Relationship between Weather Elements and the Incidence of Malaria, Measles and Cholera across Six Local Government Areas in Kogi State, Nigeria

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ABSTRACT

This study examined the relationship between weather elements and the incidence of malaria, measles and cholera across six Local Government Areas in Kogi State, Nigeria, namely Adavi, Okene, Bassa, Dekina, Kabba/Bu and Lokoja, using twenty-one years, 2005 to 2025, of monthly meteorological and disease surveillance data. Monthly rainfall, air temperature and relative humidity obtained from the Nigerian Meteorological Agency were related to monthly reported cases of each disease using multiple linear regression, fitted separately for each disease and Local Government Area. For malaria, rainfall, temperature and relative humidity were statistically significant predictors in all six Local Government Areas, with the regression models explaining between 69.1 percent and 85.6 percent of the variation in malaria incidence, the strongest fit recorded in Okene and the weakest in Lokoja. For measles, all three weather elements were likewise significant predictors in every Local Government Area, though the models explained a comparatively modest 25.7 to 35.6 percent of yield variation, reflecting the stronger role of non-climatic factors such as immunization coverage. For cholera, temperature and relative humidity were significant in all six Local Government Areas, while rainfall was significant in four of six, with the models explaining between 54.4 and 64.9 percent of the variation in cholera incidence. Across all three diseases, Okene and Kabba/Bu consistently returned among the highest explanatory power, while Lokoja and Adavi showed comparatively weaker climatic model fits despite high disease burden, suggesting that non-climatic factors play a larger role in these two Local Government Areas. The study concludes that weather elements are statistically significant, spatially varying determinants of malaria, measles and cholera incidence in Kogi State, and recommends that climate-informed early warning systems be calibrated separately for each disease and Local Government Area rather than applied uniformly across the State.

Keywords: Climate-Health Relationship, Malaria, Measles, Cholera, Multiple Linear Regression, Kogi State.

1. INTRODUCTION

Climate variability and change are increasingly recognised as significant drivers of infectious disease risk, altering the distribution and seasonality of vector borne diseases such as malaria and intensifying the risk of water borne outbreaks such as cholera, while extreme temperatures and widespread flooding further overwhelm health systems and exacerbate existing vulnerabilities (Trisos, Adelekan, Totin, Ayanlade, Efitre, Gemeda and Zakieldeen, 2022). Nigeria continues to contribute significantly to the global malaria burden, and national disease surveillance has repeatedly linked extreme rainfall and flooding to spikes in cholera and other water related illnesses (Nigeria Centre for Disease Control, 2022).

Kogi State, situated at the confluence of the Niger and Benue rivers, is particularly exposed to these climate-health risks because of its recurrent flooding and low-lying, riverine terrain (Oyedele, Kola, Olorunfemi and Walz, 2022). While the general association between weather elements and disease incidence is well established in the literature, the strength and statistical significance of this relationship is known to vary across diseases and localities, depending on each disease's transmission mechanism and each locality's hydrology, ecology and

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population characteristics (Githeko, Ototo and Guiyun, 2012). A single, state-wide climate-health relationship is therefore unlikely to adequately capture the risk faced by individual Local Government Areas.

This study addresses this gap by quantifying the relationship between rainfall, air temperature and relative humidity and the incidence of malaria, measles and cholera separately for six Local Government Areas in Kogi State, using twenty-one years of matched monthly meteorological and disease surveillance data. By fitting and comparing multiple linear regression models across diseases and Local Government Areas, the study identifies where, and for which disease, weather elements exert the strongest statistically significant influence, providing an evidence base for climate-informed, spatially differentiated disease early warning in Kogi State.

Disaggregating the analysis by both disease and Local Government Area also responds to a methodological limitation common in much of the existing climate-health literature, which often estimates a single relationship between weather and disease incidence at a national or state level. Such aggregated estimates can mask considerable local variation in transmission ecology, population vulnerability and health system capacity, producing average relationships that may not hold, or may even mislead, at the scale at which disease surveillance and intervention decisions are actually made. By contrast, the Local Government Area-level regression approach adopted here allows direct comparison of the climate sensitivity of malaria, measles and cholera both within and across six distinct localities of a single state, offering a finer-grained evidence base for local public health planning.

2. STUDY AREA

Kogi State is located in north-central Nigeria and is popularly known as the Confluence State because of the confluence of the rivers Niger and Benue at its capital, Lokoja. The State lies between longitudes 5 degrees 23 minutes East and 7 degrees 48 minutes East, and latitudes 6 degrees 30 minutes North and 8 degrees 48 minutes North, within the tropical Guinean forest-savanna mosaic ecoregion, and has a landmass of 29,833 square kilometres (Abiodun, 1985). Six Local Government Areas were purposively selected for this study, two from each of the three senatorial districts: Adavi and Okene from Kogi Central, Bassa and Dekina from Kogi East, and Kabba/Bu and Lokoja from Kogi West, selected for their proximity to major rivers, their history of recurrent flooding and their consequent vulnerability to climate-related health risks.

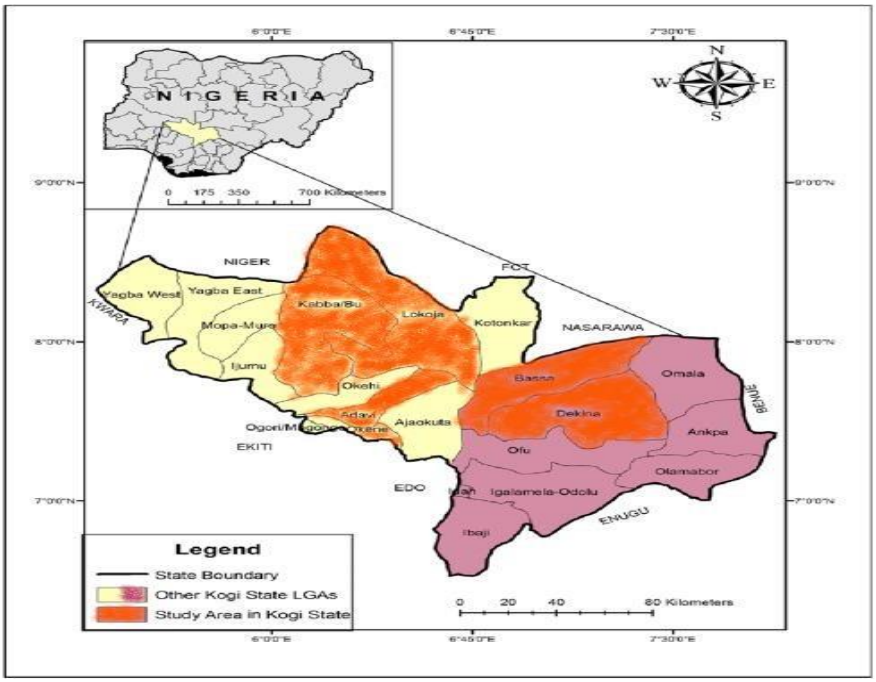


Figure 1: Map of Nigeria Showing Kogi State and the Six Study Local Government Areas

Kogi State experiences a tropical climate characterised by high temperatures, humidity and significant rainfall, with average temperatures ranging between 23.2 and 39.5 degrees Celsius and relative humidity between 30 and 70 percent. The State has a wet season from April to October, during which the bulk of the annual rainfall

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of 1,300 to 1,800 millimetres is received, and a dry season dominated by the dusty, cold Harmattan winds. Kogi State was among the states worst affected by the 2022 floods in Nigeria, and recurrent flooding continues to expose vulnerable riverine communities to disease transmission risk (Aladejana and Ebijuoworih, 2024). The State is drained by the Niger and Benue rivers and their tributaries, which meet at the confluence in Lokoja, and while these water bodies support agriculture, fishing and domestic water use, they also encourage the breeding of disease-causing pathogens through recurring flooding, erosion and water contamination.

3. METHODOLOGY

Data Sources

Monthly data on rainfall, maximum and minimum temperature, and relative humidity, covering twenty-one years, 2005 to 2025, were obtained from the archives of the Nigerian Meteorological Agency. Monthly reported cases of malaria, measles and cholera for the same period and the same six Local Government Areas were obtained from the Federal Ministry of Health, the Kogi State Ministry of Health and the Nigeria Centre for Disease Control and Prevention, yielding 252 matched monthly observations, twenty-one years multiplied by twelve months, for each disease and Local Government Area.

Derivation of Weather Variables

Monthly rainfall totals were computed by summing daily rainfall within each calendar month of each year. Mean air temperature was computed from daily maximum and minimum temperature readings, and mean relative humidity was computed from daily observations within each month. The resulting monthly time series for rainfall, air temperature and relative humidity were matched to the corresponding monthly disease incidence records for each Local Government Area.

Multiple Linear Regression Modelling

The relationship between weather elements and disease incidence was examined using multiple linear regression, fitted separately for each disease and each Local Government Area. The model took the form Yt equals b0 plus b1R plus b2T plus b3RH plus the error term, where Yt is disease incidence in month t, R, T and RH are monthly rainfall, air temperature and relative humidity respectively, and b0 through b3 are the regression coefficients estimated using ordinary least squares. The null hypothesis in each case was that a given weather element had no statistically significant association with disease incidence; the alternative hypothesis was that it did. Statistical significance was assessed at the 5 percent level, and model explanatory power was assessed using the coefficient of determination, R squared. Fitting separate models for each disease and Local Government Area allowed the strength and direction of the weather-disease relationship to be compared spatially across Kogi State.

4. RESULTS AND DISCUSSION

4.1 Relationship between Weather Elements and Malaria Incidence

Rainfall, temperature and relative humidity were all statistically significant predictors of malaria incidence in every one of the six Local Government Areas studied. The strongest model fit was recorded in Okene, where the three weather elements explained 85.6 percent of the variation in malaria incidence, followed by Kabba/Bu at 82.2 percent and Bassa at 81.1 percent. The weakest, though still substantial, fit was recorded in Lokoja at 69.1 percent. Rainfall consistently emerged as an important predictor across Local Government Areas, consistent with its role in creating the stagnant water bodies required for Anopheles mosquito breeding, while temperature and relative humidity jointly shape mosquito survival and the rate of parasite development within the vector (Githeko, Ototo and Guiyun, 2012; Yamba, Fink, Badu, Asare, Tompkins and Amekudzi, 2023).

LGA	Rainfall p-value	Temperature p-value	Relative Humidity p-value	R2
Adavi	0.0031 (S)	0.0055 (S)	0.0019 (S)	0.73
Okene	0.0055 (S)	0.0048 (S)	0.0054 (S)	0.856

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Bassa	0.0012 (S)	0.0075 (S)	0.0015 (S)	0.811
Dekina	0.0042 (S)	0.0038 (S)	0.0032 (S)	0.75
Kabba/Bu	0.0055 (S)	0.0048 (S)	0.0054 (S)	0.822
Lokoja	0.0014 (S)	0.0031 (S)	0.0015 (S)	0.691

Table 1: Significance of Weather Elements and Model Fit for Malaria Incidence by Local Government Area

Source: Author's Computation from NiMet

4.2 Relationship between Weather Elements and Measles Incidence

As with malaria, rainfall, temperature and relative humidity were statistically significant predictors of measles incidence in all six Local Government Areas. However, the explanatory power of the measles models was considerably lower than for malaria, ranging from 25.7 percent in Bassa to 35.6 percent in Okene, indicating that weather elements account for only a modest share of measles variation and that non-climatic factors, particularly routine immunization coverage and population density, play a comparatively larger role (International Journal of Biometeorology, 2011; World Health Organization, 2022). Temperature was consistently among the strongest of the three predictors across Local Government Areas, consistent with the sensitivity of measles virus aerosol survival to ambient conditions.

LGA	Rainfall p-value	Temperature p-value	Relative Humidity p-value	R2
Adavi	0.0422 (S)	0.0256 (S)	0.0338 (S)	0.262
Okene	0.0454 (S)	0.0275 (S)	0.0387 (S)	0.356
Bassa	0.0437 (S)	0.0302 (S)	0.0351 (S)	0.257
Dekina	0.0478 (S)	0.0322 (S)	0.0374 (S)	0.324
Kabba/Bu	0.0398 (S)	0.0209 (S)	0.0393 (S)	0.348
Lokoja	0.0438 (S)	0.0185 (S)	0.0412 (S)	0.293

Table 2: Significance of Weather Elements and Model Fit for Measles Incidence by Local Government Area

Source: Author's Computation from NiMet, Federal and Kogi State Ministries of Health, and NCDC Data

4.3 Relationship between Weather Elements and Cholera Incidence

Temperature and relative humidity were statistically significant predictors of cholera incidence in all six Local Government Areas, while rainfall was statistically significant in four of the six, the exceptions being Adavi, where the rainfall p-value of 0.0614 narrowly missed the 5 percent threshold, and Dekina, where the corresponding p-value was 0.0513. The models explained between 54.4 percent in Adavi and 64.9 percent in Kabba/Bu of the variation in cholera incidence, a level of explanatory power intermediate between the malaria and measles models. The comparatively weaker and sometimes non-significant rainfall effect, set against consistently significant temperature and humidity effects, is consistent with cholera transmission depending less on rainfall volume itself than on the temperature and humidity conditions that govern the survival of Vibrio cholerae in water and the subsequent exposure of riverine populations (Levy, Woster, Goldstein and Carlton, 2016).

LGA	Rainfall p-value	Temperature p-value	Relative Humidity p-value	R2
Adavi	0.0614 (NS)	0.0224 (S)	0.0353 (S)	0.544
Okene	0.0024 (S)	0.0297 (S)	0.0395 (S)	0.581
Bassa	0.0494 (S)	0.0259 (S)	0.0366 (S)	0.577
Dekina	0.0513 (NS)	0.0346 (S)	0.0409 (S)	0.56

Kabba/Bu	0.0497 (S)	0.0308 (S)	0.0422 (S)	0.649
Lokoja	0.0297 (S)	0.0024 (S)	0.0395 (S)	0.59

Table 3: Significance of Weather Elements and Model Fit for Cholera Incidence by Local Government Area

Source: Author's Computation from NiMet, Federal and Kogi State Ministries of Health, and NCDC Data

4.4 Summary of Model Explanatory Power across Diseases

Table 4 compares the explanatory power of the climate regression models across all three diseases and six Local Government Areas. Malaria returned consistently the highest R squared values, followed by cholera, with measles returning the lowest, confirming that weather elements exert their strongest, most readily modelled influence on malaria incidence, a moderate influence on cholera incidence, and a comparatively weaker, though still statistically significant, influence on measles incidence.

LGA	Malaria R2	Measles R2	Cholera R2
Adavi	0.73	0.262	0.544
Okene	0.856	0.356	0.581
Bassa	0.811	0.257	0.577
Dekina	0.75	0.324	0.56
Kabba/Bu	0.822	0.348	0.649
Lokoja	0.691	0.293	0.59

Table 4: Comparative Coefficient of Determination (R2) for Malaria, Measles and Cholera Regression Models by Local Government Area

Source: Author's Computation from NiMet, Federal and Kogi State Ministries of Health, and NCDC Data

A closer reading of Table 4 shows that the ranking of Local Government Areas by climatic model fit is not identical across diseases. Okene records the highest R squared for malaria, 0.856, and the second highest for cholera, 0.581, but only a mid-range value for measles, 0.356, while Kabba/Bu records the strongest cholera fit, 0.649, alongside a strong malaria fit, 0.822. This divergence indicates that no single Local Government Area is uniformly the most or least climate-sensitive across all three diseases, reinforcing the conclusion that climate-health relationships in Kogi State must be assessed disease by disease rather than assumed to generalise from one disease to another within the same locality.

5. DISCUSSION

The consistently high explanatory power of the malaria models, ranging from 69.1 to 85.6 percent across the six Local Government Areas, confirms that weather elements are strong, reliable determinants of malaria incidence in Kogi State, reflecting the tight ecological dependence of the Anopheles vector and the Plasmodium parasite on rainfall, temperature and humidity (Yamba, Fink, Badu, Asare, Tompkins and Amekudzi, 2023). The comparatively lower explanatory power of the measles models, 25.7 to 35.6 percent, indicates that while weather elements are statistically significant, they are secondary to non-climatic drivers such as immunization coverage and population crowding in determining measles incidence (World Health Organization, 2022), suggesting that measles early warning in Kogi State should combine weather monitoring with immunization coverage tracking rather than relying on climatic predictors alone.

Cholera's intermediate explanatory power, together with its less consistent rainfall significance, reflects a transmission pathway in which temperature and humidity, which govern pathogen survival, matter more consistently across Local Government Areas than rainfall volume itself, which may act more as a triggering event, through flooding, than as a continuously graded predictor (Levy, Woster, Goldstein and Carlton, 2016).

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This distinction has practical importance for early warning system design, since a continuous rainfall-based trigger may be less informative for cholera than a flood-event-based trigger combined with temperature and humidity monitoring.

Across all three diseases, Okene and Kabba/Bu consistently returned among the strongest climatic model fits, while Lokoja, despite its high overall disease burden identified in spatial analyses of the same study area, returned comparatively weaker climate model fits for malaria and measles. This suggests that in Lokoja, non-climatic factors, potentially including its role as the State capital and a major transport and population hub, contribute disproportionately to disease incidence relative to the other five Local Government Areas, a pattern that warrants further investigation using socio-economic and infrastructural variables alongside the climatic predictors examined here.

The variation in model fit across Local Government Areas also carries a methodological lesson for climate-health research in similarly diverse sub-national settings. Pooling data across Local Government Areas to fit a single, state-wide regression model would have concealed the spatial variation documented in Tables 1 to 4, including the near-threshold, non-significant rainfall effect on cholera in Adavi and Dekina, and would have produced a single R squared value that misrepresents both the strongest and the weakest performing localities. The disaggregated, Local Government Area-specific approach adopted in this study is therefore better suited to informing spatially targeted public health decision-making than an aggregated state-wide model would have been, even though it requires substantially more data processing and modelling effort.

These results also speak to the broader debate on the relative predictability of vector-borne, airborne and waterborne diseases under climate variability. Malaria, as a vector-borne disease with a well defined ecological dependency on temperature, rainfall and humidity through its mosquito vector, proved the most climatically predictable of the three diseases studied. Cholera, a waterborne disease whose transmission depends on the interaction between pathogen survival conditions and human exposure to contaminated water, showed intermediate predictability. Measles, an airborne disease whose transmission is heavily mediated by population immunity and social contact patterns, proved the least climatically predictable, even though weather elements remained statistically significant in every Local Government Area examined. This ordering is broadly consistent with the transmission ecology of the three disease classes documented in the wider climate-health literature (Trisos, Adelekan, Totin, Ayanlade, Efitre, Gemeda and Zakieldeen, 2022).

6. CONCLUSION

This study has quantified the relationship between weather elements and the incidence of malaria, measles and cholera across six Local Government Areas in Kogi State using twenty-one years of matched monthly data. Rainfall, temperature and relative humidity were statistically significant predictors of malaria and measles incidence in every Local Government Area, and of cholera incidence in most Local Government Areas, with malaria showing the strongest climatic model fit, cholera intermediate, and measles the weakest. These findings confirm that the relationship between weather and disease in Kogi State varies systematically by disease and by Local Government Area, and that climate-informed disease early warning systems should be calibrated separately for each disease and location rather than applied uniformly across the State.

7. RECOMMENDATIONS

i. Climate-informed malaria early warning systems, built on rainfall, temperature and relative humidity monitoring, should be prioritised across all six Local Government Areas given the consistently strong climatic model fit obtained for malaria.

ii. Measles early warning should combine weather monitoring with routine immunization coverage tracking, since climatic factors alone explain only a modest share of measles incidence variation.

iii. Cholera early warning should emphasise flood-event monitoring alongside temperature and humidity tracking, given the less consistent statistical significance of rainfall relative to temperature and relative humidity.

iv. Further research should examine non-climatic determinants of disease incidence in Lokoja and Adavi, where climatic model fits were comparatively weaker despite documented high disease burden, to identify the additional factors driving incidence in these Local Government Areas.

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