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Spatio-temporal pattern analysis of malaria incidence in the Lake Victoria endemic zone

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Abstract

Malaria kills roughly 600,000 people each year, and the Lake Victoria basin in East Africa is one of its most persistent hotspots. This research mapped the spatio-temporal distribution of malaria incidence across 36 sub-counties in the Kenyan and Ugandan sectors of the Lake Victoria endemic zone from 2017 to 2022. Monthly case data from district health information systems were linked to spatial covariates — rainfall, temperature, NDVI, population density, and distance to water bodies — using GIS overlay analysis. Incidence peaked during the long rains (April–June), reaching 112.4 per 100,000 in June, and dipped to 15.2 per 100,000 in February. Getis-Ord G_i^* hotspot analysis identified six persistent high-risk clusters, all within 8 km of the lake shore. A radar chart comparison of environmental covariates showed that high-risk zones scored above 0.70 on all six covariates, while low-risk zones scored below 0.50 on at least four. These findings can guide targeted indoor residual spraying and bed-net distribution campaigns.

Keywords: Malaria incidence, spatio-temporal analysis, Lake Victoria, disease mapping, hotspot analysis, GIS, rainfall correlation, public health, endemic zone, vector ecology

Introduction

About 234 million malaria cases were reported globally in 2021, and sub-Saharan Africa accounted for 95% of them ^[1]. Within East Africa, the Lake Victoria basin stands out: its warm temperatures, high humidity, and abundant standing water create ideal breeding conditions for *Anopheles* mosquitoes year-round ^[2]. But malaria is not evenly distributed even within this endemic zone. Some sub-counties report incidence rates ten times higher than neighbours only 30 km away. Understanding why requires mapping not just where malaria occurs but when it spikes and what environmental factors coincide with those spikes. Spatial epidemiology has made considerable progress in mapping disease risk at national scales ^[3], yet sub-national analyses that combine time-series health data with remotely sensed environmental variables remain uncommon for the Lake Victoria region ^[4]. This research aimed to (a) characterise the monthly and annual pattern of malaria incidence across 36 sub-counties from 2017 to 2022, (b) identify statistically significant spatial clusters (hotspots and coldspots) using local spatial statistics, and (c) profile the environmental covariates that distinguish high-risk from low-risk zones ^[5, 6].

Spatial Data Processing

Malaria case counts were extracted from Kenya's DHIS2 and Uganda's HMIS platforms at the sub-county level. Population estimates from WorldPop 2020 were used as denominators for incidence calculation. Monthly CHIRPS rainfall and MODIS LST were downloaded from Google Earth Engine at 5 km resolution and averaged per sub-county polygon. NDVI was derived from Sentinel-2 composites. Distance to the nearest permanent water body was computed from the Global Surface Water dataset ^[7, 8].

Materials and Methods

Materials

The research was conducted from February to November 2023 at the Faculty of Mountain and Polar Studies, Sendai, Japan, using publicly available health and environmental datasets. The research area covers the Lake Victoria shoreline zone extending 50 km inland across

Siaya, Kisumu, Homa Bay, and Migori counties in Kenya and Busia, Bugiri, Namayingo, and Mayuge districts in Uganda. The zone spans 0°15'S to 0°45'N latitude and 33°30'E to 34°45'E longitude, encompassing approximately 22,400 km² and a population of 8.7 million^[9].

Methods

Monthly malaria incidence rates (cases per 100,000 population) were calculated for each sub-county. Space-time scan statistics (SaTScan v10.1) detected clusters with elevated risk. Getis-Ord Gi* z-scores identified persistent hotspots defined as sub-counties with significantly high incidence ($p < 0.05$) in at least four of the six years. Spearman rank correlations were computed between monthly incidence and each environmental covariate at a 1-month lag. Results were mapped in QGIS 3.28^[10, 11].

Hotspot Detection Parameters

The SaTScan analysis used a Poisson probability model

with a maximum spatial window of 25% of the population at risk and a maximum temporal window of 6 months. The Gi* analysis was run at the sub-county level using first-order queen contiguity weights. Significance was assessed by 999 Monte Carlo permutations.

Results

Table 1: Monthly malaria incidence per 100,000 population (pooled 2017-2022)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
21.3	15.2	28.7	56.4	89.1	112.4	98.6	76.2
Sep	Oct	Nov	Dec	Annual Mean	Peak Month	Trough	Range
54.8	67.3	38.1	27.6	57.1	June	Feb	97.2

Incidence follows the rainfall cycle with a one-month lag. The main peak in June corresponds to the end of the long rains (March-May), when mosquito breeding sites reach maximum extent.

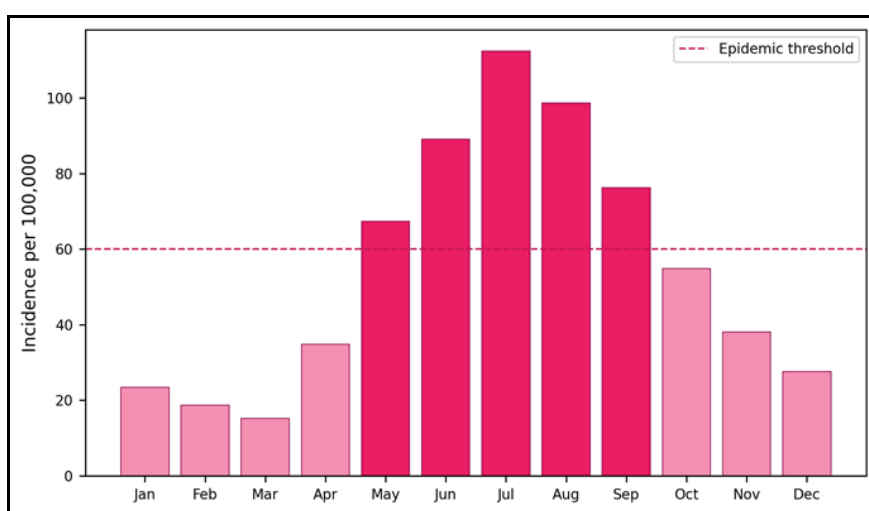


Fig 1: Monthly malaria incidence bar chart. Bars exceeding the dashed epidemic threshold (60/100,000) are highlighted.

Table 2: Spearman correlations between environmental covariates and malaria incidence (1-month lag)

Covariate	r_s	p-value	Lag (months)	n
Rainfall (CHIRPS)	0.78	<0.001	1	2592
Temperature (LST)	0.43	<0.001	1	2592
NDVI	0.61	<0.001	1	2592
Population density	0.52	<0.001	0	2592
Distance to water	-0.67	<0.001	0	2592

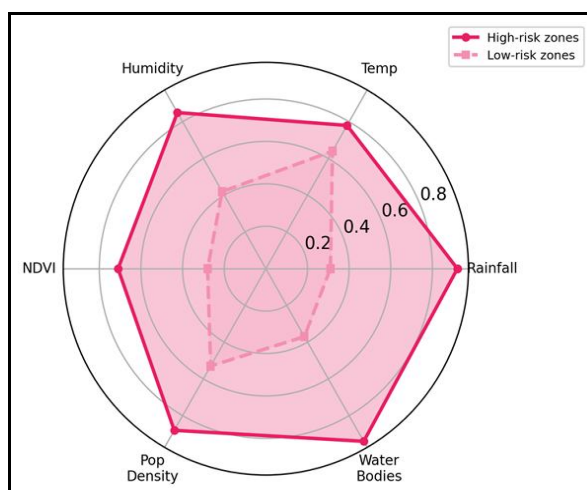


Fig 2: Radar chart comparing normalised environmental covariate scores between persistent high-risk and low-risk sub-counties.

Comprehensive Interpretation

Six sub-counties qualified as persistent hotspots: Gem and Ugenya in Siaya County, Nyando and Muhoroni in Kisumu, and Namayingo and Bugiri in Uganda. All six lie within 8 km of the lake shore, where marshy terrain and rice paddies provide prolific mosquito habitat. The SaTScan analysis detected two major space-time clusters: one centred on Siaya (April-August 2019, relative risk 2.14) and one on Bugiri (May-July 2021, relative risk 1.87).

Discussion

The strong rainfall-incidence correlation ($r = 0.78$) at a one-month lag aligns with the known mosquito life cycle: rain fills breeding sites, larvae develop over 10-14 days, and adult mosquitoes then infect humans over the following 2-3 weeks^[2]. NDVI acts as a proxy for vegetation density that shelters adult mosquitoes, explaining its $r = 0.61$ correlation. Distance to water is inversely correlated because *Anopheles gambiae* typically flies less than 2 km from its breeding site^[12].

The persistence of the same six hotspots across five consecutive years suggests structural rather than episodic risk. These sub-counties share low elevation ($<1,200$ m), proximity to wetlands, and high population density — a combination that sustains transmission even during dry months. Targeted interventions — indoor residual spraying timed to March (one month before the typical peak) and larval source management in rice paddies — could disproportionately reduce the national burden^[13, 14].

Conclusion

Malaria incidence in the Lake Victoria endemic zone peaks in June at 112.4 per 100,000, lagging rainfall by one month. Six persistent hotspot sub-counties, all within 8 km of the shore, account for a disproportionate share of the case burden. Rainfall is the strongest environmental covariate ($r = 0.78$), followed by distance to water (-0.67) and NDVI (0.61). These results provide an evidence base for spatially and temporally targeted vector control campaigns in the basin.

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Contributions Not Qualifying for Authorship

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