

THE GEOGRAPHICAL STUDY OF ANOPHELINE DENSITIES ON A SMALL SPACE, USING SATELLITE IMAGERY AND GEOGRAPHICAL INFORMATION SYSTEMS.

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ABSTRACT:

To predict the spatial distribution of anopheles in the Dielmo village (located in the southeastern part of Senegal), we used residual fauna collected from 104 different rooms during four separate trips conducted in 1994 and 1995. Thanks Generalized Estimating Equations, we were able to identify factors influencing the distribution of *Anopheles* in the village. Several variables, such as the number of persons sleeping in the room, population density around the hut, construction materials, presence of mosquito nets, were found to be significant, while many spatial variables relevant to the scale of a region (vegetation index, distance to larval sites...) were not found to be significant on the village level. As a result, it became clear that it is difficult to correctly predict the anopheline density for each house even with precise spatial data created with Satellite imagery and Geographical Information Systems (GIS). This work highlights the complexity of the geographical study of anopheline density and its limits on a small space.

KEY WORDS: Malaria, transmission, anopheles, GIS, Remote sensing, scale, Dielmo, Senegal

1. INTRODUCTION

Satellite imagery and Geographical Information Systems (GIS) analysis techniques have been used to identify areas at risk of vector-borne diseases, such as malaria, but, most of the time, they were carried out at a regional scale (Beck, 1994; Salem, 1994; Roberts, 1996; Thomson, 1996; Beck, 1997; Connor, 1997; Manguin, 1999; Beck, 2000; Thomas, 2000)

A longitudinal epidemiological and entomological follow-up began in 1990 to evaluate malaria infections and the mechanisms of protective immunity in a population living in Dielmo, a village in Senegal. Every month, an average entomological inoculation rate is calculated for the entire village and analyses are based on the assumption that the person's level of exposure to infected bites is identical (Rogier, 1993; Trape, 1994.; Rogier, 1996; Rogier, 1999; Sokhna, 2000)

However, variations in anopheles densities may be important within a same village (Smith, 1995; Minakawa, 2002). In Dielmo, we demonstrated with analysis of variance that anopheline densities collected by hut are significantly different (Vallee, personnal communication). To predict anopheline densities in the differents huts in Dielmo village, we used spatial data. Our aim was to test the relevance of spatial data (issued from Satellite imagery and Geographical Information Systems techniques) applied to a small area.

2. MATERIALS AND METHODS

2.1 Study Area

Dielmo ($13^{\circ}45'N$, $16^{\circ}25'W$), a village of about 300 inhabitants, is situated 280 km on the southeast of Dakar in the Sahelo-Soudanian region of Senegal (Map 1).



Map 1: Location of Dielmo in Senegal

The Nema, a small and permanent river, borders the village and its marshy banks provide breeding sites to anopheles throughout the year. Malaria is holo-endemic

(parasite prevalence $> 75\%$ among infants) and transmission is high and perennial, reaching its peak during the rainy season (approximately 200 infected bites/person/year).

In Dielmo, the major vectors transmitting malaria are *An. funestus*, and *An. gambiae* that account respectively for 63% and 36% of anopheles captured on humans (Konate, 1994; Fontenille, 1997).

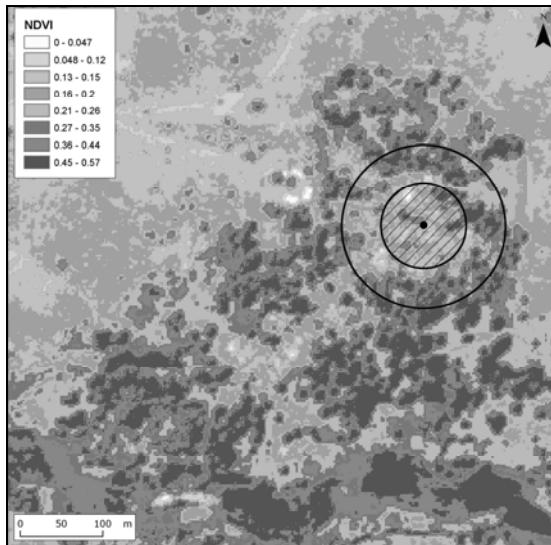
We used a GPS (Global Positioning System) to localize every house and produce an accurate map of the village. To remedy to the GPS inaccuracy which is within the scope of 10 meters, we choose to combine the use of GPS with a Quickbird satellite image that has a very fine spatial resolution (61 cm in panchromatic and 2.44 meters in multispectral).

2.2 Data

We collected morning residual fauna of *An. funestus* and *An. gambiae* in 104 different rooms of Dielmo village by pyrethrum indoor spray collection. *Anopheles* were gathered once during each mission in December 1994, March 1995, June 1995 and September 1995. Data consisted in 273 observations: only 33 rooms were surveyed 4 times.

For every room, the following data have been collected: number of people sleeping in the room, roofing materials, wall materials, presence of space between the wall and roof, presence of at least a hole of 25 cm² in the wall, the use of fumigations and mosquito nets.

Thanks to the Quickbird satellite image (captured on March 9, 2004) that has a very fine spatial resolution, we calculated the vegetation index (NDVI for Normalized Difference Vegetation Index). To take into consideration the environment surrounding each habitation, we calculated the average vegetation density within the radiiuses of 50 meters and 100 meters around each habitation (Map 2) and within a 25 meters thick polygon linking each house to the nearest point of the Nema River. We calculated the average number of persons sleeping in each room and we produced a map of the population's distribution in Dielmo in 1995. To take into consideration the population density around each habitation, the number of persons sleeping within the radiiuses of 50 meters and 100 meters around each hut, as well as the number of persons between the studied hut and the main mosquito breeding place (Nema river) were calculated. We localized cattle existing in 1995 and we separated two categories of cattle to distinguish them with many animals. Following the same way than person density, we estimated the presence of livestock within the radiiuses of 50 meters and 100 meters around each hut, as well as between the studied hut and the Nema River.



Map 2: Calculated average vegetation densities around a habitation* based on the NDVI index.

* For this habitation, the average vegetation density is 0,194 within a radius of 50 meters around the hut and 0,284 within 100 meters, indicating a low vegetation density close to the hut.

2.3 Statistical analysis to predict anopheline densities

We used the Generalized Estimating Equations (GEE) to test the predictor variables' pertinence for the whole of the 273 available entomological observations which are repeated data, meaning that we had several observations (between 1 and 4) of a same variable (number of anopheles) for each room. (Liang, 1986; Zeger, 1986)

The variable to be explained was on one hand, the number of *An. funestus*, and on the other hand, the number of *An. gambiae* caught in a room. We replaced these variables with their square roots to correspond with a distribution model of Poisson.

To evaluate the prediction's quality, we established groups of anopheline densities based on square roots. We compared, for each observation (among the 273), the predicted number of anopheles with the corresponding observed number of anopheles. The prediction is said correct if the predicted number is affected in the same group than the observed number. Then we calculated the number of predictions that are correctly affected.

3. RESULTS

3.1 Variables influencing the anopheline densities

We obtained two GEE models, one for each species of anopheles, containing only the variables significantly associated to the number of anopheles (tables 1 and 2).

Variables	Coef.	Std. Err.	z	P>z	IRR	IRR ²
mission 1	Ref.					
mission 2	1.056	0.11357	9.3	< 0.001	2.87	8.26
mission 3	0.771	0.12059	6.3	< 0.001	2.16	4.67
mission 4	0.975	0.11500	8.4	< 0.001	2.65	7.03
Persons /room	0.087	0.0193	4.5	< 0.001	1.09	1.19
Pop. 50m radius	0.005	0.0019	3	0.003	1.00	1.01
Space	0.378	0.09314	4	< 0.001	1.46	2.13
Mosquito net	-0.289	0.10036	-2.8	0.004	0.74	0.56

Table 1: Model obtained for square root of *An. gambiae*

Variables	Coef.	Std. Err.	z	P>z	IRR	IRR ²
mission 1	Ref.					
mission 2	-0.21	0.0908	-2	0.019	0.80	0.65
mission 3	-0.560	0.1048	-5	< 0.001	0.57	0.32
mission 4	-0.637	0.1022	-6	< 0.001	0.52	0.27
Persons /room	0.076	0.0247	3.1	0.002	1.07	1.16
Pop. 50m radius	0.005	0.0024	2.1	0.034	1.00	1.01
Hay	0.369	0.1072	3.4	0.001	1.44	2.09
Mosquito net	-0.334	0.1300	-3	0.01	0.71	0.51

Table 2: Model obtained the square root of *An. funestus*

The Incidence Rate Ratio (IRR) measures the relative risk for the transformed variable (square root of mosquitoes). The IRR² gives the value of risk relating to the variable of interest (number of mosquitoes).

There is an important "mission" effect. With regards to mission 1 (December 1994), missions 2 (March 1995), 3 (June 1995) and 4 (September 1995) multiplied the number of *An. gambiae* by 8.3, 4.7 and 7 and divide the number of *An. funestus* by 1.4, 3.3 and 2.5. The "person/room" effect is also significant. An additional person sleeping in a room multiplied the total number of vectors, whether *An. gambiae* or *An. funestus*, by 1.2. An additional person within a radius of 50 meters multiplied by 1.012 the number of *An. gambiae* and by 1.01 the number of *An. funestus*. This multiplying coefficient is very low, but should be compared with the number of persons within 50 meters from the hut (varying between 4 and 96), which gives therefore weight to this variable, or up to 2.6 times more vectors because of this variable alone. The presence of a space between the wall and roof (the architectural variable retained for *An. gambiae*) multiplied the number of *Anopheles* by 2.1. For *An. funestus*, the roofing material is more pertinent as a roof made of hay multiplied the number of *Anopheles* by 2.1. The use of mosquito nets (in good condition) divided the number of *An. gambiae* by 1.8 and the number of *An. funestus* by 2. However, use of fumigation is not a

variable significantly associated to the number of mosquitoes.

We tested the relevance of other spatial variables but without significant results. Distance to the Nema, vegetation density within 50 and 100 meters from houses, as well as vegetation density between the Nema and habitations, the number of persons between habitations and the Nema and the presence of livestock within 50 and 100 meters from habitations and between the Nema and habitations are not significantly associated with the number of collected *Anopheles*.

3.2 Quality of prediction of anopheline densities

Based on coefficients affected to each significant variable, we have attempted to predict the number of *Anopheles* collected in a specific hut during a given mission. The percentage of correctly affected observations at 41% is low (table 3). It was therefore not possible, based on the selected variables, to project the *Anopheles* densities in a relevant manner.

Difference in affectation	<i>An. gambiae</i>	<i>An. funestus</i>
0	112 (41%)	110 (41%)
1	136 (50%)	138 (50%)
2	24 (9%)	24 (9%)
3	1 (0%)	1(0%)
Total	273 (100%)	273 (100%)

Table 3: Percentage of observations correctly affected to the groups of densities

4. DISCUSSION AND CONCLUSION

The coefficient of common correlation helps to appreciate the hut's proper effect. The value of correlation is 0.1886 for the model performed on the square roots of *An. gambiae* and 0.2814 for the one performed on the square roots of *An. funestus*, which means that the hut's residual effect explains the 3.5% (0.18862) and 7.9% (0.28142) of the variability of the number of collected *Anopheles*. If the variables explain all the data's variability, the proper effect of the hut should be null. This means that some variables describing the hut are missing in our model, particularly for *An. funestus*.

To predict the anopheline distribution at the regional scale, it is usual to take into consideration the distance between breeding sites and habitations in urban areas (Trape, 1992; Salem, 1994) as well as in rural areas (Beck, 1994, Fontenille, 1997; Thomas, 2000; Hii, 1997)

At village scale, in Kenya (Minakawa, 2002) and in Uganda (Staedke, 2003) distance from a house to its nearest larval habitats showed a significant correlation with anopheline densities. Our study did not

demonstrate the relevance of this variable, maybe because Dielmo is a very limited space; every hut is < 300 m from the stream. A study in Sri Lanka using small distance categories (<250m/>500m) from stream can't reach statistical significance (Van der Hoeck, 1998).

Landscape description with remotely sensed data may allow locating habitats (un)favorable to *Anopheles* and predicting anopheline densities (Beck, 1997, Wekesa, 1996; Grillet, 2000; Eisele, 2003). In our study, we calculated Normalized Difference Vegetation Index (NDVI) from satellite imagery with high spatial resolution, but could not prove its relevance to the *Anopheles* density over a limited space such as Dielmo village. As shown by an article synthesizing the potential of remote sensing for human health (Herbreteau, 2005), many studies used the NDVI index (a quantitative variable that is quite commonly used to describe the type of landscape and vegetation density) at a scale that is inappropriate to qualify the environment of a vector.

Even if some variables proved to be significant, it is not possible to estimate the distribution of *Anopheles* based on these variables only. This study raises the more theoretical question on the limitations of a health geography analysis: Is the geography of anopheline densities relevant over such a limited space as Dielmo?

REFERENCES

Beck LR, Rodriguez MH, Dister SW, Rodriguez A D, Rejmankova E, Ulloa A, Meza R. A, Roberts DR, Paris JF, Spanner MA, Washino RK, Hacker C, Legters LJ, 1994. Remote sensing as a landscape epidemiologic tool to identify villages at high risk for malaria transmission. Am. J. Trop. Med. Hyg. 51 (3) : 271-280

Beck LR, Rodriguez MH, Dister SW, Rodriguez AD, Washino RK, Roberts DR, Spanner MA, 1997. Assessment of a remote sensing-based model for predicting malaria transmission risk in villages of Chiapas, Mexico. Am. J. Trop. Med. Hyg. 56 (1) : 99-106

Beck LR, Lobitz BM, Wood BL, 2000. Remote sensing and human health : New sensors and new opportunities. Emerging Infectious Diseases 6 (3) : 217-226

Connor SJ, Flasse SP, Perryman AH, Thomson MC, Connor SJ, 1997. The contribution of satellite derived informations to malaria stratification, monitoring and early warning. World Health Organization, 32p.

Eisele T, Keating J, Swalm C, Mbogo C, Githcko A, Regens J, Githure J, Andrews L, Beier J, 2003. Linking field-based ecological data with remotely sensed data using a geographic information system in two malaria endemic urban areas of Kenya. Malaria Journal 2:44

Fontenille D, Lochoouarn L, Diagne N, Sokhna C, Lemasson JJ, Diatta M, Konate L, Faye F, Rogier C, Trape JF, 1997. High annual and seasonal variations in malaria transmissions by anophelines and vector species composition in Dielmo, a holoendemic area in Senegal. *Am. J. Trop. Med. Hyg.* 56(3) : 247-253

Grillet ME, 2000. Factors associated with distribution of *An. aquaqualis* and *An. oswaldoi* in a malarious area, Northeastern Venezuela. *J. Med. Entomol.* 37(2) : 231-238

Herbreteau V, Salem G, Souris M, Hugot JP, Gonzalez JP, 2005. Sizing up human health through remote sensing : uses and misuses. *Parasitologia* 47 (1) : 63-79.

Hii JJK, Smith T, Mai A, Mellor S, Lewis D, Alexander N, Alpers MP, 1997. Spatial and temporal variation in abundance of Anopheles in malaria endemic area in Papua New-Guinea. *J. Med. Entomol.* 34(2) : 193-205

Konate L, Faye O, Gaye O, Sy N, Diop A, Diouf M, Trape JF, Molez JF, 1994. Biologie des vecteurs et transmission de *Plasmodium Falciparum*, P. Malariae et P. Ovale dans un village de savane d'Afrique de l'Ouest (Dielmo, Sénégal). *Parasite* 1 : 325-333

Liang KY, Zeger SL, 1986. Longitudinal analysis using generalized linear models. *Biometrika* 73: 13-22.

Manguin S, Boussinesq M, 1999. Apport de la télédétection en santé publique: l'exemple du paludisme et autres perspectives. *Med. Mal. Infect* 29 : 318-324

Minakawa N, Seda P, Yan G, 2002. Influence of host and larval habitat distribution on the abundance of African malaria vectors in Western Kenya. *Am. J. Trop. Med. Hyg.* 67(1) : 32-38

Roberts DR, Paris JF, Manguin S, Harbach RE, Woodruff R, Rejmankova E, Polanco J, Wuellscheger B, Legters LJ, 1996. Predictions of malaria vector distribution in Belize based on multispectral satellite data. *Am. J. Trop. Med. Hyg.* 54(3) : 304-380

Rogier C., Trape JF, 1993, Malaria attacks in children exposed to high transmission: who is protected. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 87 : 245-246

Rogier , Commenges D, Trape JF, 1996, Evidence for an age-dependant pyrogenic threshold of *Plasmodium falciparum* parasitemia in highly endemic populations. *Am. J. Trop. Med. Hyg.* 54 : 613-619

Rogier C, Ly A, Tall A, Cissé B, Trape JF, 1999, *Plasmodium Falciparum* clinical malaria: lessons from longitudinal studies in Senegal *Parasitologia* 41 : 255-259

Salem, G, Legros F, Lefebvre-Zante E, Ndiaye G, Bouganali H, Ndiaye P, Badji A, Trape JF, 1994. Espace urbain et risque anophélien à Pikine (Sénégal). *Cahiers santé* 4 : 347-357

Smith T, Charlwood JD, Takken W, Tanner M, Spiegelhalter DJ, 1995. Mapping the densities of malaria vectors within a single village. *Acta Tropica* 59 : 1-18

Sokhna C, Rogier C, Dieye A, Trape JF, 2000, Host factors affecting the delay of reappearance of *Plasmodium falciparum* after radical treatment among a semi-immune population exposed to intense perennial transmission. *Am. J. Trop. Med. Hyg.* 62(2) : 266-270

Staedke S, Nottingam E, Cox J, Kamya M, Rosenthal P, Dorsey G, 2003. Short Report: Proximity to mosquitoes breeding sites as a risk factors for clinical malaria episodes in an urban cohort of Ugandan children. *Am. J. Trop. Med. Hyg.* 69(3) : 244-246

Thomas CJ, Lindsay SW, 2000. Local-scale variation in malaria infection amongst rural Gambian children estimated by satellite remote sensing. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 94 : 159-163

Thomson MC, Connor SJ, Milligan P. J. M. , 1996. The ecology of malaria - as seen from Earth-observation satellites. *Annals of Tropical Medicine and Parasitology* 90 : 243-264

Trape JF, Lefebvre-Zante E, Legros F, Ndiaye G, Bouganali H, Druilhe P, Salem G, 1992. Vector density gradients and the epidemiology of urban malaria in Dakar, Senegal. *Am. J. Trop. Med. Hyg.* 47(2) : 181-189

Trape JF, Rogier C, Konate L, Diagne N, Bouganali H, Canque B, Legros F, Badji A, Ndiaye G, Ndiaye P, 1994. The Dielmo project: a longitudinal study of natural malaria infection and the mechanisms of protective immunity in a community living in a holoendemic area of Senegal. *Am. J. Trop. Med. Hyg.* 51(2) : 123-137

Van der Hoeck W, Konradsen F, Dijkstra D, Amerasinghe PH, Amerasinghe FP, 1998. Risk factors for malaria: a microepidemiological study in a village in Sri Lanka. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 92 : 265-269

Wekesa JW, Yuval B, Washino BK, 1996. Spatial distribution of adult mosquitoes in habitats associated with the rice agroecosystem of Northern California. *J. Med. Entomol.* 33(3) : 344-350

Zeger SL, Liang KL, 1986. Longitudinal data analysis for discrete and continuous outcomes. *Biometrics* 42(1) : 121-130

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