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ORIGINAL ARTICLE

DEFINITION OF PARAMETERS FOR MAPPING *Aedes aegypti* OUTBREAKS USING DRONES IN THE MUNICIPALITY OF ITABIRA, MINAS GERAIS, BRAZIL

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ABSTRACT

Dengue is a febrile disease caused by arboviruses transmitted by *Aedes aegypti* mosquitoes, whose symptoms range from a flu-like syndrome to serious and fatal cases. The main way to combat the disease is vector population control, which has shown unsatisfactory results. To optimize vector control response capacity, the Health Department of Minas Gerais (MG) published the Resolution SES/MG 9.035/2023, defining rules for the use of unmanned aerial vehicles (UAVs), known as drones, in the fight against *A. aegypti*. Therefore, with the aim of creating a technically viable and low-cost method for defining priority areas for intervention through UAVs, dengue cases occurring between 2018-2022 were correlated with vector density in 2022 in the municipality of Itabira/ MG. There were 1,004 confirmed cases between 2018-2022, with a correlation strength with vector density in 2022 of 76.8%, considering three strata. Statistical significance ($p< 0.05$) was identified in two assessments between neighborhoods with a difference in incidence equal to or greater than 64%. The results indicated the following descending order of priority areas for mapping using UAVs: stratum-3, stratum-1, stratum-4, and stratum-2. Considering the presented results, this study's proposal is technically and financially feasible for the municipal health surveillance service.

KEY WORDS: Dengue; Arboviruses; Disease Vector Control; Unmanned Aerial Devices.

INTRODUCTION

Dengue is a disease caused by arboviruses (viruses transmitted by arthropods), distributed in four serotypes (DENV-1 to DENV-4) and transmitted mainly by female mosquitoes of the species *Aedes aegypti*, whose symptoms vary from a flu-like syndrome to severe and fatal cases (Harapan et al., 2020). Since 1950, the number of cases has increased approximately 30 times in relation to the incidence rates prior to that year, generating

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approximately 20,000 deaths per year in a geographic area that covers more than 128 countries (Babu et al., 2023).

In Brazil, from 2018 to 2022, there were 4,682,195 probable cases of dengue recorded, resulting in 2,955 deaths (Brasil, 2023b). For the same period, the State of Minas Gerais (MG) recorded 695,534 probable cases with 312 deaths, and the municipality of Itabira presented 1,260 probable cases but without confirmed deaths (Minas Gerais, 2023a).

The occurrence of dengue is a result of various factors such as the people living in an area, insects, viruses, and environmental elements, which are reinforced by constant human mobility, producing an increase in transmission, amplification, and dissemination of the etiological agent (Guzman & Harris, 2015). This range of elements that influence the transmission chain, associated with a possible underreporting of cases in endemic regions, represents one of the most significant challenges for the public health service in Brazil, especially in environmental health surveillance, which carries out, among other attributions, the monitoring and identification of outbreaks of diseases transmitted by vectors (Batistella et al., 2003; Sarti et al., 2016).

Due to the unavailability of a vaccine in sufficient quantity to serve the entire population at risk or of antiviral medication, dengue health surveillance has as its primary way the environmental and chemical control of the population of mosquito vectors, but this activity has shown unsatisfactory results, as progressive increases in the incidence rates of the disease are still seen in Brazil and around the world (Boyce et al., 2013).

To optimize vector control response capacity, the Health Department of MG published the Resolution SES/MG 9,035 of 26/11/2023, which defines temporary financing rules for the use of unmanned aerial vehicles (UAVs), known as "drones", to combat *A. aegypti*. The use of drones prioritizes mapping and monitoring areas that are difficult to access, facilitating the identification of small objects on the surface of the earth and the perception of changes in a region in a short space of time, more precisely directing the service of endemic disease agents (Lima et al., 2021).

Advances in geoprocessing technologies have enabled the use of geographic information systems in public health, particularly in identifying areas at risk for the presence of *A. aegypti* (Chiaravalloti-Neto, 2017). Using drones as a mapping resource has spread to different regions of the world, but published studies on the subject are still scarce. Despite this, in 1998, some articles related to the theme "studies on the spatialization of dengue in Brazil" began to be published, with work carried out in the Brazilian cities of Belém/PA, Belo Horizonte/MG, Brasília/DF, Goiânia/GO, Nova Iguaçu/RJ, Porto Alegre/RS, Rio de Janeiro/RJ and São José do Rio Preto/SP, and some cities in the State of Maranhão (Araújo et al., 2008).

The SES/MG Resolution suggests providing financial resources to the 853 municipalities in the State of MG. This fund will be utilized to hire specialized companies in geoprocessing to use drones equipped with cameras for mapping urban areas at high risk for dengue transmission. The drones will identify potential breeding grounds for the dengue vector, such as swimming pools, water tanks, bottles, tires, and other residential structures. Based on this information, larvicides will be applied to target these areas. Resolution 9,035/2023 also defines that the survey of the areas to be worked by drones will be the responsibility of the Municipal Health Departments, which will be able to use data related to the rate of vector infestation, circulate on of viral serotypes, percentages of properties visited, areas difficult to access, in addition to the relationship between the number of properties and health agents (Minas Gerais, 2023b).

Based on the planning possibilities defined by the Resolution as mentioned earlier, this study presents a proposal for expanding the capacity and decision-making security for defining priority areas for drones to operate by including the component "number of suspected dengue cases" in the analysis, enabling the crossing data between vector infestation and distribution of disease cases. The data on vector infestation used in this study come from the Rapid Index Survey of *Aedes aegypti* (LIRAa), and the dengue cases were obtained through the Notifiable Diseases Information System (Sinan).

The LIRAa methodology uses a computerized system in which the neighborhoods of the municipal urban area are registered, as well as the number of blocks and properties in each of these neighborhoods, so that the system itself statistically draws the blocks and properties to be inspected by agents controlling endemic diseases. "The urban area of these municipalities should be divided into strata that present similar socio-environmental characteristics, to obtain homogeneity of each stratum and facilitate vector control actions after LIRAa. The composition of the strata should respect the range of 8,100 to 12 thousand properties, with the ideal number being around nine thousand properties. The next step is to take an independent sample, and 20.0% of the properties within the selected blocks must be inspected. In some situations, strata may be configured with the limits of two thousand to 8,100 properties, in which case 50.0% of the properties present in the selected block must be inspected", allowing the survey to be carried out in small municipalities (Brasil, 2013).

Therefore, the objective was to propose a technically viable and low-cost method for defining priority areas for intervention using UAVs, encouraging situational analysis of dengue cases, and consequently of other arboviruses in municipalities in Minas Gerais and other Brazilian States, using data from the city of Itabira as an example.

This research is important for public health and justifies the need for interdisciplinary efforts to combat diseases transmitted by *A. aegypti*, considering weaknesses in vector control.

MATERIAL AND METHODS

A descriptive study was conducted based on a survey of suspected dengue cases in the urban area of Itabira between 2018 and 2022, categorized by neighborhood of residence. The municipality of Itabira is located in the eastern region of the State of Minas Gerais (Figure 1), with a territorial area of 1,253,704 km^2, an estimated population of 113,343 inhabitants, and a characteristic biome of Atlantic Forest and Cerrado (IBGE, 2022). The study area included 77 urban neighborhoods, totaling 44,507 residences, according to data recorded in the LRS of the Ministry of Health, and LIRAa activities were related to the four strata defined by the local health service.

The data were obtained using the Notifiable Diseases Information System (Sinan-online) with the queries: “individual notification”, “evaluated period in each year of study”, “A90-Dengue”, “local of residence”, “type of output - notification list”, “field - the neighborhood of residence” and “classification: 10-dengue”. The list of neighborhoods consulted was obtained through the Locality Registration System of the Ministry of Health (LRS).

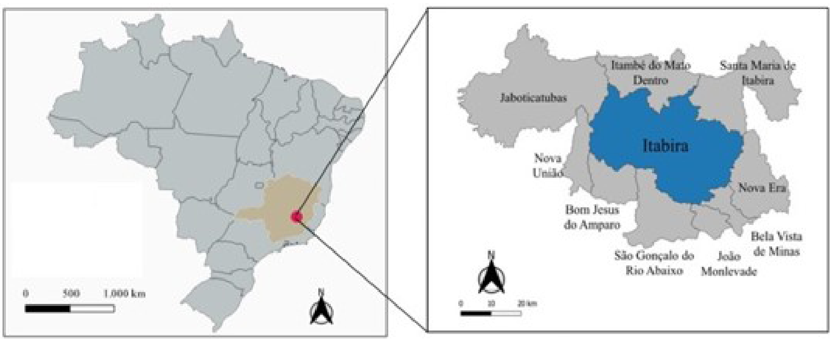

Figure 1: Location of the municipality of Itabira in relation to the State of Minas Gerais. Geographic Coordinate System, Datum SIRGAS 2000. The map was prepared using QGIS® Software version 3.34, which used the cartographic bases of IBGE (2017).

The use of suspected cases (confirmed and discarded) instead of probable cases (confirmed, under investigation, and inconclusive) had the purpose of providing the construction of 2×2 contingency tables for applying Pearson’s Chi-square test, considering the sick (confirmed cases) and not sick (discarded cases). A correlation test was also carried out between the average number of confirmed dengue cases and vector density per stratum. Statistical tests were performed using Excel® Software version 2016.

The average number of confirmed cases per stratum in the period from 2018 to 2022 was correlated to the average vector density, using information from the four results of the LIRAa for the year 2022, obtained in January, May, June, and October. Neighborhoods with a statistically significant difference between average incidence rates and which also presented medium or high-risk levels in the LIRAa results were considered priority areas.

The vector density indicator considered was the infestation index, used by the LIRAa methodology, whose percentages indicate risk levels of dengue transmission in the following order: less than 0.9%= low risk; between 1.0 and 3.9%= medium risk, and above 3.9%= high risk (Brasil, 2013).

Respecting the LIRAa sampling rules, which has the following statement: "The urban area of the municipalities must be divided into strata that present similar socio-environmental characteristics, to obtain homogeneity in each stratum and facilitate control actions vector post-LIRAa" (Brasil, 2013) regions located outside the urban and peri-urban perimeter, even registered in the LRS in the "neighborhood" category, were excluded from the list of neighborhoods analyzed, such as districts, farms, subdivisions, and farms, resulting in 77 neighborhoods.

The lifestyle habits that generate hazards for the installation of breeding sites were defined as a hypothesis (H_1) for contribution to the occurrence of dengue, based on the predominant deposits in the strata, which are subject to removal or non-insertion into the environment, by action of human will (Flauzino et al., 2011).

The Regional Health Management of Itabira provided the locality data containing the population/ neighborhood relationship, and the Municipal Health Department of Itabira provided the list of LIRAa strata. The carrying out of this work was approved by the Research Ethics Committee of the René Rachou Institute (Fiocruz-MG) under the registration of the substantiated opinion CAAE: 77068623.8.0000.5091.

RESULTS

Itabira recorded 3,576 suspected dengue cases between 2018 and 2022, with 1,004 confirmed cases and no deaths, representing 28.0% (Sinan online). In the same period, the confirmed dengue cases in the city were residents of 50 neighborhoods, whose decreasing incidence rates varied between 970.29 and 9.63 cases/100 thousand inhabitants (Table 1). The average incidence for the period was 111.40 cases/100,000 inhabitants, and the median was 81.33 cases/100,000 inhabitants. Among the 50 neighborhoods with registered cases, 11 had an incidence above the general average for the municipality (Pedreira, Água Fresca, Praia, Eldorado, Machado, Bela Vista, Clovis Alvim, Campestre, Major Lage de Cima, Clovis Alvim II, and Gabiroba).

Table 1: Decreasing average incidence rates (per 100,000 inhabitants) of confirmed dengue cases between 2018-2022 stratified by neighborhood of residence in the municipality of Itabira/MG.

Neighborhood	Incidence	Neighborhood	Incidence
Pedreira	970.29	Madre Maria de Jesus	81.30
Água Fresca	649.12	Fênix	75.18
Praia	300.62	Nossa Senhora das Oliveiras	67.85
Eldorado	251.75	Vila Paciência	63.82
Machado	184.67	Barreiro	61.06
Bela Vista	176.58	Bethânia	60.46
Clovis Alvim	160.81	Penha	59.70
Campestre	129.70	Novo Amazonas	51.49
Major Lage de Cima	127.57	Ribeira de Cima	45.45
Clovis Alvim II	124.65	Vila São Joaquim	45.12
Gabiroba	122.64	Santa Marta	43.86
Vila Piedade	110.29	Santa Tereza	43.29
Jardim dos Ipês	105.25	Vila Salica	39.06
Conceição	102.56	São Francisco	38.91
Pará	102.23	Hamilton	38.17
Amazonas	100.00	Vila São Geraldo	37.20
Santa Ruth	99.94	São Bento	34.72
Valença	98.27	Caminho Novo	32.50
João XXIII	97.87	Abóboras	26.77
Santo Antônio	93.50	Areão	19.87
Vila Técnica Conceição	92.60	Alto Boa Vista	14.74
Juca Rosa	91.01	São Marcos	13.12
Colina da Praia	87.61	Juca Batista	11.70
São Pedro	84.46	Cônego Guilhermino	9.83
14 de Fevereiro	81.35	Bálsamo	9.63

Source: Sinan On-line.

Regarding the vector component, the four LIRAa results for 2022 showed alarming results in all strata, and in all months, the infestation rate exceeded the ideal value (up to 1.0%), considered a low risk of dengue transmission, remaining between medium and high-risk levels throughout the year evaluated. Another critical factor is the predominant breeding sites, mobile deposits, and solid waste, as all of them can be removed from the environment, requiring attention and social mobilization to prevent their presence in properties, as detailed in Table 2.

Table 2: Results of the LIRAa in Itabira/MG carried out in the months of January, May, June, and October - 2022

LIRAa	Stratum 1	Stratum 2	Stratum 3	Stratum 4	Ȳ
January	4.8%	16.2%	11.0%	3.6%	8.9%
May	2.3%	10.6%	6.2%	1.8%	5.2%
June	2.2%	3.2%	1.5%	0.9%	1.9%
October	2.5%	6.2%	2.7%	1.6%	3.2%
Ȳ	2.9%	9.0%	5.3%	2.0%	
PC	B	D2	D2	B	
Risk	Medium	High	High	Medium	

Ȳ= average value; PC= predominant container; B= Mobile deposits such as vases/ bottles with water, plates and bottles; D2= Solid waste (plastic containers, PET bottles, cans), scrap and construction debris; Risk= risk of dengue transmission.
Source: Municipal Health Department of Itabira/MG

The correlation between the average number of confirmed dengue cases and the vector density demonstrated proportionality in strata 1, 3, and 4. However, the result of stratum 2 does not match expectations, as it represents the stratum with the highest vector density but with the lowest number of dengue cases, as shown in Figure 2.

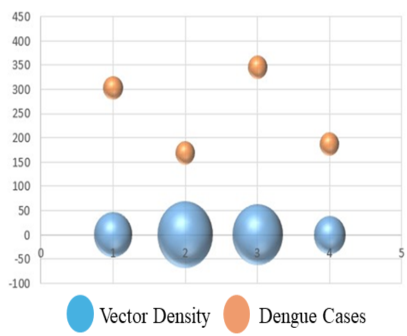

Figure 2: Correlation between vector density and confirmed dengue cases by stratum between 2018-2020, Itabira/MG. Source: Sinan on-line; LIRAa/ Itabira-2022.

Figure 3 presents the Chi-square test results, considering the criteria of similarity between incidence rates and proximity between neighborhoods. After defining H_1, the criteria described in Figure 3 (a-g), containing seven combinations between incidence rates and distance between neighborhoods, were submitted to Pearson's Chi-square test to determine priority areas, that is, areas with significant differences in incidence rates, therefore with a greater probability of dengue occurrence.

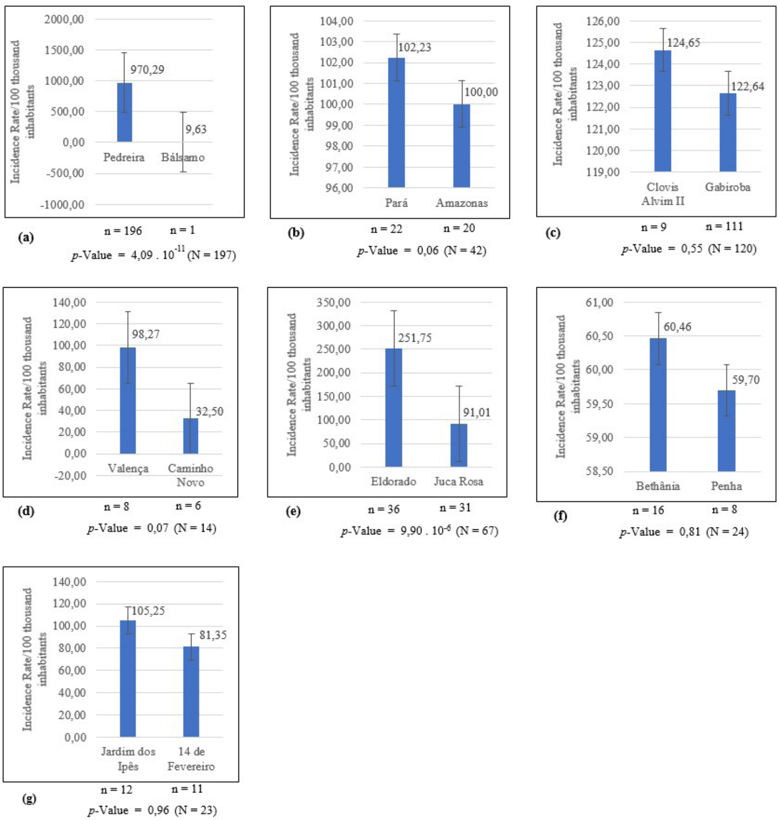

Figure 3: Results of the Chi-square test, using criteria of similarity between incidence rates and neighborhood proximity. (a) Neighborhoods with higher and lower incidence (regardless of strata); (b) Neighborhoods with similar incidences, located in different strata but close together; (c) Neighborhoods with similar incidences, located in the same stratum; (d) Neighborhoods with different incidences, located in various strata, but close together; (e) Neighborhoods with different incidences, located in the same stratum; (f) Neighborhoods with similar incidences, located in more distant strata; (g) Neighborhoods with different incidences, located in more distant strata.

There was statistical significance in the evaluations between the neighborhoods with the highest and lowest incidence - regardless of the strata (Figure 3a) and between the neighborhoods with different incidences located in the same stratum (Figure 3e). However, in other analysis combinations, where significant results were expected, the test considered the hypothesis H_0, suggesting that the observed incidence rates are influenced by chance, as in the comparison between neighborhoods with different incidences located in more distant strata (Figure 3g).

DISCUSSION

The 1,004 cases of dengue confirmed between 2018 and 2022 in Itabira are related to residents distributed in 50 neighborhoods (Table 1), representing 64.9% of the total neighborhoods evaluated in this study, with a population exposed to a more significant hazard of contracting dengue proportionally estimated at 73,599 inhabitants. The estimate of exposed people was adjusted according to the population projected by the IBGE, as the LRS considers the average of four people per property used in zoonosis control programs in Brazil (Brasil, 2014), whose resulting value would be 168,071 inhabitants, exceeding the IBGE (2022) estimate of 113,343 inhabitants for the entire municipality.

In addition to the significant number of people at risk, it is important to consider that dengue outbreaks occur cyclically every 3 to 5 years (OPAS, 2023), and a similar pattern of case distribution could be observed in the data collection in this study, with a progressive increase between 2018 and 2020 and a drop in registrations from the end of 2020, continuing until 2022.

Therefore, this cyclical scenario of an imminent outbreak reinforces that implementing effective environmental health surveillance, with efficient human and technological resources available to minimize the impacts of vector dispersal, is increasingly necessary at the municipal level (Oliveira et al., 2023).

The results of the LIRAa for the year 2022, presenting strata 1 and 4 classified as medium risk and the others as high risk, with average percentage values of the home infestation rate (IIP) between the extremes of 2% (stratum 4) to 9% (stratum 2), demonstrated vulnerabilities for the circulation of the virus in the studied population (Table 2), since the ideal percentage for IIP is below 1%, representing one of the main goals of the National Program of Dengue Control (Brasil, 2002).

A similar study carried out by Rodrigues et al. (2019) in the city of Uberlândia/ MG, using LIRAa data from the years 2014 to 2016, demonstrated that in all years evaluated, the second survey, carried out in March, presented results with a more significant number of neighborhoods classified at high risk of transmission, and the one carried out in October/ 2015 presented the lowest index for the period. The authors explained that this last result resulted from a possible vector control and social mobilization service improvement.

It is important to highlight that from 2022 onwards, municipal endemic disease control services were encouraged to carry out four LIRAa activities per year (previously there were three), and from 2023, the Health Surveillance Actions Qualification Program (PQA-VS) of the MS consolidated this practice in the service routine nationwide (Brasil, 2023a). Therefore, the present study considered the second LIRAa, the one generated by the municipal service of Itabira in the month of May, and in the comparative study referring to March.

Although Itabira's IIP/2022 presents a higher percentage in the first LIRAa, carried out in January, it represents a result consistent with the study carried out in Uberlândia/ MG, as the first and second LIRAa are carried out during the rainy season, between October to March (INMET, 2017), considered critical for the occurrence of large dengue outbreaks, particularly in densely populated urban areas (Lowe et al., 2021). The positive correlation between the increase in vector density in humid months and the incidence of dengue is admitted in numerous published studies, which considered that IIP was closely associated with rainfall. However, other studies have demonstrated that isolated meteorological conditions, without the existence of a container, do not provide sufficient conditions for the proliferation of *A. aegypti* (Rizzi et al*.,* 2017).

The research by Santos et al. (2022) also demonstrated that the occurrence of dengue fever and other arboviruses does not depend solely on climatic conditions when they described a null correlation between infestation rates and the incidence of these diseases in the municipality of Ribeirão Preto, located in the State of São Paulo.

In the present work, the comparison between the average incidence of dengue cases occurring between the years 2018 and 2022 and the vector density in the year 2022 (Figure 2) showed a weak correlation (p= 0.00335; R^2= 0.00001), with a percentage close to 0.001%. This result was influenced by the profile of stratum 2, which presented the highest vector density among the strata worked by the municipality but the lowest incidence rate of the disease, representing a scenario contradictory to what was expected (Corrêa, 2005). The discrepancy in the correlation result for stratum 2 could be demonstrated when the analysis was carried out only with strata 1, 3, and 4, generating p= 0.877 and R^2= 0.768, with an association strength of 76.8%.

Although the factors that condition the increase in dengue cases are poorly understood, except the seasonality variable (Vernal et al., 2021), in the context of health surveillance, possible explanations for the situation observed in stratum 2 may be related to underreporting of cases, overestimation of LIRAa results or individual susceptibility (Nascimento et al., 2020).

This information suggests that the urban structure and mainly the behavioral pattern of the inhabitants of a region can exert environmental pressure for the spread of *A. aegypti* greater than climatic variables in certain circumstances, as they can produce breeding sites inaccessible to health agents, posing an imminent danger for an increase in the incidence of dengue (Brasil, 2022). In this aspect, Sá et al. (2019) reported that the success of vector monitoring depends on overcoming the Flexnerian biomedical model, with the need to stop evaluating only biological or climatic variables and to consider social determinants of health as vulnerability factors in the place where one lives.

For this reason, the present study considered as hypothesis H_1 the lifestyle habits related to the accumulation of waste and unusable waste of residents in the sampled neighborhoods as an intervening factor for the increase in breeding sites and, consequently, more significant occurrence of dengue in the municipality of Itabira.

Among the seven combinations of incidence rates and distance between neighborhoods, Figures 3a and 3e showed statistical significance, the first of which related the neighborhoods with the highest and lowest average incidence found in this study, in which the neighborhoods had a difference of 99% between the incidences. Figure 3e evaluated neighborhoods with different average incidence rates but located in the same stratum, with a difference of 64% between them.

The other five combinations did not present significant differences between the average incidence rates; however, it was expected that among the more distant neighborhoods or located in diverse strata, there would be statistical significance, considering that different strata have different socio-environmental characteristics, promoting inequalities in the transmission pattern of the disease (Brasil, 2013; Drumond et al., 2020).

In association with factors related to lifestyle habits, it is important to consider that population density per neighborhood can contribute to a more significant accumulation of garbage, scrap, and other artifacts that enable the maintenance of containers for the vector, demonstrating that the population difference of 66% between the neighborhood with the highest incidence (Pedreira with 1,526 inhabitants) and the one with the lowest incidence (Balsamo with 519 inhabitants) may be a significant attribute for the spread of *A. aegypti* (Rodrigues et al., 2016).

The complexity of the relationships between entomological indices and dengue occurrence was discussed by Fustec et al. (2020) in a prospective hospital-based case-control study, the results of which suggested that monitoring the presence of DENV-infected *Aedes* could be a better indicator of the risk of disease occurrence, rather than traditional entomological indices, based on larval stages of the vector, subject to high mortality until the intermediate pupal stage.

Lifestyle habits can exert more environmental pressure than climate variables on the occurrence of dengue, as statistical analyses have not demonstrated a defined pattern for the occurrence of the disease. Based on the approach adopted here, the best criterion for defining priority areas is the association between the average number of dengue cases per stratum and the vector density, with priority given to the average number of cases. Considering that the infestation rate presented an important inconsistency in the stratum 2 correlation analysis, operational failures may have influenced field service or information system records. The results presented here demonstrated that the proposal of this study is viable in its technical and financial aspects for the municipal health surveillance service, as it uses data generated in the service routine.

CONFLICTING INTEREST

There is no conflict of interest to declare.

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