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Ecological and anthropogenic determinants of malaria vector spatio-temporal dynamics in southern Côte d'Ivoire

Déterminants écologiques et anthropiques de la dynamique spatio-temporelle du vecteur du paludisme dans le sud de la côte d'ivoire

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Abstract:

Malaria is one of the most important health problems at global scale related to a single bite from a malaria-bearing mosquito. Various initiatives are under way for its elimination. As a contribution, this paper elaborates on the main reasons for rural community complaints about mosquito nuisance in order to produce baseline data useful for the understanding of the issue raised. Exhaustive visual inspections were made to identify and count larvae using dipping and pipetting methods. Probability sampling method was used for household surveys. The geographical location of the study area coupled with the socio-economic activities of the community sustains the development of mosquito larvae habitats source of mosquito density increase. The resurgence and intensification of mosquito nuisance in the time periods 2000-2005 and 2010-2015 are related to large-scale agricultural activities. The weak Pearson correlation coefficient (0.29) shows that mosquito do not have preference between man-made and natural habitats. However, Aedes (75%), Anopheles (56.5%) and Culex (45.5%) mostly prefer temporal habitats to lay eggs. The complaints of rural communities are related to their unawareness of mosquito life cycle.

Résumé:

Le paludisme est l'un des grands problèmes de santé à l'échelle mondiale lié à une simple piqûre de moustique vecteur de paludisme. Diverses initiatives sont en cours pour son élimination. En guise de contribution, cet article élucide les principales causes des plaintes des communautés rurales au sujet des nuisances de moustiques dans l'optique de produire des données de base utiles à la compréhension du problème en question. Les prospections larvaires exhaustives ont permis de compter les larves par les méthodes de dipping et pipette Pasteur. La méthode d'échantillonnage probabiliste a été utilisée pour les enquêtes ménages. La situation géographique de la zone d'étude couplée aux activités socio-économiques des communautés explique le développement des gîtes larvaires à la base des fortes densités de moustique. La résurgence et l'intensification des nuisances de moustiques au cours des périodes 2000-2005 et 2010-2015 sont liées aux activités agricoles de grande envergure. Le faible coefficient de corrélation de Pearson (0,29) atteste que les moustiques n'ont pas de préférence entre les habitats artificiels et naturels. Néanmoins, les *Aedes* (75%), les *Anophèles* (56,5%) et les *Culex* (45,5%) préfèrent pondre leurs œufs dans des habitats temporaires. Les plaintes des communautés rurales relèvent de leur ignorance du cycle de vie du moustique.

Keywords / Mots clés

Malaria vector, population awareness, GIS, health geography, Côte d'Ivoire
Vecteur de paludisme, conscientisation de la population, SIG, géographie de la santé, Côte d'Ivoire

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BACKGROUND

As HIV/AIDS, malaria is one of the most important health problems at global scale (WHO, 2004): 3.2 billion people are at risk for malaria. In 2015, it was estimated 214 million new cases (uncertainty range: 149 - 303 million); leading to 438 000 malaria-related deaths (uncertainty range: 236 000 - 635 000) worldwide; deaths in children under 5 years was 306 000 (uncertainty range: 219 000 - 421 000). Malaria is endemic in 97 countries, particularly in sub-Saharan Africa were 90% of all malaria deaths are recorded (WHO, 2015).

Face to this global threat, wide-ranging actions were undertaken: (i) the Roll Back Malaria initiative with the goal of halving the global burden of malaria by 2010 was created in 1998 by international institutions;

two years later, the Abuja Declaration on Roll Back Malaria in Africa was signed by African leaders with the objective of reducing malaria mortality by 50% on the continent by the year 2010 (WHO, 2016); (ii) as of 2014, US$ 2.5 billion are annually invested for malaria control in the world. This should increase to US$ 7.7 billion by 2025 (WHO, 2015).

As a result of the global commitment, malaria mortality rates have declined by 60% globally, since 2000; almost the same rates among children less than 5 years (WHO, 2016). On the basis of this global progress in malaria control, efforts have to be maintained as disparities still exist at country level and may reverse the trend. In so doing, several strategies are used for malaria vector control in Africa. Most of ongoing researches on malaria prevention and control focus on (i) collection, storage, harmonization and exchange of data; (ii) development of effective malaria vector control methods such as Long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS); (iii) cost-free distribution of insecticidal nets and insecticides to population, access to diagnostic testing and treatment, larval source management, etc. (WHO, 2012; WHO, 2013; WHO, 2015).

Effectiveness of these strategies is mostly based on the identification of productive larval habitats related to physical environment and human activity. In Côte d'Ivoire where malaria rates are estimated to 33% of all deaths (Kimou, 2010), there is a high need of understanding the spatial dynamics and patterns of mosquito breeding sites. In view of this, a number of entomology-GIS based field investigations were conducted to understand the complaints of Chiépo (southern Côte d'Ivoire) inhabitants about mosquito-related nuisance increase. The field workflow is based on the hypothesis that ecological and anthropogenic determinants are the guiding threads of mosquito nuisance increase. Therefore, this paper elaborates in details on these determinants responsible for the development of mosquito breeding habitats in the study area. The outputs shall contribute to gather baseline data useful to ongoing vector control activities.

CONCEPTUAL FRAMEWORK

Factors determining malaria incidence

There are enough scientific results that demonstrate the existence of relationships between environmental factors such as precipitation, temperature, insolation, water resources, topography and malaria incidence in populations (Bruce-Chwatt and Zulueta, 1985; WHO/RBM, 2001; Rogers et al., 2002; Hernández-Avila et al., 2006; Ernst et al., 2009; Some, 2010; Lowe et al., 2013; Texier et al., 2013) : ecological factors influence malaria transmission and epidemiology (Texier et al., 2013); meteorological factors such as temperature is the major factor influencing the development of mosquitoes and malaria parasites; water-related factors ensure the development of suitable breeding habitats (Casman and Dowlatabadi, 2002), etc. Moreover, human-related activities are also responsible for the propagation of malaria (Hernández-Avila et al., 2006; Casman and Dowlatabadi, 2002).

Population awareness of malaria

Malaria awareness of the at-risk population is one of the key determinant factors in the progress of malaria elimination (Klein et al., 1995; Rodríguez et al., 2003; Nganda et al., 2004). Very often half of the population has insufficient malaria knowledge. A study conducted by Tang et al. (2016) showed that 48 % of population in rural China has insufficient malaria knowledge. India has similar problem with 43.7 % of its population with poor malaria awareness (Yadav et al., 2014). This percentage is lower when considering the part of population that are aware of the causes and the major symptoms of malaria (Yadav et al., 2014; Tang et al., 2016).

HYPOTHESIS

Based on (i) the geographical location of the study area in southern Cote d'Ivoire, (ii) the rural communities' socio-economics activities and on (iii) the fact that mosquito naturally develop according environmental and man-made determinants, the current study assumes that the rural communities' complaints about mosquito nuisance increase in Chiepo is related to their poor malaria awareness.

MATERIALS AND METHODS

Study area

Chiépo sub division is part of Divo department, located in southern Côte d'Ivoire (figure 1). As regards climatic conditions, it is a warm and humid area with an average annual rainfall reaching between 1200 and 1700 mm spread over rainy seasons (Apr.-Jul.; Sept.-Nov.) and dry seasons (Dec.-Mar.; Jul.-Sept.);

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the relative humidity is 85%; the mean annual temperature is 26.9°C (temperature range of 3.2°C); the annual solar radiation ranges from 1800 to 2000 hours (Kalms and Kesse, 1977).

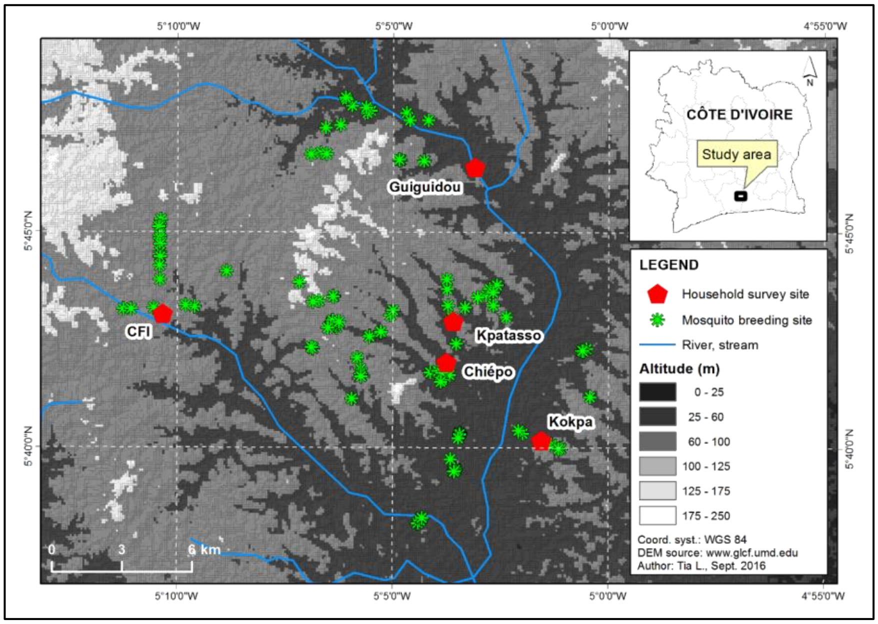


Figure 1: Geographical location of the study area

The relief is fairly flat with ferralitic coastal plains (0-200 m) propitious for swampy lowland and floodplain ecosystems. The soils are well drained with clay texture, rich in feldspar (Mangenot, 1955). The area is drained by the Gô and Gogny rivers and their tributaries. Two hydro-agricultural dams (120000 m3 and 350000 m3) are constructed on the Gô River on behalf of the Guiguidou rice-growing project.

The main forms of natural vegetation belong to the guinean region rich in species such as Terminalia ivorensis, Khayaivorensis, Chlorophoraexcelsa, le Tiéghémellaheckelii, Triplochitonscleroxylon, etc. (Guillaumet and Adjanohoun, 1971).The area is dominated by forest relics as results of intense anthropogenic activities which reduce the vegetation cover to fallow shrubs and tiny forest plots.

The 27757 inhabitants of Chiépo sub division (Projection from RGPH, 1998) consist of autochtons (Didas de Ménéhiri), non-natives (Baoulé, Akyés, Agny, Wê, Avicam, etc.) and foreigners from ECOWAS. Growing cash crops (coffee, cocoa, rubber, oil palm, coconut…), food crops (plantain, rice, maize, cassava…), vegetable crops (ginger, pepper, lettuce, cabbage, black pepper, tomato, onion…), food gathering (orange, mango, papaya, avocado, kolanut, lemon, mushrooms...), livestock and fisheries, traditional crafts are currently among the main economic activities within these communities.

Study sites selection

The choice of the villages and the households was based on the judgmental sampling method: permanent resident household heads above 18 years of ages were chosen; villages were chosen according to human activities and landscape ecology (table 1).

GIS-entomology field survey

The interdisciplinary GIS-Entomology team conducted exhaustive basic and short-term (two weeks) field surveys. The method aimed at detecting potential mosquito breeding sites and quantifying accurately mosquito larval density. The surveys emphasized on larval habitats, mostiquo genus identification, density dynamics, ecological and anthropogenic parameters, etc. Mosquito larvae genus were identified by the Entomologist and recorded by the GIS specialist on GIS-Entomology field survey forms (table 2) together with the spatial reference (use of a GPS Garmin eTrex 10) and description of the breeding site at a given locality.

- Larvae counting equipment
Topographical map and motorbike to get around
GIS-Entomology data sheets

Locality name	Characteristics
Chiépo **UTM - WGS 84, Zone 30 N** **Coord.: Lat. 629878; Long. 271618**	▪ Head of sub division ▪ Highest number of inhabitants ▪ Presence of basic infrastructures ▪ Presence of cash crops (large-scale coffee, cocoa, coconut plantations, oil palm, rubber, etc.) ▪ Intense commercial activities ▪ Presence of fish ponds
Kokpa **UTM - WGS 84, Zone 30 N** **Coord.: Lat. 627105; Long. 272055**	▪ Important lowlands ▪ Large number of swamps in rainy season ▪ Large number of fish ponds
Kpatasso **UTM - WGS 84, Zone 30 N** **Coord.: Lat. 671261; Long. 272074**	▪ Presence of rubber and cocoa plantations ▪ Very few complaints about mosquito nuisances ▪ Chosen for comparison purpose
Guiguidou **UTM - WGS 84, Zone 30 N** **Coord.: Lat. 638274; Long. 272475**	▪ Presence of an agro-management project ▪ Two hydro-agricultural dams on the river Gô ▪ Development of irrigated rice perimeters (443 ha)
CFI **UTM - WGS 84, Zone 30 N** **Coord.: Lat. 632816; Long. 259511**	▪ Large-scale oil palm plantations for more than 30 years now

Source: Field investigations, 2015

Table 1: Characteristics of the localities selected for household surveys

Pairs of gloves and boots for protection
Dipper 350 ml,
Fine strainer
Larval Container,
Plastic Pasteur pipette 3 ml
Plastic water container 6 L
A digital camera (for sites description and illustration);

- Breeding site inspection

The dipping and the pipetting methods were used to sample from artificial containers, large water bodies (rice fields, streams, swamps, ditches, etc.) and small breeding sites (cocoa pods, puddles, hoof-prints, containers, etc.) because they are the most common methods (Goddard, 2012; Williams and Pinto, 2012). Visual inspections were made to count larvae. At each potential breeding site, the metallic dipper 350 ml was used to collect water in a careful manner to avoid larvae dive beneath the surface; a fine metal strainer was used to collect larvae in muddy or troubled water. In this case, the contents of the strainer were washed into small plastic containers 6 L and larvae were counted. The appropriate number of dips were taken from each breeding site and reported on GIS-Entomology data sheets. The same entomologist conducted the entire survey in order to reduce biases in sampling and larvae counts.131 potential breeding sites were inspected in two weeks' time during the short rainy season (Sept. 2015).

The characteristics of each potential breeding site were recorded, namely: type of breeding site (permanent, semi-permanent, temporal); origin of water (man-made, rain); nature of the water (puddle, rice field, and ditch); characteristics of water (dark, clear, sunny, polluted, and turbid); ecological parameters (vegetation type, landform, elevation, etc.); type of human activity (rice fields, cash crops, traditional crafts, etc.).

Estimation of larval density

The estimation of larval density (D) was based on the formula (Belkin, 1954):

$$D = \frac{TLP}{ND\ x\ V}$$

Three indices were computed as follows (Belkin, 1954; Williams and Pinto, 2012):

-*Mosquito Breeding Index (BI)*:

$$BI = \frac{TLP\ x\ BP}{ND}$$

- *Absolute Breeding Index (ABI)*:

$$ABI = \frac{BPsp}{BP}$$

- *Relative Breeding Index (RBI)*:

$$RBI = \frac{BPsp}{BPp}$$

Where TLP is the total number of larvae and pupae taken, ND is the total number of dips counted, BP is the total number of breeding sites surveyed, BPp is the total number of positive breeding sites and BPsp is the total number of breeding sites positive for a given species (or genus), V is the volume of the dipper.

Household survey

The probability sampling method was used for the household surveys. The number of household (n) to be investigated was estimated based on the equation as follows (Gotteland and Haon, 2005):

$$n = \frac{z^2 * p(1-p)}{e^2}$$

where z is the level of confidence of 95% (1.96), e is the margin of error of 5% (0.05) and p is the proportion of household to be investigated (0.2). A total number of 200 households distributed over 5 villages and 42 remote hamlets were investigated by questionnaires.

Data processing

Following field investigations, raw data were compiled in a GIS-Database and transformed into statistics in Microsoft Excel and vector files using the software ArcGIS (ESRI, NY). Additional geographical data related to housing, socio-economy, administrative boundaries, hydrography was added to the data sets. The SPSS software (IBM Corporation, NY) was used to analyze correlations between mosquito density, ecological and anthropogenic determinants. Final thematic maps were designed using GIS methods.

RESULTATS

Population awareness about mosquito nuisance

The average household size in the study area is 7.6 (Min. = 1; Max. = 32 and Sdtdev = 4.5). In details, it varies from 6.7 (Min. = 1; Max. = 32 and Sdtdev = 4.7) in Chiépo to 9.2 (Min. = 2; Max. = 24 and Sdtdev = 5.3) in Kokpa (figure 2). These averages are similar to levels observed in most rural areas of the country. All households surveyed (100%) lived in lowlands, close to permanent mosquito larval habitats, such as swamps, rivers, rice fields, hydro-agricultural dam, fish ponds, wild garbage dumps, etc. These ecological and living conditions are precisely the causes for the high level of General Breeding Index (GBI) in CFI (0.72), Guiguidou (0.70) and Chiépo (0.66) (figure 5).

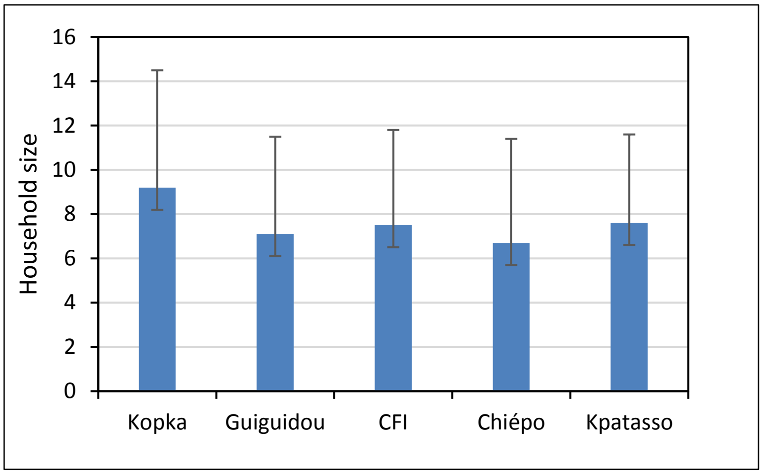


Figure 2: Overview of household size in study sites (2015). Error bar values are based on standard deviation

This study confirms the most widespread complaints of the rural community about mosquito nuisance, particularly in the localities of Guiguidou, Chiépo and CFI. From 1990 to 2015, 100% of the household were concerned with increasing mosquito abundance. More than 53% of the household surveyed mentioned two important time periods of mosquito nuisance increase: 2000-2005 and 2010-2015 (figure 3). Almost all household (98.5%) have been suffering from malaria.

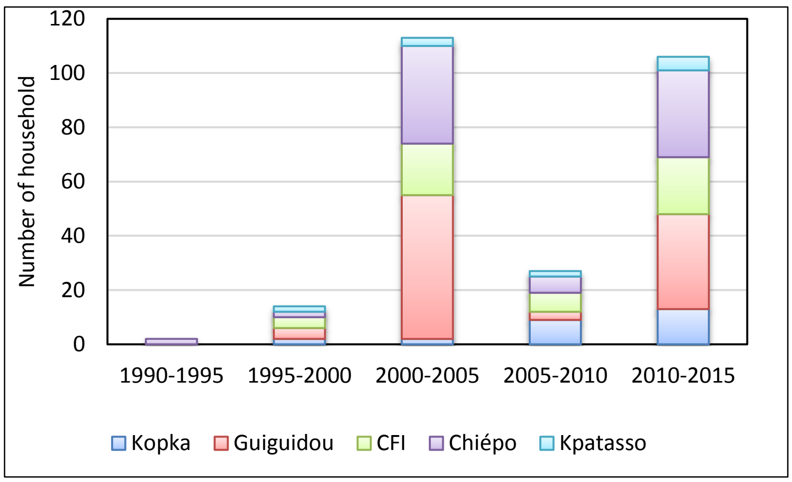


Figure 3: Awareness of the rural community about mosquito nuisance increase: 1990-2015

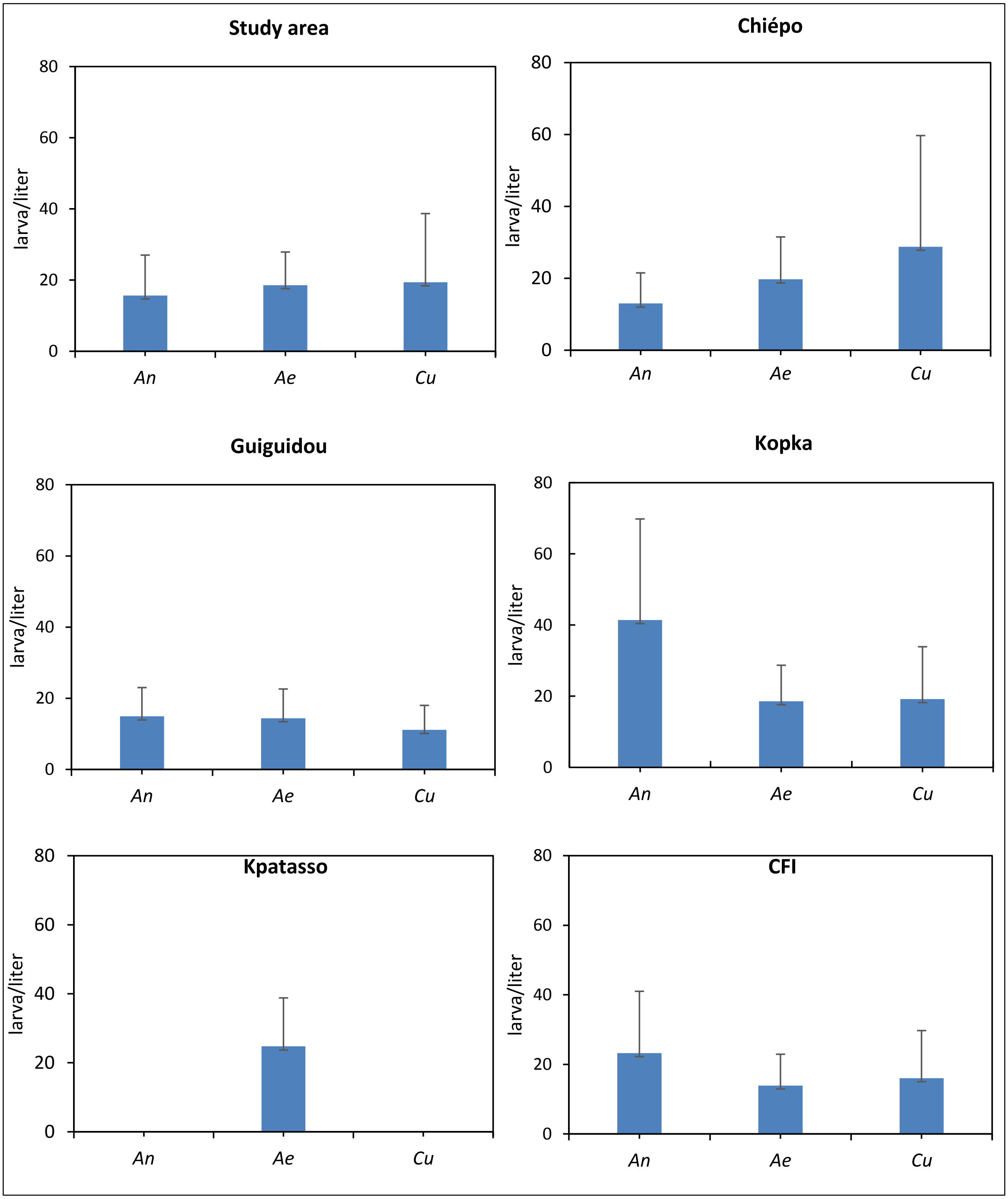
SPATIAL DISTRIBUTION OF MOSQUITO LARVA DENSITY

The average larval density in the study area is 18 larvae per liter (Min. = 1.7; max. = 131.4 and Sdtdev = 15.1). In details, Culex have the highest density (Mean = 19.4; Min. = 1.7; max. = 131.4 and Sdtdev = 19.3), followed by Aedes (Mean = 18.6; Min. = 4.3; max. = 28.9 and Sdtdev = 9.3) and Anopheles (Mean = 15.7; Min. = 3.9; max. = 41.4 and Sdtdev = 11.3).

Kokpa (26.4 lv/l) and Chiépo (20.5 lv/l) are the most dominant localities in terms of mosquito density; Guiguidou (13.5 lv/l) is the last after CFI (17.7 lv/l). Anopheles density is dominant in three localities upon five. Only Aedes (24.7 lv/l) was recorded in all breeding sites inspected in Kpatasso (figure 4).

These results are confirmed by the analysis of the Absolute Breeding Index (ABI) which shows that Guiguidou (0.45), CFI (0.39) and Chiépo (0.34) are the localities of high mosquito nuisance (figure 5). The Relative Breeding Index (RBI) of Anopheles precises that the localities of malaria prevalence are in order of importance Chiépo (0.52), CFI (0.31) and Guiguidou (0.21); Kpatasso (0) and Kokpa (0.07) are less concerned about malaria (figure 6). This is why very few households complain about mosquito nuisance in Kokpa (12.3%) and Kpatasso (4.7%) in 2010-2015. Finally, the important density of Anopheles genus among the mosquito recorded in the study sites concurs with the high prevalence of malaria among 98.5%

of the household in the study area. Mosquito larval densities could be higher if the surveys occurred during the long rainy season (April-July).



Meaning of abbreviations: An = Anopheles, Ae = Aedes, Cu = Culex
Figure 4: Mosquito mean larva density

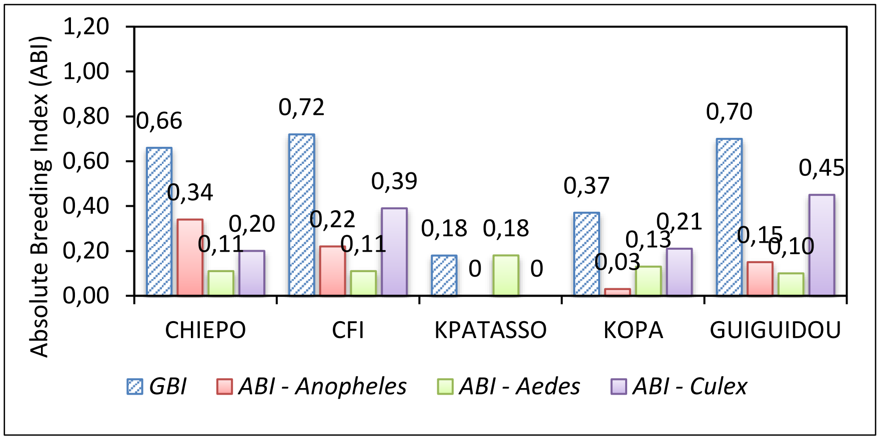


Figure 5: Absolute Breeding Index (ABI)

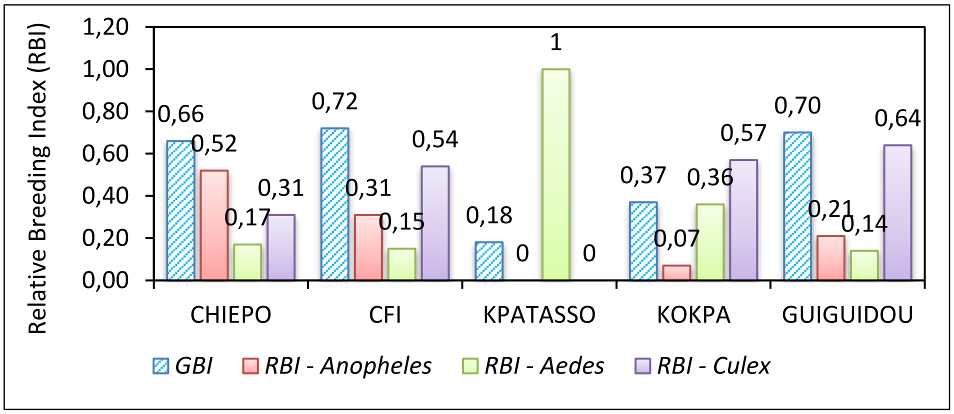


Figure 6: Relative Breeding Index (RBI)

Determinants of breeding site development

As mentioned in the previous results, the determinants of mosquito breeding habitats development are mainly:

- ecological determinants: the geographical location, swampy lowland and floodplain ecosystems, high relative humidity, hydromorphic soils, favorable air temperature, area watered by permanent rivers and their tributaries, etc.

- anthropogenic determinants: construction of hydro-agricultural dams and oil palm agro-industrial factory, creation of new cash crop and food plantations (coffee, cocoa, rubber, oil palm, coconut, rice, banana plantain...), livestock, fisheries, traditional crafts, etc.

Analysis of correlations between ecological and anthropogenic determinants with mosquito breeding sites preference reveals a weak Pearson correlation coefficient of 0.29 ($p < 0.01$). It is the same result with the three mosquito genus (table 3). Permanent (46.6%) and temporal (49.6%) mosquito breeding sites are the most dominant in the study area (figure 7). Permanent habitats consist of swamps, fish ponds, rice fields, rivers and streams, dams, traditional livestock drinking troughs… and temporal habitats are hosted by ruts, puddles, empty cocoa pods, containers, waste water from public water pump and households, etc.

DISCUSSIONS

The rural community of the study area has been complaining about mosquito nuisance increase in particular time periods. Indeed, the geographical location of this area in swampy lowlands and floodplain ecosystems, under tropical climatic conditions coupled with the socio-economic activities of the community, sustain the development of mosquito larvae habitats source of mosquito density increase. This often occurred when larvae habitats are created by human or animal activities in propitious conditions where larvae develop (Gimnig et al., 2002; Shililu et al. 2003; Kenea et al., 2011; WHO, 2013; Amarasinghe et al., 2014; Gone et al., 2014). Population complaints indicate their ignorance of mosquito life cycle and reproduction habits.

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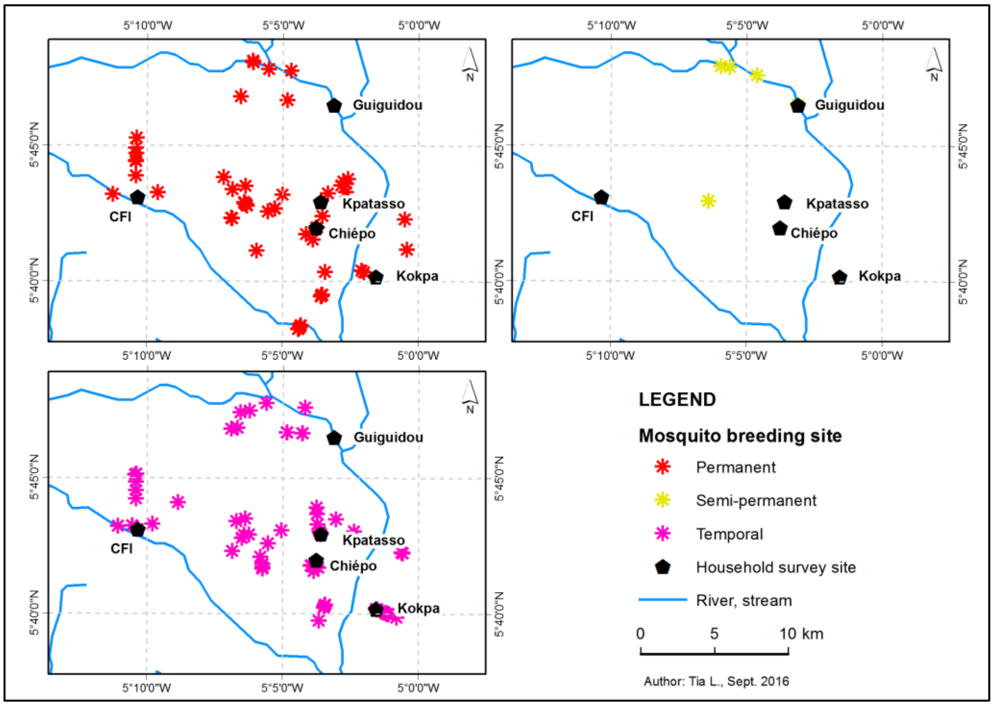

Figure 7: Spatial distribution of potential mosquito breeding site inspected in 2015

		Breeding site type	*Anopheles*	*Aedes*	*Culex*
Ecological and anthropogenic factors	Pearson Correlation	,294**	-,162	-,280**	-,048
	Sig. (2-tailed)	,001	,064	,001	,585
	N	131	131	131	131
Breeding site type	Pearson Correlation	1	-,108	-,202*	,000
	Sig. (2-tailed)		,218	,020	,999
	N	131	131	131	131
**. Correlation is significant at the 0.01 level (2-tailed).					
*. Correlation is significant at the 0.05 level (2-tailed). N = Total number of inspected mosquito breeding sites					

Table 3: Results of the analysis of Pearson correlation coefficient between mosquito larvae and ecological-anthropogenic determinants

Indeed, the high increase of mosquito nuisance during the time period of 2000-2005 is mainly related to the construction of two hydro-agricultural dams (120.000 m3 and 350.000 m3) in 1998, on the Gô River in the locality of Guiguidou, for the implementation of the rice-growing project with 443 hectares of rice fields created. This project launched in 1995 was initiated as an example of Sino-Côte d'Ivoire agricultural cooperation. Moreover, in 1999-2000 populations from the locality of CFI and the surroundings of Chiépo were encouraged to create oil palm plantations in order to feed the oil palm agro-industrial factory of PALMCI. In addition, there was an increasing and general interest in the creation of new rubber plantations due to the spikes in the price of rubber on the market. The creation of new plantations throughout the years boosted the development of new mosquito breeding habitats. These explain why most of the complaints (95.6%) about mosquito nuisance in 2000-2005 come from Guiguidou (46.9%), Chiépo (31.9%) and CFI (16.8%). The resurgence in mosquito nuisance in 2010-2015 reported by 53% of the

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household surveyed can be explained by the development of new traditional livestock, fish ponds activities, traditional production of alcohol, etc. Additionally, in 2013 a new rice agro-industrial factory called ALLADIOH was established and it promoted the creation of irrigated rice plantations which were sources of development of new mosquito breeding habitats.

The weak Pearson correlation coefficient (0.29) between ecological-anthropogenic determinants and mosquito breeding sites preference shows that mosquito do not have preference between man-made and natural habitats. Robert et al., (1998); Minakawa et al., (1999) and Ye-Ebiyo et al., (2003) came up with the same conclusion in their respective studies on Anopheles gambiae. In general, mosquitos develop when and where conditions permit. Very often environmental factors such as precipitation, temperature, insolation, water resources, and topography are of high importance (Bruce-Chwatt and Zulueta, 1985; Some, 2010). However, in the current study area Aedes (75%), Anopheles (56.5%) and Culex (45.5%) prefer temporal habitats to lay eggs. Permanent habitats are their second choice respectively for 18.8%, 30.4% and 42.4%. This is also the case in different geographical locations where Anopheles gambiae prefer sunny temporal or semi-temporal breeding habitats (Gillies and Coetzee, 1987; Hamon et al., (1956).

CONCLUSION

As this study was conducted to figure out the inner reasons of the rural community complaints about mosquito nuisance, it was deemed preferable to conduct mosquito breeding sites inspection at genus level. Field investigations show that people from the study area are geographically located in places where ecological factors are propitious to mosquito development. Moreover, the combination of their economic activities and daily habits create favorable conditions to host productive mosquito habitats.

The resurgence and intensification of mosquito nuisance in the time periods of 2000-2005 and 2010-2015 is related to large-scale agricultural activities such as construction of hydro-agricultural dams, creation of rubber, oil palm and irrigated rice plantations, traditional livestock and production of alcohol, fish ponds activities, etc.

These results confirm the hypothesis of the study in the sense that mosquito nuisance increase is related to ecological and anthropogenic determinants. Population’s complaints about mosquito nuisance increased are related to their poor malaria awareness. Although this study was not guided by the purpose of determining malaria prevalence, it came out with the concordance between the high number of people suffering from malaria (98,5%) and the significant density of Anopheles larvae in the same localities (18 larvae per liter; Min. = 1.7; max. = 131.4 and Sdtdev = 15.1). Complementary research activities need to be undertaken to confirm malaria prevalence in the area. Moreover, outreach campaigns are needed to inform the rural communities on malaria vector prevention and control.

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ANNEX

Table: Overview of the GIS-Entomology field survey form

Investigator 1:……..……………………… Investigator 2:……..………………………					Locality name:………………………………… Date:……………………………………… ……		
Larva code : *Cu* = *Culex*, *An* = *Anopheles*, *Ae* = *Aedes*, Pu = Puppa ID = breeding site Nr., GCP = GPS ground control point Nr., PIC = site picture Nr.							
ID	**GCP**	**PIC**	**Larva code**	**Larva count**	**Dip count**	**UTM Coordinates**	**Site description**
……	……	……	……….. ……….. ………..	………………. ………………. ……………….	……….. ……….. ………..	Lat.………………… Long……………. ….	……………………… ……………………… ………………………
……	……	……	……….. ……….. ………..	………………. ………………. ……………….	……….. ……….. ………..	Lat.………………… Long……………. ….	……………………… ……………………… ………………………
…	…	…	…	…	…	…	…

Source: Survey form designed by Tia L., 2012

LIST OF ABBREVIATIONS

Cu = Culex, An = Anopheles, Ae = Aedes, Pu = Puppa

GCP = ground control point, PIC = picture

GBI = General Breeding Index, ABI = Absolute Breeding Index, RBI = Relative Breeding Index

Max. = Maximum, Min. = Minimum, Sdtdev = Standard deviation

RGPH = Recensement Général de la Population et de l’Habitat

UTM = Universal Transverse Mercator, WGS = World Geodetic System

WHO = World Health Organization