

Contribution of Geographic Information Systems (GIS) in the Analysis of Parasitic Diseases: The Example of the Malaria in the City of Bouaké in Côte d'Ivoire

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Abstract

Malaria is the most widespread parasitic disease in the world and the most deadly parasitosis in tropical regions. Using a Geographic Information System integrating epidemiologic, entomologic, socio-demographic, cartographic, positioning Global Positioning System (GPS) data and information from satellite images, the objective of this study is to identify areas at risk of malaria transmission as well as their determinants.

Our results highlighted spaces at malaria risks and allowed to distinguish two major categories of larval lodges, humid shallows and paddy fields in Bouaké where the number of *Anopheles An. Gambiae* was significantly higher ($p < 0.001$). Moreover, it was also observed an absolute link between the level of parasitic load of the north-west and north-east neighborhoods and level of malaria prevalence ($p = 0.0275$).

Key words: Bouaké; Larval lodge; *Anopheles An. Gambiae*; Malaria; Geographic information system

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INTRODUCTION

Malaria is the most widespread parasitic disease in the world (Mouchet et al., 2004). It remains one of the

most frequent scourges and probably the most deadly parasitosis in tropical regions (Machault et al., 2009) despite the increase of financing and the coverage of programs to combat this disease. According to the World Health Organization (WHO, 2014), 350 to 500 million cases of malaria are recorded around the world with more than a million deaths. Children under five years of age are the most stricken strata with the disease. Malaria is the cause of 18% of children less than five years. Africa is by far the most concerned continent with more than 80% of death (UNICEF, 2004). Approximately 25% to 35% of clinical consultations, 20% to 45% of hospitalizations, and 15% to 35% of deaths in hospitals are due to this illness in sub-Saharan Africa (WHO, 2005).

In Côte d'Ivoire, malaria represents the first cause of morbidity and mortality. According to a situational analysis of epidemiological data of malaria carried out in 2010 by the National Malaria Control Program (NMCP), about 50% of consultations in health facilities of first contacts were related to malaria. Malaria is a major public health problem in Bouaké. On the basis of data of the Department of Information, Planning and Evaluation of the Ministry of Health (DIPE, 2012), the rate of prevalence of malaria in the neighborhoods of Bouaké was estimated to 65.15%. This rate is exceed the national rate (30%) and the rate of the cities in Côte d'Ivoire (40%) (PNLP, 2003).

Measures for the prevention of fight against malaria have been established by the Department of National Malaria Control Program of Bouaké. Those measures mainly consisted in campaigns to raise awareness of the mass and the distribution of insecticide-treated nets with long duration of action (MILDA). In 2012, a number of 1.063 MILDA have been distributed. In 2014, it is more than 19.789 MILDA that have been offered to pregnant women and children of less than one year (DIPE, 2014).

Furthermore, a budget line of more than two billion FCFA for the purchase of MILDA and a free care policy on all treatments benefits and prevention related to malaria in the public health facilities, have been put in place by the Ivorian health authorities to help the city of Bouaké to significantly reduce its rate of morbidity that remains the highest in the country.

In spite of these actions carried out on the territory of Bouaké, the rate of prevalence of malaria remains high. According to the DIPE in 2015, the prevalence rate was estimated at 70.01% against 65.15% in 2012. In the fight against malaria, several studies have shown that the mere distribution of mosquito nets and the use of persistent-acting insecticides spraying products (PID) to eliminate mosquitos remain insufficient means to reduce the morbidity and mortality rates because these means of protections protect only a low percentage of the population at risk (Carnevale, 1988; Mouchet, 2004; WHO, 2014).

The prevalence of malaria is the combination and interaction between of abiotic factors (environmental, climatic, ecological, meteorological and anthropogenic) and biotic factors (endemic vector species, sensitivity of the human population, resistance of pests to antimalarial drugs, resistance of vectors to insecticides) (Rogers et al., 2002; Machault et al., 2009). The implementation of an adequate strategy to fight malaria must take into account environmental factors (altitude, climate, landscape, rainfall, anthropogenic, etc.). In addition, the transmission of malaria is different from one region to another, from one village to another, and sometimes within the same village (Amat-Roze, 2004).

The outcomes of the epidemiological investigation in November 1998, carried out by a team of the National Institute of Public Health for the project "Water and Health" in Bouaké, showed that parasitic diseases do not affect the population the same way relative to the age, sex, and ethnic group of the individuals, but that the neighborhood is the main factor of differences in the prevalence of these diseases (Cot et al., 1995). The results of this epidemiological investigation made it possible to show that the peripheral neighborhoods of the city such as "Kotia", "Bobo" and "Broukro" (Figure 1) differed from central neighborhoods by displaying stronger prevalence.

A Geographic Information System (GIS) was required to organise and process data on the varied modes of organization of the neighborhoods, the health inequalities across neighborhoods and the environmental factors. Several studies in the literature have shown the importance of the GIS in the analysis of the organization or the dissemination of parasitic diseases (Barreto et al., 1993; Malone et al., 1997; Thomson et al., 1999; Jeanne, 1999; Machault et al., 2009). Those studies sought to

determine areas at risk and the factors associated with the epidemiological, entomological, socio-demographic, cartographic, Global Positioning System (GPS) data, and information stemming from satellite images after processing. Indeed, GIS has a great capacity to create new information, allowing to characterize and hierarchize spaces at risk in terms of diseases with vectorial and hydric contamination, and as well as social, biogeographic, environmental factors and above all their interactions which potentially expose a space to the risk of parasitic diseases (Daval, 2006). Using this common methodology, this study aims is to create a GIS to identify areas at risk of malaria transmission as well as their determinants while taking into account the context and the means of local structures.

The connection of information in the GIS results in the modeling of space at risk, located and identified in such a way that the efforts to control and intervention strategies are the most effective and targeted as possible in the city of Bouaké.

1. MATERIAL AND METHODS

1.1 Presentation of the Study Site

Bouaké is a medium sized city, located in the center of Côte d'Ivoire, in a forest-savanna transition zone at about 350 km from Abidjan, the economic capital city (Figure 1). The third economy of the country after Abidjan and San Pedro, Bouaké is located at the crossroads of the major road and rail axes, and at the edge of two large areas with complementary economies. This geographic situation renders the city a privileged place of exchange. Its growth is due to the trade of cola, cotton, cocoa, coffee, etc. and the establishment of a Gonfreville textile factory since 1921 (PNLP, 2003). These commercial and industrial activities play an important role in inhabitants' life as well as in the organization of the urban and peri-urban space.

In 2014, the city of Bouaké had 542.000 inhabitants (INS, 2014) divided on 72 km², with a population density of 8 inhabitants/km². Bouaké is located in a climatic transition zone that has four seasons (two rainy seasons and two dry seasons). The average annual rainfall oscillates between 1.000 and 2.000 mm (Dossou -Yovo et al., 1998).

The temperature varies little over the year, with averages between 28°C and 32°C. The annual relative humidity is between 75% and 90% (Affian, 2002).

Bouaké is a very undulated city with humid shoals arranged for gardening and rice cultivation (Dossou-Yovo et al., 1995). This action of man has created biotopes made of different vegetations, but above all, exposes the inhabitants who attend and use these spaces to potential risks of transmission of parasitic diseases.

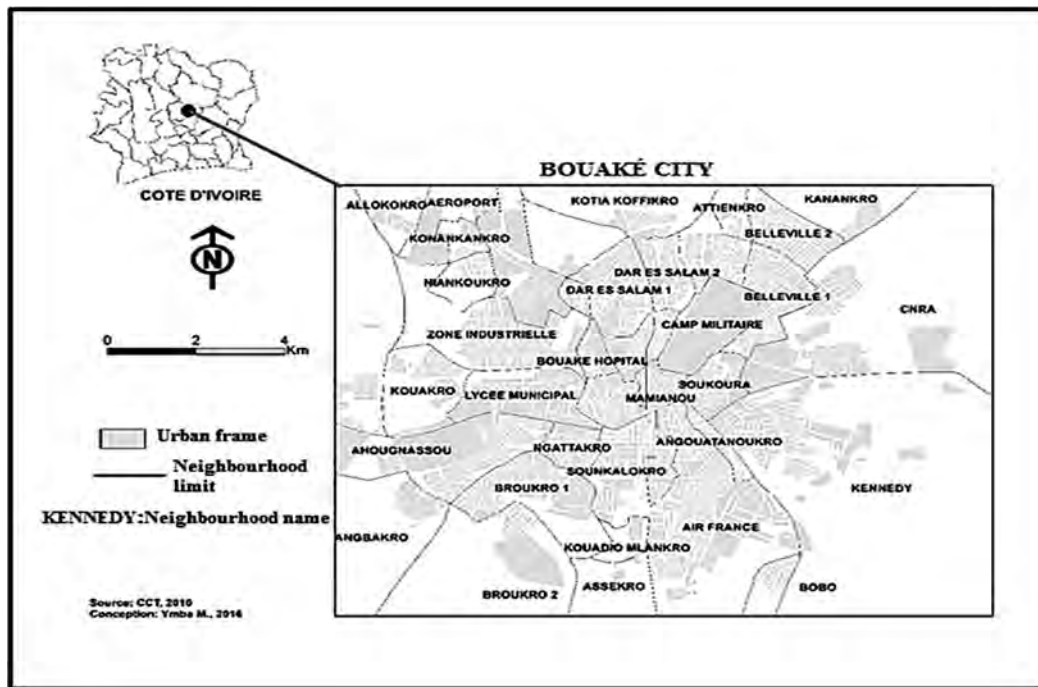


Figure 1
Presentation of the City of Bouaké in Côte d'Ivoire

1.2 Data

1.2.1 Acquisition of Available Epidemiological Data

Malaria prevalence data of malaria of the 41 neighborhoods of the city of Bouaké for 3.289 children of age 5 to 15 from 2.331 households have been obtained through exhaustive surveys conducted in June 2015 by the Department of National Malaria Control Program Bouaké in the context of the project “what strategy for fighting against malaria” funded by the government of Canada.

1.2.2 Acquisition of Entomological Data

The data used to estimate the population density of Anopheles in Bouaké come from the database of the Laboratory of Natural Science’s data bank of the University Nangui Abrogoua of Abobo-Adjamé in Abidjan.

In 2015, within the framework of the project “What strategy for fighting against malaria”, researchers conducted several missions to catch Anopheles, *An. gambiae*, vector of malaria contamination in most of the cities in West Africa (Dossou-Yovo et al., 1998). The captures took place during the dry season when the temperature is higher (January-February-March), the cold season (August-September), and the rainy season (June-July) in different urban areas.

In total, three capture methods have been used, they are: The residual fauna, that is, the morning harvest of resting Anopheles in the house through pyrethrin; the capture on humans inside or outside houses using the WHO’s standard methodology; with a rhythm of two consecutive days per month between 6 pm and 6 am by teams of three people.

The choice of the selection of capture points was made in a reasoned way according to the availability and agreement of the inhabitants in islets previously drawn in each neighborhood. Five points of capture were selected in the various neighborhoods of the city, namely 205 points of capture.

Using the key by Gilles and Demeillon (1968), the *An. gambiae* Anopheles could be identified among the population of mosquitos captured. The monthly average formed the unit of analysis of data.

1.2.3 Acquisition of Cartographic Data

Vegetation, topographic, geologic maps and maps of land cover and use at 1/150.000° covering the study areas have been provided by the Centre de Cartographie et de Télédétection (CCT, 2015) of the National office of Technical study and Development (BNETD, 2015).

1.2.4 Emplacement Data Collection

We geolocated (the geographic coordinates, latitude, and longitude) areas of study as well as the areas of census of the *An. gambiae* anopheles population in Bouaké using the Garmin GPS device. These ground based surveys took place from May to August 2015.

1.2.5 Satellite Data Acquired

The remote sensing images acquired on September 5th, 2015 stem from the images of the French satellite SPOT 5. We got these images of a part of Bouaké from the CCT. The main characteristics of the SPOT 5 images obtained are multispectral with 10 m of spatial resolution. The spectrum of the visible has the following values respectively: Band 1: green (0.50-0.59 µm), Band 2: Red (0.61-0.68 µm) and the Near Infrared Band 3: (0.78-0.89 µm).

1.2.6 Sociodemographic Data Acquired and Selected

We acquired data on the number of inhabitants per neighborhood and the populations' main activities from the Statistics National Institute of Côte d'Ivoire (INS, 2014). In addition, the information about the number and type of health facilities have been collected from the annual reports of health statistics Department of Côte d'Ivoire (DIPE, 2015).

Surveys by interview with the household heads enabled us to get more accurate information on the individuals' main activities related to water, the type of agricultural practices, the incomes, the level of education, etc. The household heads were asked about the distance run through and the time distance necessary to access health care services. These data have been collected in June 2015 during the field missions.

1.3 Methods of Data Processing

1.3.1 Processing of Satellite Images

We calculated the Normalized Difference Vegetation Index (NDVI) using the SPOT satellite images of 10 m spatial resolution. It is the most commonly used index to study the epidemiology of malaria (Machault et al. 2009). The NDVI captures in only one index the combined effects of temperature, humidity, rainfall, sunshine, altitude, type and use of soils.

The formula used to calculate the NDVI is the following: $NDVI = (PIR - R) / (PIR + R)$

The values of NDVI is between -1 and +1. Each 10 m pixel contains a NDVI value.

The calculation of the NDVI has allowed the spatial mapping of the risk of malaria by the identification of environments conducive to the presence of larval shelters. The software idrisi, version 5 was used to process the images.

1.3.2 Construction of a Geographic Information System (GIS)

A Geographic Information System (GIS) of malaria has been built in order to spatially identify the areas at risk, and study their potential determinants in order to establish a predictive model of prevalence.

The GIS permitted to jointly analyze the paddy fields surfaces and their altitude with entomological, epidemiological, cartographic, Global Positioning System (GPS) data, the satellite and socio-demographic images in the perspective of modeling the malarial risk in the living space of Bouaké.

The GIS has been built using ArcGIS 10.2.1 and the digitized maps provided by the Cartographic Center for Remote Sensing (CCRS, 2015) of Abidjan.

Furthermore, SPEARMAN and khi2 tests have been used to evaluate the correlation between the areas of malaria at risk and the malaria prevalence rates recorded in the neighborhoods of Bouaké. The significance threshold has been set at 0.05.

2. RESULTS AND DISCUSSION

2.1 Spatial Analysis for the Identification of Space at Risk of Malaria in Bouaké

Figure 2 presents the digital terrain model (DTM) of Bouaké from the contour lines. It is the digital representation of the relief and the hydrological phenomena obtained from the integration of topographic data. The DTM is associated with the urban west of the city that helps note that the urban space is very hilly, furrowed by watercourses. The central urbanization fronts extend up to the humid shoals, spaces where important areas of water accumulation have been inventoried. This level of drainage had already been reported in the study implemented by Dossou-Yovo et al. in 1998 about the impact of the paddy fields arrangements on the malaria contamination in Bouaké. The authors showed that the city was very hilly with several kilometers of marshy ribbons furrowed by numerous small watercourses spaced out by a distance varying from 500 m to 800 m.

Since the 2000s, most of the identified shallows inside and around the city are regularly exploited for growing vegetables and rice. This human's action has created biotopes released from any wild vegetation, but above all, has caused a widening of workable humid bands resulting in the creation of larval cottages favorable to the *An. gambiae* Anopheles, a vector of malaria transmission.

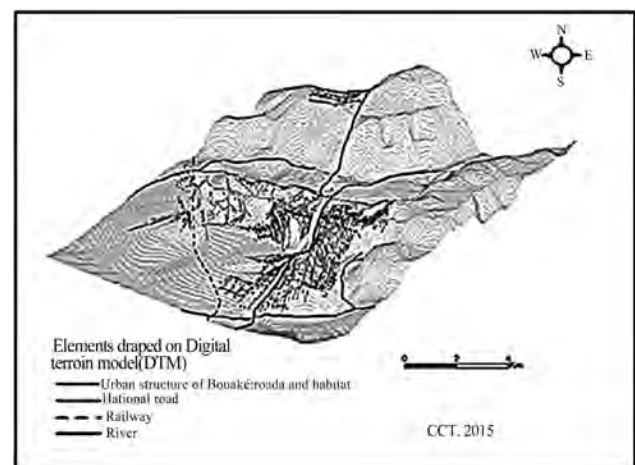


Figure 2
Digital Terrain Model of the City of Bouaké (DTM)

The ecology of anopheles is closely related to surface water and anthropogenic factors. This combination affects the birth of anopheles space at risk, that is, space where there is more risk to be bitten by Anopheles. The lowland areas with high densities (more than 1.000 inhabitants/km², Figure 5) are then highly exposed to mosquitoes' bites. The populations living in those areas are also those that are the most precarious (54% of the households live

in extreme poverty and more than 50.05% of them are illiterate). In Cote d'Ivoire, the poverty threshold is less than 450 FCFA, namely less than one dollar a day (PNUD, 2008).

Those households do not have the means and the appropriate knowledge to use or acquire the means of protection such as the mosquito nets or products of insecticide. They are also the one who has the least good access to health care facilities (level of accessibility to health services is 12.36%, DIPE, 2014).

The results from the DTM allowed the calculation of the space at risk and revealed the sensitive areas of potential concentration of *An. gambiae* Anopheles, mosquitos responsible for the transmission of malaria that

kills millions of people each year and more particularly children less than 5 years (WHO, 2014). But, this modeling does not take into account the vegetation. Yet, it preconditions the appearance and the persistence of Anopheles larval cottages, the speed of development of larvas, the abundance of vectors, their life rate, their scattering and the duration of the Plasmodium extrinsic cycle (Machault et al., 2009).

Figure 3 represents the image from the NDVI classification using the SPOT image. Each 10 m pixel contains a NDVI value. The green colors in the north-west and east correspond to the vegetation, the denser the vegetation, the darker the green. The brown colors correspond to bare soil and the built city of Bouaké.

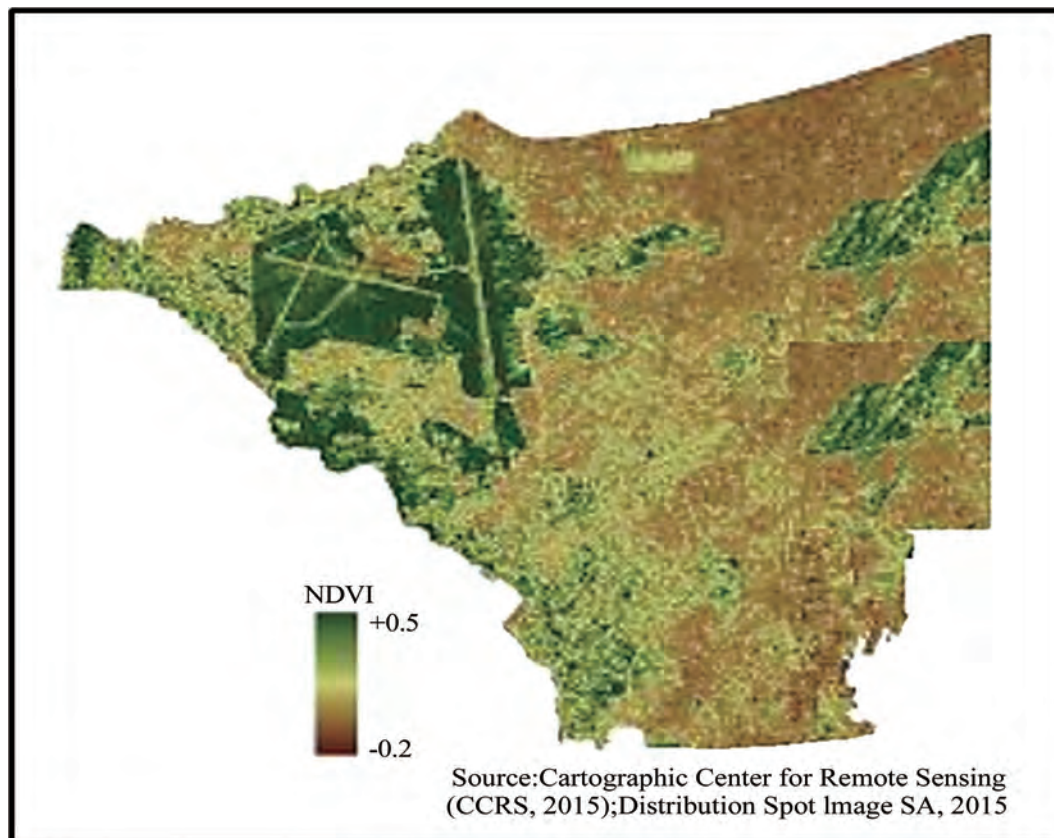


Figure 3
Image From the Normalized Difference Vegetation Index (NDVI) of the Town of Bouaké

The NDVI calculated permitted to map the risk of malarial through the identification of favorable environments to the presence of larval cottages for areas displaying a NDVI more than 0.5. These areas correspond to the high population density of Anopheles captured during the field surveys and the distribution of cases of malaria (Figures 4 and 5). The identification of environments conducive to the presence of larval cottages by the NDVI calculation has already been observed in studies conducted on French military during their short-term mission in intertropical Africa.

The average NDVI calculated using the data from the Moderate Resolution Imaging Spectroradiometer (MODIS)—Terra sensor for the environments where the troops were exposed, was significantly and strongly associated with risk of access to malarial (ROBERT et al., 1992; Machault et al., 2008).

The presence of vegetation is due in large part to the urban inland valley rice and vegetables growing. Its incidence on malaria contamination is very varied (Yovo et al., 1998). It creates a very favorable and particular ecological situation for the rapid multiplication of *An.*

gambiae anopheles which is recognized as the unique vector of malaria contamination in West African cities (Randolph et al., 2000). This observation is consistent with the one undertaken in Mali using the multiplicity of images. Some differences of paddy fields temporal profiles have been spotted and associated with different levels of larval cottages density (Mushinzimana et al., 2006).

The results show that the obtained data can be useful for malaria control. The NDVI enables the mapping of environments conducive to the presence of larval cottages and permits to identify the larval cottages surface to treat around the habitable areas.

However, our results do not take into account the possible ecological changes. In a village in Kenya, a study showed that the presence of *An. arabiensis* larval cottages was associated with ecological changes relative to time (Jacob et al., 2007). Also, it would have been interesting to create a model including the NDVI, the temperature, the rainfall measured in weather stations, the number of malaria cases. This would have allowed to predict the incidence of malaria. This methodology is appropriate for

the endemic areas like Bouaké. The application of this model has not been possible due to lack of data for this study. But, the methodology used reveals space at risk for malaria transmission and allows the distinction of two main categories of cottages: the humid shallows and the paddy fields in Bouaké.

2.2 Connection of the Anopheles Aggressiveness Localization and the Distribution of Cases of Malaria in the City of Bouaké

The GPS technology allowed us to geolocate the entomological data collected in the field and to integrate them in the GIS created in order to obtain a map of spatial distribution *An. gambiae* anopheles density that is parasitic charges relatively to the city neighborhoods (Figure 4). On the map, it is observed that most of the *An. gambiae* anopheles were captured in the north-west, north-east and south-east neighborhoods of the city (more than 9 000 *An. gambiae* anopheles per month). It is noted that areas with high parasitic charges are close to each other. They represent endemic areas at risk of malaria. People with a high parasitic load will foster the contamination if they are stung by an anopheles.

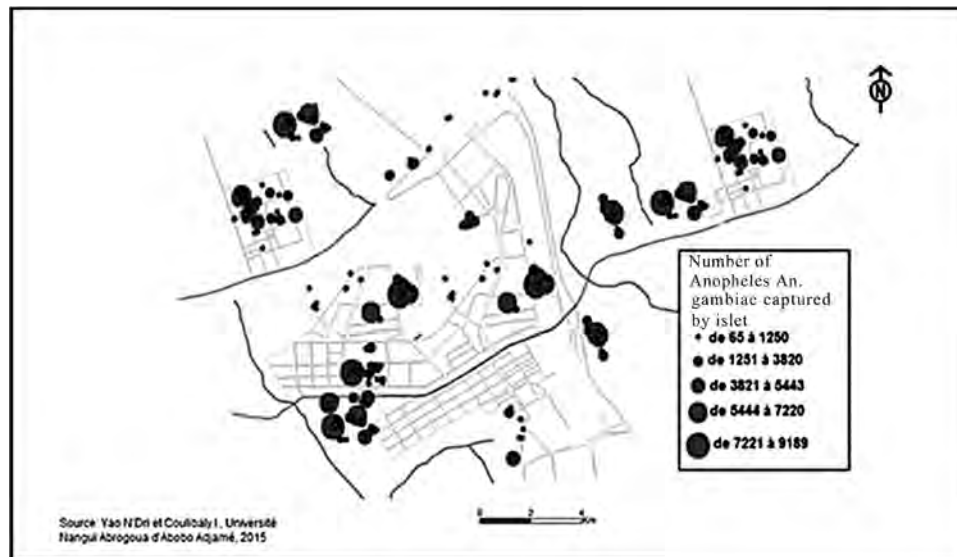


Figure 4
Level of load of Anopheles *An. Gambiae* Captured by Neighborhood in the City of Bouaké

In the neighborhoods with high parasitic loads, a significantly more important abundance of these vectors is noted for the very humid shallows ($p < 0.001$) and the farming areas (rice and gardens) identified using the spatial analysis except for south-west neighborhoods (Figures 2 and 3). In the neighborhoods where arranged or humid shallows for rice and vegetables cultivations are found the *An. gambiae* anopheles number was considerably higher ($p < 0.00001$). Similarly, a significant correlation is noted between the humid shoals and the level of prevalence of malaria ($p = 0.001$). However, we notice an absolute correlation between the neighborhoods

with parasitic charge level and the level of prevalence of malaria ($p = 0.0275$).

The situation observed in south-west neighborhoods could be explained by the fact that the neighborhoods are dominated by precarious housing characterized by makeshift building materials and the absence of proper sanitation using pipe canalization to evacuate the waste water. Because this situation in the neighborhoods, as it was observed during our surveys in the field, there are waste water around houses, wild grasses, spaces favorable to the larval cottages proliferation and to the high density of *An. gambiae* anopheles (Pictures 1 and 2).

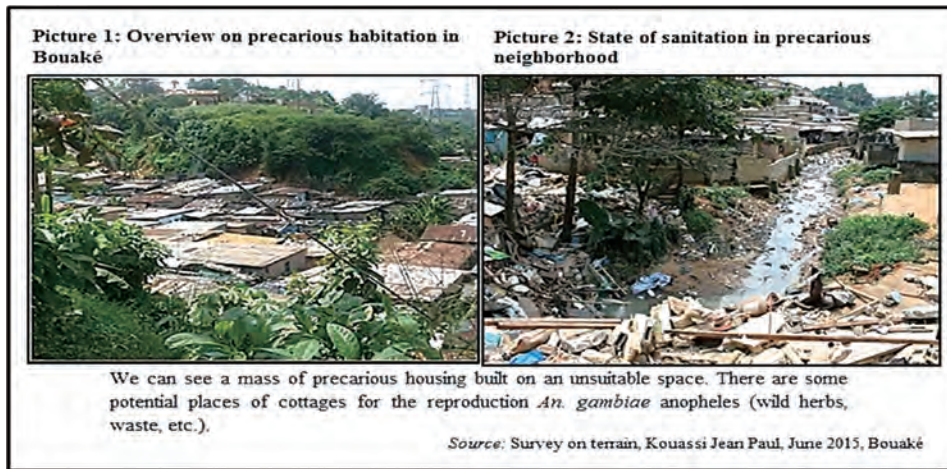


Figure 4 showed us that there were relatively high parasitic load pockets precisely in the neighborhoods in north-west, north-east, south-east of the city and others were where the areas did not display very high parasitic load as in neighborhoods in the south-east located in the periphery of the city. The representativeness of the analyzed sample and the variability of this parasitic load limit the value of this result over time. The connection with the map of the prevalence brings elements of reflection on the location of space where the contamination of malaria is high and the associated factors in order to set up prevention strategies adapted to the reality of each endemic area identified.

The geolocation of epidemiologic data of the prevalence and the density of the population shows a cluster of neighborhoods apparently endemic close to high human density (more than 2.000 inhabitants/km²) (Figure 5). This result is consistent with Jeanne's (1991). It is

noted that most of the areas with high rate of prevalence are located in the vicinity of farming areas or in humid shoals (Figures 2 and 3) where the rate of prevalence increases significantly as a function of the density regardless of the area of the city. Those results have already been observed in the town of Bouaké by the study carried out by Dossou-Yovo et al. in 1998 on the impact of facilities of paddy fields on the transmission of malaria and by Cot et al. in 1995 on the differences in the rate of prevalence between the neighborhoods of Bouaké.

The comparison of the maps of parasitic loads and of the prevalence (Figures 4 and 5) shows that the strong prevalence rates are associated with significant loads of vectors with the exception of the south-east where the prevalence of malaria is medium sized. This observation can be explained by phenomenon of immunity that is acquired by being bitten by infected Anopheles (Roudier, 2006).

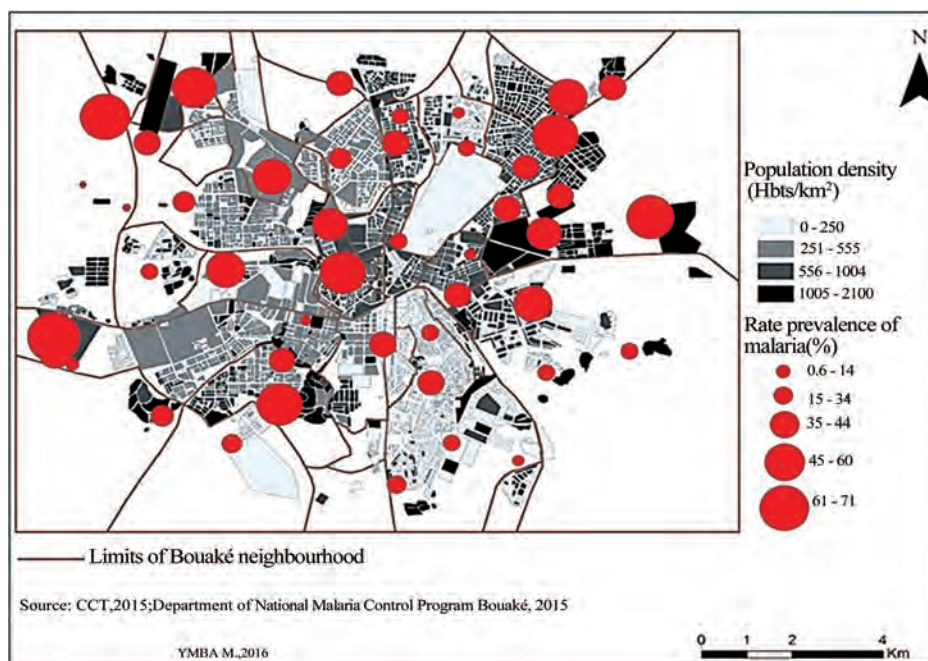


Figure 5
The Density of the Population and the Spatial Distribution of Cases of Malaria in Bouaké

A spatial interpolation using the KRIGING method (Jeanne, 1999), geostatistical technique based here on the calculation of semivariances, allowed us to express the trends of data aggregation on malaria (Figure 6)

and then distinguish the main areas of hyper-endemic neighborhoods (in dark color) and the non-hyper endemic areas (in light color).

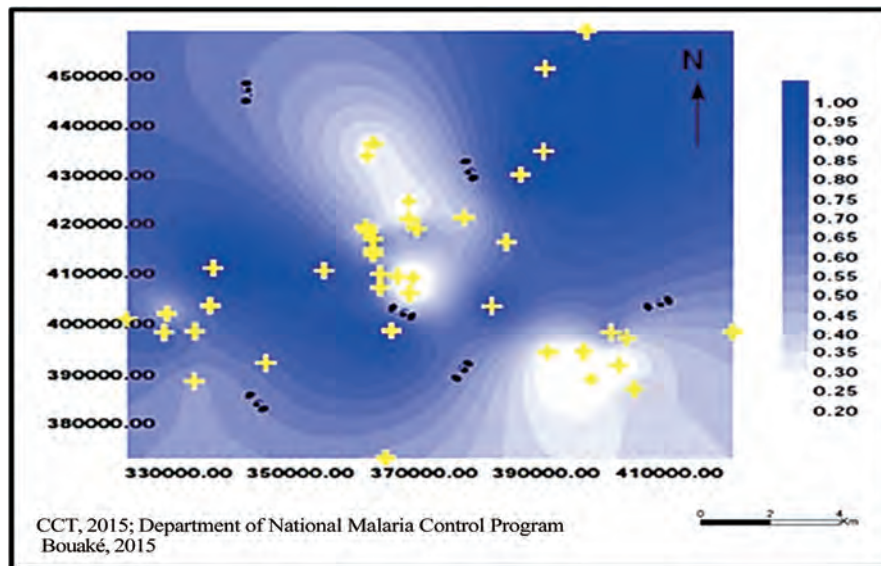


Figure 6
Spatial Interpolation Using Data of Prevalence of Malaria From 41 Neighborhoods of the City of Bouaké

The hyper-endemic areas with high rates of prevalence are inside the humid shoals and are crossed by the main river lines of the city. The non-hyper endemic areas are located in the center of the town and south-east in low upland. In the case of the urban environment, it is generally allowed that the rate of transmission is low and decreases as one moves toward the city center (Dossou-Yovo et al., 1998). Consequently, the proximity to the farmed and humid shallows constitute the factors of potential risks identified and linked to the level of prevalence.

In this part, we identified the endemic spaces that must be treated with priority and draft a predictive model of prevalence. However, we have not been able to locate all of the malarial spaces at risk and to detect epicenters at risk in order to prevent the emergence of new epidemics of malaria. Additional and exhaustive field surveys in the city's neighborhoods will help refine our results.

Furthermore, an in-depth study of the conditions for the transmission of malaria in the city is also necessary. In the existing Geographic Information System, the integration of other data from the processing of high-resolution satellite images, such as the types of bare soils, types of vegetations, hydrogeological and behavioral data, and entomological data can may allow to create models much more relevant to control malaria.

CONCLUSION

The creation of the Geographic Information System enabled to identify the areas at risk of malaria transmission as well as their relevant determinants while taking into

account the context and the means of local structures. The integration of environmental data, epidemiologic data, entomologic data, socio-economic data and satellite images is of great interest in the analysis of parasitic diseases and pathologies related to the environment in general.

Our studies show that the GIS is a powerful and efficient tool to fight against malaria. Since several years, the outcomes of many studies show that the GIS can be an important source of data for the establishment of models: predictive models of prevalence for malaria, the design of maps of entomological, parasitological, and epidemiologic risks of malaria. Then, it can therefore improve the planning, the effectiveness, and the efficiency of the malaria control.

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