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Biophysical, Entomological and Socio-Environmental Factors and Strategies for the Prevention of Malaria in the Communes of Bassila and Copargo in Northern Benin

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Abstract

Malaria transmission results from a combination of several determinants including biophysical, entomological and socio-environmental. This study aims to identify the determinants of malaria in the communes of Bassila and Copargo and the prevention strategies against malaria vectors used by households. This is a cross-sectional study whose methodological approach consisted of documentary research, socio-anthropological surveys, entomological field surveys, interviews and direct observation of 382 randomly selected households. The collected data were processed and analyzed using Excel 2016. The results of our study show that climatic parameters, hydrography and soils, play a part in the occurrence of malaria in Bassila and Copargo through the ecological conditions offered to vectors and parasites. The vectors encountered are *Anopheles gambiae s.l.* and *Anopheles funestus s.l.* with a predominance of the *Anopheles gambiae s.l.* complex. Depending on the season, there is a predominance of *Anopheles gambiae* and *Anopheles coluzzii* species of the *an gambiae* complex. During the dry season (February to March), *An. coluzzii* predominates (88.61%) and during the rainy season, the predominance of *An. gambiae* was observed (76.07%). Population growth, low standard of living, soil type, poor management of the living environment and the perception of the disease by the population also influence malaria transmission. Long-lasting insecticide-treated net is the most widespread strategy with 95% coverage in Bassila and 97% in Copargo in 2020. It is complemented by indoor residual spraying in Copargo which covers 83% of households but is not implemented in Bassila. Endogenous means developed such as the use of smoke coils, fences, and local plants by the populations were also identified in both communes. Although biophysical and entomological factors are favorable, the social standard of living, the living environment, and the behavior of the population contribute greatly to the ineffectiveness of malaria vector control strategies, which is illustrated by the increase in malaria cases in the communes evaluated.

Keywords

Biophysical, Entomological and Socio-Environmental Factors, Preventive Strategies, Malaria, Bassila, Copargo Benin

1. Introduction

The sub-Saharan African region is marked by the double burden of communicable and non-communicable diseases, all against a background of poverty. Since the emergence of humans, malaria has been a component of the African environment [1].

In 2019, the number of malaria cases was estimated at 229 million with 409,000 deaths [2]. Of all human-infested species, *Plasmodium falciparum* is the most lethal and widespread in sub-Saharan Africa [3]. The female anopheles is the exclusive vector of the strictly human-to-human disease. Of more than 500 known species of Anopheles, nearly 50 are capable of transmitting *Plasmodium* [4]. Malaria transmission results from a combination of several determinants including biophysical, entomological and socio-environmental.

Benin is one of the countries in the sub-Saharan region of Africa where the population health indicators are most alarming. The number of malaria cases recorded in health facilities from 1981 to the present day has made it the most important parasitic disease. In 2019, a total of 2.599.896 cases of malaria were recorded in health facilities, representing 46.8% of all consultations. The incidence for both forms (simple and severe) is 212 per 1000 inhabitants [5]. Yet the country has been committed since 2000 to strengthening malaria control efforts through various strategies coordinated by the National Malaria Control Program [6].

In response to the ongoing threat of malaria, National Malaria Control Programs (NMCPs) use several strategies including vector control for prevention. The two main methods of malaria vector control are indoor residual spraying (IRS) and the use of long-lasting insecticidal nets (LLINs) [7] [8].

The bioclimatic diversity from the southern forest to the northern savannah of Benin induces very varied malaria transmission facies. Little work has been done on malaria transmission in the dry savannah zone in the north of the country [9]. The department of Donga is among the most affected by this endemic according to the latest statistics from the Ministry of Health; its incidence for simple and severe cases was 33.5% in 2019 [5]. Malaria transmission in this department, which comprises four communes (Bassila, Copargo, Djougou and Ouaké) that are subdivided into two health zones (Bassila and Djougou-Copargo-Ouaké), is intense and almost permanent. This is despite the mass distribution of long-lasting insecticide-treated nets (LLINs) to everyone every three years, most recently in 2023, and the residual indoor residual spraying (IRS) carried out from 2017 to 2021, but only in the Djougou-Copargo-Ouaké health zone. This study aims to identify the biophysical, entomological and sociodemographic determinants of malaria in the communes of Bassila and Copargo and the prevention strategies against malaria vectors used by households.

2. Materials and Methods

2.1. Study Area

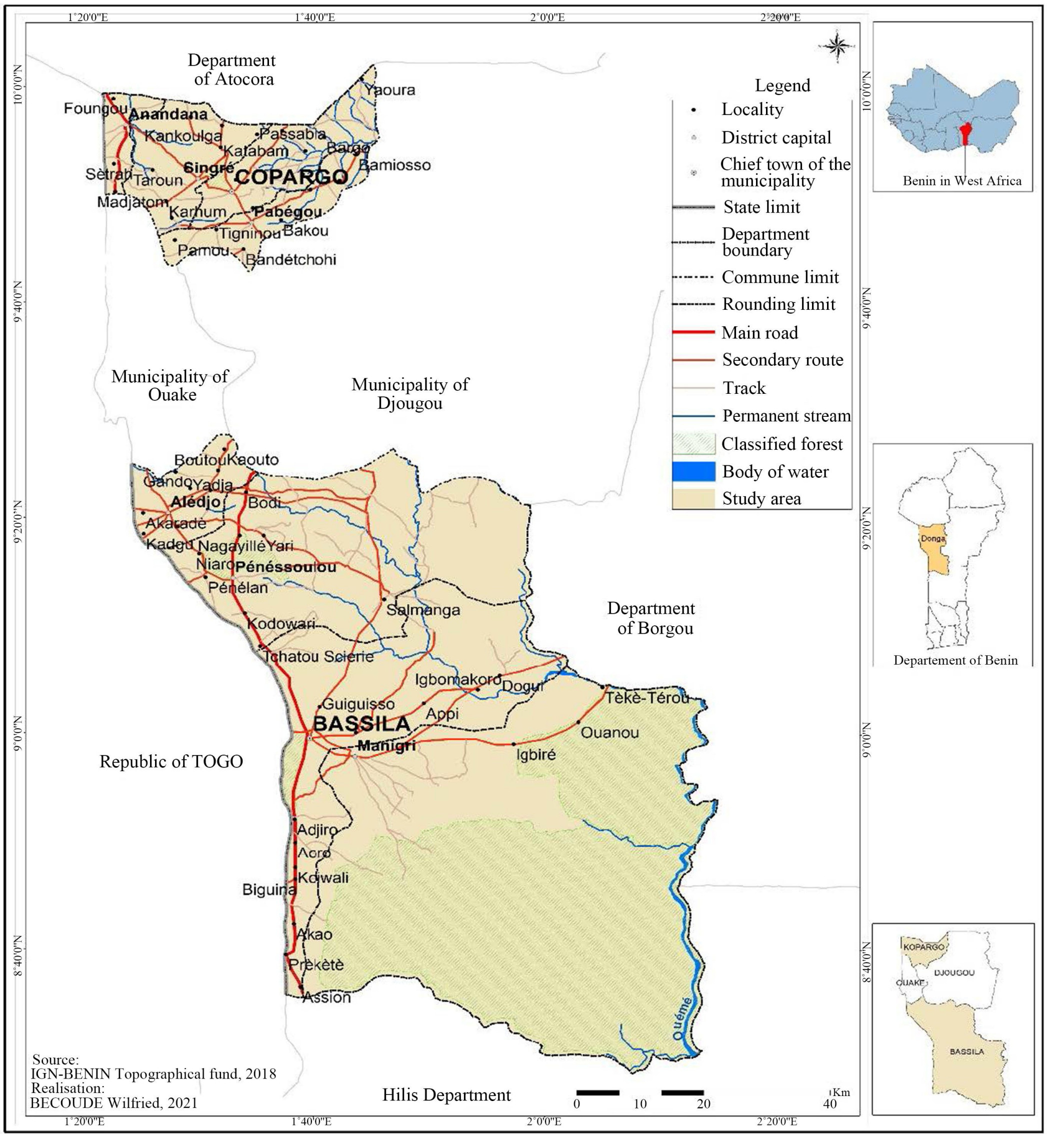


Figure 1. Map of the geographical location of the communes of Bassila and Copargo (Becoude N'kouey, 2021).

The study was conducted in Northwestern Benin in the communes of Bassila and Copargo, which are located in the Donga department, from October to November 2020. The commune of Bassila is located between 8˚30' and 9˚30' North latitude and 1˚30' and 2˚15' East longitude. The commune of Copargo is located between 9˚45' and 10˚00' North latitude and 1˚30' and 1˚45' East longitude (**Figure 1**).

2.2. Data Collection

This research is a cross-sectional study conducted in the communities of two districts of the communes of Bassila and Copargo using documentary research, socio-anthropological surveys and direct observations in the field. The methodological approach used consisted of the collection and processing of data and the analysis of the results obtained.

2.3. Sampling

Households were sampled using the simple random sampling method. The people targeted in the households were those who met the following criteria: being the head of the household; being at least 18 years old to allow reliable reporting of knowledge about malaria; and having benefited from at least one of the control strategies. The other resource persons (traditional practitioners, health authorities, health personnel, and local elected officials) were chosen according to their knowledge and involvement in the fight against malaria.

The department of Donga has four communes subdivided into two health zones, namely the Bassila health zone and the Djougou-Copargo-Ouaké health zone. Several means of malaria prevention are implemented in each of the two zones. Given the size of the two zones and considering that the same means of prevention are implemented in the same zone, only one commune was chosen in each health zone (Bassila for the Bassila health zone and the commune of Copargo for the Djougou-Copargo-Ouaké health zone). Also, due to limited resources, only two arrondissements in each of the two selected communes were considered, *i.e.*, one peri-urban arrondissement and one rural arrondissement. In the commune of Bassila, the surveys were conducted in villages or neighborhoods in the central arrondissements of Bassila and Pénéssoulou. In the commune of Copargo, villages or neighborhoods in the central arrondissement of Copargo and that of Singré are involved.

The sample size was determined according to Schwarts's (1995) formula

$n = Z\alpha^2 \times p.q/i^2$

With:

n = sample size

$Z\alpha = 1.96$ (95% confidence level)

p: estimated prevalence. The prevalence of malaria in the Donga department in 2018 according to the EDSB-V is 47%, p = 0.47.

p = total number of households in the districts/total population of the municipality.

$q = 1 - p$

I = margin of error at 5% (standard value of 0.05) which gives the desired precision or confidence interval.

We have: $Z\alpha = 1.96^2$ and $I = 0.05^2$; therefore, $\mathbf{n} = \mathbf{382}$.

A total of 382 households were surveyed in the two communes, 191 households per commune. You should first indicate the total number of communes before you calculate the numbers you will be working with. The localities visited were chosen based on the criteria of ease of communication and accessibility due to the period of the collection (October to November 2020).

The arrondissements of Bassila and Pénéssoulou were selected in the commune of Bassila, as were those of Copargo and Singré in the commune of Copargo.

Direct observation, the Active Participatory Research Method (MARP) and interviews were employed to collect socio-anthropological data. Household visits made it possible not only to identify the socio-economic factors of the two communes, but also to investigate socio-environmental factors through the households' standard of living, presentation of their living environment, sanitation measures adopted, perception of and knowledge about malaria, and strategies used to combat disease vectors.

The aim of using the Active Participatory Research Method (APRM) was to work in harmony with the local population to gather information about malaria and prevention methods. There were two types of interviews: semi-structured and focused. Semi-structured interviews were conducted with individuals involved in the study. Focused interviews, also known as direct interviews or focus groups, were conducted with heads of households.

Entomological surveys on malaria vectors were conducted in 2020 by our team from the Entomological Research Center of Cotonou in both communes from February to December 2020 (February to March 2020 for the dry season and June to December 2020 for the rainy season).

Data collection was based on night captures of human subjects. These captures of aggressive mosquitoes were carried out from 8:00 pm to 6:00 am, on human volunteers who had previously given their consent for the activity to take place. In the study area, capture devices were placed outside and inside 4 houses per household chosen as capture points, *i.e.*, 16 capture devices per municipality. The collection took place at a rate of 2 consecutive nights per season.

These capture sites did not vary throughout the study. The captured mosquitoes were kept individually in hemolysis tubes plugged with cotton and kept by time slot and by point. These mosquitoes were identified the next morning according to genus and species using the Gillies and Meillon (1968) key [10]. All these mosquitoes were kept on silica gel for the investigation of infection by the enzyme-linked immunosorbent assay (Elisa CSP) method. Thus, the aggressiveness rates of the vectors and the Entomological Inoculation Rates (EIR) were determined [11].

Climatic data from 2011 to 2018 obtained from Benin weather and health data from Bassila and Copargo from 2011 to 2020 collected on the DHIS2 platform and in the Ministry of Health's health statistics directories were used.

2.4. Data Analysis

The data collected were processed using Excel 16 and then analyzed using a combination of SWOT (Strength, Weakness, Opportunity, and Threat) and PEIR (Pressure-State-Impact-Response) models. To assess the relationship between climatic parameters and malaria incidence, we performed Pearson correlation analyses between average monthly rainfall, temperature, and relative humidity and the number of reported malaria cases from 2011 to 2018. Pearson's correlation coefficients (r) were used to quantify the strength and direction of linear associations. Additionally, trend analysis of malaria cases over time (2011-2020) was performed using time-series line graphs to visualize fluctuations in simple and severe malaria incidence. However, potential confounding factors (e.g., socio-economic conditions, access to health care, or household-level interventions such as LLINs and IRS) were considered in the interpretation of results.

3. Results

Malaria transmission in the communes of Bassila and Copargo is the result of a combination of several determinants including biophysical, entomological and socio-environmental determinants.

3.1. Biophysical Factors

The climate is one of the most important ecological parameters of human life [12]. In the communes of Bassila and Copargo, the climate is Sudano-Guinean with two distinct seasons: a dry season and a rainy season. Rainfall in the commune of Bassila is estimated to average between 1,100 and 1,400 mm per year in the forest ecosystems. In Copargo, rainfall averages about 1100 mm per year. The daily temperatures in these two municipalities vary between 18˚C and 38˚C. In the hottest months of the year, the average maximum temperature is 30.46˚C and in the coldest months the average minimum is 25.12˚C. The relative humidity varies between 16% and 99% and reaches its peak during the rainy season [13].

Mosquitoes have four main life stages. The first three of these the egg, larval and pupal stages are aquatic. These aquatic forms develop in collections of water known as "breeding grounds", the characteristics of which vary according to the species of mosquito [14]. Each species lays its eggs in specific breeding grounds, which can be natural, such as puddles, holes in trees, rocks and shells, or artificial, such as containers of various sizes and materials, crawl spaces and sewage works. These grounds can be filled with fresh, brackish or salt water, and can be more or less rich in organic matter. Investigations carried out among the target populations of the two communes revealed that the majority of malaria cases occur during the rainy season: 62% of households (119 households) in the commune of Bassila and 67% of households (128 households) in the commune of Copargo. Rainfall favours the development of mosquitoes by feeding the puddles and ponds in which they breed. Table 1 presents the correlation analysis carried out to understand the influence or possible relationship between certain climatic parameters (mean rainfall, mean temperature and mean relative humidity) and malaria. These different elements play an important role in bioclimatology.

Table 1. Correlation between climatic parameters and malaria in the communes of Bassila and Copargo.

Climatic parameters	**Average rainfall**		**Average temperature**		**Average relative humidity**	
Municipality	Bassila	Copargo	Bassila	Copargo	Bassila	Copargo
Correlation coefficients for Malaria	0.26	0.49	−0.87	−0.71	0.82	0.86

Source: DHIS2 health data and Benin Meteorology (2011-2018), 2020.

Analysis of Table 1 shows that the correlation between malaria and average annual rainfall is moderate for the commune of Copargo and low for the commune of Bassila (0.49 and 0.26). In other words, this relationship highlights the influence or relationship between the increase in the number of malaria cases and rainfall. Consequently, the link between rainfall and malaria is less apparent in Bassila than in Copargo. While upstream rainfall plays a key role in the multiplication of the vector, other factors downstream certainly favour the occurrence of the disease. It should be noted that when there is more rainfall and the water current is stronger, mosquito larvae are more likely to be carried away, which could impact disease transmission.

Average annual temperatures in the communes of Bassila and Copargo were negatively and strongly correlated (−0.87 and −0.71) with malaria. The average temperatures were favorable to the increase in cases.

Thus, higher temperatures lead to fewer cases of malaria. Air temperature affects the water content of breeding sites through evapotranspiration. The closer temperatures are to the observed averages, the greater the impact on transmission.

Temperature has a nonlinear influence on the different stages of mosquito development, with threshold effects observed. If the water temperature in larval breeding sites is too low, the development of aquatic stages is limited or even halted, while an increase in temperature up to a different threshold value tends to accelerate it. Provided it remains within an optimal range, an increase in air temperature also favours the survival and activity of the adult stage, including taking blood meals [13].

Relative humidity is positively correlated with malaria. These variables evolve in the same direction as their correlation coefficient (0.82 and 0.86). Relative humidity and temperature thus appear to be the climatic parameters most favorable to the occurrence of malaria in the communes of Bassila and Copargo, against which control strategies are implemented.

3.2. The Hydrographic Network

The hydrographic network in the communes of Bassila and Copargo is fairly dense, with numerous permanent and temporary watercourses, particularly in Bassila.

During the rainy season, three rivers and seven springs cross and water the commune of Bassila. Apart from the Tèrou river, the others (the Awo and the Kémétou) dry up in the dry season. This commune has low-lying areas and water reservoirs and is a transhumance corridor.

The commune of Copargo is crossed by 55 km of waterways, including one river and three springs. The most notable rivers are the Ouémé, Yari, Gbangbaré, Saguigui, Pabégou, Baana, Sountchoulou, Danêgou, Sounêgou, N'kouéma and Makouloukou. All of these rivers have seasonal flows, except the permanent flow of the Ouémé towards the Atlantic Ocean.

Towards the end of the rainy season, the decrease in water flow helps maintain certain larval breeding sites. Temporary puddles formed by the rain or in riverbeds and shallows encourage an increase in anopheline density.

Conversely, during periods of drought, the evaporation of these puddles leads to the disappearance of many potential breeding sites, thereby reducing the number of vectors.

3.3. Types of Soil

The soils in the commune of Bassila are mainly tropical ferruginous soils. These soils are found throughout the commune and, in places, ferralitic and hydromorphic soils on rock can be observed. Ferruginous soils are clay-rich and slow down water infiltration, favouring the retention of stagnant water and contributing to the development of larval breeding sites and anopheline density.

The soils in the Copargo commune are also tropical ferruginous soils. The arrondissements of Anandana and Singré are covered by non-concretionary, leached, tropical ferruginous soils. Ferralitic soils can be found in Pabégou and Anandana, alongside a few rare soils with hydromorphic tendencies. These soils are extremely fragile and, when the forest cover protecting them from erosion and leaching is destroyed, they rapidly transform into lateritic cuirasses. The degree of permeability of these cuirasses influences the persistence of breeding sites and favours mosquito proliferation. **Figure 2** shows the soil types in the communes of Bassila and Copargo.

Analysis of **Figure 2** reveals several soil units. In these two communes, there is a trend towards soil impoverishment and degradation due to demographic pressure and poor agricultural practices. This results in the destruction of plant cover, creating more breeding sites and allowing vectors to develop.

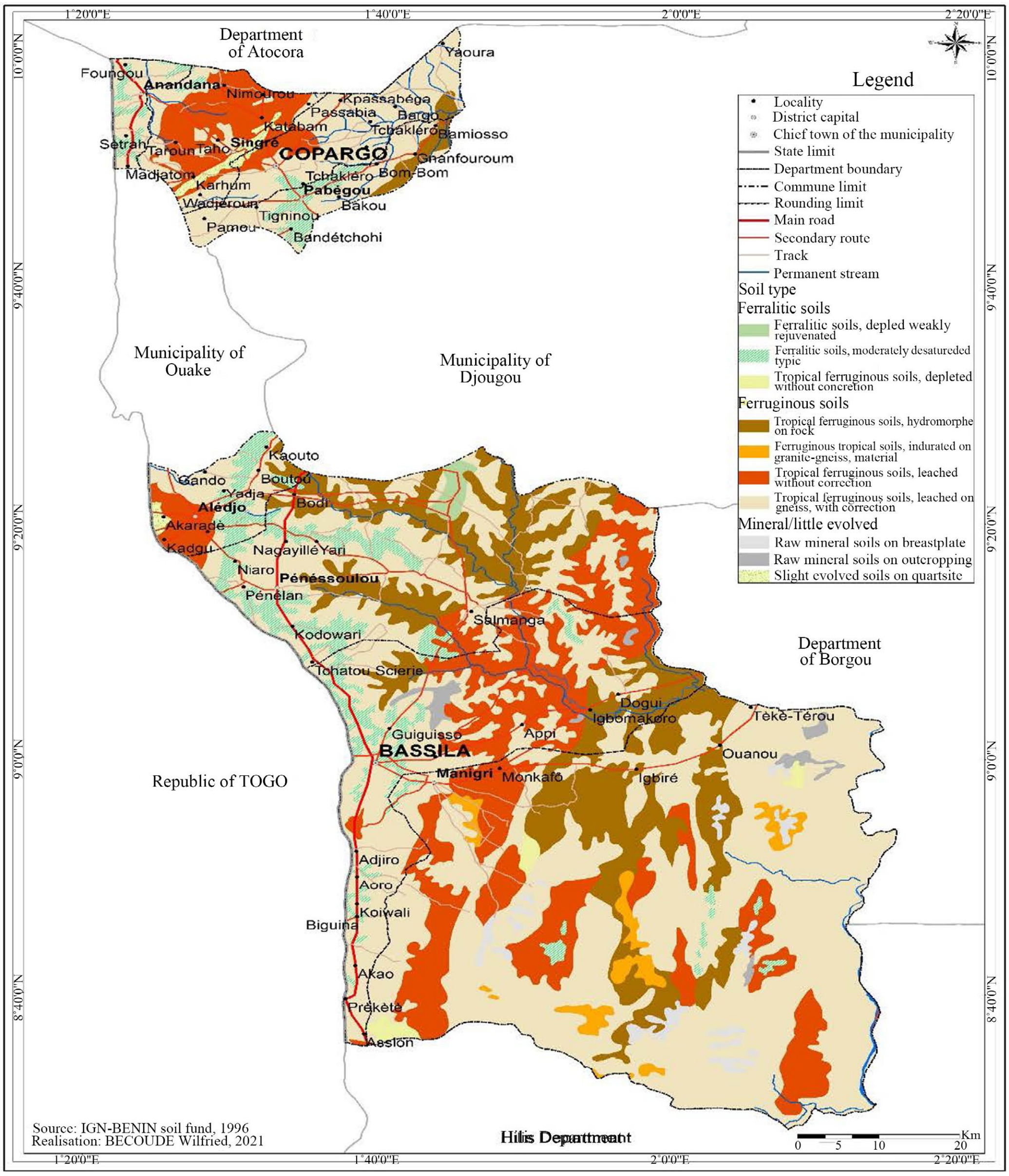


Figure 2. Soil units of the communes of Bassila and Copargo (Becoude N'kouey, 2021).

3.4. Plant Formations

The plant formations in the commune of Bassila cover an area of 3457 km², accounting for 61% of the commune's total surface area. Two types of formations have been identified: natural formations and plantations (**Figure 3**). Natural formations can be distinguished by several physiognomic units. These include gallery forests and trees and shrub savannahs. Almost half of the commune's surface area (2.437 km²) is occupied by managed gallery forests. Notable examples include the forests of Bassila, Biguina, Pénéssoulou, Monts Kouffé and Wari-Maro, which are home to species such as *Khaya senegalensis* (caïlcédrat), *Milicia excelsa* (iroko), *Ceiba pentandra* (kapokier) and *Cola cordifolia* (kola). Tree and shrub savannahs are dominated by *Adansonia digitata* (baobab), *Vitellaria paradoxa* (shea), *Parkia* *biglobosa* (néré) and *Khaya senegalensis* (cedar).

In the commune of Copargo, these formations consist of wooded and grassy savannahs, which are characteristic of the area. The main shrub species are shea (*Vitellaria paradoxa*), dwarf (*Parkia biglobosa*), mango (*Mangifera indica*) and citron (*Khaya senegalensis*), all of which are widespread. There is a classified forest covering 1.091 hectares.

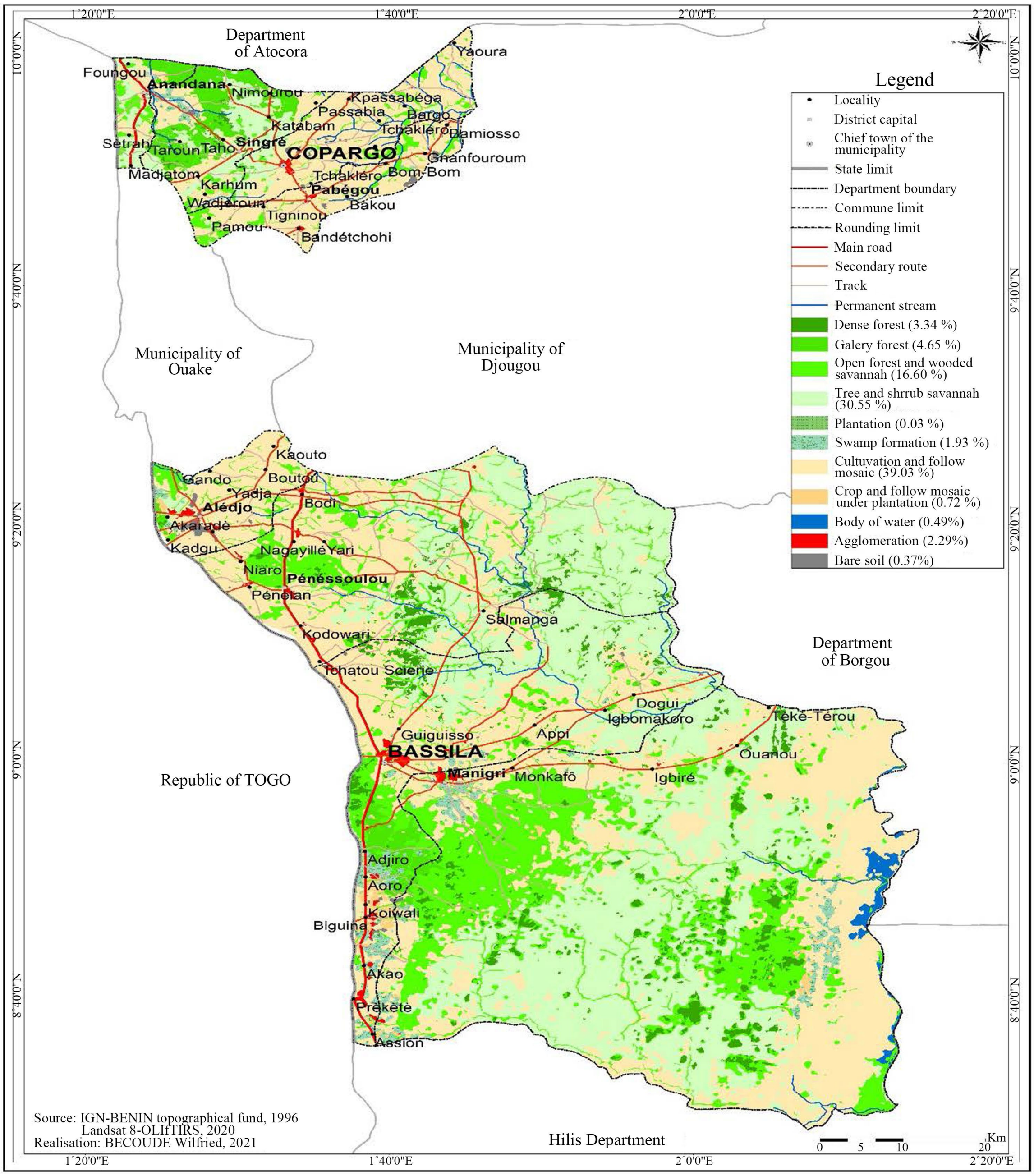


Figure 3. Land use in the communes of Bassila and Copargo (Becoude N'kouey, 2021).

Figure 3 illustrates the abundance of vegetation, including dense forests, forest galleries, open forests and wooded savannahs, as well as trees and shrubs. The density of anophelines varies depending on the type of vegetation and the species' preferences. Some species prefer shady vegetation, while others, such as Anopheles gambiae, prefer sunny areas for roosting. More than three-quarters of the surface area of these two communes is covered by crop and fallow mosaics, tree and shrub savannahs, open forests and wooded savannahs. Most of these savannahs are very sunny, which increases anopheline density. Additionally, the nectar of certain plants attracts adult mosquitoes. During the rainy season and for around three weeks afterwards, vegetation can be found almost everywhere in these two communes, in both peri-urban and rural districts. This vegetation, especially close to dwellings, provides shelter for mosquitoes and plays a major role in their proliferation. Rainfall favours the growth of vegetation, which provides a source of sugar and resting places for adult mosquitoes.

In short, anopheline density is the result of a combination of biophysical factors that make up the vector's ecological environment. Malaria vector species are distributed according to the conditions offered by the biotope, their host and breeding site preferences, and anthropogenic factors.

3.5. Entomological Factors

The communes of Bassila and Copargo are full of a diversity of mosquitoes. Several species of mosquitoes have been encountered. In the commune of Bassila, these are *Anopheles gambiae s.l., Anopheles funestus*, *Anopheles ziamani*, *Culex quinquefasciatus*, *Culex nebulosus*, *Culex descens*, *Culex tigripes*, *Mansonia africana* and *Aedes aegypti*. In the municipality of Copargo, the species encountered are: *Anopheles gambiae s.l*, *Anopheles funestus*, *Anopheles pharaensis*, *Anopheles coustani*, *Culex quinquefasciatus*, *Culex nebulosus*, *Culex tigripes*, *Mansonia africana*, *Mansonia uniformis*, and *Aedes aegypti* [11]. None of these mosquito species is currently involved in malaria transmission. The malaria vectors encountered are *Anopheles gambiae s.l.* and *Anopheles funestus s.l.* However, the *Anopheles gambiae s.l.* complex is more abundant in both communes. Depending on the season, *Anopheles gambiae* and *Anopheles coluzzii* are predominant. During the dry season (February to March 2020), *An. coluzzii* predominates (88.61%) and during the rainy season, the predominance of *An. gambiae* was observed (76.07). *An. gambiae* is more active in the rainy season than in the dry season, in rural areas than in urban areas [12]. According to a recent study conducted in the Donga department, *An. gambiae* shows exophilic and exophagic characteristics in the commune of Bassila while in the commune of Copargo, it shows mixed characteristics; it is present and active both inside and outside the dwelling [8]. From February to March 2020, the sporozoite index (SI) represents the percentage of *An. gambiae* among which the salivary glands contain sporozoites within twenty-four hours of capture was 0.00 in Bassila and 0.050 in Copargo. However, between June and December 2020, this index was twice as high in Bassila (0.02) as in Copargo (0.014). The Entomological Inoculation Rate (EIR), which measures the intensity of transmission through the average number of infecting bites during a given period, was low in both communes (0.00 in Bassila and 0.03 in Copargo) during the February-March 2020 period. However, during the June-December period, this rate is significantly higher in Bassila (0.37) and Copargo (0.14). The number of *An. gambiae* bites per man per night during the February-March 2020 period were 2.25 in Bassila and 0.63 in Copargo, but during the June-December period, it was 22.17 in Bassila and 10.53 in Copargo, *i.e.*, ten (10) times higher in this period in both communes [11].

3.6. Socio-Environmental Factors

The populations of the communes of Bassila and Copargo have increased considerably, from 46.416 inhabitants to 130.091 inhabitants between 1992 and 2013 for the commune of Bassila and from 35.665 inhabitants to 70.938 inhabitants for the commune of Copargo. Estimates of population data by the Ministry of Health indicate a population of 167.955 in the commune of Bassila and 97.068 in the commune of Copargo in 2020. The average size of a household in the commune of Bassila according to the investigations is 10.11 compared to 9.8 in the commune of Copargo. The galloping growth of the population is a determining factor in the occurrence of malaria. Thus, in the communes of Bassila and Copargo, this increase can be a factor favorable to the occurrence of malaria through the habits and lifestyle of the populations, the management of the environment and the living environment. It also leads to an anthropization of the environment, which results in a modification of the vegetation cover (deforestation), modifications of the hydrographic network (dams, irrigation, drilling) and urbanization.

Households with a high standard of living have the capacity to build houses or to make improvements that can facilitate the prevention of certain water-related diseases such as malaria, cholera, etc. The characteristics of the standard of living of the households surveyed in this research are perceived through the level of education, the sector of activity and the construction materials of the dwelling represented in **Table 2**.

Table 2 shows that 38% of the heads of households surveyed in the commune of Bassila and 40% in the commune of Copargo have no Formal Education, compared to 22% and 26% respectively who have at least a primary level of education in the same communes. These proportions of no formal education are not without impact on the knowledge, understanding and implementation of awareness messages in order to prevent and fight malaria effectively.

Agriculture remains the principal activity of the populations in both communes, with 51% of households surveyed in Bassila and 55% in Copargo. Trade ranks second (16%), followed by handicrafts (12%) in the commune of Bassila, while in Copargo, handicrafts (15%) rank second and trade (13%) rank third among the activities carried out by the population. The dominance of these three sectors of activity is explained by the fact that these are both rural communes that border Togo. Most of these activities are carried out informally, which reflects the low income of the population and their ability to effectively prevent malaria.

Table 2. Demographic characteristics of a household.

Features		Bassila		Copargo	
		Workforce	(%)	Workforce	(%)
Level of education	No Formal Education	72	38	77	40
	Primary	43	22	48	26
	Secondary cycle 1	34	18	23	12
	Secondary cycle 2	27	14	32	16
	University	15	8	11	6
Total		**191**	**100**	**191**	**100**
Sectors of activity	Agriculture	99	52	105	55
	Handicraft	23	12	27	14
	Trade	28	15	21	11
	Public	18	9	15	8
	Private	8	4	6	3
	Other	15	8	17	9
Total		**191**	**100**	**191**	**100**
Structure of the house	Hard	55	29	31	16
	Semi-hard	99	52	95	50
	Banco	37	19	65	34
Total		**191**	**100**	**191**	**100**
Roof of the house	Sheet metal	166	87	160	84
	Straw	11	6	23	12
	Dale	14	7	8	4
Total		**191**	**100**	**191**	**100**

Source: Field surveys, October-November 2020.

There is also a predominance of semi-hard structures (buildings) in both communes, 52 percent in Bassila and 50 percent in Copargo; Banco structures (34 percent) in the commune of Copargo versus 19 percent in Bassila; and hard structures (29 percent) in Bassila versus 16 percent in Copargo. As for roofs, those made of sheet metal (87% in Bassila and 84% in Copargo) were the most common during the investigations in both communes. These statistics confirm the low standard of living of the populations of the communes of Bassila and Copargo, making them more vulnerable to malaria risk.

As much as climatic conditions favor the development of malaria germs and pathogens, the lifestyle of the populations contributes to the proliferation of its vectors. Indeed, the periodic absence of sanitation around the houses, the erection of waste dumps near the houses, the absence of cesspools or the multiplicity of open-air cesspools, the type of shower characterized by the non-existence of cesspools to collect water to prevent it from stagnating, and the poor management of wastewater promote the proliferation of mosquitoes which can serve as a context for the vectors. The images in Figure 4 provide an overview of the management of the living environment in the communes of Bassila and Copargo.

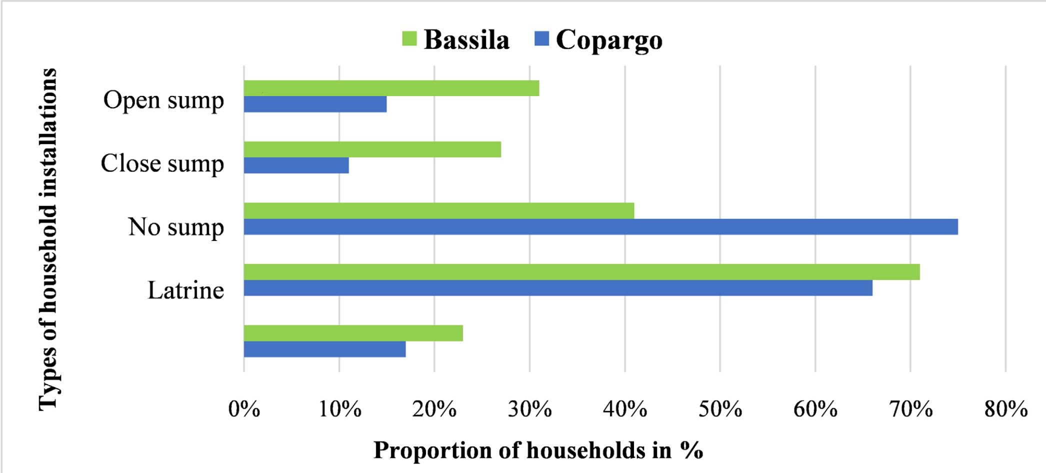
Figure 4. Panel A: 1.1 stagnant wastewater from a concession at Kparakouna in the Copargo district 1.2 wild garbage dump at Zongo in the Copargo district 1.3 Potential mosquito breeding area near Pioneer Camp in the Bassila district.

3.7. Stagnant Wastewater from a Concession at Allan in the Bassila District

Environmental management remains a challenge that requires the attention of both public authorities and the general public. This is necessary in order to eliminate all causes of unhealthy conditions that generate public health problems from the living environment. This must include domestic installations and fittings that reduce mosquito density and limit their activity. During our investigations, we encountered a number of such facilities. These included:

- the construction of cesspools to collect and channel wastewater;
- the installation of screens and curtains on doors and windows to restrict mosquito access to dwellings.

Figure 5 shows the types of sanitation facilities found in the households visited in Bassila and Copargo. It also illustrates the level of sanitation in the surveyed households.



Source: Field surveys, October-November 2020.

Figure 5. Level of household sanitation and facilities.

This figure shows that a high proportion of households (41% in Bassila versus 75% in Copargo) do not have cesspools for water drainage.

There are two types of cesspools: closed cesspools, which slow down mosquito breeding, and open cesspools, which are more favourable. Investigations revealed a low proportion of households with closed cesspools, particularly in the Copargo district (10% versus 27% in Bassila). Open cesspools were found in 32% of households in Bassila, compared to 15% in Copargo.

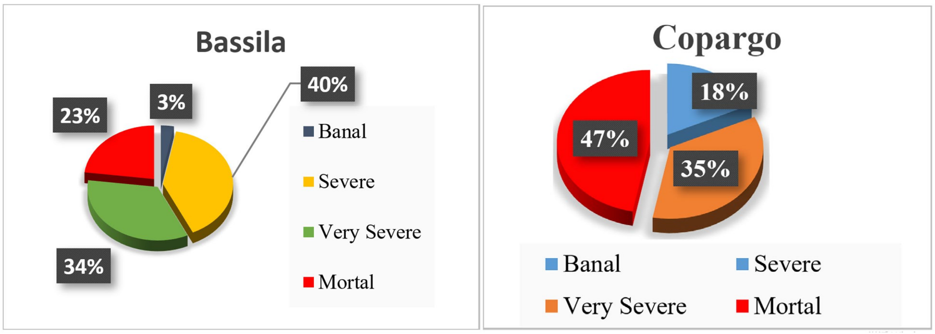
In conclusion, households with no cesspools or open cesspools are at a higher risk of contracting the disease as mosquitoes will find it easier to lay their eggs in the water, thus sustaining transmission.

There was also a low proportion of households in the two districts that had installed screens and curtains on their doors and windows (23% in Bassila versus 17% in Copargo), which makes it easier for mosquitoes to enter homes. Photo 2 shows the two types of pits: one open in Pénéssoulou and one closed in Copargo.

Shooting: Bécoudé, October-November 2020.

Figure 6. Panel B: Open pit at Penesoulou (1.1), closed pit at Copargo (1.2).

People's knowledge and experiences of malaria shape an image of the disease that could be described as perception. Effective prevention of malaria can therefore be conditioned by the population's perception of the disease. Figure 6(1.1) and Figure 6(1.2) show the perception of the populations of the communes of Bassila and Copargo on malaria.



(a) (b)

Source: Field surveys, October-November 2020.

Figure 7. (a) Perception of malaria by the population of Bassila; (b) People's perception of malaria in Copargo.

Figure 7(a) shows that 40% of the people surveyed in the commune of Bassila recognize malaria as a serious disease, 34% as a very serious disease, 23% as a fatal disease, and 3% as an ordinary disease. For 97% of the people interviewed, malaria appears to be a serious or even fatal disease.

Analysis of Figure 7(b) reveals that 47% of respondents in the commune of Copargo declared malaria to be a fatal disease, 35% a very serious disease, and 18% a serious disease. No respondent (0%) recognized malaria as a common disease.

3.8. Malaria Preventive Control Strategies and Malaria Cases Trends

Malaria transmission is only possible when *Anopheles* mosquito can reproduce and when the parasite can complete its life cycle in the body of the infected mosquito. This means that the mosquito must have good longevity to allow the parasite to continue its cycle and thus have a good vectorial capacity. Preventive control of malaria is an upstream control that consists of fighting the mosquito vector of the disease. Several preventive malaria control strategies are implemented in the communes of Bassila and Copargo. They fall into two categories: modern strategies and traditional strategies, which all aim to prevent the disease by focusing on the vector. The modern strategies refer to those promoted and distributed by national or international health programs based on scientifically validated interventions. These include Long-Lasting Insecticidal Nets (LLINs), Indoor Residual Spraying (IRS), and Intermittent Preventive Treatment with Sulfadoxine-Pyrimethamine (IPT-SP). In contrast, traditional strategies are local and community-derived practices such as the use of mosquito-repelling plants, smoke coils, herbal teas, and domestic fumigation, often based on ancestral knowledge and passed on orally.

Table 3 presents the malaria prevention strategies in the communes of Bassila and Copargo.

Table 3. Malaria preventive control strategies.

Municipalities	Modern preventive malaria control strategies			Traditional strategies			
	LLIN	**IRS**	**IPT/SP (dose)**	**Insecticide bombs, Smoke coils, Fences**	**Repellent plants**	**Fumigation**	**Herbal teas**
Bassila (%)	Yes (95%)	No (Absent)	Yes (81%)	Yes (BI: 58%; SF: 27%; G: 23%)	Yes (13%)	Yes (3%)	Yes (59%)
Copargo (%)	Yes (97%)	Yes (83%)	Yes (76%)	Yes (BI: 37%; SF: 15%; G: 17%)	Yes (9%)	Yes (5%)	Yes (42%)

Legend: Insecticide bombs: BI; Smoke coils: SF anti-mosquitoes; Fences: G. LLIN: Long-lasting Insecticidal Nets, IRS: Indoor Residual Spraying, IPT/IPT: Intermittent Preventive Treatment of Sulfadoxine Pirimethamine. **Source:** Field surveys, October-November 2020.

Table 3 shows that LLIN is the most widespread strategy, with 95% coverage in Bassila and 97% in Copargo.) It is complemented by IRS in Copargo, which covers 83% of households and is absent in the commune of Bassila. Endogenous means such as insecticide bombs, smoke coils, fences and plants used as repellents, for fumigation or even herbal teas by the populations were also identified in both communes. The most important observation is the habit of taking herbal tea to prevent malaria in both communes. In the communes of Bassila (59%) and Copargo (42%), the households surveyed have adopted this habit. Households frequently combined both approaches into practice.

3.9. Evolution of Malaria Cases

Figure 8(a) and Figure 8(b) show the evolution of malaria cases in the two communes.

(a) (b)

Source: DHIS2 health data 2011-2020.

Figure 8. (a) Evolution of simple malaria cases in Bassila and Copargo; (b) Evolution of severe malaria cases in Bassila and Copargo.

Figure 8(a) shows that in the commune of Bassila, the years 2013, 2014, 2018, and 2019 were years that recorded increases in malaria infestation of more than 10.000 cases. The increase in severe cases observed in Figure 8(b) occurred from 2013 to 2015 and from 2018 to 2019.

LLINs, the use of insecticide bombs and smoke spirals and endogenous means are the main means used in this commune. From 2011 to 2020, there have been four mass LLIN distribution campaigns at a rate of one distribution every three years (2011, 2014, 2017, 2020). Despite the LLIN distribution campaign organized in 2014, the number of cases increased by more than 20.000 compared to 2012 with the peak of severe cases (4355) recorded in the same year (2014). This can be explained through several hypotheses such as: populations using LLINs properly, populations adopted behaviors and habits that increased exposure to vectors, universal coverage not reached in LLINs, lack of sanitation, climate change, residual transmission, resistance of vectors to insecticides, etc. It should be noted that none of these strategies have been able to prevent an increase in cases. Also, between 2018 and 2019, there has been a drastic increase in cases (about 20.000) with the highest peak in 2019, but with fewer severe cases than the period 2013-2015. The use of LLINs alone as a vector control strategy may explain this as the net is only used during sleep at night (around 10 pm), yet populations spend time unprotected before this time or sometimes even sleep outside without protection. In 2020, there was a decrease in cases, both simple and severe, which can be explained in part by the recent distribution of LLINs (2020) which had a high coverage rate.

In the commune of Copargo, between 2011 and 2017, Figure 8(a) shows that there was a gradual increase in cases of simple malaria with a peak in severe cases in 2013 (Figure 8(b)). It is from 2018 onwards that there was a sharp increase in simple malaria cases (more than 7.000 new cases) but with a considerable drop in severe cases already from 2017, the year in which IRS started to be implemented in the said commune. Theoretically, associated with LLIN, the number of malaria cases should decrease but the opposite is observed except for severe cases in the commune of Copargo. This could be due to the behavior of the populations who either do not use the LLIN every time or properly, or stay outside for a long time in the evening without protection against vectors, etc. The distribution of LLINs and the implementation of IRS in the same year (2017) could be the origin of the decrease in severe cases and, by extension, in mortality, even though transmission is on the rise. In sum, vector control strategies aimed at controlling the vector and thus reducing malaria transmission in the communes of Bassila and Copargo have not achieved their objectives. It is thus clear that given the evolution of cases, these different malaria vector control strategies are facing difficulties that undermine their effectiveness. In addition, the difference in demographic weight, the case reporting system, the development of resistance and human factors may explain the difference in the number of cases between the two communes.

4. Discussion

Malaria in the communes of Bassila and Copargo is influenced as much by climatic and entomological factors as by socio-environmental factors which amplify the risk of infection. Thus, the populations are permanently exposed to the risk of malaria because of the endemicity of the disease. With an average rainfall of 1100 to 1400 mm, average temperatures between 26˚C and 28.5˚C and a relative humidity averaging 61%, these two communes offer favorable climatic conditions for the proliferation of vectors and the malaria pathogen. Through a study conducted by Yadouleton *et al.* (2013) and Tokponnon *et al.* (2023) [9] [13] in Copargo to identify the vectors present and estimate the level of transmission, these authors demonstrated that the anopheline density increases considerably during the rainy season and this increase is related to rainfall, which confirms the results produced by our work at the entomological research center of Cotonou. Diouf *et al.* (2015) [14] proved that the rainy season remains the most favorable period for the proliferation of malaria-carrying mosquitoes in Senegal. Moussa (2011) [15] in his work confirms that the main climatic factors that are rainfall, temperature and relative humidity are the key determinants of the proliferation and distribution of malaria vectors and pathogens. Rainfall cannot be dissociated from temperature, which is a factor controlling the development of mosquitoes both in water and on land and influences sporogony.

Malaria is closely linked to both climate and poverty. Tren (2004) [16] points out that malaria declined in Europe and America when living standards improved, swamp drainage reduced the number of mosquito nests, and mosquito nets and glass windows helped prevent bites. Households with a high standard of living have the opportunity to build modern houses with adequate facilities (cesspools, indoor toilets, screens on doors and windows, water pipes), purchase repellents, and use brewers.

The low standard of living of the populations of these two communes as reflected in the level of education, types of activities, and types and materials of construction constitutes an impediment to the control of malaria. Results from a cross-sectional study conducted by Ngatu *et al.* (2019) [17] on environmental and socio-demographic factors associated with household malaria burden in Congo showed that households with low monthly income, low literacy, and those who reported no periodic WASH intervention were more likely than others to report malaria cases. Also, a recent study conducted by Mutegeki *et al.* (2017) [18] among South African women also showed that low literacy was associated with a history of malaria. The level of education is an important indicator in the choice and adoption of means of prevention against different pathologies within the community (Kouassi, 2015) [19]. This is confirmed by 38% of the heads of households surveyed in Bassila and 40% of the heads of households in Copargo who have no formal education, which could contribute to a poor understanding or implementation of sensitization and recommendations. For example, 27% of heads of households in Bassila and 21% of heads of households in Copargo do not know how to properly maintain a mosquito net.

With 70% of the population in Bassila and 75% of the population in Copargo linking malaria to mosquitoes, 63% of the same population in Bassila and 66% in Copargo fear mosquito bites. For the rest (34% and 37%), it is rather the noise nuisance that disturbs them. Padonou (2012) [20] made a similar observation in the department of Ouémé in southern Benin. This finding is an argument that partly explains the resurgence of the disease due to the lack of sufficient individual measures to protect oneself from mosquitoes.

The living environment represents the environment in which communities live. Reciprocally, the health status of these communities is reflected through the living environment. With an environment characterized by a lack of sanitation, the absence of appropriate sewage collection pipes, and shower stalls that allow water to stagnate, it is logical that the populations are under threat from malaria. Adissoda (2008) [21] made a similar observation in the commune of Parakou where, according to the author, in addition to the climate parameters, the lifestyle of the populations contributes to the proliferation of vectors. Houndedji (2015) [22] in a study conducted in the commune of Ouidah followed the same logic, noting that a polluted environment, a total lack of hygiene, and practices and behaviors that run counter to the rules of hygiene constitute conditions favorable to the deterioration of the health of the population and expose them to malaria.

In the face of this disease, several means of fighting have been determined in the two communes. These include modern and traditional means. In terms of malaria prevention, the strategies are mainly directed towards vector control which targets the vector of the disease. Thus, LLINs, IRS, insecticide bombs, smoke spirals, sticks and local plants are present. LLINs rank first with 97% and 95% of LLIN coverage, respectively, in the two communes (Bassila and Copargo) and are the main malaria prevention strategy. These coverage rates are close to the administrative coverage rates in the Donga department (92.97%) reported by Aikon *et al.* (2020) [23] during the mass distribution campaign in 2020. These findings are in line with recent work by Filémon *et al.* (2023) [24], who reported that although LLIN ownership reached nearly 99% in the Cotonou V health zone during the dry season, the actual net integrity was often compromised, and usage varied according to environmental and structural factors (Filémon *et al.*, 2023) Similarly, the EDSB-V survey (2017-2018) had found in the same department in 2017, a 95% LLIN ownership rate of at least one LLIN by households. This high coverage rate is not synonymous with accessibility, which represents a valuable indicator of LLIN assessment. Indeed, 10% of the population of Bassila and 14% of the population of the commune of Copargo do not have access to LLINs. In the commune of Copargo, 27% of households and in the commune of Bassila, 24% of households have not reached the ratio of one LLIN for every two people according to our surveys. These proportions are different from the administrative coverage data reported in 2020 by the PNLP. Through a household survey conducted after the 2011 LLIN distribution campaign, Tokponnon *et al.* (2013) [7] made a similar observation in Donga department with LLIN coverage rates different from the administrative coverage reported by the health system. Koenker *et al.* (2018) [25] also demonstrated in a study on the evaluation of universal coverage with LLINs in 33 sub-Saharan African countries between 2005 and 2017, that a goal of 80% of households having at least one LLIN for every two people is not achievable at the national or even international level.

From the evolution of cases, it is easy to understand that the coupling of IRS and LLIN has not achieved the expected results. Despite 87.6% coverage in 2019 in the commune of Copargo, malaria transmission remained high (6.000 new cases). Similar patterns have been observed in Burkina Faso, where Namountougou *et al.* (2023) [26] reported persistent malaria transmission despite high LLIN and IRS coverage. They attributed this persistence to changes in mosquito behavior and physical deterioration of nets. The same observations were made by Akogbeto *et al.* (2020) [8] in all regions of Benin that benefited from the intervention. The results of a study conducted by Makoutodé *et al.* (2015) [26] in the septentrion concluded that the implementation of IRS coupled with LLIN in highly endemic areas would significantly reduce malaria cases if certain implementation conditions were met. However, the ineffectiveness of this combination in the commune of Copargo may be due to the failure to meet certain conditions.

The use of coils (anti-mosquito spiral) as a means of protection against malaria vectors is observed at 58% in Bassila and 37% in Copargo. In a study conducted by Dansou and Odoulami (2015) [27] in the commune of Pobè in southeastern Benin, it was observed that 68% of survey households used anti-mosquito coils. Still according to the same authors, the work of Carnevale *et al.* (2012) [28] notes that they have an irritating effect on the mucous membranes (coughing) and are annoying due to certain products resulting from their combustion. This confirms that their use presents health risks. According to Lukwa and Chiwade (2008) [29], the use of spirals is not considered to have a protective effect against malaria. In view of its heavy use to curb nuisances in our communities, further evaluation of its use as a means of protection against disease vectors is needed.

Traditional strategies such as mosquito control in rooms and fumigation with plants are considered archaic practices by young people and are adopted exclusively by the elderly and women living in poverty, according to Djame *et al.* [30]. This was confirmed in the communes of Bassila and Copargo through the low proportions (13% and 3% in Bassila and 9% and 5% in Copargo) of households using these practices. These results differ from those of Dansou and Odoulami (2015) [27] who report a rate of 52% of households in the commune of Pobè in southeastern Benin using so-called "natural" plant-based repellents to drive away or kill mosquitoes. However, they agree on the low persistence of repellents and the risks of skin reactions.

Half of the households visited showed an interest in taking herbal teas to prevent malaria. These results confirm the work of Tajbakhsh *et al.* (2021) [31] who conducted an analysis on the interest and need for the use of African plants in the fight against malaria. Out of a total of 200 research articles identified, the majority of which were conducted in Nigeria, a neighboring country of Benin where practices are similar, the analysis revealed the use and research of plants with antimalarial properties. 502 species of plants had been identified on the African continent as seeking indigenous solutions to the problem of malaria. The same analysis concludes that efforts must be made to take better account of the practices of populations in the fight against malaria.

Several determinants are involved in malaria transmission, but the factors amplifying the recrudescence are man and his actions. Thus, limitations have been noted in the implementation of these proposed means of control, which alone cannot be effective in these communities. No preventive means alone can ensure total protection. Diallo (2018) [32] points out that, to be effective, it is necessary to insist on the simultaneous observance of protective measures against mosquito bites. The net, to be effective, must be properly and continuously used but supplemented with IRS in highly endemic areas if resources allow. The high cost of IRS may limit its widespread use and sustainability, which explains its absence in the commune of Bassila, which is one of the largest in the country [33].

5. Conclusions

Malaria transmission results from a combination of several determinants. This study presented the different factors that favor malaria in the communes of Bassila and Copargo.

Through the ecological environment they offer to vectors and parasites, climate parameters have a role in the occurrence of malaria but are not the only determinants in the communes of Bassila and Copargo. While natural and entomological factors are favorable, the standard of living, the living environment, and the perception and behavior of the population contribute greatly to the ineffectiveness of malaria vector control strategies, which is illustrated by the increase in cases.

Author Contributions

TTF, KWRBBN, AA RO, AS, GGP, TA, and MA participated in the development of the protocol, oversaw its implementation, and wrote the article. AS, KWRBBN participated in data collection. TA and MA supervised all the work and the writing of the final document.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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