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Density of *Culex quinquefasciatus* Associated with Socio-Environmental Conditions in a Municipality with Indeterminate Transmission for Lymphatic Filariasis in the Northeastern Region of Brazil

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Abstract: Lymphatic filariasis (LF) is a neglected tropical disease associated with poverty and poor environmental conditions. With the inclusion of vector control activities in LF surveillance actions, there is a need to develop simple methods to identify areas with higher mosquito density and consequent risk of *W. bancrofti* transmission. An ecological study was conducted in Igarassu, Metropolitan Region of Recife, Pernambuco, Brazil. The mosquitoes were captured in 2,060 houses distributed across 117 census tracts. The vector density index (VDI) was constructed, that measures the average number of lymphatic filariasis transmitting mosquitoes per number of houses collected in the risk stratum. Moreover, the social deprivation indicator (SDI) was constructed and was carried out through principal component factor analysis. The average number of female *C. quinquefasciatus* found in the high-risk stratum was 242, while the low-risk stratum had an average of 108. The overall VDI was 6.8 mosquitoes per household. The VDI for the high-risk stratum was 13.2 mosquitoes per household, while for the low/medium-risk stratum, it was 5.2. This study offers an SDI for the density of *C. quinquefasciatus* mosquitoes, which reduces the cost associated with data collection and allows for indicating priority areas for vector control actions.

Keywords: Lymphatic filariasis; Culex quinquefasciatus; vector density index; social deprivation indicator

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1. Introduction

Lymphatic filariasis (LF) is a neglected tropical disease transmitted by mosquitoes and associated with poverty and poor environmental conditions [1]. The Global Programme to Eliminate Lymphatic Filariasis (GPELF) was launched in 2000 by the World Health Organization (WHO) with the goal of eliminating the disease as a public health problem by 2030 [2].

In Brazil, LF is an urban disease and its etiological agent is *Wuchereria bancrofti*, with *Culex quinquefasciatus* as the transmitting mosquito [4,5]. Maceió - Alagoas [6] and Belém – Pará [7] have indicators of transmission interruption [6,7]. Pernambuco, Recife, Olinda, and Jaboatão dos

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Guararapes are under surveillance after Mass Drug Administration (MDA), while Paulista provides individual treatment to cases due to low infection prevalence [8]. Nine other municipalities, Abreu e Lima, Cabo de Santo Agostinho, Camaragibe, Igarassu, Ilha de Itamaracá, Ipojuca, Itapissuma, Moreno, and São Lourenço da Mata, which are adjacent to endemic areas, are considered to have undetermined transmission of filariasis [9].

The presence of the transmitting mosquito, unplanned urbanization, and migration pose a risk for LF transmission [9]. In order to implement or develop vector control actions, it is necessary to identify the areas and population groups most exposed to mosquitoes and, therefore, prioritized groups for the surveillance actions [10,11]. Composite indexes appear to be a useful tool for this identification [12–14].

With the inclusion of vector control activities in LF surveillance actions, there is a need to develop simple methods to identify areas with higher mosquito density and consequent risk of *W. bancrofti* transmission [15–17]. In this perspective, the objective of this study was to analyze the spatial distribution of *C. quinquefasciatus* density according to socio-environmental conditions in an area with undetermined transmission of *W. bancrofti*.

2. Materials and Methods

The study was conducted in the municipality of Igarassu, located in the Metropolitan Region of Recife, Pernambuco, northeastern Brazil. It is one of the nine municipalities with undetermined LF status in Pernambuco, northeastern Brazil. Historically, it has had cases of microfilaremia [18] identified and no treatment interventions in its population. Furthermore, there is no record of any investigation into *C. quinquefa*sciatus mosquitoes [9]. An ecological study was conducted, with the unit of analysis being the urban census tracts of Igarassu.

The Vector Density Index (VDI) measures the average number of lymphatic filariasis transmitting mosquitoes per number of houses collected in the risk stratum. It was calculated using the following formula:

$$\text{VDI} = \frac{number\ of\ female\ Cx.quinquefasciatus\ captured\ per\ risk\ stratum}{number\ of\ households\ analyzed\ per\ risk\ stratum}$$

For the construction of the Social Deprivation Indicator (SDI), Pearson correlation of 10 socio-environmental variables provided by the 2010 demographic census (Table 1) was measured, and only variables that showed statistical significance ($p < 0.05$) remained in the process.

Table 1. Variables eligible for composing the social deprivation indicator, Igarassu, 2022.

Variable	Definition	Indicator
WATS	Households with inadequate water supply	Proportion of households without internal water plumbing and without access to public water supply network relative to the total number of permanent private households
BATHR	Households without exclusive use bathrooms for residents	Proportion of households without showers or bathtubs and exclusive use of toilet facilities for household residents.
GARB	Households with inadequate garbage collection	Proportion of households with garbage collection by public or private company services relative to the total number of permanent private households.
ELEC	Households without electricity	Proportion of households without any type of electricity supply
HOUS	Households with 6 or more residents	Proportion of households with 6 or more residents
SEW	Households without sewage system	Proportion of households without drainage system for waste from the bathroom or toilet.

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ISEW	Households with inadequate sewage systems	Proportion of households without plumbing for waste from the bathroom or toilet, connected to a collection system that leads to a general drainage system in the area, region, or municipality, even if the system does not have a sewage treatment plant.
ILIND	Illiterate individuals who are household heads	Proportion of household heads who either did not know how to read and write, those who learned but forgot due to an unconsolidated literacy process, and those who could only sign their own name.
RACE	Resident individuals self-declared as black race or ethnicity	Proportion of resident individuals self-declared as black race or ethnicity
REND	Individuals responsible with no positive income	Proportion of individuals responsible for permanent private households with no positive income, meaning no type of earnings in value.

Source: IBGE, 2010 [19]

Before initiating the estimation of the SDI, the variables composing it were examined using the Kaiser-Meyer-Olkin (KMO) [20] test and Bartlett's test of sphericity [21].

The correlation between eligible variables and the number of female mosquitoes was evaluated using Spearman's correlation [22]. Variables with significant correlation were selected. The selected variables were then normalized to belong to the interval 0-1 using the following equation:

$$Z_i = \frac{X_i - min(X)}{max(X) - min(X)} \quad [1]$$

which,
i = Census tract;
X = Variable to be normalized.

After finding the acceptable factors, the index was normalized to the range 0-1 by the equation:

$$SDI = \frac{CP_i - min(CP_i)}{max(CP_i) - min(CP_i)} \quad [1]$$

The construction of the SDI was carried out through principal component factor analysis, which reduces many variables to a smaller number, now referred to as factors. The variables forming a factor need to be correlated with each other for the model to be appropriate [23]. The technique produces regression coefficients (loadings or factorial loadings) that indicate the relationship between the factor and each original variable. Additionally, it determines the percentage of total variance explained for each extracted factor. In this study, among the extracted factors, the one that explained a variance greater than 1 (eigenvalue > 1) was selected. The values of the extracted factor (factor scores) are estimated by regression. This factor constituted the SDI [24].

To obtain strata, the SDI was subjected to the k-means clustering technique, in which the number of SDI bands was identified by the elbow graph. To explain the relationship between the SDI and the VDI, the Poisson-Inverse Gaussian regression model [25] was employed, which showed adjustment according to the Akaike metric (AIC) [26]. All calculations were performed using the R statistical programming language version 4.1.0, and the adopted significance level was 5%.

The mosquitoes were captured in 2,060 houses distributed across 117 census tracts. Maps of the census tracts from the IBGE website [19] were consulted and then manipulated to define quadrants. In each quadrant, a line was drawn diagonally across the 2nd and 3rd quadrants, connecting opposite quadrants. From the midpoint of each quadrant (2nd and 3rd), the streets were defined, in this case, two, that would be in each midpoint of these quadrants. For each street, 10 households were selected,

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totaling 20 per census tract. This selection followed the listing of the first 10 households (according to the numbering) located on the right side of the street.

The heads of households were given an informed consent form, and upon their agreement to participate, signed the form. Collections were then conducted between 9 and 12 AM using electric aspirators indoors, following the protocol by Ramesh et al. [27]. The mosquitoes were aspirated and stored in fine mesh cages for later storage in a -20ºC freezer. The mosquitoes were identified based on characteristics described by Forattini et al. (1965) [28].

The study was approved by the Research Ethics Committee of the Instituto Aggeu Magalhães, FIOCRUZ - PE, under approval number 039627/2019.

3. Results

The seven variables that comprised the SDI ($p < 0.05$) were: proportion of households without public water supply, proportion of households without adequate sewage systems, proportion of households without garbage collected by sanitation services, proportion of households with 6 or more residents, proportion of illiterate household heads, per capita household income, and per capita income of household heads.

Bartlett's test of sphericity ($\chi^2 = 372.47$; $p < 0.01$) and the KMO (0.68) indicated that the correlations among the variables were suitable for exploratory factor analysis. There was a statistically significant correlation among the seven eligible variables for forming the SDI, considering Spearman's correlation (Table 2). The variables with the greatest weight in the index were per capita household income (-0.474), the proportion of illiterate household heads (0.466), and per capita income of household heads (0.466).

Table 2. Pearson and Spearman Correlation between the variables comprising the SDI and the number of female *C. quinquefasciatus* Mosquitoes in Igarassu, 2022.

Variable	Acronyms	Pearson Correlation		Spearman Correlation	
		Estimate	p-value	Estimate	p-value
Proportion of households without public water supply	WATS	0,34	0,00	0,41	0,00
Proportion of households without exclusive-use bathrooms for residents	BATHR	0,06	0,54	0,34	0,00
Proportion of households without any kind of sewage system	SEW	0,06	0,54	-0,13	0,21
Proportion of households without adequate sewage system	ISEW	0,10	0,30	0,10	0,30
Proportion of households without garbage collected by sanitation services	GARB	0,37	0,00	0,32	0,00
Proportion of households without electricity	ELEC	0,03	0,74	0,23	0,02
Proportion of households with 6 or more residents	HOUS	0,16	0,11	0,22	0,03
Proportion of illiterate individuals responsible for the household	ILIND	0,26	0,01	0,10	0,30

Proportion of resident individuals of black race/color	RACE	0,02	0,80	0,08	0,40
Proportion of household heads with no positive income	REND	-0,10	0,31	0,09	0,37
Per capita household income	RENDo	-0,21	0,03	-0,34	0,00
Per capita income of household heads	RENDp	-0,16	0,11	-0,32	0,00

Source: Authors, 2023.

Table 3 presents the correlation matrix, applying exploratory factor analysis via principal components. The index is represented according to equation (2), which the general variance is explained by 43.7% through component 1, which constitutes the SDI:

$$SDI = 0.191X_1 + 0.261X_2 + 0.332X_3 + 0.388X_4 + 0.466X_5 + (-0.474X_6) + (-0.439X_7)$$
[2]

X_1= Proportion of households without public water supply;
X_2 = Proportion of households without adequate sewage system;
X_3 = Proportion of households without garbage collected by sanitation services;
X_4 = Proportion of households with 6 or more residents;
X_5 = Proportion of illiterate household heads;
X_6 = Per capita household income;
X_7 = Per capita income of household heads;

Bartlett's test of sphericity (χ^2 = 372.47; p < 0.01) and the KMO (0.68) indicated that the correlations among the variables were suitable for exploratory factor analysis. There was a statistically significant correlation among the seven eligible variables for forming the SDI, considering Spearman's correlation (Table 2). The variables with the greatest weight in the index were per capita household income (-0.474), the proportion of illiterate household heads (0.466), and per capita income of household heads (0.466).

Table 3. Correlation Matrix of Variables Regarding Socio-Environmental Conditions by Census Tract, Igarassu, 2022.

KMO (0,68[1])	Variáveis	WATS	ISEW	GARB	HOUS	ILIND	RENDo	RENp
0,56	**WATS**	1	0,01	0,23	0,27	0,46	-0,05	0,06
0,60	**ISEW**		1	0,10	0,49	0,24	-0,24	-0,20
0,87	**GARB**			1	0,25	0,47	-0,36	-0,30
0,68	**HOUS**				1	0,54	-0,32	-0,30
0,75	**ILIND**					1	-0,53	-0,53
0,59	**RENDo**						1	0,93
0,57	**RENp**							1

Source: Authors, 2023.

To create the SDI strata, the k-means clustering technique was applied, resulting in four chosen strata. The result of the four strata is presented in Table 4. Strata 1, 2, and 3 (very low risk, low risk, and medium risk) were not statistically significant. Stratum 4 (high risk) is statistically significant, meaning that the average number of female *C. quinquefasciatus* in this stratum is statistically different from the others. Therefore, it was useful to merge the strata that were not significant.

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Table 4. Results of the Poisson-Inverse Gaussian regression model and absolute and relative frequencies of the risk strata of the social deprivation indicator, Igarassu, 2022.

Strata	SDI		Model with 4 bands				Model with 2 bands			
	min	max	Coeff.[1]	p-value	N	%	Coeff.[1]	p-value	N	%
Very low risk (1)[2]	0,00	0,20	4,51	0,00	12	11,7%	4,68	0,00	82	79,6%
Low risk (2)	0,21	0,34	-0,13	0,68	37	35,9%	-	-	-	-
Medium risk (3)	0,35	0,48	0,45	0,16	33	32,0%	-	-	-	-
High risk (4)	0,51	1,00	0,93	0,01	21	20,4%	0,81	0,00	21	20,4%
Dispersion parameter	-	-	1,66	0,01	-	-	1,82	0,00	-	-

Source: Authors, 2023

[1] Parameter estimates given by the regression model for the respective risk stratum/dispersion parameter.

[2] Risk stratum 1 represents the intercept of the regression model.

The average number of female *C. quinquefasciatus* found in the high-risk stratum was 242, while the low-risk stratum had an average of 108. This means the high-risk stratum had 2.24 times more mosquitoes on average than the low-risk stratum ($p < 0.01$, Table 4).

A total of 26,027 *C. quinquefasciatus* were collected from the 2,060 investigated households. Of the captured mosquitoes, 14,920 (58%) were female, and among them, 8,783 (59%) were engorged. The overall vector density index (VDI) was 6.8 mosquitoes per household. Figure 1 shows the distribution of the SDI by census tract. The VDI for the high-risk stratum was 13.2 mosquitoes per household, while for the low/medium-risk stratum, it was 5.2 ($p < 0.01$).

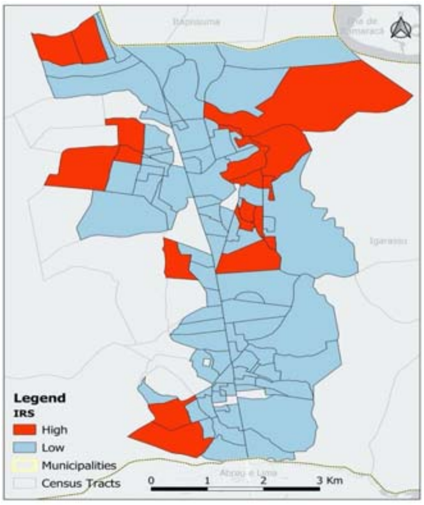

Figure 1. Spatial representation of the social deprivation indicator, Igarassu, 2022.

4. Discussion

The SDI proposed in this study was constructed from variables that reflect socio-environmental precarities associated with the density of female *C. quinquefasciatus*. The worst socio-environmental conditions were associated with a higher vector density index (VDI). The high-risk stratum consisted of 21 census tracts, three of which were considered high-priority areas for potential surveillance actions in the municipality.

Due to the complexity involved in lymphatic filariasis (LF), the environment, and vectors, strategies for its elimination as a public health problem must be tailored to environmental and socio-economic precarities [29–31]. Stratifying the space according to these factors serves as a supporting tool for planning disease control actions [32–35].

The use of census tracts as the spatial unit of analysis in the development of the SDI offers the advantage of representing the most disaggregated level of population and socio-environmental data, likely ensuring better homogeneity among the population. The ability to conduct analyses in micro-areas facilitates the implementation of selective and specific actions for controlling endemic diseases [12,36]. In Brazil, the demographic census uses census tracts for registration control, with updates occurring every ten years [19].

The variables used to analyze the census tracts were related to precarious conditions in sanitation, income, housing conditions, and population density. These variables are often associated with breeding sites for *C. quinquefasciatus*, which are artificial reservoirs filled with water containing organic matter and decomposing material, having a dirty appearance and always located near human habitations [37,38]. Simonsen et al. (2013) [32], in their review of filarial disease in urban environments, describe precarious socio-environmental conditions as the most common causes for the formation of mosquito breeding sites and thus for LF transmission. In this study, two risk strata were formed, low and high risk, with the latter exhibiting the worst sanitary conditions, the highest number of adult mosquitoes, and thus deserving the most attention from LF surveillance.

The highest Vector Density Index (VDI) was also identified in the high-risk stratum, with 13.2 mosquitoes per household, while the areas considered low-risk had approximately 5.2 mosquitoes per household. Lupenza et al. (2021) [39] emphasize that a high number of mosquitoes increases the bite rates for household occupants, thereby increasing the risk of LF infection. As such, the vector control efforts within the Global Program to Eliminate Lymphatic Filariasis (GPELF) should focus on environmental improvements.

Monitoring LF infection in populations through risk indicators is a simple, easy-to-apply, and low-cost tool for filariasis elimination programs in urban areas [14,40,41]. The ability to link this method's construction with the vector and the sanitary conditions of an area allows for tracking the risk of filariasis transmission in non-endemic locations, with low prevalence, and in the context of elimination. Thus, this study presents a possible method of territorial surveillance based on the detection of new transmission foci independently of human cases.

In 2022, Xavier and collaborators [42] used a socio-environmental risk indicator, previously validated by Bonfim et al. (2011) [43] in a study related to human prevalence for LF, to identify areas with the highest risk for LF vector density. Although they had similar objectives, this current study innovatively presents the construction of an indicator created through principal component analysis to estimate the specific risk of higher vector counts. Using this approach, 10 variables related to precarious socio-environmental conditions were evaluated, and the most statistically significant ones that best described the risk of *C. quinquefasciatus* breeding sites were selected.

5. Conclusions

Rapidly and cost-effectively detecting areas indicated for vector control can be highly valuable for health services, and the main objective of estimating the chances of filarial infection transmission based on higher vector density has been achieved. The results of this study offer an SDI for the density of *C. quinquefasciatus* mosquitoes, which reduces the cost associated with data collection and allows for indicating priority areas for vector control actions.

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