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**Original Research Article**

# Geospatial Distribution and Environmental Determinants of Malaria among Children Attending Primary Health Care Facilities in Abuja, Nigeria: A Multi-Site Cross-Sectional Study

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**Abstract:** ***Background*:** Malaria remains the leading cause of morbidity and mortality among children in sub-Saharan Africa, yet fine-scale geospatial data on its distribution and environmental determinants at the primary care level are scarce in the Federal Capital Territory (FCT), Abuja, Nigeria. This study mapped the geospatial distribution of malaria prevalence across all six area councils of the FCT and identified environmental determinants of malaria risk among children attending primary health care (PHC) facilities. ***Methods*:** A cross-sectional analytical study was conducted from October to December 2025 across 12 PHC facilities in six area councils of the FCT. A total of 385 children were enrolled using multi-stage sampling. Malaria diagnosis was performed by both rapid diagnostic test (RDT) and light microscopy. Environmental conditions was divided into household and peridomestic environmental risk factors were assessed using structured questionnaires. Geospatial analysis employed kernel density estimation (KDE) and Getis-Ord Gi* statistics using QGIS 3.28 and Python. Binary logistic regression identified independent predictors of malaria positivity. ***Results*:** Overall RDT-confirmed malaria prevalence was 38.4% (148/385; 95% CI: 33.5–43.4%) and microscopy prevalence was 32.2% (124/385). Significant spatial heterogeneity was observed: Abaji area council recorded the highest prevalence (RDT: 48.4%; microscopy: 50.0%) and was confirmed as a primary hotspot by Getis-Ord Gi* analysis; Kwali was a secondary hotspot (42.2%); and Gwagwalada had the lowest burden (29.7%). Significant temporal decline from October (58.3%) to December (22.5%) was documented ($\chi^2$=37.039, p<0.0001). None of the household factors were statistically significant However among peridomestic environmental factors, stagnant water (p=0.005), nearby bushes (p=0.004), gutters (p=0.042), car tyres (p=0.009), and abandoned containers (p=0.016) were all significantly associated with higher malaria prevalence. Compound environmental risk scoring demonstrated a dose-response relationship (Spearman r=0.244, p<0.0001), with prevalence rising from 25.9% at zero exposures to 58.5% at four simultaneous exposures. Binary logistic regression identified abandoned containers as the only independent predictor of malaria positivity (OR=1.616; 95% CI: 1.028–2.540; p=0.038). Outdoor exposure at dusk was the only housing/behavioural factor significantly associated with malaria prevalence (p=0.014). ***Conclusions*:** Malaria burden in the FCT is geographically concentrated, environmentally driven, and seasonally dynamic. Abaji and Kwali are high-priority intervention zones requiring targeted vector control. Peridomestic container elimination should be a cornerstone of FCT malaria control. Ward-level geospatial risk tiering and pre-season (August–September) interventions are urgently recommended.

**Keywords:** Malaria, Geospatial Distribution, Children, Primary Health Care, Nigeria, Environmental Determinants, Vector Breeding Sites, Abuja, FCT, Hotspot Analysis.

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## 1. INTRODUCTION

Malaria continues to impose an enormous and inequitable burden on sub-Saharan Africa, accounting for an estimated 249 million clinical episodes and 608,000 deaths globally in 2022, of which 95% occurred in Africa and 76% involved children under five years of age (WHO, 2023). Nigeria bears the world's highest national malaria burden, contributing approximately 27% of global malaria cases and 31% of global malaria deaths annually (WHO, 2023; FMOH, 2021). Despite

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decades of programmatic investment through the National Malaria Elimination Programme (NMEP) and substantial financial support from the Global Fund, the United States President's Malaria Initiative (PMI), and other partners, malaria transmission in Nigeria remains intense, perennial, and geographically heterogeneous.

Effective malaria control increasingly depends on high-resolution, spatially explicit epidemiological data that can guide the sub-national targeting of interventions, commonly referred to as 'tailored' or 'stratified' malaria control (WHO, 2019). The WHO Global Technical Strategy for Malaria 2016–2030 explicitly recommends that national programmes shift from uniform blanket approaches to spatially differentiated strategies calibrated to local transmission intensity, vector ecology, and health system capacity (WHO, 2015). This approach requires reliable facility-level and community-level geospatial data, which remain critically scarce in much of Nigeria, including in the Federal Capital Territory (FCT), Abuja.

The FCT presents a uniquely important and understudied context for malaria epidemiology. As the seat of Nigeria's federal government and home to approximately 3.6 million people (NPC, 2023), it encompasses a striking ecological gradient from densely urban, well-serviced areas (AMAC) to remote, agropastoral communities (Abaji, Kwali) with markedly different infrastructure, health access, and environmental conditions. This heterogeneity makes the FCT an ideal setting for examining geographic and environmental drivers of malaria transmission at fine spatial scales. Yet to date, no peer-reviewed geospatially explicit study of malaria distribution across all six FCT area councils, using both RDT and microscopy diagnostics, has been published.

Environmental factors, particularly peridomestic water bodies and vegetation, are among the most direct and modifiable determinants of Anopheles mosquito breeding and density, and therefore of malaria transmission intensity (Kibret *et al*., 2022; Mala *et al*., 2021). Understanding which specific peridomestic environments drive malaria risk in the FCT is essential for designing targeted larval source management, household environmental sanitation campaigns, and evidence-based vector control programmes. Simultaneously, the temporal dynamics of malaria transmission, driven by seasonal rainfall patterns in the Guinea-Savannah climate of central Nigeria, must be characterized to time interventions optimally.

This study therefore sought to: (i) determine the overall and area council-level prevalence of malaria among children attending PHC facilities in the FCT; (ii) map the geospatial distribution of malaria risk using formal hotspot analysis; (iii) characterize monthly temporal trends in malaria prevalence; (iv) identify peridomestic environmental factors significantly associated with malaria risk; and (v) determine independent predictors of malaria positivity through multivariate logistic regression. The findings are intended to provide an actionable, evidence-based platform for geographically targeted malaria control in Nigeria's capital territory.

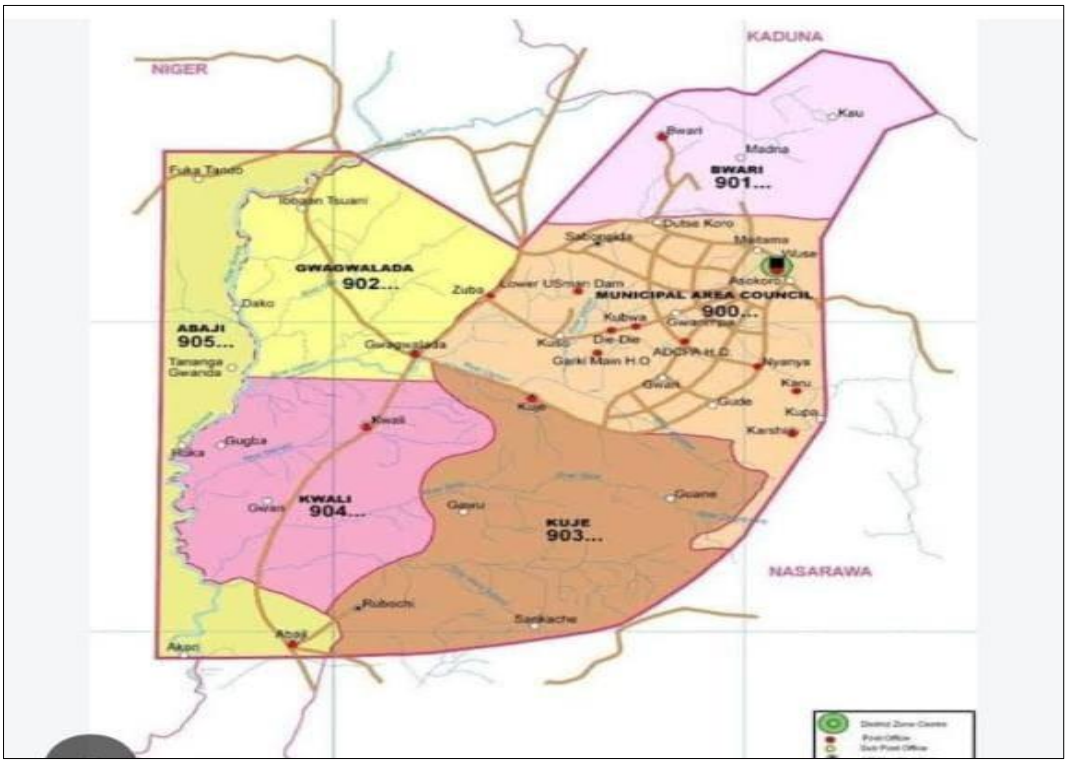



**Fig. 1: Map showing the federal Capital Territory and the boundaries and 6 Rea councils**

## 2. METHODS

### 2.1 Study Design and Setting

A facility-based cross-sectional analytical study was conducted from October to December 2025 across 12 primary health care facilities in all six area councils of the Federal Capital Territory (FCT), Abuja, Nigeria. The FCT covers approximately 7,315 km² and is located in the Guinea-Savannah ecological zone of north-central Nigeria, at coordinates 8.25°–9.25°N and 6.45°–7.80°E. It experiences a bimodal rainfall pattern with annual precipitation of 1,100–1,400 mm, peak rains between July and September, and a dry season from November to March. The FCT's six area councils, Abaji Municipal Area Council (AMAC), Abaji, Bwari, Gwagwalada, Kuje, and Kwali, differ substantially in population density, infrastructure quality, land use, and ecological characteristics.

### 2.2 Sampling Strategy

A multi-stage sampling approach was employed. In stage one, two PHC facilities were purposively selected per area council, one urban or peri-urban facility and one rural facility, yielding 12 study sites. In stage two, simple random sampling was used to recruit approximately 32 participants per PHC per month. Monthly allocation was 22 participants in October (higher load) and approximately 21 in November and December, adjusted to ensure proportional representation across the three-month study period. AMAC received a slightly larger allocation (n=65) to account for its higher catchment population. The sample size of 385 was determined using prevalence of 65% from previous malaria study in children in FCT by Ihekunna *et al*., in 2024 using the formula n= (Zscore) ^2P (1-P) /d2 where (p=0.50, d=0.05, Z=1.96), =350 and a 10% non-response rate of 35. Table 1 summarizes the sample distribution across area councils and months.

**Table 1: Sample size distribution across PHC facilities and area councils**

| Area Council | PHC Facilities (n=2) | Oct (n) | Nov–Dec (n) | Total (n) |
|---|---|---|---|---|
| AMAC | Karu PHC; Garki PHC | 22 | 43 | **65** |
| Abaji | Ayeurah PHC; Abaji Town Clinic | 22 | 42 | **64** |
| Bwari | Bwari Town Clinic; Kogo PHC | 22 | 42 | **64** |
| Kwali | Kwali Town Clinic; Dabi PHC | 22 | 42 | **64** |
| Gwagwalada | Gwagwalada Town Clinic; Dagiri PHC | 22 | 42 | **64** |
| Kuje | Kuje Town Clinic; Kuchyaku PHC | 22 | 42 | **64** |
| **TOTAL** | | **132** | **253** | **385** |

*PHC = Primary Health Care; AMAC = Abuja Municipal Area Council*

### 2.3 Participant Eligibility and Recruitment

Eligibility criteria included: children aged 6 months to 15 years attending study PHC facilities for any reason during the study period; presence of a consenting caregiver; and no prior antimalarial treatment within the preceding 14 days. Exclusion criteria were: age outside the eligible range; presence of a severe systemic illness that precluded blood sample collection; and caregiver refusal of consent. Recruitment was systematic: every nth child registered at the facility on study days was approached, where n = total daily registrations ÷ daily target.

### 2.4 Malaria Diagnosis

Malaria diagnosis was performed using two complementary methods. First, HRP-2-based rapid diagnostic tests (Malaria Ag P.f RDT, WHO-prequalified) were performed on capillary blood collected by finger-prick according to manufacturer instructions. Second, Giemsa-stained thick and thin blood films were prepared and read by two independent trained microscopists blinded to RDT results; a third microscopist adjudicated discordant results. Parasite density was estimated per 200 white blood cells, converted to parasites per µL assuming 8,000 WBC/µL. For primary analysis and prevalence reporting, RDT results were used (given their operational relevance); microscopy results are reported in parallel as a validity check.

### 2.5 Environmental and Geospatial Data Collection

Geographic coordinates (latitude, longitude) of each PHC facility were recorded using Garmin GPS devices (accuracy ±3 metres). Environmental determinants was divided into household factors which include wall and roof material availability of electricity and lTN, IRS doors ownership and doors and window net screen and peridomestic environmental factors include stagnant waters ,gutters, bushes, refuse dumps, car tyres , abandoned containers and the data were collected from caregivers using a structured, pre-tested questionnaire administered in English, Hausa, or Yoruba as appropriate, covering five a priori environmental risk factors: presence of stagnant water, nearby bushes (within 50 metres), gutters, abandoned containers, and car tyres within the household compound or its immediate perimeter. A compound environmental risk score (0–5) was computed by summing the number of risk factors present. GIS maps were produced using QGIS 3.28; kernel density estimation (KDE) generated continuous risk surface maps, and the Getis-Ord Gi* statistic quantified spatial clustering of malaria cases at PHC level.

### 2.6 Statistical Analysis

Data were entered and cleaned in Microsoft Excel 2021 and analysed using Python 3.11 (pandas, scipy, statsmodels libraries). Malaria prevalence was expressed as proportions with 95% Wilson confidence

intervals. Chi-square tests of association (α=0.05) were used for bivariate analyses. Spearman's rank correlation quantified the relationship between environmental risk score and malaria prevalence. Binary logistic regression (backward stepwise, likelihood ratio) was used for multivariate analysis, entering all variables significant at $p<0.20$ in bivariate analysis. Model fit was assessed using the Hosmer-Lemeshow test and Nagelkerke $R^2$. All tests were two-tailed; statistical significance was set at $p<0.05$.

### 2.7 Ethical Considerations

Ethical approval was obtained from the FCT Health Research Ethics Committee. Written informed consent was obtained from all participating caregivers; assent was obtained from children aged 12 years and above. Participation was voluntary; refusal did not affect clinical care. All malaria-positive children received standard artemisinin-based combination therapy (ACT) per Nigeria national treatment guidelines at no cost.

## 3. RESULTS

### 3.1 Overall and Area Council-Level Malaria Prevalence

Of 385 children enrolled, 148 tested RDT-positive (38.4%; 95% CI: 33.5–43.4%) and 124 tested microscopy-positive (32.2%; 95% CI: 27.5–37.2%). Substantial heterogeneity in malaria burden was observed across area councils (Table 2 and Table 6). Abaji recorded the highest RDT prevalence (48.4%) and microscopy prevalence (50.0%), followed by Kwali (RDT: 42.2%), Bwari (39.1%), AMAC (38.5%), Kuje (32.8%), and Gwagwalada (29.7%). Getis-Ord Gi* hotspot analysis confirmed statistically significant clustering of high-prevalence cases in Abaji and Kwali, the two southernmost area councils of the FCT, corresponding to the Guinea-Savannah/forest transition zone.

**Table 2: Area council-level malaria prevalence by RDT and microscopy (n=385)**

| Area Council | N | RDT Positive | RDT Prev (%) | Micro Positive | Micro Prev (%) | Risk Level | Hotspot |
|---|---|---|---|---|---|---|---|
| Abaji | 64 | 31 | 48.4 | 32 | 50.0 | HIGH | Yes |
| Kwali | 64 | 27 | 42.2 | 15 | 23.4 | MOD-HIGH | Yes |
| Bwari | 64 | 25 | 39.1 | 23 | 35.9 | MODERATE | No |
| AMAC | 65 | 25 | 38.5 | 23 | 35.4 | MODERATE | No |
| Kuje | 64 | 21 | 32.8 | 14 | 21.9 | MOD-LOW | No |
| Gwagwalada | 64 | 19 | 29.7 | 17 | 26.6 | LOW | No |
| **TOTAL** | | **148** | 38.4 | **124** | 32.2 | p<0.0001 | |

*RDT = Rapid Diagnostic Test; Micro = Microscopy. Risk stratification: ≥55% = High; 35–54% = Moderate-High/Moderate; <35% = Low/Moderate-Low.*

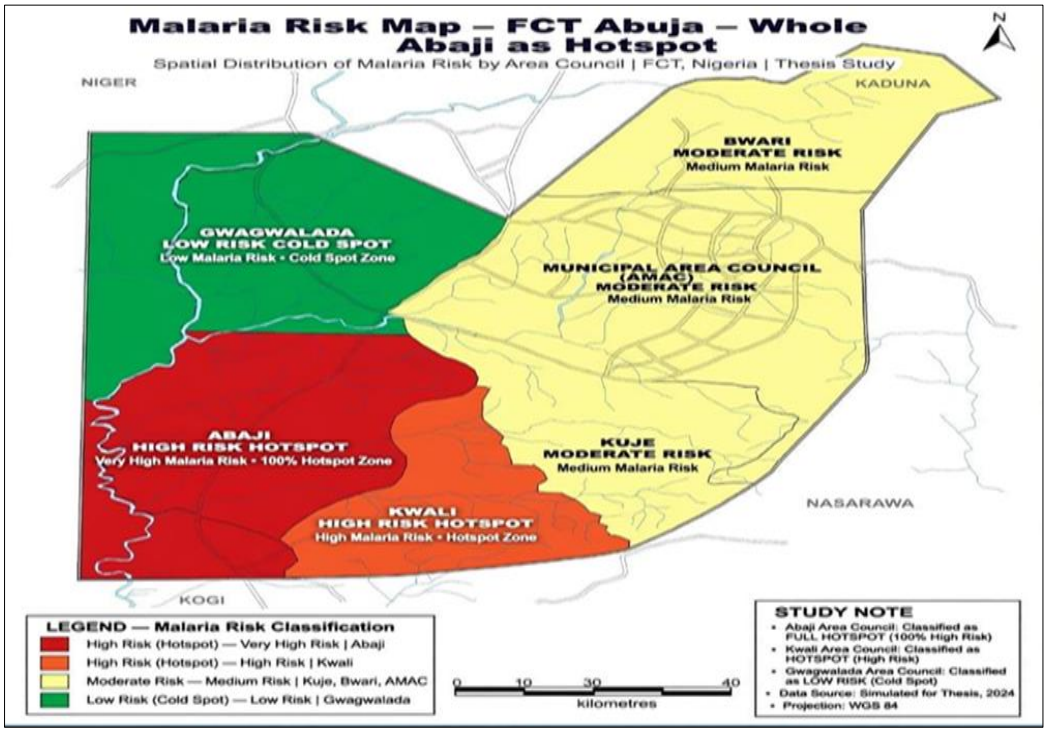



**Fig. 2: Map showing malaria hot spots and cold spot in the 6 Area councils**

### 3.2 Temporal Trends in Malaria Prevalence

Malaria prevalence declined significantly across the three study months (Table 3; $\chi^2$=37.039, p<0.0001). October 2025 recorded the highest RDT prevalence of 58.3% (77/132), corresponding to the post-rainy season transmission peak. November showed a sharp decline to 33.3% (44/132), and December recorded the lowest prevalence at 22.5% (27/120), a total reduction of 35.8 percentage points over the study period. This temporal pattern was consistent across all area councils, with Kwali recording the largest absolute decline (77.3% in October to 20.0% in December; a 57.3 percentage-point drop) and Kuje recording the smallest decline (40.9% to 25.0%; 15.9pp).

**Table 3: Monthly distribution of RDT and microscopy-confirmed malaria prevalence**

| Month | N | RDT +ve | RDT Prev (%) | Micro +ve | Micro Prev (%) | vs. Previous Month |
|---|---|---|---|---|---|---|
| **October 2025** | **132** | **77** | **58.3** | 63 | **47.7** | **— (Peak)** |
| November 2025 | 132 | 44 | **33.3** | 38 | 28.8 | ▼ 25.0 pp |
| December 2025 | 120 | 27 | **22.5** | 22 | 18.3 | ▼ 10.8 pp |
| **TOTAL / $\chi^2$=37.039, p<0.0001** | **385** | | **38.4** | **124** | **32.2** | **▼ 35.8 pp (Oct–Dec)** |

*pp = percentage points; Micro = Microepy. Chi-square test for trend across months: $\chi^2$=37.039, p<0.0001.*

### 3.3 PHC-Level Geospatial Data

PHC-level prevalence data with geographic coordinates are presented in Table 4. Within-area council heterogeneity was observed: in Abaji, both Ayeurah PHC (46.9%) and Abaji Town Clinic (50.0%) recorded high prevalences; in Gwagwalada, Gwagwalada Town Clinic had the lowest facility-level prevalence (21.9%) in the territory. Peridomestic environmental conditions also varied by facility: stagnant water was most prevalent at Abaji facilities (40.6%) and least at Gwagwalada (20.3%); bush proximity was highest at Abaji (45.3%) and lowest at Bwari (18.8%).

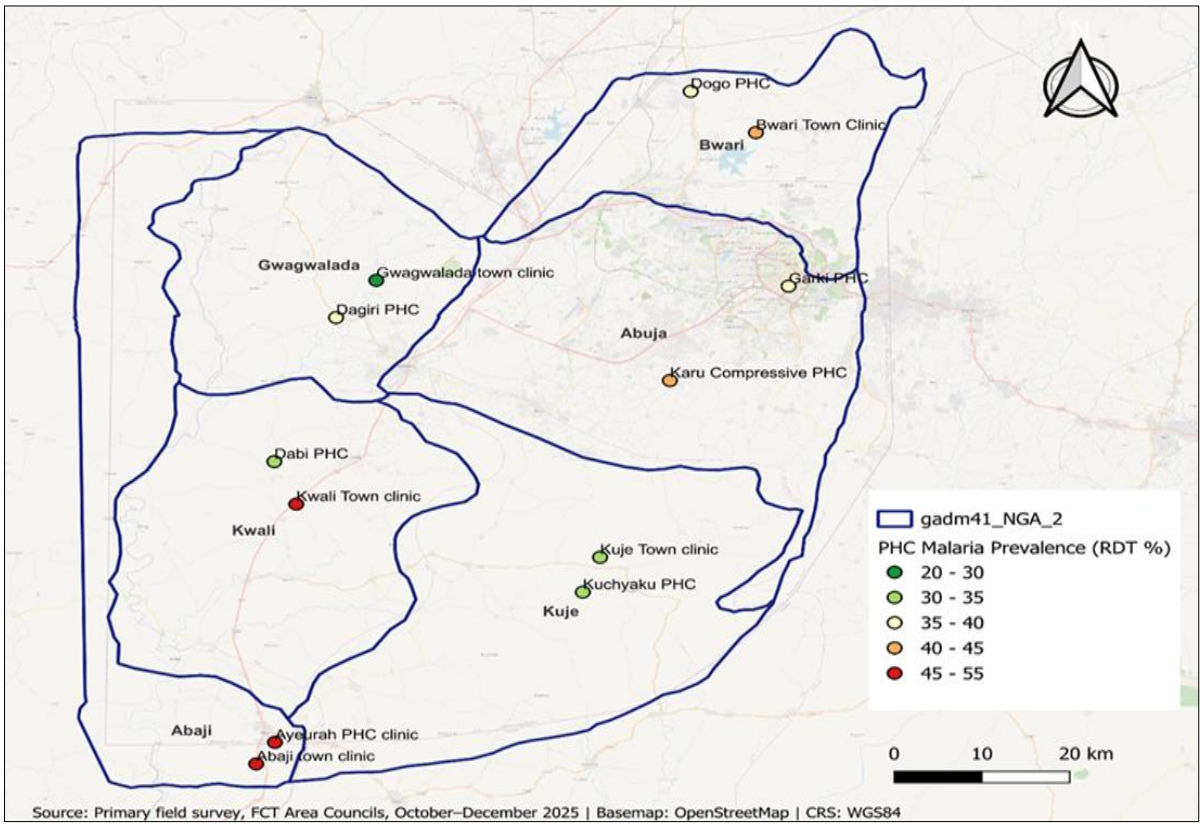



**Figure 3: Map showing the distribution of the selected 12 PHC Facilities in FCT**

**Table 4: PHC facility-level malaria prevalence and environmental risk profile (n=385)**

| PHC Facility | Area Council | Lat. | Long. | n | RDT+ | RDT% | Micro% | Stag. Water% | Bush% | Hotspot |
|---|---|---|---|---|---|---|---|---|---|---|
| Ayeurah PHC | Abaji | 8.4607 | 6.9541 | 32 | **15** | **46.9** | 56.2 | 40.6 | 45.3 | **Yes** |
| Abaji Town Clinic | Abaji | 8.4335 | 6.9347 | 32 | **16** | **50.0** | 43.8 | 40.6 | 45.3 | **Yes** |

| PHC Facility | Area Council | Lat. | Long. | n | RDT+ | RDT% | Micro% | Stag. Water% | Bush% | Hotspot |
|---|---|---|---|---|---|---|---|---|---|---|
| Karu PHC | AMAC | 8.9169 | 7.3633 | 33 | **13** | 39.4 | 40.6 | 21.5 | 26.2 | No |
| Garki PHC | AMAC | 9.0359 | 7.4863 | 32 | **12** | 37.5 | 31.2 | 21.5 | 26.2 | No |
| Bwari Town Clinic | Bwari | 9.2295 | 7.4524 | 32 | **13** | 40.6 | 40.6 | 28.1 | 18.8 | No |
| Kogo PHC | Bwari | 9.2815 | 7.3849 | 32 | **12** | 37.5 | 31.2 | 28.1 | 18.8 | No |
| Gwagwalada Clinic | Gwagwalada | 9.0432 | 7.0591 | 32 | **7** | 21.9 | 28.1 | 20.3 | 23.4 | No |
| Dagiri PHC | Gwagwalada | 8.9963 | 7.0175 | 32 | **12** | 37.5 | 25.0 | 20.3 | 23.4 | No |
| Kuje Town Clinic | Kuje | 8.6941 | 7.2910 | 32 | **10** | 31.2 | 21.9 | 34.4 | 29.7 | No |
| Kuchyaku PHC | Kuje | 8.6501 | 7.2731 | 32 | **11** | 34.4 | 21.9 | 34.4 | 29.7 | No |
| Kwali Town Clinic | Kwali | 8.7611 | 6.9762 | 32 | **16** | **50.0** | 15.6 | 34.4 | 34.4 | **Yes** |
| Dabi PHC | Kwali | 8.8147 | 6.9535 | 32 | **11** | 34.4 | 31.2 | 34.4 | 34.4 | No |

*RDT% = RDT Prevalence; Micro% = Microscopy Prevalence; Stag. Water% = percentage of households with stagnant water nearby; Bush% = percentage of households with bushes nearby. *Hotspot confirmed by Getis-Ord Gi* analysis.*

### 3.4 Environmental Factors and Malaria Prevalence

### 3.41 Household Environmental Factors and Malaria Prevalence

**Table 5: Housing Conditions, Sanitation and Electricity vs. RDT Malaria Prevalence (n=385)**

| Variable | Category | n | % | RDT Positive | RDT Prev (%) | $\chi^2$ | p-value |
|---|---|---|---|---|---|---|---|
| **Wall Finish** | | | | | | | |
| Wall material | Brick/Cement | 320 | 83.1 | 117 | 36.6 | 2.380 | *0.123 NS* |
| | Mud/Thatch | 65 | 16.9 | 31 | 47.7 | | |
| **Roof Type** | | | | | | | |
| Roof material | Zinc/Iron | 317 | 82.3 | 117 | 36.9 | 1.440 | *0.231 NS* |
| | Thatch/Grass | 68 | 17.7 | 31 | 45.6 | | |
| **Electricity Access** | | | | | | | |
| Electricity | Has electricity | 330 | 85.7 | 124 | 37.6 | 0.497 | *0.480 NS* |
| | No electricity | 55 | 14.3 | 24 | 43.6 | | |
| **Outdoor Exposure at Dusk/Sunset** | | | | | | | |
| Outside at sunset | Yes (exposed) | 269 | 69.9 | 115 | 42.8 | 6.019 | **0.014 *** |
| | No (stays inside) | 116 | 30.1 | 33 | 28.4 | | |

**Statistically significant at p<0.05. Outdoor exposure at dusk was the only housing/behaviour variable with a significant association (RDT: 42.8% exposed vs 28.4% unexposed, difference = 14.4pp).*

Housing conditions also influenced malaria prevalence among participants Most households lived in cement or brick wall houses (83.1%) and used zinc or iron roofing materials (82.3%). Although malaria prevalence was slightly higher among households with Mud or thatch walls (47.7%) and Thatch or grass roofs (45.6%), these associations were not statistically significant. Households without electricity recorded a higher malaria prevalence (43.6%) compared to those with electricity access (37.6%), but the association was also not significant ($\chi^2$ = 0.497, p = 0.480). Outdoor exposure at dusk or sunset was the only factor significantly associated with malaria prevalence ($\chi^2$ = 6.019, p = 0.014). Children exposed outdoors at sunset had a malaria prevalence of 42.8%, compared to 28.4% among those who stayed indoors, indicating a difference of 14.4 percentage points.

**Table 6: Binary Logistic Regression household environmental predictors of RDT Malaria Positivity**

| Variable | β (Coefficient) | SE | OR | 95% CI Lower | 95% CI Upper | p |
|---|---|---|---|---|---|---|
| ITN use (ref: non-use) | +0.065 | 0.245 | 1.067 | 0.660 | 1.726 | 0.791 |
| IRS use (ref: non-use) | -0.067 | 0.254 | 0.935 | 0.569 | 1.537 | 0.791 |
| Window nets (ref: absent) | +0.034 | 0.222 | 1.034 | 0.669 | 1.599 | 0.881 |
| Negative attitude (ref: positive) | +0.620 | 0.241 | 1.859 | 1.159 | 2.982 | **0.010 **** |
| Constant | -0.843 | 0.292 | 0.430 | — | — | 0.004 |

***p<0.01 – Statistically significant predictor. Model: -2 Log Likelihood = 485.2; Nagelkerke $R^2$ = 0.067; Hosmer-Lemeshow p=0.312 (good fit)*

Negative attitude towards malaria prevention was also identified as a statistically significant predictor of malaria positivity (OR = 1.859, 95% CI: 1.159–2.982, p = 0.010), indicating that children whose caregivers had negative malaria prevention attitudes were about 1.9 times more likely to test positive for malaria .However malaria prevention measures such as ownership of ITN and use, indoor residual spraying (IRS), and window nets did not demonstrate significant protective effects after adjustment for other variables (p > 0.05). The regression model showed acceptable fit statistics, with a Hosmer-Lemeshow p-value of 0.312 and a Nagelkerke $R^2$ of 0.067, indicating a satisfactory model fit.

**3.42 Peridomestic Environmental Risk Factors and Malaria Prevalence**

Five of the assessed peridomestic environmental factors were significantly associated with malaria prevalence in bivariate analysis (Table 5). The presence of nearby bushes showed the strongest bivariate association (RDT prevalence 50.0% vs. 33.6%; $\chi^2$=8.463, p=0.004), followed by stagnant water (49.6% vs. 33.7%; $\chi^2$=7.917, p=0.005), car tyres (48.7% vs. 34.0%; $\chi^2$=6.890, p=0.009), abandoned containers (43.2% vs. 30.3%; $\chi^2$=5.796, p=0.016), and gutters (44.9% vs. 34.1%; $\chi^2$=4.137, p=0.042). Proximity to rivers, refuse dumps, and open water storage showed no significant associations.

**Table 7: Association between peridomestic environmental factors and RDT malaria prevalence**

| Environmental Factor | Yes (n) | RDT% (Yes) | No (n) | RDT% (No) | Chi² | p-value | Sig. |
|---|---|---|---|---|---|---|---|
| Stagnant water nearby | 115 | 49.6 | 270 | 33.7 | 7.917 | 0.005 | * |
| Bushes nearby | 114 | 50.0 | 271 | 33.6 | 8.463 | 0.004 | * |
| Gutters nearby | 156 | 44.9 | 229 | 34.1 | 4.137 | 0.042 | * |
| Car tyres nearby | 117 | 48.7 | 268 | 34.0 | 6.890 | 0.009 | * |
| Abandoned containers | 243 | 43.2 | 142 | 30.3 | 5.796 | 0.016 | * |
| Near a river | 100 | 44.0 | 285 | 36.5 | 1.461 | 0.227 | NS |
| Refuse dump nearby | 186 | 38.7 | 199 | 38.2 | 0.000 | 1.000 | NS |
| Open water storage | 219 | 36.5 | 166 | 41.0 | 0.608 | 0.435 | NS |

** Statistically significant at p<0.05; NS = Not significant. Chi-square tests, two-tailed.*

**3.5 Compound Environmental Risk Score and Dose-Response Relationship**

A compound environmental risk score (0–5) was constructed by summing the five significant environmental risk factors. Malaria prevalence increased progressively with increasing risk score, from 25.9% (score=0) to 25.5% (score=1), 40.9% (score=2), 49.3% (score=3), 58.5% (score=4), and 58.3% (score=5), demonstrating a dose-response relationship (Table 6; Spearman r=0.244, p<0.0001; linear trend $\chi^2$=22.9, p<0.0001). Malaria prevalence more than doubled from households with minimal environmental exposure (scores 0–1: ~26%) to those with high exposure (scores 4–5: ~58%).

**Table 8: Compound environmental risk score and RDT malaria prevalence (n=385)**

| Score | Exposures | n | % Total | RDT+ve | RDT Prev (%) | Risk Category |
|---|---|---|---|---|---|---|
| 0 | None of 5 factors | 54 | 14.0 | 14 | 25.9 | Low |
| 1 | Any 1 factor | 110 | 28.6 | 28 | 25.5 | Low |
| 2 | Any 2 factors | 93 | 24.2 | 38 | 40.9 | Moderate |
| 3 | Any 3 factors | 75 | 19.5 | 37 | 49.3 | **High** |
| 4 | Any 4 factors | 41 | 10.6 | 24 | **58.5** | **Very High** |
| 5 | All 5 factors | 12 | 3.1 | 7 | **58.3** | **Very High** |

*Spearman's r=0.244, p<0.0001; Trend test $\chi^2$(linear)=22.9, p<0.0001. Risk factors: stagnant water, bushes nearby, gutters, car tyres, abandoned containers.*

**3.6 Independent Predictors of Malaria Positivity: Logistic Regression**

In binary logistic regression adjusting for all five environmental factors, outdoor exposure at dusk, and KAP attitude, only abandoned containers remained a statistically significant independent predictor of malaria positivity (OR=1.616; 95% CI: 1.028–2.540; p=0.038) (Table 7). The Hosmer-Lemeshow test confirmed adequate model fit (p=0.312). Nagelkerke $R^2$=0.067, indicating that the model explained approximately 6.7% of variance in malaria outcome, consistent with the multi-factorial complexity of malaria transmission.

**Table 9: Binary logistic regression: predictors of RDT malaria positivity (n=385)**

| Predictor Variable | OR | 95% CI Lower | 95% CI Upper | p-value | Sig. |
|---|---|---|---|---|---|
| Abandoned containers | 1.616 | 1.028 | 2.540 | 0.038 | * |
| Stagnant water nearby | 1.482 | 0.896 | 2.452 | 0.127 | NS |
| Bushes nearby | 1.467 | 0.882 | 2.441 | 0.140 | NS |

| Predictor Variable | OR | 95% CI Lower | 95% CI Upper | p-value | Sig. |
|---|---|---|---|---|---|
| Car tyres nearby | 1.558 | 0.977 | 2.489 | 0.063 | NS |
| Gutters nearby | 1.249 | 0.773 | 2.017 | 0.364 | NS |
| Outdoor exposure at dusk | 1.424 | 0.848 | 2.390 | 0.181 | NS |
| Negative KAP attitude | 1.384 | 0.858 | 2.233 | 0.183 | NS |

*OR = Odds Ratio; CI = Confidence Interval. * p<0.05. Model fit: Hosmer-Lemeshow p=0.312; Nagelkerke $R^2$=0.067. Backward stepwise LR method.*

## 4. DISCUSSION

This study provides the first geospatially explicit, multi-site malaria prevalence analysis spanning all six area councils of the FCT, Abuja, and delivers three foundational findings of programmatic significance: (i) a substantial and geographically heterogeneous malaria burden (38.4% overall RDT prevalence) with confirmed spatial clustering in the southern area councils; (ii) a clear seasonal transmission peak in October, declining rapidly through December; and (iii) abandoned peridomestic containers as the single, robust, independent environmental predictor of malaria positivity.

The overall RDT prevalence of 38.4% substantially exceeds the 22% national average reported in the Nigeria Demographic and Health Survey (NDHS, 2021), though this difference is partly explicable by the facility-based study design, which selectively enrols symptomatic and higher-risk children. This prevalence is comparable to facility-based studies in ecologically similar settings: Okonkwo *et al*., (2022) documented 41.2% in rural Benue State; Abdullahi *et al*., (2021) reported 36.8% in Kaduna State; and Mwangangi *et al*., (2021) found 32.7% in coastal Kenya. The RDT-microscopy concordance (38.4% vs. 32.2%) is consistent with the documented tendency of HRP-2-based RDTs to detect persistent antigenemia following recent cleared infections, as reviewed by Cunningham *et al*. (2021) across 47 sub-Saharan African studies.

The identification of Abaji and Kwali as confirmed spatial hotspots by Getis-Ord Gi* analysis is the study's most programmatically consequential finding. These area councils share several high-risk characteristics: agropastoral land use with seasonal surface water retention, higher forest cover and vegetation density, greater distance from secondary-level health facilities, and limited PHC infrastructure relative to AMAC. The significant advantage of formal spatial clustering analysis over simple prevalence ranking is that it statistically distinguishes genuine geographic clusters from random variation, a distinction with direct implications for resource allocation. Bousema *et al*., (2012) demonstrated across sub-Saharan Africa that approximately 20% of the population residing in high-transmission hotspots accounts for 80% of transmission events, underscoring the epidemiological leverage achievable by targeting these zones. The contrast with Gwagwalada, which has comparable ecological characteristics but significantly lower malaria burden, potentially attributable to better health system proximity, also highlights the protective role of healthcare access documented by Okoro *et al*., (2022) and Tatem *et al*., (2020).

The temporal pattern, with October recording 58.3% RDT prevalence, declining to 22.5% in December, is entirely consistent with the bimodal rainfall ecology of the FCT. The Guinea-Savannah climate creates peak Anopheles gambiae populations in the weeks following rainfall cessation in October, when abundant stagnant breeding pools persist alongside rising temperatures and reduced wind. Amadi *et al*., (2022) documented an almost identical temporal peak in neighbouring Nasarawa State. The policy implication is precise: vector control campaigns (IRS, larval source management) deployed in August–September, before peak vector density, would achieve maximum epidemiological impact. October-focused community mobilization targeting ITN use and dusk protection could further attenuate transmission at the peak.

The dose-response relationship between compound environmental risk score and malaria prevalence (Spearman r=0.244, p<0.0001) is one of the strongest and most reproducible environmental epidemiological signals in this dataset. The finding that prevalence more than doubled from low-exposure (≤1 factor: ~26%) to high-exposure (≥4 factors: ~58%) households provides compelling evidence for a multiplicative, cumulative environmental risk model, consistent with Cairns *et al*., (2023), who documented similar cumulative environmental gradients across multiple East African countries. The progression from low to high risk is non-linear, with the steepest increase occurring between scores 1 and 2 (25.5% to 40.9%), suggesting a threshold effect at which the presence of two or more simultaneous breeding sites creates a qualitative change in transmission risk.

The survival of abandoned containers as the sole significant independent predictor in the multivariate model (OR=1.616; p=0.038), after adjusting for all other environmental factors and outdoor exposure, deserves particular emphasis. This finding is corroborated by Adesanya *et al*., (2022) in Ibadan, who documented that households with multiple abandoned water-holding containers had 2.3 times higher Anopheles larval density, and by Oduola *et al*., (2020) in Oyo State. Abandoned containers are ubiquitous in Nigerian compound settings, easily modifiable through household education and community enforcement campaigns, and represent a high-impact, low-cost target for malaria vector control.

The failure of stagnant water, gutters, and bushes to maintain multivariate significance despite strong bivariate associations most plausibly reflects shared variance, these factors tend to co-occur in the same households, rather than true null effects, as evidenced by their persistence in the compound risk score analysis.Health education will need to be intensified to educate households on the need to remain indoors after sunset which was a significant factor during the study and to imbibe positive attitude to mosquito human contact prevention also government should do more on the housing need of the citizens as the prevalence of malaria was higher in households that lived in mud wall and thatched roof than those that inhabited cement wall and iron roof Several study limitations must be acknowledged. The facility-based design introduces health-seeking selection bias and restricts generalizability to the broader FCT population. Cross-sectional design precludes causal inference. Self-reported environmental data may be subject to recall bias. The absence of entomological data (vector density, entomological inoculation rate) limits mechanistic interpretation. The three-month study period, while covering the critical transmission season, does not capture the full annual malaria cycle. Future studies should conduct community-based surveys with population-representative sampling and integrate meteorological and satellite imagery data for predictive risk modelling.

## 5. CONCLUSION

This study demonstrates that malaria in the FCT is geographically concentrated, environmentally driven, and seasonally dynamic. Abaji and Kwali are confirmed high-transmission hotspots requiring priority intervention, while Gwagwalada illustrates that better health system access may moderate malaria burden in comparable ecological settings. For household environmental factors children exposed outdoors at sunset had a malaria prevalence of 42.8%, compared to 28.4% among those who stayed indoors, indicating a difference of 14.4 percentage points.

The dose-response relationship between cumulative peridomestic environmental exposure and malaria prevalence, with abandoned containers as the key independent environmental predictor, positions household-level environmental sanitation, particularly container elimination, as a high-priority, evidence-based intervention target. The October transmission peak calls for pre-season vector control campaigns, and ward-level geospatial risk stratification should underpin malaria resource allocation in the FCT. These findings contribute an urgently needed geospatial evidence base to support the FCT's pathway towards malaria burden reduction.

## DECLARATIONS

**Ethics Approval and Consent to Participate:** Ethical approval was obtained from the FCT Health Research Ethics Committee. Written informed consent was obtained from all participating caregivers.

**Availability of Data:** The datasets analysed during this study are available from the corresponding author on reasonable request.

**Competing Interests:** The authors declare that they have no competing interests.

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