Natural Basis for the Proliferation of Malaria Vectors in Northern Benin (West Africa)

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Abstract: Background: Malaria transmission is based on four essential elements: the vector, the parasite, humans and the environment. However, of the four elements, the environment is not sufficiently exploited. Methods: In the research presence carried out in 6 localities in North Benin, we used a microscopic vision of the health geographer, focusing on certain components of geography, entomology and meteorology to show what to show spatial disparities in malaria transmission using Arcgis 10.4, Global Mapper and SPSS 21.0 for regression and correlation analysis. Results: The results of our research show that the slopes are unstable. Also, the lower the altitude, the lower the water kinetics and consequently a lot of water stagnation favourable for the development of mosquito breeding sites. The explanatory power of the regression model means that 54.3% of the variation in positive mosquito breeding is explained by human population density. Conclusions: Benin must make significant progress in the elimination of malaria using a new effort to understand the ecology of vector mosquitoes based on spatial disparities in the fight against malaria.

Keywords: GIS, Climate, *Anopheles gambiae* (s.l.), Vector Control, Benin

1. Introduction

Malaria is caused by the *Plasmodium* parasite and transmitted by mosquito vectors of the *Anopheles* genus. The parasite and the vector that sustain malaria transmission require precise environmental conditions.

Malaria is limited to tropical regions, affecting more Sub-Saharan African countries where distribution of it transmission risk is unequal [1].

Therefore malaria result from the complexity of the relationships between parasits, hotes and environment.

[2] Various anthropogenic factors underline the spatial distribution of the risk of malaria transmission. It has previously been determined that agricultural and hydraulic developments, human mobility, forms of governance and urbanization may favor malaria transmission [3]. For example, infrastructure developments such as dam lakes, sanitation canals, and flooded rice paddies, increase the number of breeding sites of *Anopheles* mosquitoes.

The physical geography of northern Benin is a significant bedrock for the proliferation of malaria vectors in some areas: for example, rice farm areas and vegetable gardens, which were once not wet enough for permanent malaria

transmission, are affected [4]. In northern Benin, malaria cases have increased in high-altitude areas, previously unaffected by the expansion of rice farming [5]. Moreover the presence of woodland and wooded savannas, hitherto too shady allows the development of the *Anopheles* larvae. These environment changes modify the spatial distribution of malaria vectors and extend the number of malaria transmission risk for months.

Anopheles mosquitoes were known to be associated to rural areas and hence, theoretically less common in urban areas [6]. In practice, the adaptation of certain species to urban areas and the practice of market gardening in or around the major agglomerations are at the origin of the persistence of anopheline populations in the city. The risk of malaria transmission is heterogeneous and varies over time. There is a great variation of risk within the same zone, even only a few kilometers away. The transmission varies over time according to the seasons but also according to the years depending on the level of climatic events. This study is initiated to investigate the physical basis of the distribution of malaria vectors in northern Benin in order to help the Ministry of Health to design better control strategies.

The slope is often qualified to participate in the description of natural sites such as mountains, hills, streams, canyons, banks, etc., either human constructions such as roads, railways, aqueducts, roofs, and pedestrian ways [7]. The slope of the ground is one of the essential parameters of the flow of the water in the rivers and more generally, the gravitational flow [8]. The slope can be a natural constraint for human settlement: it can be the scene of landslides, avalanches or landslides.

The purpose of these maps is either to prevent existing risks or to prevent the installation of new sources of danger [9].

2. Materials and Methods

2.1. Study Area

The study area covers the departments of Donga (Djougou, Ouake, Copargo health zone) and Alibori (Kandi, Gogounou, Segbana health zone). The municipalities of Djougou, Copargo and Ouaké are located between 9 ° 18'37 "and 10 ° 4'44" north latitude and between 1 ° 19'27 "and 2 ° 13'55" east longitude. The municipalities of Gogounou, Kandi and Ségbana are located between 10 ° 27'56 "and 11 ° 42'9" N north latitude and between 2° 8'39 "and 3° 54'20" longitude East.

2.2. Mapping Method Used

The following data was used:
1) The 19252, 19253, 19153, 19152, 19353, 19254 and 19254 Landsat OLI TIRS ortho-rectified satellite images respectively of July 2015 with a resolution of 30 m.
2) The 2000 SRTM DEM satellite image, enhanced on June 26, 2009 with a resolution of 30 m

3) The slope map is based on a digital terrain model with a resolution between 1 and 25 meters.

The GIS software, map processing and images used are respectively ArcGIS 10.3, Global Mapper v15. The laptop, scanner and digital camera facilitated the collection, archiving and processing of data. The topographic slope is the tangent of the slope between two points of a terrain, and therefore its angle to the horizontal [10].

We determined the density of the population by boroughs by dividing the number of inhabitants of the borough by its area expressed in square kilometers.

The demographic data and their area of the districts of the Alibori and Donga health zones came from the final results of the fourth General Population and Housing Census (GPHC4) of National Institute of Statistics and Economic Analysis (NISEA) and National Geographical Institute (NGI).

2.3. Statistical Analyzes

The global significance of the model and the regression coefficients are displayed according to the values of the two statistical tests: the statistical test (F) and the student test (t). The calculated values of these two statistical tests are given by SPSS 21 software. Five main variables are considered in this section. These are positive larval breedings, population density, topographic slope, elevation and temperature.

2.4. Mapping of Land Use and Adult Mosquito Collections Methods

Landsat image analysis consists of six steps: acquisition and pre-processing of data (choice of sites studied and preparation of data for the next steps), color composition, maximum likelihood classification, vectorization, validation, and analysis of results.

3. Results

3.1. Influence of Altitudes in the Sanitary Zones

Figure 1 is the altitude representation of the KGS and DCO sanitary zone. In Alibori department (Figure 1 a), the altitude varies from 185 to 408 m with a drop of 223 m. The high altitude localities exist in all districts of the sanitary zone. In Angaradebou, district of Kandi the altitude gradient is oriented South-North. Areas of low altitude are located in the North and those of high altitudes in the South of the localities concerned. However, the higher the altitude values, the more the terrain slopes and more the kinetics of the water is high; there is therefore a strong runoff of water.

Similarly, the lower the altitude value the lower the kinetics of water. As a result, infiltration followed by water stagnation support the development of mosquito breeding sites.

The terrain is rugged with the predominance of a plateau which extends from Kandi to Gogounou. From an altitude of 200 to 300 m, it is limited to the East by the valley of Sota and to the West by the valley of Alibori. The entire plateau slopes slightly towards the Niger valley. The morphology of

the relief includes a series of cuesta with flat tops coated by ferruginous sandstone.

As for the DCO health zone, the altitude varies from 295 to 644 m with a drop of 349 m (Figure 1 b). The high altitude zone forms a line crossing the localities of Copargo, Pabegou, Singré, Komdè, Tchalinga, Barei, Bariénou and Pélébina of the health zone. From theses localities, waters are drained towards their outlets which constitute the humid zones favorable to the proliferation of mosquitoes in the sanitary zone (Figure 1b). The kinetics of water in the district of Ouaké is strong, which means that runoff outweighs stagnation or infiltration. Consequently, the development of mosquito breeding sites is reduced in this district compared to other within the same department.

In total, it can therefore be deduced that the majority of the populations of localities of Donga and Alibori, notably those of Copargo, Bariénou, Komdè, Tchallinga, Sèmèrè II, Singré, Anadana, Djougou 1, Sonsoro, Sam, Ouèrè, Ségbana, Libantè, Liboussou and Kandi I are most exposed at risk of malaria transmission.

In the Donga, there is a watershed, the highest point of the relief that drains the waters to both sides. On the other hand, in the Alibori, several high points have been identified draining the mosquito larvae breeding grounds in several regions.
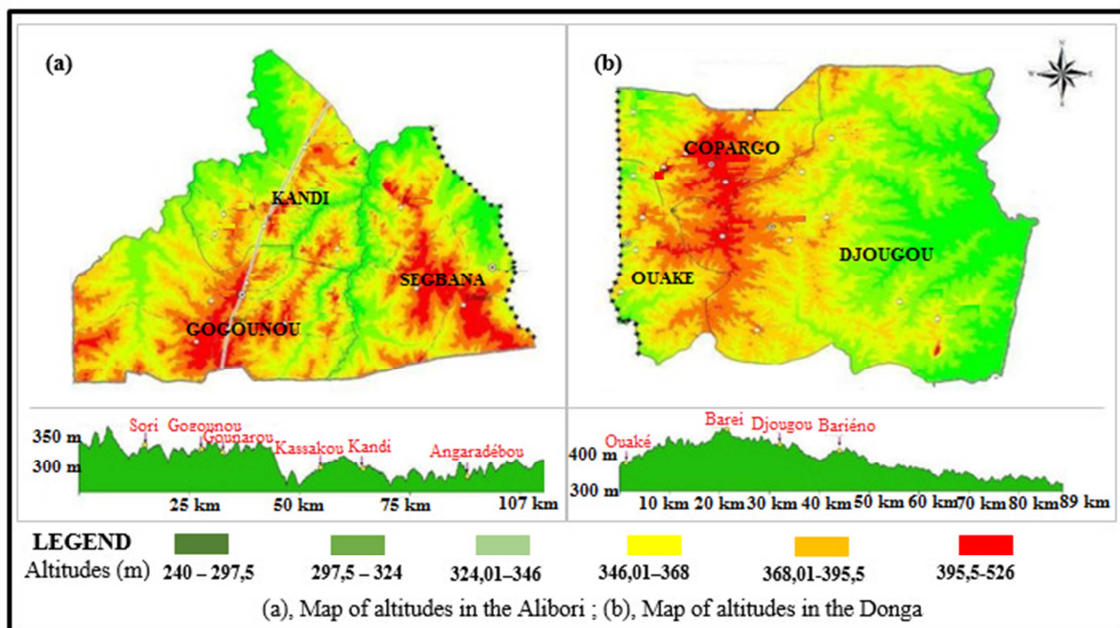

Figure 1. *Map of altitudes in study zone.*

3.2. Comparative Study Between Positive Larval Breedings and the Physical Parameters of the Area

From table 1, it appears that the average number of positive larval breeding per borough required is close to 844. In these results, the standard deviation is 124.981. With normal data, most of the observations are based on nearly 7 standard deviations on each side of the average Anopheles mosquito breeding site. Similarly, the average density of its population is around 247.27 hts / km2, which produces the average standard deviation of 288.549. These normal data reveal that most of the observations are less than one standard deviation side of the average population density. In addition, with normal temperature data, most observations are divided into 5 standard deviations on each side of the mean temperature. The high standard deviation of positive larval breeding indicates that these variables are more widely dispersed than the density of the population.

From the analysis of the correlation matrix below, it is noted that there is a significant linear correlation (1%) between the positive deposits of mosquitoes and the density of the human population. On the other hand, no correlation at 1% is significant between the positive deposits of mosquitoes and the other parameters (Table 2).

The equation of the multiple regression model is as follows: $Y = a + bx + cy + dz + e\beta$, so

$PosLB$ = 1012.293 + 2.873 DensPop – 1.799 Alt + 10. 56 Slope – 12. 106 Temp. (Table 3).

This regression model shows the number of mosquito larva positive hosts equals 1012 by boroughs when the value of the other parameters is zero. In addition, Table 4 shows that the calculated Fisher statistic is 5.563. This statistic is read at the threshold of 0.002 or 0.2%. This threshold is well below the critical threshold of 1%. So the model is globally significant.

The explanatory power of the R-Square adjusted model = 0.543 or 54.3%. This means that 54.3% of the variations in positive mosquito breeding are explained by the density of the human population. The remaining 45.7% are explained by other variations that were not included in the model (Table 3).

Table 1. *Descriptive statistics of variables.*

Variables	Average	Standard deviation	N
Positive larval breeding	844	124.981	
Population Density	247.27	288.549	
Altitudes	416.27	10.447	33
Slopes	22.5824	17.40925	
Temperature	30.39	5.95	

Data source: Data of André Sominahouin

Table 2. *Analysis of the bivariate correlation of the variables.*

		PosLB	PopDens	Alt	Slopes	Temperature
PosLB	Correlation of Pearson	1	0.652*	0.082	0.115	0.161
	Sig. (bilatérale)		0.000	0.649	0.525	0.372
	N	33	33	33	33	33
PopDens	Corrélation of Pearson	0.652	1	0.045	-0.115	0.029
	Sig. (bilatérale)	0.000	-	0.802	0.524	0.871
	N	33	33	33	33	33
Altitudes	Corrélation of Pearson	0.082	0.045	1	-0.076	-0.189
	Sig. (bilatérale)	0.649	0.802	-	0.674	0.292
	N	33	33	33	33	33
Slopes	Corrélation of Pearson	0.115	-0.115	-0.076	1	-0.053
	Sig. (bilatérale)	0.525	0.524	0.674	-	0.768
	N	33	33	33	33	33
Temperature	Corrélation of Pearson	0.161	0.029	-0.189	-0.053	1
	Sig. (bilatérale)	0.372	0.871	0.292	0.768	-
	N	33	33	33	33	33

Table 3. *Coefficients of the regression correlation.*

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		A	Std Error	Beta		
1	(Constante)	1012.293	2179	-	0.466	0.645
	Population Density	2.873	0.610	0.675	4.713	0.000
	Altitudes	-1.799	2.862	-0.091	-629	0.535
	Slopes	10.560	16.663	0.091	0.634	0.531
	Temperature	-12.106	49.020	-036	-0247	0.807

Table 4. *Model Summary of the analyze de regression.*

Model	R	Ajusted R-square	Variation of F	df	Sig. Variation de F
1	0.665[a]	0.543	5.563	4	0.002

4. Discussion

The results presented in this study show that the topography of the KGS and DCO health zones have biophysical characteristics favorable to the development of mosquito vectors of malaria. The unevenly distributed vegetation is characterized by a strong presence of water and develops on a hierarchical spatial structure. This is indicated by the dominance of the open forest and the co-dominance of gallery forest, tree and shrub savannah and wooded savanna. This finding confirms Hoffman's (1985) report that species dominance is the key difference between disturbed and natural environments in the Sudan savannah zone [13]. Plant formations are fragmented at various levels not only by anthropogenic factors [14] but also by several natural (non-anthropogenic) factors. It can therefore be deduced that the biophysical base contributes greatly to the multiplication of vectors and that the vegetal formations of the classified savannas are wet and in the process of being grown with enough mosquitoes.

The weak rainfall patterns and annual rainfall in the KGS health zone confirm the influence of the Sahelian climate in the extreme north of Benin. This is related to the proximity of the Sahelian zone under constant continental flows of dry air from the Egyptian-Lybian anticyclone. These results are comparable to those of Houndénou and Hernandez [15], Houndénou [16], Vissin [17], and Totin et *al* [18]. The number of tasks is relatively high for all plant formations except for the clear forest in the classified forests of Kétou, Ouémé-Boukou and the open forest and grassy savannah in the classified forest of Dogo [19].

According to Saunders et *al*., [20], forests will be more vulnerable to human activities when the number of tasks is high.

Through June 2014, there were 17 published studies that have used geospatial technologies (GIS, GPS and/or RS) to understand and predict malaria risks [21-32], develop malaria risk maps, [32, 33] and provide findings for targeted interventions strategies in Bangladesh. To supply feedback to

the National Malaria Control Program (NMCP), national malaria risk maps were produced [13, 34]. Long-term average monthly rainfalls and minimum/maximum temperatures ranges were interpolated, and elevation and vegetation coverage data were obtained using satellite imagery. GIS was also employed to develop maps of posterior distributions of predicted prevalence [30].

Our work is consistent with that of Jaissa Man realizes in 2017 which showed that mosquitoes are one of the most prevalent and troublesome menaces that come with rains in India. This is a particularly rampant problem in places like Bengal, Karnataka, Maharashtra, Tamil Nadu, and areas towards the North East as these environments are favourable for mosquito breeding. Yet, other areas too, witness issues like stagnant water and poor drainage, which also cause mosquitoes to multiply.

In addition, the study area of Alibori is essentially based on its specialization in cotton cultivation (Northern Benin Cotton Zone). This area is watered by several tributaries of the Niger River and is influenced by the continental trade wind as early as November. This favors the prevalence of *An. gambiae* s.l main vector of malaria in the department.

With the abundance of malaria vector breeding sites in the districts where the Benin NMCP extended IRS, Geographic Information System and Remote Sensing can be used to monitor vector's oviposition site/breeding ground and thereby predict their abundance. There has been a proliferation of some vector species in those districts with extended IRS with an increase in stagnant water, particularly during the rainy seasons, from deforestation for agricultural purposes, providing more breeding sites for the mosquitoes [35]. It has been noted that during the dry and malaria off-seasons, cases were found clustered around natural streams and canals in the Chittagong Hill Tracts region [34]. Locating land use patterns across the vector breeding sites and using remotely sensed climatic environmental data, particularly temperature, humidity, and rainfall as they correlate to malaria outbreaks, could provide useful information on the planning of vector control in this region. This same approach was applied in Indonesia and revealed malaria vector abundance in certain areas where malaria control programs were then implemented with significant success [36]. The topographic variable can also be remotely-sensed to predict malaria vector's breeding site in malaria endemic areas [37].

Our results are consistent with those of Tadesse et al in 2011 showing the influence of the physical characteristics of the larval habitat. In fact, the results of the multiple regression analysis showed that vegetation, water transparency, precipitation, and fauna were more important in explaining *Anopheles*' larval abundance than other variables. On the other hand, the nature of the bottom surface and the microhabitat were more important in determining the *Culex* larval density than the transparency of the water.

5. Conclusion

The fight against malaria vectors must no longer ignore

cartography, a real information and decision-making tool for predicting malaria risks. GIS techniques and other additional interventions are then capable of reducing residual malaria transmission in order to target vectors that escape the main control tools.

In order to eradicate malaria in these high-risk areas, it is recommended to make sufficient use of environmental aspects, to asphalt these areas in order to clean up and improve the living environment of the populations.

Ethics Approval and Consent to Participate

Consent for Publication

Not applicable.

Availability of Data and Materials

The data used and/or analysed in this study are available from the corresponding author on reasonable request.

Competing Interests

The authors declare that they have no competing interests.

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Authors' Contributions

AS, MCA, RA, SL, RO, GGP conceived the study. AS, MCA, BA, FT, ASS have participated in the design of the study. Entomologic data was collected by AS, RL, ASS, FT, CH and laboratory analysis was carried out by AS, BA, FA. AS drafted the manuscript.

Statistical data analysis by BA. FD, FT, RO, and ASS critically revised the manuscript for intellectual content. All authors read and approved the final manuscript.

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