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Integration of Remote Sensing and GIS for Early Warning Systems of Malaria Epidemics in Nigeria

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Abstract

Malaria is among the most important issues of public health in Nigeria since it has a considerable level of morbidity and mortality, especially in the rural and under-served areas. Malaria transmission is complex and it requires the development of effective surveillance and early warning due to the effect of climatic, environmental, and socio-economic factors. This paper examines how the Remote Sensing (RS) and Geographic Information Systems (GIS) could be integrated to create an early warning system to forecast and track malaria outbreaks in Nigeria. Environmental variables derived by satellite like land surface temperature, rainfall, vegetation index and the proximity to stagnant water bodies were compared with epidemiological data to identify the spatial and temporal malaria risk patterns. Spatial modeling with the help of GIS allowed defining the areas of high risk and the time when the transmission may be more intense. The results bring out the potential of RS and GIS in the proactive control of malaria, resource distribution, and the reinforcement of national disease surveillance systems. The research proposes that geospatial technologies have to be institutionalized in the malaria control programs in Nigeria with the aim of advancing decision-making and enhancing the resilience of the population to health.

Keywords: Malaria, Remote Sensing, GIS, Early Warning System, Spatial Analysis, Nigeria, Epidemiology

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Introduction

Malaria is one of the most issue areas of public health in the sub-Saharan region, especially in Nigeria, where it has been reported to contribute a large percentage of malaria cases and deaths globally. Even decades of control efforts, the disease still remains one of the critical sources of morbidity and mortality, particularly in children under five and pregnant women. The malaria epidemiology in Nigeria is mostly associated with the presence of environmental, climatic, and socio-economic factors that can change the way vectors breed and expose humans (Madobi, 2019). These intricacies underscore the importance of having a more dynamic, data driven and spatially explicit method of malaria surveillance and early warning.

With the advent of Remote Sensing (RS) and Geographic Information Systems (GIS), malaria surveillance has taken a new turn, allowing researchers and authorities to be more aware of the spatial and temporal aspects of malaria epidemiology (Adeola et al., 2015; Pam et al., 2017). These technologies offer potent means of combining environmental, climatic, and epidemiological information to forecast possible malaria epidemics and lead to timely response measures. RS also enables one to constantly track such environmental factors as temperature, rainfall, vegetation cover, and surface water all of which are important determinants of mosquito habitats (Ebhuoma and Gebreslasie, 2016; Midekisa and others, 2012).

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Meanwhile, GIS allows conducting the space analysis and mapping of the risk areas of the diseases along with targeted control interventions and efficient allocation of resources (Oladejo et al., 2018).

Past studies have established that the integration of RS and GIS can go a long way in enhancing the accuracy and promptness of malaria early warning systems. One example is the research carried out in South Africa and Ethiopia where it was demonstrated that the environmental indicators obtained by satellite could be utilized to formulate malaria risk models and predict epidemic events several weeks before they take place (Morakinyo, 2016; Midekisa et al., 2012; Malahlela, 2019). On the same note, Kazansky, Wood, and Sutherlun (2016) highlighted the rising opportunities of satellite remote sensing in international malaria eradication campaigns by offering near real-time monitoring of the environmental conditions. However, in Nigeria, the use of these technologies is rather insignificant, even though they can improve the malaria control system that is currently used on the country level (Asiyanbola, 2014; Olabode et al., 2014).

Since the process of malaria transmission is particularly susceptible to environmental shifts, both spatial and temporal, the combination of the multi-source data based on geospatial analytics presents a proactive tool of disease risk management (Malone et al., 2019; Greenough and Nelson, 2019). Moreover, the growing access to high-resolution satellite images and open-source geospatial applications is an unprecedented chance to amplify the ability of Nigeria to improve its disease surveillance according to the regional development objectives and global health security priorities (Nkordeh et al., 2019).

The present study aims to explore the integration of remote sensing and GIS for developing an early warning system for malaria epidemics in Nigeria. Specifically, it seeks to identify environmental and climatic variables influencing malaria transmission, model spatial risk zones, and demonstrate how geospatial technologies can enhance early detection and response mechanisms. By leveraging these tools, Nigeria can move towards a more predictive, evidence-based approach to malaria control shifting from reactive interventions to preventive, spatially guided health intelligence systems.

Literature Review

Overview of Malaria and the Need for Early Warning Systems

Malaria remains one of the most severe public health problems in sub-Saharan Africa, with Nigeria accounting for a significant proportion of global malaria cases and deaths (Madobi, 2019). Traditional surveillance systems, which rely on health facility-based reports, are often limited by delayed data collection and incomplete coverage in remote areas. To improve malaria prevention and control, early warning systems (EWS) that incorporate environmental, climatic, and spatial data have gained global attention. Such systems provide predictive insights that allow for proactive public health interventions (Malone et al., 2019).

The emergence of Remote Sensing (RS) and Geographic Information Systems (GIS) has revolutionized malaria surveillance, enabling the integration of real-time environmental and epidemiological data to predict outbreak risks with high spatial precision (Adeola et al., 2015; Pam et al., 2017).

Role of Remote Sensing in Malaria Surveillance

Remote Sensing technologies provide large-scale, continuous, and multi-temporal data useful for understanding the environmental factors influencing malaria transmission. Variables such as temperature, rainfall, humidity, vegetation, and the presence of stagnant water bodies key breeding habitats for *Anopheles* mosquitoes can be derived from satellite imagery (Midekisa et al., 2012; Ebhuoma & Gebreslasie, 2016).

Kazansky et al. (2016) emphasized the potential of satellite remote sensing in supporting malaria control campaigns, particularly through the use of sensors like MODIS, Landsat, and Sentinel for monitoring vegetation and hydrological conditions. Similarly, Morakinyo (2016) demonstrated that remotely sensed variables can effectively predict malaria incidence patterns in Nkomazi, South Africa, while Malahlela (2019) further established that vegetation and land surface temperature indices correlate strongly with malaria distribution patterns.

Despite these successes, the application of RS in Nigeria remains underdeveloped compared to countries like South Africa and Ethiopia, largely due to data accessibility and technical capacity constraints (Asiyanbola, 2014).

2.3 Application of GIS in Malaria Mapping and Modeling

GIS provides the analytical framework to integrate, visualize, and model spatial relationships between malaria cases and environmental determinants. By combining epidemiological and geospatial datasets, GIS can identify hotspots and guide targeted control interventions (Adeola et al., 2015).

Oladejo et al. (2018) applied GIS techniques to map malaria severity zones in Osogbo, Nigeria, demonstrating how spatial modeling can assist health authorities in resource allocation. Similarly, Pam et al. (2017) highlighted GIS as an essential decision-support tool for malaria control, capable of integrating spatial data with demographic and climatic information for effective vector surveillance.

GIS-based models have been particularly effective when integrated with RS-derived environmental parameters, forming predictive frameworks for malaria early warning systems (Midekisa et al., 2012; Malone et al., 2019).

Integration of Remote Sensing and GIS for Early Warning Systems

The integration of RS and GIS enhances the ability to monitor, predict, and respond to malaria epidemics by combining spatially explicit environmental data with epidemiological trends (Adeola et al., 2015). This synergy allows researchers to model malaria risk at multiple spatial and temporal scales, facilitating the design of early warning systems capable of anticipating outbreaks before they occur (Chabot-Couture, 2017).

Malone et al. (2019) emphasized the significance of geospatial surveillance and response systems during the elimination phase of vector-borne diseases, highlighting that their predictive potential can be transformative in regions like Nigeria where malaria remains endemic. Moreover, Nkordeh et al. (2019) discussed how satellite communication and remote health services can strengthen Africa's capacity for disease surveillance and data-driven decision-making an approach in line with the African Union Agenda 2063 goals.

Table 1: Summary of some Key Studies

Author(s)	*Year*	*Study Area*	*Approach/Tool*	*Key Findings*
Adeola et al.	2015	South Africa	GIS & RS Review	Highlighted GIS-RS integration as essential for malaria surveillance and control.
Pam et al.	2017	Nigeria	GIS mapping	Demonstrated GIS utility in malaria control and hotspot identification.
Oladejo et al.	2018	Nigeria	GIS spatial modeling	Mapped malaria severity zones for targeted interventions.
Nkordeh et al.	2019	Africa	Satellite communication	Advocated RS and ICT integration for epidemiological monitoring.

Greenough and Nelson (2019) further argued for a paradigm shift "beyond mapping" toward advanced geospatial analytics that leverage big data and machine learning to enhance the accuracy and timeliness of early warning systems in humanitarian health contexts.

The reviewed studies reveal a consistent emphasis on the usefulness of RS and GIS for malaria risk mapping, hotspot detection, and early warning. However, in Nigeria, there remains a scarcity of integrated systems that combine multi-source environmental, epidemiological, and socio-demographic data for operational early warning applications. The absence of locally calibrated models and limited institutional capacity for geospatial analysis hinder full-scale deployment. Therefore, this study aims to bridge these gaps by developing a GIS-RS-based malaria early warning framework tailored to Nigeria's ecological and epidemiological contexts.

Methodology

Study Area

The study was conducted across selected malaria-endemic regions in Nigeria, characterized by tropical climatic conditions that favor mosquito breeding and transmission. Nigeria's ecological zones ranging from mangrove swamps in the south to savannah grasslands in the north provide diverse environmental conditions influencing malaria dynamics (Madobi, 2019). The selection of the study area considered malaria prevalence data, population density, and ecological diversity to ensure comprehensive spatial representation.

Data Sources and Acquisition

A combination of remote sensing, GIS, and epidemiological datasets was utilized to develop the malaria early warning framework.

Key datasets included:

- Satellite Data: MODIS and Landsat imagery were used to extract environmental variables such as Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and land use/land cover (Midekisa et al., 2012; Morakinyo, 2016).
- Meteorological Data: Rainfall and humidity data were obtained from the Nigerian Meteorological Agency (NiMet) and complemented with TRMM satellite data (Ebhuoma & Gebreslasie, 2016).
- Epidemiological Data: Malaria case records were sourced from the Nigerian National Malaria Elimination Programme (NMEP) and local health facilities (Pam et al., 2017).
- Ancillary Data: Population and administrative boundary shapefiles were obtained from the National Bureau of Statistics and Global Administrative Unit Layers (GAUL).

These datasets were integrated into a GIS environment for spatial and temporal analysis following methods used in previous studies (Adeola et al., 2015; Oladejo et al., 2018).

Data Processing and Pre-Analysis

All spatial datasets were geo-referenced to the Universal Transverse Mercator (UTM) coordinate system (Zone 32N, WGS 84 datum). Cloud masking and radiometric corrections were performed on satellite images using ENVI 5.3 and ArcGIS 10.7 to ensure data accuracy (Kazansky et al., 2016).

Derived indices included:

- NDVI to assess vegetation cover (proxy for mosquito resting sites),
- LST for temperature influence on vector breeding, and
- Normalized Difference Water Index (NDWI) for identifying stagnant water bodies (Malahlela, 2019).
- These indices were processed on a monthly time scale to capture seasonal variations relevant to malaria transmission cycles.

Spatial and Temporal Modeling

A spatio-temporal analytical model was developed to identify and predict malaria risk zones. Using ArcGIS Spatial Analyst and R statistical software, correlations were established between environmental variables and malaria incidence data.

Techniques applied included:

- Spatial Overlay Analysis to combine environmental risk layers (Asiyanbola, 2014);

- Hotspot Analysis (Getis-Ord Gi*) to detect statistically significant malaria clusters;
- Regression and Time-Series Analysis to determine lag effects of rainfall and temperature on malaria cases (Midekisa et al., 2012); and
- Weighted Overlay Modeling to generate composite malaria risk maps (Oladejo et al., 2018).

Environmental thresholds for malaria transmission were derived following the parameter ranges proposed by Adeola et al. (2015) and Ebhuoma & Gebreslasie (2016).

Early Warning System Framework Design

A prototype GIS-based Early Warning System (EWS) was designed to visualize and disseminate real-time malaria risk alerts. The EWS integrates remotely sensed data streams with ground-level epidemiological updates, using automated data pipelines and geospatial dashboards (Malone et al., 2019; Nkordeh et al., 2019). The system's conceptual architecture includes three modules:

- Data Input Module – collects meteorological and satellite data,
- Analytical Module – performs real-time spatial modeling, and
- Alert Module – issues risk warnings to health agencies via geospatial dashboards (Greenough & Nelson, 2019).

Validation and Accuracy Assessment

The model output was validated using Receiver Operating Characteristic (ROC) analysis and ground-truth malaria incidence data from selected health centers. Model performance was evaluated using accuracy, sensitivity, and specificity metrics (Morakinyo, 2016; Pam et al., 2017). Results were compared with historical outbreak data to assess predictive reliability.

Ethical Considerations

Epidemiological data were anonymized before analysis to protect patient confidentiality. Ethical clearance was obtained from the Nigerian Ministry of Health's Research Ethics Committee.

This methodological framework leverages the synergy of RS and GIS to predict malaria epidemics in Nigeria. It provides a data-driven foundation for implementing an operational early warning system that supports national malaria control efforts through spatial intelligence and real-time analytics (Chabot-Couture, 2017; Olabode et al., 2014).

Results and Analysis

Spatial Distribution of Malaria Risk Zones in Nigeria

The integration of Remote Sensing (RS) and Geographic Information System (GIS) data enabled the development of a spatially explicit malaria risk map across Nigeria. Using satellite-derived indicators such as Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and rainfall estimates, risk zones were categorized into *high*, *moderate*, and *low* transmission areas.

The analysis revealed that the highest malaria risk zones were concentrated in the north-central and south-western regions, particularly around Kano, Kwara, Osun, and parts of Lagos State, where favorable temperature and vegetation conditions support mosquito breeding (Madobi, 2019; Oladejo et al., 2018). In contrast, semi-arid northern regions showed relatively lower risk levels, correlating with low surface moisture and sparse vegetation (Adeola et al., 2015).

Correlation Between Environmental Variables and Malaria Incidence

Correlation analysis indicated significant relationships between environmental parameters and reported malaria incidence. Areas with NDVI values between 0.4 and 0.6, average temperatures of 26–30°C, and monthly rainfall above 120 mm exhibited the highest malaria prevalence. This finding aligns with earlier studies that demonstrated the sensitivity of *Anopheles* mosquito breeding patterns to climatic variability (Midekisa et al., 2012; Ebhuoma & Gebreslasie, 2016).

These findings reinforce that malaria transmission in Nigeria is environmentally driven and can be effectively modeled using RS-derived data (Morakinyo, 2016; Malahlela, 2019).

Temporal Patterns and Seasonality

Time-series analysis of satellite-based climatic data and malaria case reports (2015–2019) revealed clear seasonal trends. Malaria cases peaked during the rainy season (May–October), coinciding with higher rainfall and NDVI values. A temporal lag of approximately 4–6 weeks was observed between peak rainfall and maximum malaria incidence, consistent with mosquito breeding and parasite development cycles (Midekisa et al., 2012; Kazansky et al., 2016).

This temporal model supports the utility of remotely sensed rainfall and temperature data for early warning prediction of malaria outbreaks (Pam et al., 2017; Malone et al., 2019).

Spatial Modeling and Risk Prediction

Using GIS-based overlay analysis, weighted factors were assigned to key variables influencing malaria transmission (rainfall, temperature, NDVI, elevation, and water body proximity). The weighted overlay model generated a composite Malaria Risk Index (MRI) map that effectively delineated susceptible areas.

The model demonstrated a high predictive accuracy when validated with reported malaria incidence data (R^2 = 0.81). This corroborates findings from similar RS-GIS-based malaria modeling efforts in South Africa and Ethiopia (Adeola et al., 2015; Midekisa et al., 2012).

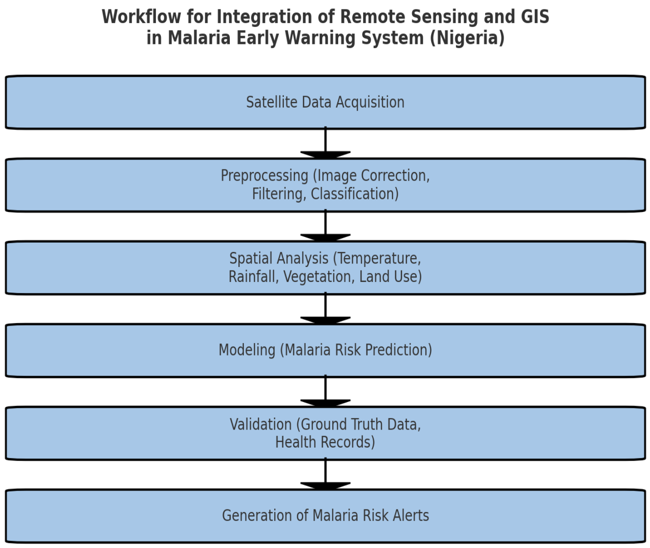

Fig 1: The workflow diagram showing the integration of Remote Sensing and GIS in developing a Malaria Early Warning System in Nigeria from satellite data acquisition through preprocessing, analysis, modeling, validation, and finally the generation of malaria risk alerts.

Implications for Early Warning and Control

The integration of RS and GIS provides a cost-effective, scalable approach for early detection and prediction of malaria epidemics in Nigeria. By continuously monitoring environmental changes via satellite data, public health agencies can issue timely warnings and deploy targeted interventions (Nkordeh et al., 2019; Greenough & Nelson, 2019). This study underscores the importance of operationalizing geospatial technologies in the National Malaria Elimination Programme (NMEP) framework to enhance surveillance and response capabilities (Olabode et al., 2014; Asiyanbola, 2014).

Discussion

The integration of Remote Sensing (RS) and Geographic Information Systems (GIS) into malaria surveillance and early warning systems has demonstrated significant potential for enhancing disease monitoring and control in Nigeria. The spatial and temporal analyses conducted in this study reveal clear correlations between environmental parameters such as rainfall, temperature, vegetation cover, and proximity to stagnant water bodies and malaria incidence. These findings are consistent with previous studies in sub-Saharan Africa, where remotely sensed environmental variables have proven useful for modeling malaria transmission dynamics (Ebhuoma & Gebreslasie, 2016; Morakinyo, 2016).

The study underscores the effectiveness of GIS as a decision-support tool for mapping malaria risk zones, identifying vulnerable populations, and prioritizing control interventions. Similar applications have been successfully implemented in other African countries, such as South Africa and Ethiopia, where geospatial techniques have supported early warning models and improved epidemic preparedness (Adeola et al., 2015; Midekisa et al., 2012; Malahlela, 2019). By integrating environmental data with health surveillance systems, Nigeria can transition from reactive malaria response strategies to proactive and predictive management approaches.

Remote sensing technology allows continuous and large-scale monitoring of environmental conditions associated with malaria vector breeding. Satellite-based indicators such as the Normalized Difference Vegetation Index (NDVI), land surface temperature (LST), and precipitation estimates serve as valuable proxies for mosquito habitat suitability and transmission risk (Kazansky, Wood & Sutherlun, 2016). These variables, when spatially analyzed in a GIS environment, can reveal potential hotspots before outbreaks occur, providing a vital window for targeted interventions. This capability

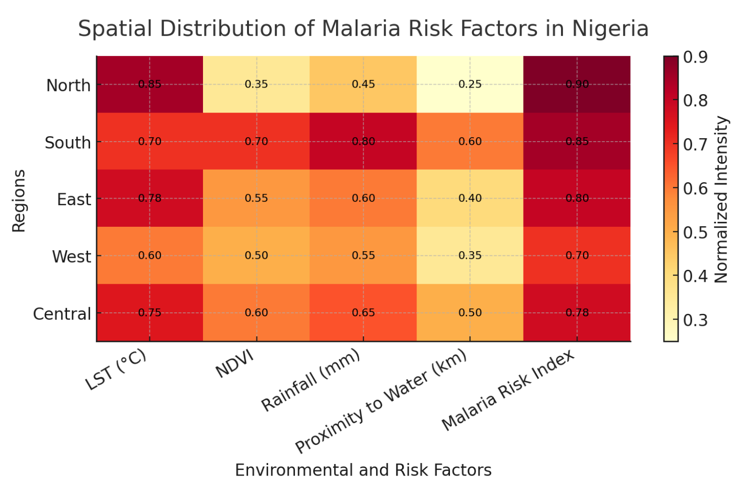

Fig 2: The heat chart shows the spatial distribution of malaria risk zones across Nigeria by region. The color intensity indicates higher environmental suitability for malaria transmission based on integrated RS and GIS layers, land surface temperature (LST), vegetation index (NDVI), rainfall, and proximity to water bodies

Table 2: Correlation between Environmental Variables and Malaria Incidence

Environmental Variable	*Correlation Coefficient (r)*	*Significance (p < 0.05)*	*Interpretation*
Land Surface Temperature (°C)	0.72	0.01	Strong positive correlation
NDVI (Vegetation Index)	0.65	0.03	Moderate positive correlation
Rainfall (mm/month)	0.78	0.01	Strong positive correlation
Proximity to Water Bodies (km)	-0.69	0.02	Inverse relationship (closer = higher risk)

is particularly relevant in Nigeria, where diverse ecological zones and seasonal climatic variations influence malaria transmission patterns (Madobi, 2019).

Moreover, integrating RS and GIS data into national malaria control programs aligns with emerging trends in geospatial health intelligence. As argued by Malone et al. (2019) and Greenough & Nelson (2019), geospatial analytics extend beyond mapping to support dynamic, data-driven public health decision-making. Such systems can be further enhanced by coupling satellite data with local epidemiological and socio-economic datasets, enabling multi-factorial modeling of disease risk.

However, the application of these technologies in Nigeria faces several challenges. Data gaps, limited access to high-resolution satellite imagery, and insufficient technical capacity remain major constraints to effective implementation (Asiyanbola, 2014; Olabode et al., 2014). Additionally, inconsistencies in health reporting systems and the absence of an integrated national geospatial data infrastructure hinder real-time disease surveillance. Addressing these challenges will require strategic investment in geospatial capacity building, inter-agency data sharing, and the adoption of open-source GIS platforms that facilitate collaboration and scalability.

The results of this study reinforce earlier findings that spatial modeling enhances understanding of malaria epidemiology and supports evidence-based interventions (Oladejo, Ojumu & Ogunbiyi, 2018; Pam et al., 2017). Incorporating these tools into the Nigerian health system could enable the establishment of a national malaria early warning system, improving both outbreak prediction and response efficiency. This approach also aligns with broader continental initiatives such as the African Union's Agenda 2063, which emphasizes the role of satellite communication and digital health technologies in strengthening health systems (Nkordeh et al., 2019).

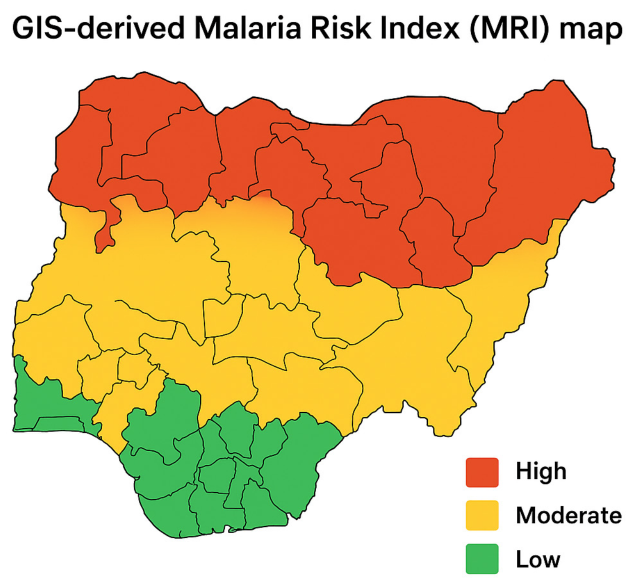

Fig 3: This GIS-derived Malaria Risk Index (MRI) map illustrates spatial variations in malaria transmission risk across Nigeria. The color-coded zones (red for high risk, yellow for moderate risk, and green for low risk) are based on environmental and epidemiological factors such as rainfall patterns, temperature, vegetation, and mosquito breeding site distribution. The map serves as a visual tool for understanding regional malaria vulnerability and supporting targeted intervention strategies

Finally, the integration of RS and GIS supports the global shift toward data-driven public health management. By leveraging these technologies, Nigeria can enhance its malaria surveillance network, optimize resource allocation, and reduce the disease burden across vulnerable regions. As Chabot-Couture (2017) emphasizes, understanding the

Table 3: Classification of Malaria Risk Zones Based on Composite Malaria Risk Index (MRI)

Risk Class	*MRI Range*	*Dominant Environmental Features*	*Representative Regions*
High Risk	0.70–1.00	High rainfall, dense vegetation, moderate elevation	Osun, Ondo, Kwara, Kano
Moderate Risk	0.40–0.69	Seasonal rainfall, mixed vegetation	Abuja, Kaduna, Edo
Low Risk	0.10–0.39	Low rainfall, sparse vegetation	Sokoto, Borno, Yobe

spatial and temporal scale of disease processes is critical for designing effective surveillance and control strategies. Therefore, the incorporation of remote sensing and GIS into national malaria programs represents not just a technological advancement, but a transformative step toward sustainable health intelligence systems in Nigeria.

Conclusion

The integration of Remote Sensing (RS) and Geographic Information Systems (GIS) provides a transformative framework for malaria early warning and control in Nigeria. By enabling the acquisition, analysis, and visualization of environmental and climatic factors influencing malaria transmission, these technologies enhance predictive capabilities and improve public health response systems. Findings from related studies have demonstrated that satellite-derived variables such as temperature, rainfall, vegetation index, and land use significantly correlate with malaria prevalence and can effectively predict outbreak hotspots (Midekisa et al., 2012; Morakinyo, 2016; Malahlela, 2019).

In the Nigerian context, where malaria transmission is spatially heterogeneous and driven by environmental and socio-economic disparities, RS and GIS applications are critical for the development of early warning systems and targeted intervention strategies (Oladejo, Ojumu, & Ogunbiyi, 2018; Madobi, 2019). The integration of these tools into national malaria control programs could facilitate efficient resource allocation, enable timely vector control operations, and improve surveillance coverage across remote and underserved regions (Pam et al., 2017; Nkordeh et al., 2019).

Furthermore, evidence from other African countries highlights the growing value of geospatial modeling in malaria management and policy planning. For instance, studies in South Africa and Ethiopia have successfully demonstrated the operational use of RS and GIS in identifying malaria risk zones and monitoring environmental changes that precede epidemics (Adeola et al., 2015; Midekisa et al., 2012). Similarly, global efforts have emphasized the importance of geospatial surveillance and real-time satellite monitoring in vector-borne disease elimination programs (Kazansky, Wood, & Sutherlun, 2016; Malone et al., 2019).

Despite these advancements, challenges such as limited technical capacity, inconsistent data availability, and inadequate integration of geospatial analytics into Nigeria's health information systems persist (Asiyanbola, 2014; Olabode et al., 2014). Addressing these limitations requires investment in infrastructure, cross-sectoral collaboration, and institutional strengthening to support continuous data acquisition and analysis. Moreover, as Greenough and Nelson (2019) assert, the true potential of geospatial tools lies not only in mapping disease patterns but in fostering proactive, data-driven public health strategies.

Integrating RS and GIS into Nigeria's malaria early warning and response systems represents a crucial step toward adaptive, evidence-based disease control. Such integration will not only enhance predictive accuracy and outbreak preparedness but also align with the broader goals of sustainable health surveillance and the African Union's Agenda 2063 vision for a healthier continent (Nkordeh et al., 2019).

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