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Spatio-Temporal Analysis of Malaria Prevalence in the Cocody-Bingerville Health District and Optimization of Control Strategies: Case of First-Contact Health Facilities from 2014 to 2019 (Abidjan, Southern Côte d'Ivoire)

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Abstract

Malaria remains a major public health problem of great concern to the international community. According to the 2021 Annual Report on the Health Situation, the incidence of malaria in the cocody-bingerville health district is the highest (126%) in the Abidjan 2 health region, reflecting a high transmission dynamic. This situation makes it an area deserving special attention from health authorities. This study assessed malaria prevalence in first-contact health facilities (ESPC) between 2014 and 2019. The objective was to analyze the spatio-temporal dynamics of malaria prevalence in ESPCs and identify those most vulnerable to malaria in order to prioritize interventions. The results show that 3.70% of health centers recorded low prevalence, 68.52% moderate prevalence, and 27.78% high prevalence over the 2014-2019 period. The malaria situation remains worrying throughout the Cocody-Bingerville health district. Only the CSU-DM Public Colombie of Cocody-Bingerville and Cocody M'Pouto recorded low prevalence (<100‰) in 2015 and 2016. Moderate prevalence dominates over the 2014-2019 period across the cocody-bingerville health district, with rates between 100‰ and 350‰.

Keywords

Spatio-Temporal Dynamics, Spatial Statistics, GIS, Malaria, Cocody-Bingerville, Côte d'Ivoire

1. Introduction

Malaria remains a major public health problem, particularly in sub-Saharan Africa where the burden of morbidity and mortality associated with this disease remains high (OMS, 2021, 2023). The threat posed by malaria, a vector-borne disease, and its associated consequences increasingly drive public health specialists to develop and employ new control methods. Certain indicators such as prevalence provide a measure of the malaria situation in a given region at a specific point in time. In health planning, authorities therefore require decision-support tools that enable them to simultaneously consider temporal and spatial dimensions and take appropriate action. As Zanin (2006) observed, even if a map is worth more than a lengthy discourse, it is also a highly effective means of expressing phenomena that would be difficult or impossible to convey otherwise. Iyangui (2014) echoes this view, arguing that knowledge of and monitoring of the spatial distribution of public health data have become essential for planning malaria control interventions.

In Côte d'Ivoire, malaria is the leading cause of outpatient consultations and hospital admissions, accounting for approximately 40% of health care visits (PNLP, 2018).

In the Cocody-Bingerville health district, located in the southern part of the country, malaria transmission is persistent, influenced by climatic, environmental, and socio-economic factors (Adou et al., 2019). Primarily mosquitoes of the genus *Anopheles*, notably *An. gambiae* and *An. funestus*, drive transmission. The predominant pathogen is Plasmodium falciparum, responsible for the majority of clinical cases and severe forms of the disease. Other *Plasmodium* species (*P. malariae*, *P. ovale*) are rare, while *P. vivax* is virtually absent from this region (PNLP, 2020; Loukou et al., 2024).

A spatio-temporal analysis of malaria prevalence in this area would improve understanding of epidemiological dynamics and help identify high-risk zones. Such approaches have already demonstrated their utility in optimizing malaria control strategies elsewhere in Africa (Gaudart et al., 2006; Manguin et al., 2010). However, few studies have focused on first-contact health facilities, which are nonetheless essential for early detection and case management.

This study aims to analyze the spatio-temporal evolution of malaria prevalence in the Cocody-Bingerville district between 2014 and 2019, using data from primary health care centers. The objective is to highlight epidemiological dynamics and identify high-risk areas in order to provide health authorities with decision-support tools for more effective prioritization of interventions and more rational allocation of resources.

2. Materiels et Methods

2.1. Study Area

The study was conducted in October 2020 in the Cocody-Bingerville health district, located between 5˚27'36" and 5˚17'55" North latitude and 3˚57'19" and 3˚42'58" West longitude (Figure 1). The district encompasses the municipality of Cocody and the sub-prefecture of Bingerville. It is bordered to the north and northeast by the Anyama and Alepé health districts, to the southeast by Grand Bassam, to the west by the Abobo-Est and Adjamé-Plateau-Attécoubé health districts, and to the south by the Treichville-Marcory and Koumassi-Port-Bouët-Vridi health districts. It has an extensive lagoon frontage and covers an area of 429.75 km^2.

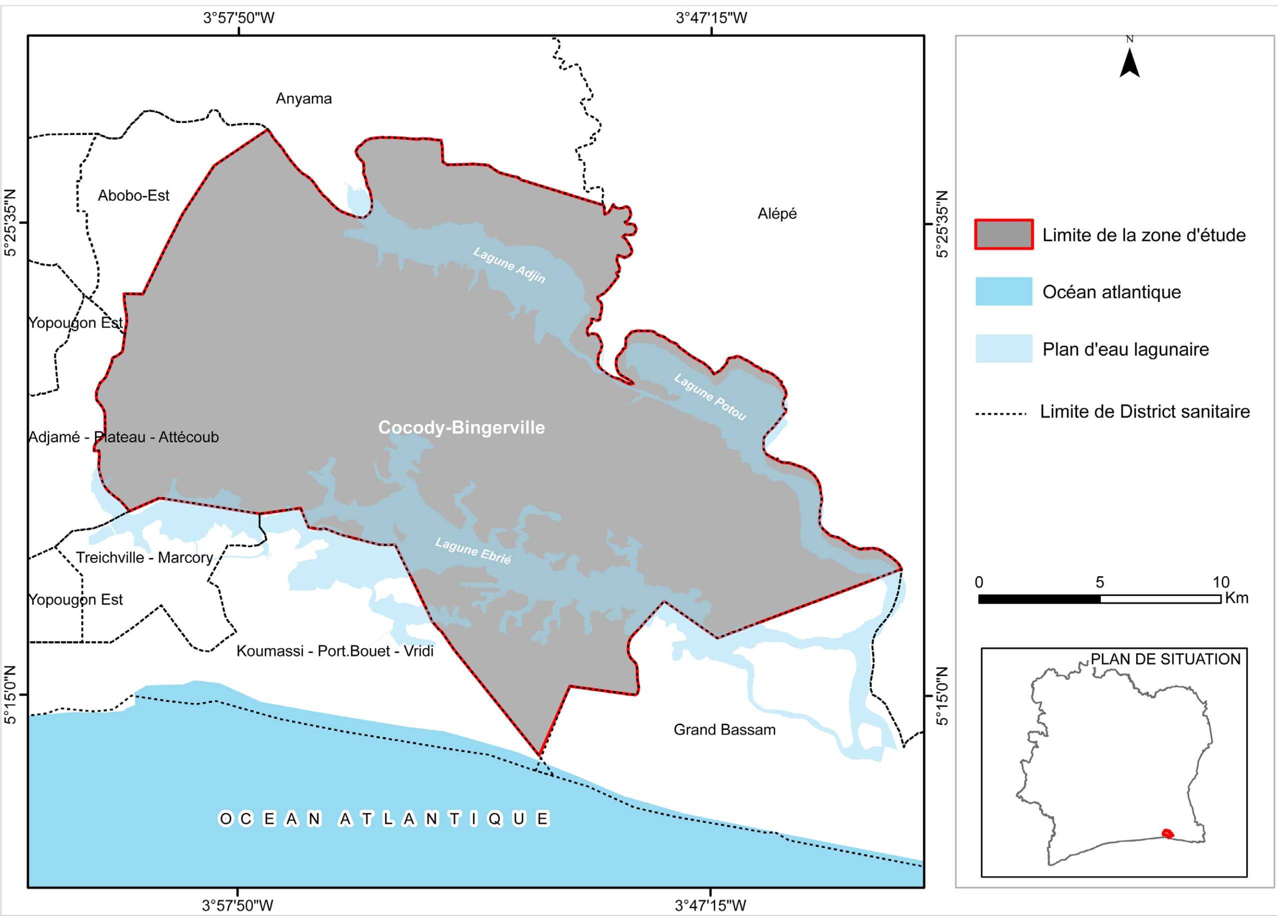

Figure 1. Location map of the study area.

The population of the Cocody-Bingerville health district increased from 308,097 in 1998 to 897,239 in 2021 (INS, 2022). The climate is that of the northern littoral zone of the Gulf of Guinea—a transitional equatorial climate characterized by high humidity and inter-annual rainfall exceeding 1500 mm. The hydrographic network is dense, with the district bordered by the Ebrié, Adjin, and Potou lagoons. Three catchment basins (Agnéby, Comoé, Mé) and several small rivers (Anguédédou, Gougbo, Banco) feed the Ebrié Lagoon. The topography consists of plains and low plateaus with a relatively dense drainage network.

The vegetation is characterized by a variety of plant landscape types, including dense, semi-deciduous, and ombrophilous forests degraded by anthropogenic activities, pre-lagoonal savannahs, mangroves, and swamp forests

2.2. Data Sources

The data used comprised two main components. First, a base map at a scale of 1:150,000 for the cities of Cocody and Bingerville, acquired from OCHA in March 2012, was geo-referenced in the WGS 84 geodetic reference system and projected in UTM Zone 30N. Second, annual malaria prevalence data from 2014 to 2019 were obtained from the Ministry of Health through the Directorate of Epidemiological Information and Planning. These data relate exclusively to first-contact health facilities, namely Urban Health Centers (CSU), Rural Health Centers (CSR), and Urban Health Training Units (FSU).

A total of 18 first-contact health facilities were included in the study: 11 CSUs, 5 CSRs, and 2 FSUs. These structures are where the majority of patients seek care first and therefore maintain more complete and representative registers of recorded cases. They directly reflect the health reality of local populations, as they represent the primary points of malaria diagnosis and treatment. Prevalence data are annual and are derived from the registers of these health facilities.

3. Methodology

3.1. Malaria Prevalence Mapping

As part of this study, prevalence calculations were carried out using Excel, in accordance with Equation (1) below. The numerator corresponds to the number of positive cases observed, that is, the population that tested positive for malaria in a given health area at time t. The denominator represents the population at risk, meaning all individuals exposed to malaria in the same health area and during the same period t:

$$\text{Prevalence} = \frac{N \text{ Number of cases observed during period } t}{\text{Population at risk during that period}} * 100 \quad (1)$$

The time period t was evaluated annually over the 2014-2019 study period. Data files were imported into a geodatabase using ArcGIS geographic information system software to enable spatial join with the database of first-contact health facilities in the study area. Following this join, geoprocessing operations were performed to produce the health maps required for analysis. Statistical evaluation of the spatial distribution of prevalence data was conducted using the Spatial Autocorrelation geostatistical tool, based on the Nearest Neighbor Ratio (NNR) index. This index determines whether the observed spatio-temporal variability is random, dispersed, or aggregated: a value less than 1 indicates aggregation, while a value greater than 1 indicates a tendency toward dispersion.

In order to optimize the spatio-temporal analysis, cartographic representation rules were applied, including the use of proportional circles and pie charts. The classification of prevalence levels was based on WHO (2019) reference guidelines, distinguishing three categories: low prevalence (<100‰), moderate prevalence (100‰ - 350‰), and high prevalence (≥350‰). A specific field was created in ArcGIS to automatically calculate the mean prevalence per health center over the study period, enabling the mapping of average prevalence. According to WHO criteria, a high-transmission area is characterized by a Plasmodium falciparum prevalence of ≥35‰ with an annual parasite index of approximately 450 per 1000 inhabitants, while a moderate-transmission area corresponds to a prevalence between 10‰ and 35‰ with an annual parasite index of 250 - 450 per 1000 inhabitants (**Figure 2**).

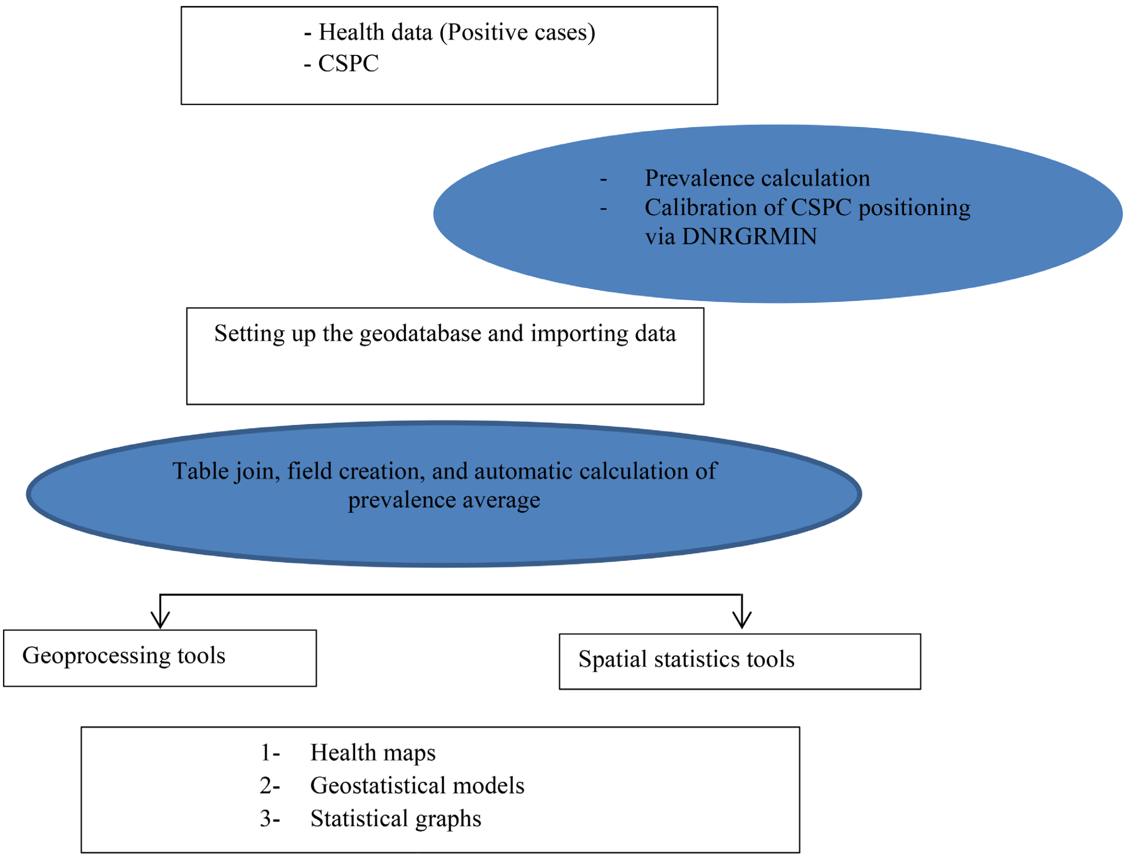

Figure 2. Methodology flowchart for the elaboration of prevalence map data.

3.2. Data Analysis Tools

ArcGIS software (version 10.2.1) was used for database design, geoprocessing operations, production of health and spatial statistics maps, and overall spatial analysis. DNRGARMIN software was used to calibrate the geographic coordinates of the health centers. Microsoft Excel was used to generate charts. Prevalence was calculated as the proportion of observed cases of a disease during a given time period t relative to the population from which the cases were drawn at that period. Prevalence was reported relative to the population of a health area, defined as a geographically delimited entity comprising a set of villages in rural settings and/or streets in urban settings, based on socio-demographic affinity criteria, with a generally served population of approximately 1000 inhabitants.

4. Results

4.1. Spatio-Temporal Analysis of Malaria Prevalence (2014-2019)

Figure 3 presents a descriptive statistical analysis of the spatio-temporal heterogeneity of malaria prevalence in the Cocody-Bingerville health district between 2014 and 2019.

In 2014, 16 out of 18 first-contact health facilities (ESPCs) (88.88%), including the CSU-DM Public Colombie of Cocody-Bingerville, Cocody M'Pouto, and the FSU Communautaire Nimatoulahi of Cocody, recorded moderate prevalence. Two ESPCs (11.12%) namely the CSR-D Public Village Marchoux of Gnakan Nassy and the CSR-DM Public of Abatta recorded high prevalence. No low-prevalence cases were observed.

In 2015, 2 ESPCs (11.12%) including the CSU-DM Public Colombie of Cocody-Bingerville and Cocody M'Pouto—recorded low prevalence. Ten ESPCs (55.55%), including the CSR-DM Public of Elokaté and the CSU-DM Communautaire of Cocody Angré, recorded moderate prevalence. Six ESPCs (33.33%), including the CSU-DM Public Génie 2000 of Cocody-Bingerville and the CSR-DM Public of Abatta, recorded high prevalence.

In 2016, 2 ESPCs (11.12%) the same as in 2015 recorded low prevalence. Twelve ESPCs (66.66%), including the CSR-DM Public of Akoue-Agban and the CSU-D Public of Cocody Nord, recorded moderate prevalence. Four ESPCs (22.22%), including the CSR-D Public Village Marchoux of Gnakan Nassy, recorded high prevalence.

In 2017, 11 ESPCs (61.11%) recorded moderate prevalence. Seven ESPCs (38.89%), including the CSR-DM Public of Adjin and the CSU COM Akouédo, recorded high prevalence. No low-prevalence facility was observed.

The overall synthesis for the period 2014-2019 revealed marked heterogeneity in the distribution of prevalence levels: 3.70% of ESPCs recorded low prevalence, 68.52% moderate prevalence, and 27.78% high prevalence. The CSU-DM Public Colombie of Cocody-Bingerville and Cocody M'Pouto were the only facilities to record low prevalence (<100‰), and this only in 2015 and 2016. Moderate prevalence (100‰ - 350‰) dominated throughout the study period. However, four ESPCs the CSR-DM Public of Abatta, the CSR-D Public Village Marchoux of Gnakan Nassy, the CSU Com Akouédo Attié, and the CSR-DM Public of Adjin maintained persistently high prevalence from 2015 to 2019, requiring special attention.

4.2. Overall Prevalence Trends (2014-2019)

Figure 4 highlights two distinct trends in the distribution of malaria prevalence.

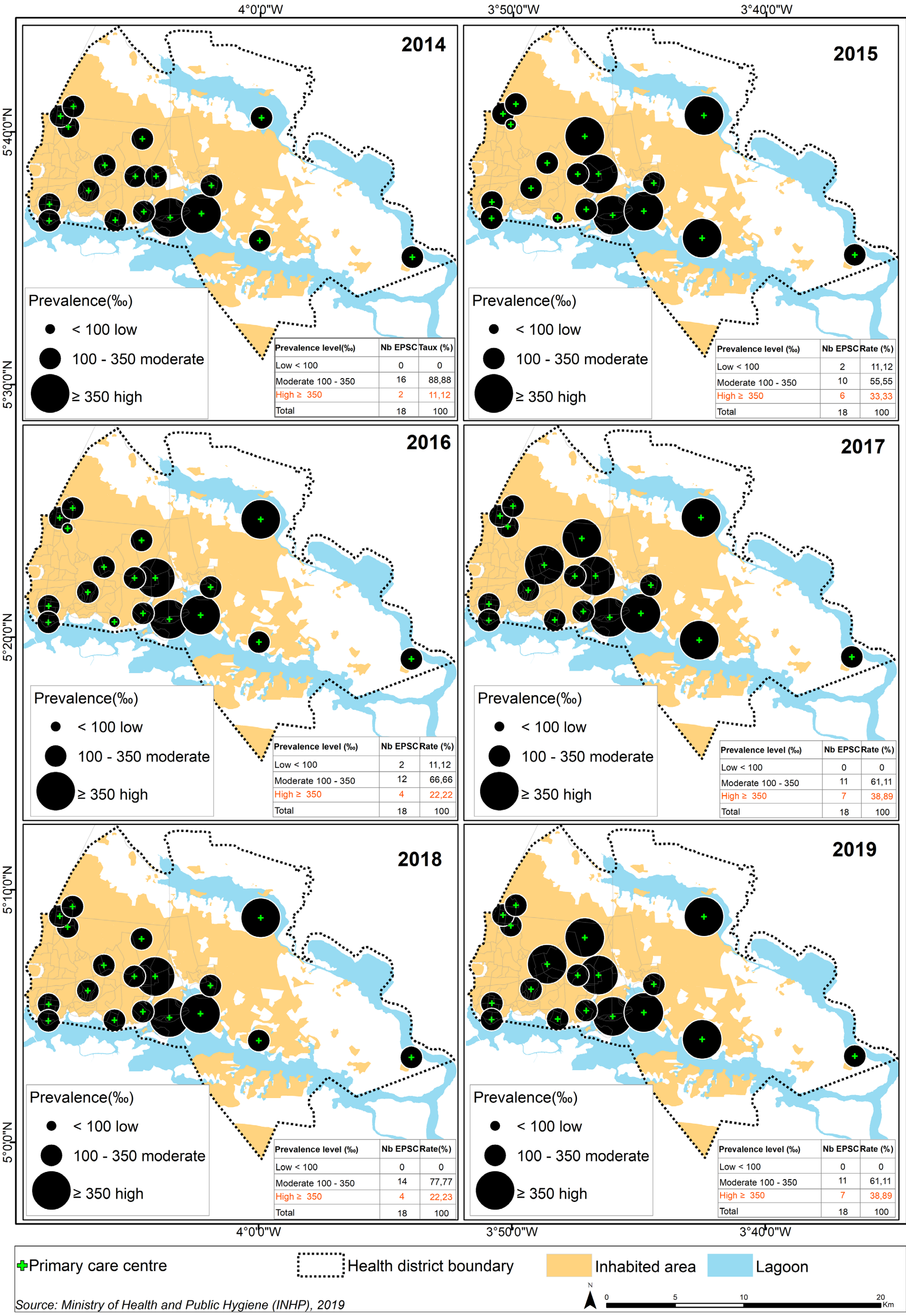

Figure 3. Spatio-temporal evolution of malaria prevalence in ESPCs from 2014 to 2019.

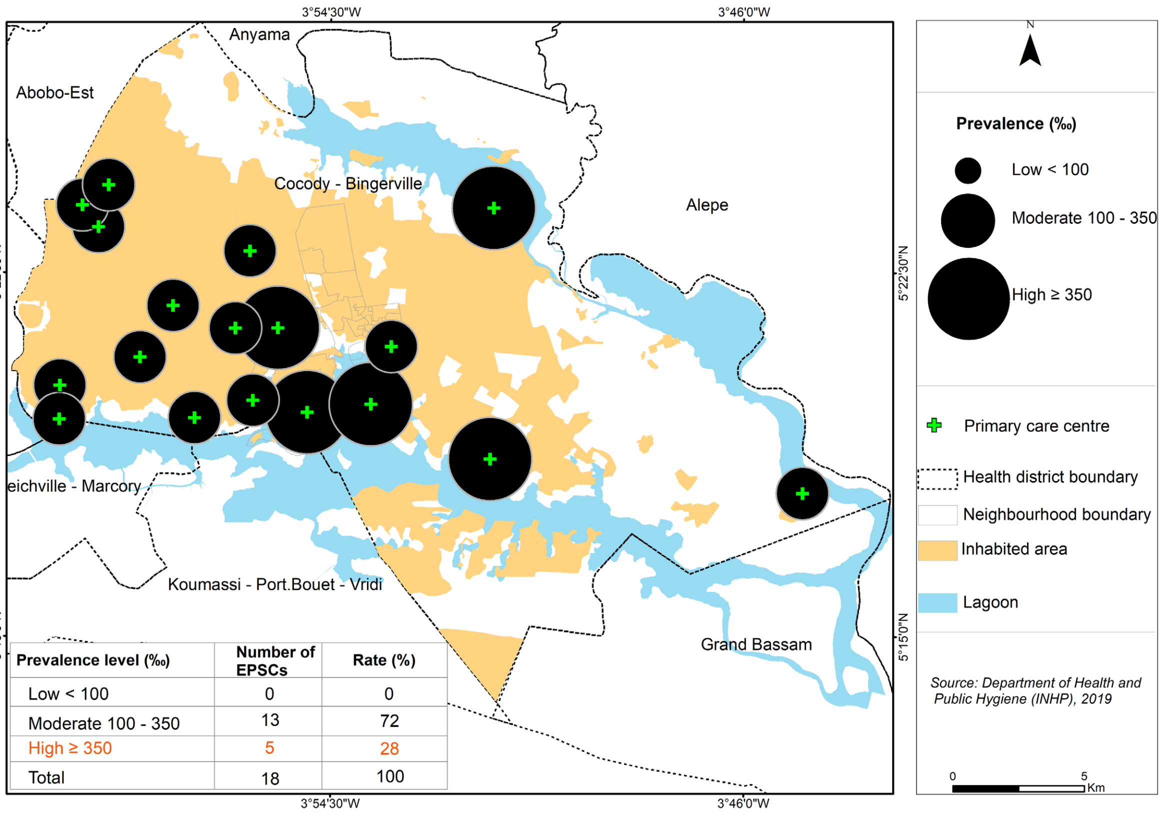

Figure 4. Overall malaria prevalence over the 2014-2019 period.

A first trend, characterized by moderate prevalence (100‰-350‰), was observed in the following health facilities: CSU-DM Public Colombie of Cocody-Bingerville, CSU-DM Public of Cocody M'Pouto, CSU-DM Public Génie 2000, FSU Communautaire Nimatoulahi of Cocody, CSU-D Public of Cocody M'Badon and Cocody Nord, CSR-DM Public of Elokaté, CSU-DM Communautaire of Cocody-Angré, Cocody-Palméraie, and Cocody-Anono, and FSU Communautaire of Cocody-Angré Blockauss.

A second trend, marked by high prevalence (≥350‰), was identified in five ESPCs: CSR-DM Public of Akoue-Agban, CSR-DM Public of Adjin, CSU Com Akouédo Attié, CSR-DM Public of Abatta, and CSR-D Public Village Marchoux of Gnakan Nassy.

Furthermore, Figure 5 reveals an upward trend in malaria prevalence over the 2014-2019 period, with a notable increase from 109‰ to 625‰. This progression confirms a worsening of malaria transmission over the six-year study period.

4.3. Geostatistical Analysis of Malaria Prevalence

The Nearest Neighbor Ratio (NNR) constitutes a relevant statistical tool for assessing the spatial structure of public health phenomena. In this study, its application enables determination of whether the distribution of health facilities presenting different malaria prevalence levels is random or follows a pattern of aggregation or dispersion. This spatial test specifically highlights the clustering of

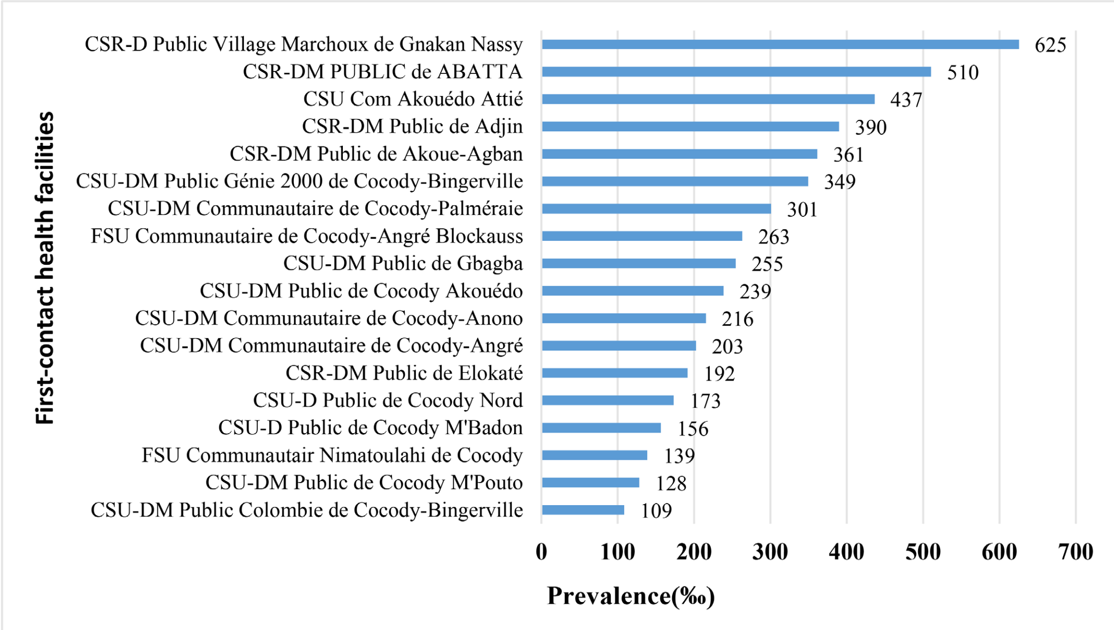

Figure 5. Trend diagram of overall malaria prevalence from 2014 to 2019.

health facility locations—and more specifically those with high prevalence—rather than an analysis of individual malaria cases.

When the p-value is less than 0.05, as observed in this study ($p = 0.000004 < 0.05$), the hypothesis of random distribution is rejected and a significant spatial structure is concluded. This indicates that the spatial concentration of high-prevalence facilities is not due to chance, but rather reflects the influence of environmental and socio-economic factors. The NNR thus demonstrates that malaria prevalence follows a non-random spatial organization, justifying the need for targeted interventions in the identified clustered areas (Figure 6, Table 1).

5. Discussion

5.1. Spatio-Temporal Analysis of Malaria Prevalence (2014-2019)

The results of the spatio-temporal analysis of malaria prevalence in the Cocody-Bingerville health district between 2014 and 2019 revealed marked heterogeneity, with a dominance of moderate (68.52%) and high (27.78%) prevalence. These observations are consistent with trends reported in other regions of sub-Saharan Africa, where malaria remains endemic due to environmental and socio-economic factors favoring *Plasmodium* transmission (OMS, 2023).

The dominance of moderate prevalence (68.52% of ESPCs) and the persistence of high-prevalence foci (27.78% of ESPCs) suggest unequal disease transmission, likely influenced by local factors such as access to healthcare, environmental conditions, and preventive behaviors (Ouedraogo et al., 2018). The absence of low-prevalence facilities in 2014 and 2017, contrasting with their appearance in 2015 and 2016, may reflect seasonal variations or targeted interventions such as

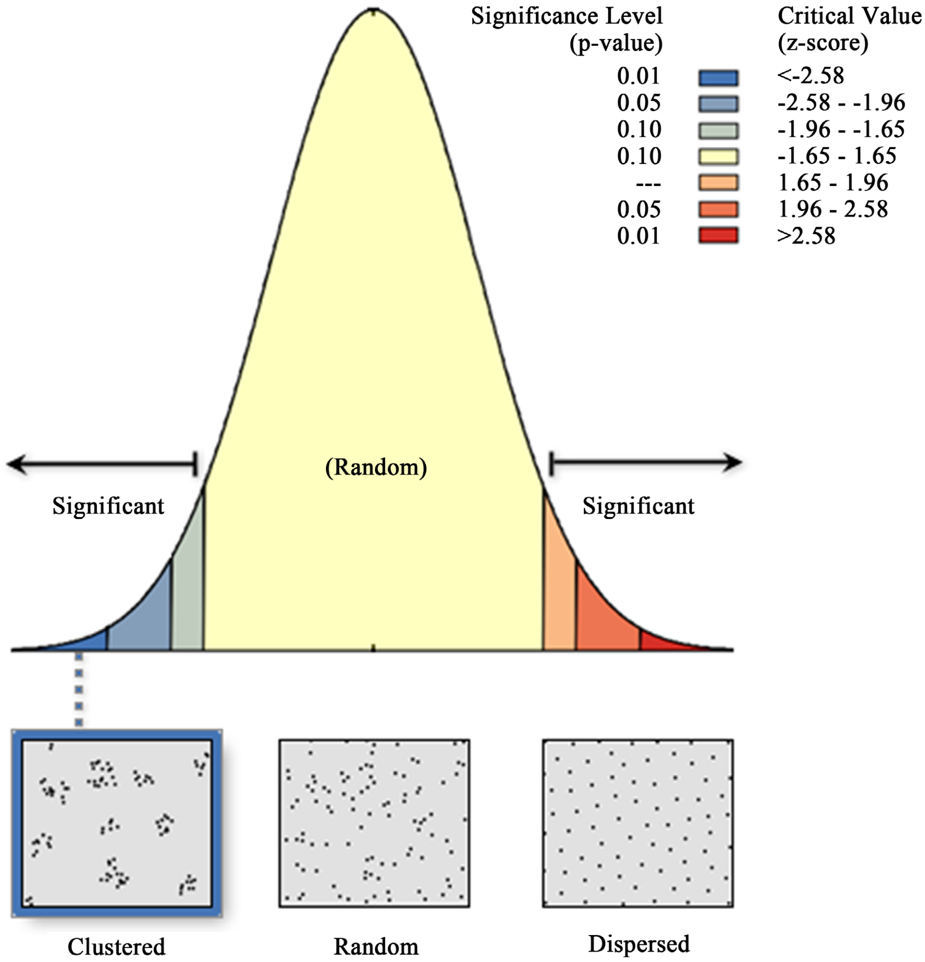

Figure 6. Spatial autocorrelation test average nearest neighbor summary.

Table 1. Nearest neighbor ratio (NNR) results.

Statistical Indicator	Value
Nearest Neighbor Ratio (NNR)	0.474173
Z-score	−4.609818
p-value	0.000004

insecticide-treated net distribution campaigns (Bhatt et al., 2015). targeted interventions such as insecticide-treated net distribution campaigns (Bhatt et al., 2015). The four ESPCs that maintained persistently high prevalence (Abatta, Gnakan Nassy, Akouédo Attié, Adjin) require urgent attention, as they may represent areas of persistent transmission driven by unfavorable socio-economic or environmental conditions (Tusting et al., 2013).

5.2. Overall Prevalence Trends

Figure 4 highlights two distinct trends: a dominant moderate prevalence and a high prevalence localized in five ESPCs. The overall increase in prevalence from

109‰ to 625‰ between 2014 and 2019 (**Figure 5**) is alarming. This polarization may be explained by geographic disparities in vector exposure, or by the combined effects of environmental (urbanization, climate), biological (vector and parasite resistance), and socio-economic factors, as observed in other urban settings in sub-Saharan Africa (Diboulo et al., 2016; Ranson & Lissenden, 2016).

This upward trend underscores the urgency of strengthening control strategies, particularly through integrated approaches combining vector control and community education (OMS, 2021).

5.3. Geostatistical Analysis and Spatial Autocorrelation

The NNR index (0.474) and Z-score (−4.61) confirm an aggregated distribution of malaria cases, indicating the presence of transmission hotspots. These results corroborate recent studies identifying malaria clusters associated with environmental factors such as proximity to stagnant water bodies or dense vegetation (Manguin et al., 2010). The highly significant p-value (0.000004) reinforces the relevance of these clusters and justifies targeted interventions in these areas. A geospatial approach to identify and monitor these hotspots could optimize resource allocation, as proposed by the "risk stratification" methodology (Garske et al., 2013).

This study illuminates the complex spatio-temporal dynamics of malaria in Cocody-Bingerville, marked by local disparities and a worsening trend. Environmental, socio-economic, and behavioral factors likely play a key role in this heterogeneity. For effective interventions, it is essential to combine hotspot-targeted strategies with broader public health policies, building on updated geostatistical data and multidisciplinary partnerships (Hay et al., 2013).

6. Study Limitations

This study has several limitations that should be taken into consideration. First, it relies solely on data from first-contact health facilities, which may reduce the representativeness of findings by excluding hospital and private health structures. Second, the analysis focused on prevalence without directly integrating intervention variables or socio-behavioral factors, thereby limiting the ability to evaluate the effectiveness of control strategies. Third, data quality depends on health facility registers, which may contain biases related to under-reporting or data entry errors. Additionally, self-medication—a widespread practice in the context of malaria in Côte d'Ivoire—represents an important but difficult-to-measure factor: many cases may not be recorded in health facilities, leading to an underestimation of true prevalence. Finally, the study period (2014-2019) does not allow for capturing more recent developments, particularly those linked to climate change or new public health policies.

7. Conclusion

Malaria remains a major public health challenge in the Cocody-Bingerville health district, where transmission is persistent and influenced by climatic, environmental, and socio-economic factors. The spatio-temporal analysis conducted over the 2014-2019 period using data from first-contact health facilities revealed marked heterogeneity in the distribution of prevalence rates: 3.70% of facilities recorded low prevalence, 68.52% moderate prevalence, and 27.78% high prevalence. The overall upward trend observed underscores the need for risk area prioritization and health planning adapted to local specificities.

These results constitute a decision-support tool for health authorities to more effectively guide interventions and improve resource management in the fight against malaria. Future studies should integrate additional socio-environmental and behavioral variables, extend the analysis to a more recent time period, and incorporate data from hospital and private facilities, so as to provide a more comprehensive picture of the epidemiological situation in this health district.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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