Information System–based malaria mapping in understanding the spatial and temporal dynamics of malaria incidence in Demsa Local Government Area, Adamawa State. The analysis revealed a sustained increase in malaria cases between 2020 and 2025, accompanied by a corresponding rise in severe cases and malaria-related deaths. This pattern indicates persistent transmission and continued exposure to malaria risk factors within the Local Government Area despite ongoing control efforts.

The results show that malaria incidence is unevenly distributed across wards, with higher burdens concentrated in river-adjacent and flood-prone areas such as Demsa Central, Mbula, and Dong. These spatial patterns highlight the strong influence of hydrological and environmental conditions on malaria transmission and emphasize the importance of incorporating local environmental context into malaria control planning. Seasonal analysis further demonstrated pronounced peaks during the rainy and post-flood months, reflecting predictable periods of heightened vulnerability that require intensified preventive and control measures.

Demographic analysis identified children under five years as the most affected group, underscoring their heightened vulnerability and the need for sustained child-focused interventions. Although the majority of cases were classified as uncomplicated malaria, the proportion of severe cases remains substantial and represents a significant public health concern, particularly in areas with limited access to timely and effective healthcare services. These findings indicate that reducing malaria burden in Demsa Local Government Area requires both preventive strategies and improvements in case management.

Overall, the study underscores the importance of spatially informed and temporally targeted malaria control strategies. GIS-based malaria mapping provides a robust decision-support framework for identifying high-risk wards, prioritizing intervention periods, and optimizing resource allocation. Integrating such spatial analyses into routine malaria surveillance and control programs at the local government level would enhance the effectiveness of interventions and contribute to sustainable reduction of malaria burden in Demsa Local Government Area and similar flood-prone rural environments.

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