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ORIGINAL ARTICLE

Spatial distribution and temporal behavior of the Zika virus in the municipality of Araguaína/Tocantins, 2016 to 2023

Distribuição espacial e comportamento temporal do vírus Zika no município de Araguaína/Tocantins, 2016 a 2023

Distribución espacial y comportamiento temporal del virus Zika en el municipio de Araguaína/Tocantins, 2016 a 2023

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RESUMO

Justificativa e Objetivos: analisar a distribuição epidemiológica espacial das infecções pelo vírus Zika e seu comportamento temporal no município de Araguaína, estado do Tocantins, Brasil, enfatizando a relevância da vigilância contínua e métodos de controle e prevenção. **Métodos**: este foi um estudo ecológico de séries temporais e tendência dos casos confirmados de vírus Zika no município de Araguaína-TO. O padrão sazonal da doença foi avaliado pelo diagrama de controle, contendo índices por ano e níveis por semana epidemiológica. Os dados de análise espacial foram distribuídos com o auxílio do software QGIS por bairros, delimitando clusters de alto e baixo risco. **Resultados**: o município relatou 2.031 casos no período avaliado, sendo 519 confirmados, com uma tendência estacionária de baixos índices e padrão sazonal. Os indivíduos mais afetados foram do sexo feminino, pardos, idade entre 20 e 39 anos, e nível de escolaridade inferior a 12 anos de estudo. A doença apresentou características heterogêneas dentro do município, afetando tanto grandes centros demográficos, quanto bairros periféricos. **Conclusão**: o discernimento acerca das características epidemiológicas é importante para promover políticas públicas e educação em saúde destinadas ao desenvolvimento de mecanismos de previsão de surtos, além de estratégias para o controle das infecções, visando reduzir e/ou sanar novas epidemias dessa arbovirose através da interdisciplinaridade de atuação.

Descritores: *Zika Vírus. Epidemiologia. Análise Espacial. Estudos Ecológicos.*

ABSTRACT

Background and Objectives: To analyze the spatial epidemiological distribution of Zika virus infections and its temporal behavior in the municipality of Araguaína, state of Tocantins, Brazil, emphasizing the relevance of continuous surveillance and control and prevention methods. **Methods:** Ecological study of time series and trends of confirmed Zika virus cases in the municipality of Araguaína-TO. The seasonal pattern of the disease was assessed using a control chart containing indices per year and levels by epidemiological week. Spatial analysis data were distributed with the help of QGIS software by neighborhoods, delineating high and low-risk clusters. **Results:** The municipality reported 2,031 cases during the assessed period with 519 confirmed, showing a stationary trend with low indices and a seasonal pattern. The most affected individuals were female, of mixed ethnic background, aged between 20 and 39 years, with less than 12 years of schooling. The disease exhibited heterogeneous characteristics within the municipality, affecting both large demographic centers and peripheral neighborhoods. **Conclusion:** Understanding the epidemiological characteristics is important for promoting public policies and health education aimed at developing mechanisms for predicting outbreaks, as well as strategies for controlling infections to reduce and/or prevent new epidemics of this arbovirus through interdisciplinary action.

Keywords: *Zika Virus. Epidemiology. Spatial Analysis. Ecological Studies.*

RESUMEN

Justificación y Objetivos: Analizar la distribución epidemiológica espacial de las infecciones por el virus del Zika y su comportamiento temporal en el municipio de Araguaína, estado de Tocantins, Brasil, enfatizando la importancia de la vigilancia continua y los métodos de control y prevención. **Métodos:** Estudio ecológico de series temporales y tendencias de los casos confirmados de virus del Zika en el municipio de Araguaína-TO. El patrón estacional de la enfermedad fue evaluado mediante un gráfico de control que contenía índices por año y niveles por semana epidemiológica. Los datos de análisis espacial fueron distribuidos con la ayuda del software QGIS por barrios, delimitando clústeres de alto y bajo riesgo. **Resultados:** El municipio reportó 2.031 casos durante el período evaluado, de los cuales 519 fueron confirmados, mostrando una tendencia estacionaria con índices bajos y un patrón estacional. Los individuos más afectados fueron mujeres, de origen étnico mixto, con edades entre 20 y 39 años y un nivel educativo inferior a 12 años de estudio. La enfermedad presentó características heterogéneas dentro del municipio, afectando tanto a grandes centros demográficos como a barrios periféricos. **Conclusión:** El conocimiento sobre las características epidemiológicas es importante para promover políticas públicas y educación en salud dirigidas al desarrollo de mecanismos para la predicción de brotes, así como estrategias para el control de las infecciones, con el objetivo de reducir y/o prevenir nuevas epidemias de esta arbovirosis mediante la acción interdisciplinaria.

Palabras Clave: *Virus Zika. Epidemiología. Análisis Espacial. Estudios Ecológicos.*

INTRODUCTION

Arboviruses are considered pathologies of viral etiology transmitted by arthropods, mainly by hematophagous mosquitoes of the genera *Aedes*, *Culex* and *Lutzomyia*, and are an eminent global public health problem. To date, only a few arboviruses cause clinically significant human diseases and are transmitted by mosquitoes, including *Alphaviruses* such as Chikungunya, and *Flaviviruses* such as Zika, Dengue and West Nile.[1,2]

The ability to adapt to new environments, vectors and hosts through viral mutation and genetic plasticity imposed by environmental changes caused by anthropogenic action, increased international exchange and climate change, gives these microorganisms the potential to cause widespread outbreaks and epidemics. These changes have a direct impact on the transmissibility of these zoonotic infections, allowing the mosquito vector to live closer to humans and spread to new areas.[1,2]

Zika is an important arbovirus disease caused by the Zika virus (ZIKV), which is responsible for clinical manifestations such as arthralgia, myalgia, fever, maculopapular rash, conjunctivitis, and others. It was initially isolated in West Africa in the late 1940s and remained restricted to the African continent until 2007, when it attracted global attention due to an outbreak in Micronesia. From there, the virus spread to other Pacific islands, emerging as a generalized epidemic in Latin America. In 2015, it arrived in Brazil through infected travelers serving as reservoirs for transmission by the *Aedes aegypti* mosquito and sexual or transplacental activity, and then, reports of a mild disease began to increase in the Brazilian northeast.[3,4]

It is estimated that from 2015 to the end of 2016, more than 1.6 million cases of this arbovirus occurred in the country. The Northeast region concentrated the largest number of cases, followed by the Central-West and North regions. In 2016 alone, 10,867 cases were reported, of which 2,366 were confirmed, and of these, 200 deaths were recorded, determining a fatality rate of 8.5% for the disease. Regarding the notification of this arbovirus disease in the state of Tocantins, the capital Palmas had the highest proportion of cases with values above 200/100,000 inhabitants.[5–7]

In addition, the SARS-CoV-2 pandemic, the novel coronavirus 2019 (COVID-19), directly impacted the epidemiological patterns of ZIKV, mainly by diverting resources and attention from epidemiological surveillance to combating the coronavirus. With the overload of health systems, there was a reduction in the notification of cases and monitoring of arbovirus diseases, making it difficult to accurately assess the incidence of ZIKV during this period. In addition, measures such as social isolation and reduced population mobility may have indirectly influenced the transmission of ZIKV by altering contact between humans and vectors. This repercussion highlights the need to maintain continuous and integrated surveillance, even in health emergency scenarios.[8]

In this context of dissemination, a dramatic increase in cases of microcephaly, Guillain-Barré syndrome, meningoencephalitis and myelitis was detected among newborns, in addition to other congenital manifestations (congenital Zika syndrome), such as musculoskeletal and ocular malformations. A causal relationship was established between ZIKV infection and its teratogenic effect with tropism for developing nerve cells, leading the Brazilian Ministry of Health and the World Health Organization to declare a Public Health Emergency of National and International Concern.[7, 9, 11]

Even though knowledge about this disease has advanced and now there is possibility of serological diagnoses and prophylaxis against the vector, it still represents a potential challenge for public health due to the unavailability of vaccines as a prophylactic method or effective antivirals for the treatment of a disease that can be fatal or incapacitating. Additionally, the economic impact can be presumed, since repercussions after the acute phase, such as neurological disorders with generalized muscle weakness and paralysis, interfere with occupational activities.[2,12]

It is also important to highlight that the possibility of other manifestations arising from the coinfection of ZIKV with other diseases cannot be ruled out. Although the lethality of ZIKV infection is low, the fact that most infected people are asymptomatic contributes to its spread and may be associated with the emergence of new cases and outbreaks. Therefore, it is not possible to exclude the need for new investigations, nor the continuous work of entomological and epidemiological surveillance of healthcare in detecting and monitoring cases in order to establish methods for controlling and preventing this disease.[2,5,11]

Given this situation, this study proposes to carry out a spatial epidemiological analysis of reported cases of ZIKV infection in the municipality of Araguaína, state of Tocantins, from 2016 to 2023.

METHODS

This is an ecological time series analytical study of confirmed cases of ZIKV infection in the period from 2016 to 2023 in the municipality of Araguaína, northern region of the state of Tocantins.

Considered the second most populous city in the state according to the last Census, the municipality has an estimated population of 171,301 inhabitants in a total area of 4,004.646 km², subdivided into 124 neighborhoods.[13]

The region is currently a major economic center with privileged logistics and federal highways that contribute to the city's intense interpersonal traffic. The city is also considered a reference and health center for neighboring municipalities, which may impact the spread of vectors and/or diseases imported into the municipality.

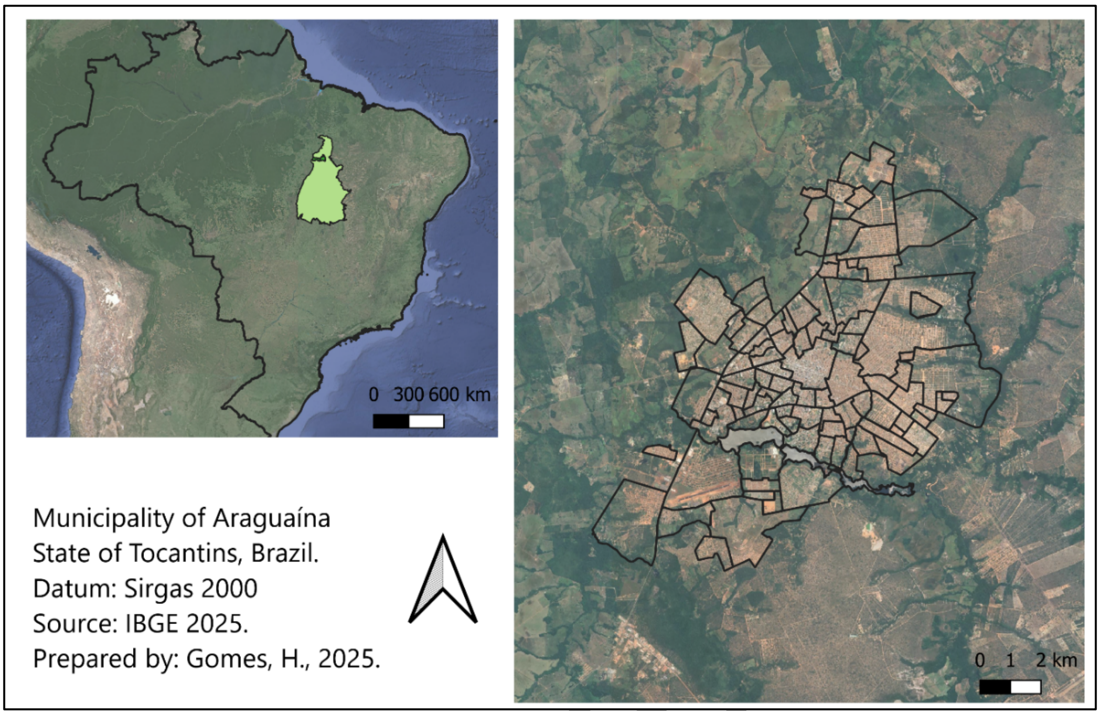

Figura 1. Municipality of Araguaína, State of Tocantins, Brazil. Source: Gomes et al, 2025.

In the development of the study, all confirmed cases of Zika in the municipality were analyzed, excluding inconclusive or probable cases without confirmation. Epidemiological data on confirmed cases of Zika, as well as sociodemographic and clinical characteristics were collected through the Health Information System provided by DATASUS through Tabnet. Information regarding the Building Infestation Index (BII) was provided by the health department of the municipality of Araguaína through the arbovirus department. Data were organized, processed and statistically analyzed using Excel and the Statistical software for data science (Stata MP-64).

The BII is a metric widely used in public health surveillance to assess the degree of infestation by vectors, such as *Aedes aegypti*. This index is calculated based on the proportion of properties in which the breeders of these vectors are identified in relation to the total number of properties inspected in a specific area. Infestation rates were categorized as follows: 0 to 1% (low risk), 1 to 3.99% (alert), and greater than 3.99% (high risk). The variations observed were organized according to the average infestation rates during the study period, providing a comprehensive and detailed view of the dynamics of the infestation in the municipality.[14]

First, the analyzes were performed by converting the absolute case values into incidence using the following formula: confirmed cases of the disease divided by the population at risk, multiplied by one hundred thousand.[15]

The control chart was designed to analyze the risk levels of disease progression with analysis of the rates per year (2016 to 2023) and later of the levels per epidemiological week (52) of the post-pandemic biennium to determine the seasonal pattern of the disease in the municipality.[14]

To analyze the concentration of cases, a cartographic map with the division of the neighborhoods of the municipality of Araguaína was generated, in which information on the incidence of the disease was inserted. The incidence was represented using the proportional symbols technique, which adjusts the size of circles according to the density of the occurrence of the phenomenon of interest. The values of the BII by neighborhood were represented choroplethically using a color scale according to the different risk levels. Data organization, spatial analyzes and generation of the final map layout were performed using the Quantum GIS (QGIS) software, allowing a clear and precise visualization of the variables analyzed.

As this is open-access public domain information and investigators have no access to sensitive data, the study was not submitted to the Human Research Ethics Committee (CEP) for evaluation, in accordance with CNS Resolution No. 510 of 2016, article 2, VI.

RESULTS

During the years of the study, the city of Araguaína reported 2,031 cases of ZIKV in SINAN. Of these, only 519 cases were confirmed, with emphasis on the years 2016 and 2017, which together represented more than 90% of notifications.

Regarding the epidemiological profile, women had a higher incidence (67.43%), a higher percentage of cases occurred in individuals of mixed ethnic background (81.69%), young adults in the age group 20-39 years (46.24%), with a maximum education of nine to 12 years (38.92%). Of the total confirmed cases, 99.03% evolved to cure (Table 1).

Table 1. Sociodemographic and clinical characteristics and evolution of confirmed cases of Zika virus in the municipality of Araguaína-TO from 2016 to 2023.

Characteristics	**N (%)**	**P**
Female	350 (67.44)	
Male	169 (32.56)	0.002
Total	519 (100)	
Age range (in years)		

0-4	27 (5.2)	
5-9	24 (4.62)	
10-19	94 (18.11)	
20-39	240 (46.24)	0.0001
40-59	120 (23.12)	
≥ 60	12 (2.31)	
Unknown	2 (0.38)	
Race/skin color		
White	72 (13.87)	
Black	8 (1.54)	
Yellow	3 (0.57)	
Mixed ethnic background	424 (81.69)	<0.0001
Indigenous	4 (0.77)	
Unknown	8 (1.54)	
Education in years		
0	2 (0.38)	
< 9	172 (33.14)	
9-12	202 (38.92)	0.003
> 12	83 (15.99)	
Unknown	23 (4.43)	
Not applicable	37 (7.13)	
Evolution		
Cure	518 (99.04)	
Death	1 (0.19)	< 0.0001
Unknown/blank	4 (0.77)	

According to the control chart for Zika incidence in the period evaluated (Figure 2), there was a stationary trend dynamic with low rates. Most cases described for the years 2022 and 2023 were concentrated between epidemiological weeks 9 and 25, reflecting the seasonality of this arbovirus.

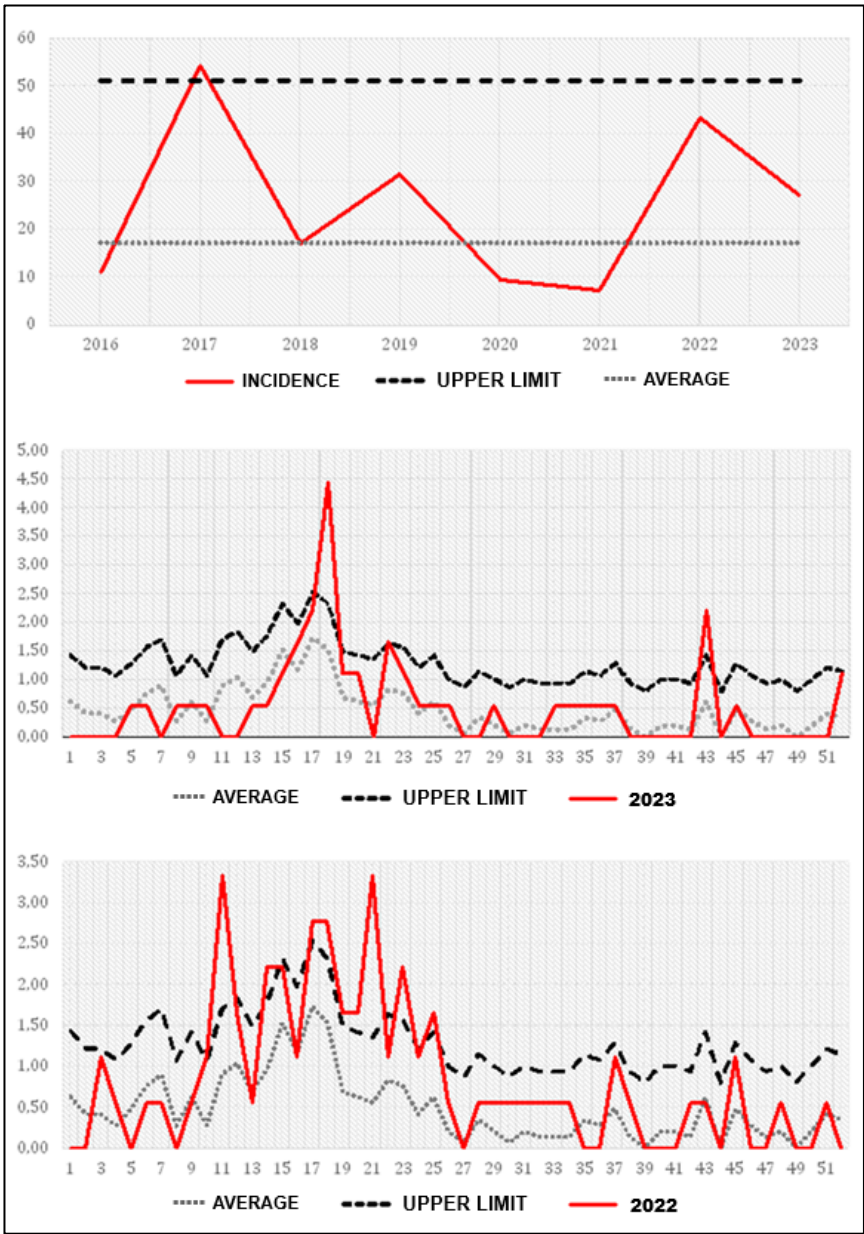

Figure 2. Control chart for Zika incidence for the period 2016 to 2023 and according to epidemiological week for the years 2022 and 2023 (incidence per 100,000 inhabitants).

Regarding the spatial distribution pattern, the manifestation of this arbovirus disease presented heterogeneous characteristics within the municipality. The centers with the highest population densities were some of the areas at high risk for transmission, according to the BII, with emphasis on the neighborhoods of Araguaína Sul, São João and the central sector.

Despite the varied presentation in the territory, much of the incidence was also focused on some peripheral regions with socio-environmental characteristics favorable to the spread of *A. aegypti*, mainly Lago Azul 1 and 2, Jardim Filadélfia and Bairro Senador (Figure 3).

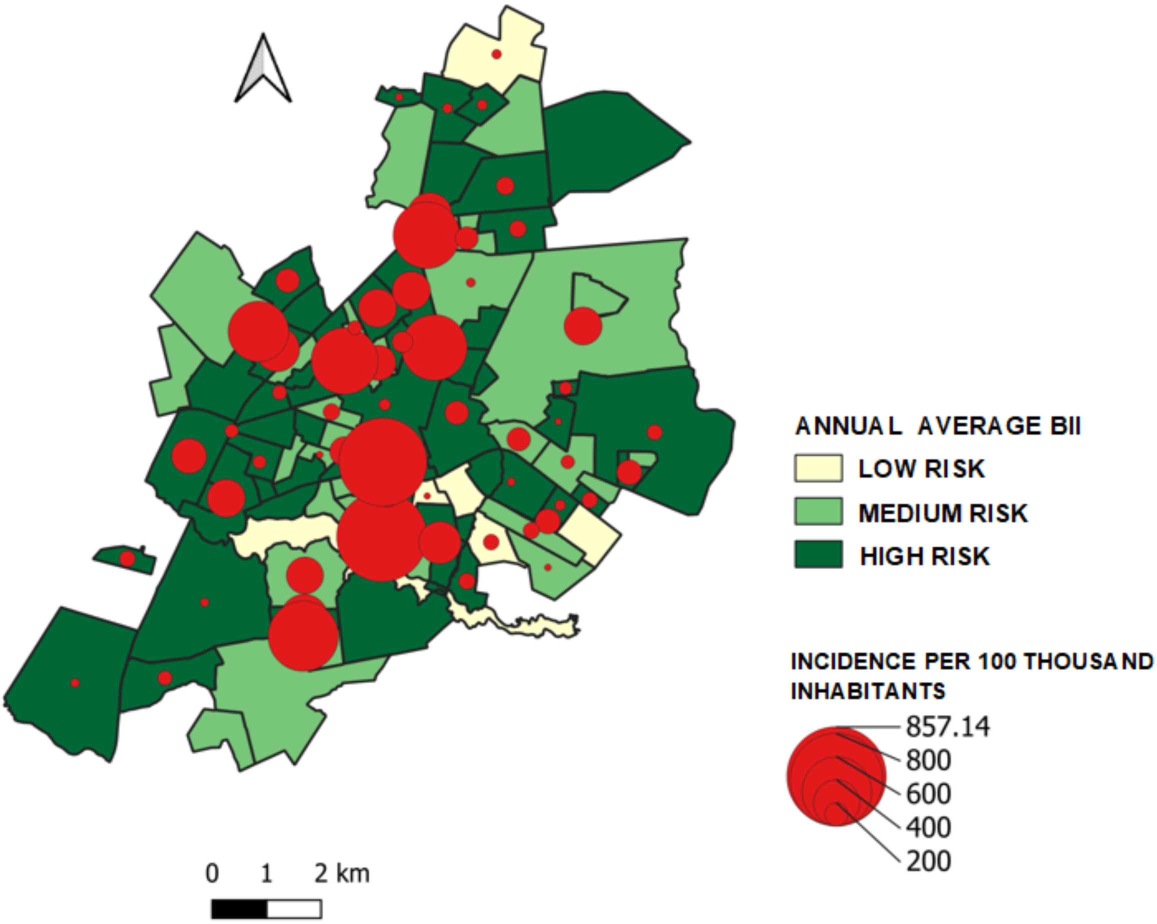

Figure 3. Zika incidence levels and annual average building infestation rate by neighborhood in the municipality of Araguaína, state of Tocantins.

DISCUSSION

The city of Araguaína has historically been known for fluctuations in rainfall and air temperature, presenting favorable conditions for the spread of arboviruses transmitted by the *A. aegypti* mosquito. In addition, its strategic spatial position between the states of Pará and Maranhão together with economic centers such as the cities of Marabá-PA, Imperatriz-MA and the capital Palmas-TO, and intercity land transport may favor an epidemiological corridor between different ecosystems, contributing to the migratory dynamics of infections.[16,17]

In this study, the epidemiological pattern of ZIKV infection in the city was concentrated in females and the age group of 20-39 years, although it can affect the entire population at different ages.[18] The phenomenon described as "feminization of poverty" may reflect a household profile of women, mainly in the most peripheral areas of the city, favoring greater contact with the vector. Furthermore, some studies suggest that women, because they take greater care of their health, generally seek more medical care than men, and may not be the most affected by the disease but contribute more to notifications.[19,20]

Therefore, underreporting is still a common phenomenon in Brazil, which may occur due to diagnostic errors, asymptomatic infections and problems in accessing health services. In fact, the similarity of symptoms between arboviruses (Dengue, Zika and Chikungunya) and the benign and self-limiting nature of most ZIKV infections may interfere with the diagnosis. Thus, the lower incidence in men may also be justified by their low demand for healthcare in the face of an oligosymptomatic disease. This fact can be mitigated with strategies aimed at this public, such as the National Men's Health Program created by the Ministry of Health, educational campaigns aimed at primary care, such as the Blue November, and encouragement of routine care and preventive health in the workplace as well.[21]

The noticeable discrepancy between the most affected age groups, more common in the economically active population aged between 20 and 39 years old, followed by the range between 40 and 59 years can be explained by the greater movement of these people in their work activities and contact with different risk environments. Furthermore, the prevalence in lower levels of education can be justified by difficulties in understanding and managing preventive measures, contributing to the increase in suspected cases.

Similar to previous ecological studies,[22] in the present study, a positive association between ZIKV infection and residents who self-identify as mixed ethnic background was observed. Currently, some evidence suggests that both social origin and race interfere in income inequality in our country, with repercussions on access to essential services, such as health, education and employment. In the scenario of infectious diseases, this reality may reflect greater vulnerability of a certain portion of the population, such as people of mixed ethnic background, as they often live in more exposed areas to vectors and face barriers in accessing preventive and care measures. However, public policies such as *Bolsa Família* and other income transfer programs have played an important role in mitigating this disparity, improving living conditions and consequently reducing the incidence of diseases.[23,24]

It is also noteworthy that according to the 2022 IBGE Census,[25] the majority of the Brazilian population (45.3%) declared themselves as being of mixed ethnic background, providing a large contingent of susceptible individuals.

Regarding the temporal distribution of cases, a greater number of notifications was observed in the first epidemiological weeks, reflecting the seasonal nature of the rain in the region, providing hot and humid climates with suitable environments that accelerate the vector's reproductive cycle, in line with research in other cities such as Teresina-PI and Goiânia-GO.[22] It is well known that inadequate water treatment, precarious sewage systems and accumulation of stagnant water increase soon after the start of the rainy season. These data reinforce the need to intensify vector control campaigns and personal protective care at this time of year.

Most notifications occurred in the early years of the epidemic in Brazil, between 2016 and 2017, with sporadic cases remaining at a steady level in the following years, which suggests a certain effectiveness in the implementation of public policies to control the disease. Among these measures, the importance of the joint participation of Community Health Agents (CHA), Endemic Disease Control Agents (ACE), zoonosis agents and the population itself stands out. Identifying and controlling potential mosquito breeding sites, personal protection with repellents, and continuing health education have a positive impact on reducing transmission.[26]

The spatial distribution analysis showed a diverse characteristic of affected areas, spreading throughout the region and maintaining a higher incidence in some neighborhoods in the city center and the outskirts.[27] There was a tendency for notification in areas of greater population density with vegetation and a nearby lake, such as in the Lago Azul 1 and 2 sectors, Jardim Filadélfia and Bairro Senador, where there is peridomicile habitat for vectors, facilitating mosquito-human contact and making the population more susceptible. Some studies have also identified that neighborhoods close to water reservoirs, such as lakes and streams, were more affected by arboviruses.[28,29]

It is a fact that the process of urbanization and verticalization of the city associated with inadequate infrastructure increased residual waste, and a dynamic population migration favors closer coexistence between humans and mosquitoes. It is suggested that cities with better economic indicators and higher population density have a high prevalence of arboviruses (Dengue, Zika and Chikungunya), a phenomenon observed in the two largest cities in Tocantins (Araguaína and Palmas).[19]

Although health and selective collection coverage are good, this is justified in central and more agglomerated areas, since the high population density associated with the production of non-organic waste, irregular disposal of litter on the streets and around homes, construction waste and a large flow of people, facilitate the spread of the disease by acting as possible temporary breeding grounds for the mosquito.[26,30,31]

The heterogeneity of affected locations observed in this study may suggest that the daily movement of individuals to central neighborhoods, whether for work or leisure activities, has a positive impact on the infection that affects the most remote areas of the city, since when individuals return to their homes, they can contribute to the spread. Although the behavioral profile of some arboviruses has been reported in previous studies,[20] a flow analysis, evaluating the likely infection environment and the place of residence could provide more information about the role of local population mobility in the spread of infections by vector mosquitoes.

This study presents relevant results, but some limitations arising from the use of secondary data must be considered. It was not possible to include variables related to income, social vulnerability index and selective waste collection, restricting the analysis of the interaction between socio-environmental and economic factors, which may have compromised the identification of more comprehensive patterns. Added to this is the potential for underreporting, since asymptomatic or oligosymptomatic patients may not seek health services or live in areas of poor offer of these services, which may underestimate the real magnitude of the phenomenon investigated.

It is essential to consider these limitations during the interpretation of results, recognizing the need for future studies using primary data in order to minimize these biases.

However, this study advances knowledge and its contributions will certainly support the establishment of new public policies and health education aimed at preventive measures, prioritizing public resources for regions of the city with higher risks and incidence of cases. Therefore, interdisciplinarity in the fight against this arbovirus, addressing issues of health, environment and other fields of knowledge, becomes of utmost importance for the control of ZIKV infections by offering a more comprehensive view of the problem.

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REFERENCES

1. Donalisio MR, Freitas ARR, Zuben APBV. Arboviruses emerging in Brazil: challenges for clinic and implications for public health. Rev Saude Publica. 2017;51(0). https://doi.org/10.1590/s1518-8787.2017051006889

2. Lima-Camara TN. Emerging arboviruses and public health challenges in Brazil. Rev Saude Publica. 2016;50(0). https://doi.org/10.1590/s1518-8787.2016050006791

3. Teixeira GA, Dantas DNA, Carvalho GAF de L, et al. Análise do conceito síndrome congênita pelo Zika vírus. Cien Saude Colet. 2020 Feb;25(2):567–74. https://doi.org/10.1590/1413-81232020252.30002017

4. Freitas P de SS, Soares GB, Mocelin HJS, et al. Síndrome congênita do vírus Zika: perfil sociodemográfico das mães. Revista Panamericana de Salud Pública. 2018 Mar 19;43:1. https://doi.org/10.26633/RPSP.2019.24

5. França GVA de, Pedi VD, Garcia MH de O, et al. Síndrome congênita associada à infecção pelo vírus Zika em nascidos vivos no Brasil: descrição da distribuição dos casos notificados e confirmados em 2015-2016. Epidemiologia e Serviços de Saúde. 2018 Jun;27(2). https://doi.org/10.5123/s1679-49742018000200014

6. Vanderlei J da S, Franchi EPLP, Gomes NS, et al. Perfil de gestantes comfirmadas para zika vírus e assistência pré-natal na atenção primária à saúde de Palmas, Tocantins, 2016. Revista de Patologia do Tocantins. 2018 Sep 9;5(3):12–7. https://doi.org/10.20873/uft.2446-6492.2018v5n3p12

7. Rodrigues M da SP, Costa M da CN, Barreto FR, et al. Repercussões da emergência do vírus Zika na saúde da população do estado do Tocantins, 2015 e 2016: estudo descritivo*. Epidemiologia e Serviços de Saúde. 2020 Jul;29(4). https://doi.org/10.5123/s1679-49742020000400008

8. MICROBE, The Lancet. Arboviruses and COVID-19: the need for a holistic view. The Lancet Microbe, [S.L.], v. 1, n. 4, p. 136, ago. 2020. Elsevier BV. http://dx.doi.org/10.1016/s2666-5247(20)30101-4.

9. Noor R, Ahmed T. Zika virus: Epidemiological study and its association with public health risk. J Infect Public Health. 2018 Sep;11(5):611–6. https://doi.org/10.1016/j.jiph.2018.04.007

10. Falcão Neto PA de O, Branco M dos RFC, Costa S da SB, et al. Análise espacial da taxa de detecção de casos suspeitos de síndrome congênita pelo vírus Zika, Maranhão, 2015 a 2018. Revista Brasileira de Epidemiologia. 2022;25. https://doi.org/10.1590/1980-549720220002.

11. Shariff S, Kantawala B, Hamiidah N, et al. Zika virus disease: an alarming situation resurfacing on the radar – a short communication. Annals of Medicine & Surgery. 2023 Oct;85(10):5294–6. https://doi.org/10.1097/MS9.0000000000001183.

12. Musso D, Ko AI, Baud D. Zika Virus Infection — After the Pandemic. New England Journal of Medicine. 2019 Oct 10;381(15):1444–57. https://doi.org/10.1056/nejmra1808246

13. BRASIL. Instituto Brasileiro de Geografia e Estatística. Cidades e Estados 2022. Disponível em: https://www.ibge.gov.br/cidades-e-estados/to/araguaina.html

14. Brasil. Ministério da Saúde. Secretaria de Vigilância em Saúde e Ambiente. Monitoramento dos casos de arboviroses até a semana epidemiológica 52 de 2022. Boletim epidemiológico. Brasília: Ministério da Saúde; 2022. V. 54. Disponível em: https://www.gov.br/saude/pt-br/centrais-de-conteudo/publicacoes/boletins/epidemiologicos/edicoes/2023/boletim-epidemiologico-volume-54-no-01/.

15. Medronho R; Bloch KV; Luiz RR; Werneck GL (eds.). Epidemiologia. Atheneu, São Paulo, 2009, 2ª Edição. ISBN: 9788573799996

16. Almeida RAS de, Oliveira IB de. Índice de qualidade de uso da água subterrânea (E-IQUAS): aplicação para comunicar o estado da água em dois estudos de caso - Camaçari (BA) e Verdelândia (MG). Águas Subterrâneas [Internet]. 2017 Jul;31(1):88–103. Available from: https://doi.org/10.14295/ras.v31i1.28522

17. Sá ELR de, Rodovalho C de M, Sousa NPR de, et al. Evaluation of insecticide resistance in Aedes aegypti populations connected by roads and rivers: the case of Tocantins state in Brazil. Mem Inst Oswaldo Cruz. 2019;114. https://doi.org/10.1590/0074-02760180318

18. Da Silva Lemos MH, Lourival Lopes Filho L, De Oliveira Costa MA, et al. Distribuição espacial dos casos de Zika vírus em um estado do Nordeste Brasileiro. Nursing (São Paulo). 2022 Oct 3;25(293):8762–75. https://doi.org/10.36489/nursing.2022v25i293p8762-8775

19. Gomes H, de Jesus AG, Quaresma JAS. Identification of risk areas for arboviruses transmitted by Aedes aegypti in northern Brazil: A One Health analysis. One Health. Elsevier BV 2023 Jun;16; v. 16, p.100499. https://doi.org/10.1016/j.onehlt.2023.100499

20. Johansen IC, Castro MC de, Alves LC, et al. Population mobility, demographic, and environmental characteristics of dengue fever epidemics in a major city in Southeastern Brazil, 2007-2015. Cad Saude Publica. 2021;37(4). https://doi.org/10.1590/0102-311x00079620

21. Paula CR, Lima FH, Pelazza BB, et al. Desafios globais das políticas de saúde voltadas à população masculina: revisão integrativa. Acta Paul Enferm. 2022;35:eAPE01587. DOI: http://dx.doi.org/10.37689/acta-ape/2022AR0001587.

22. Rosado LEP, Aquino EC de, Brickley EB, et al. Socioeconomic disparities associated with symptomatic Zika virus infections in pregnancy and congenital microcephaly: A spatiotemporal analysis from Goiânia, Brazil (2016 to 2020). PLoS Negl Trop Dis. 2022 Jun 17;16(6):e0010457. https://doi.org/10.1371/journal.pntd.0010457.

23. Salata A. Race, Class and Income Inequality in Brazil: a social trajectory analysis. Dados, Rio de Janeiro, v. 63, n. 3, p. 1-40, 2020. FapUNIFESP (SciELO). http://dx.doi.org/10.1590/dados.2020.63.3.213.

24. Oliosi JGN; Reis-Santos B; Locatelli RL, et al. Effect of the Bolsa Familia Programme on the outcome of tuberculosis treatment: a prospective cohort study. The Lancet Global Health, [S.L.], v. 7, n. 2, p. 219-226, fev. 2019. Elsevier BV. http://dx.doi.org/10.1016/s2214-109x(18)30478-9.

25. BRASIL. Instituto Brasileiro de Geografia e Estatística. Cor ou raça 2022. Disponível em: https://educa.ibge.gov.br/jovens/conheca-o-brasil/populacao/18319-cor-ou-raca.html#:~:text=De%20acordo%20com%20os%20resultados,92%2C1%20milh%C3%B5es%20de%20pessoas

26. Pereira EDA, Carmo CN do, Araujo WRM, et al. Distribuição espacial de arboviroses e sua associação com um índice de desenvolvimento social e o descarte de lixo em São Luís, Maranhão, 2015 a 2019. Revista Brasileira de Epidemiologia. 2024;27. https://doi.org/10.1590/1980-549720240017.2

27. Lima MAO, Cerqueira HM de L, Almeida IFB de, et al. Distribuição espacial de dengue, chikungunya e Zika e os determinantes socioeconômicos em um município da Bahia. Revista de Ciências Médicas e Biológicas. 2022 Feb 11;20(4):551–9. https://doi.org/10.9771/cmbio.v20i4.38344

28. Costa AG da, Santos JD dos, Conceição JKT da, et al. Dengue: aspectos epidemiológicos e o primeiro surto ocorrido na região do Médio Solimões, Coari, Estado do Amazonas, no período de 2008 a 2009. Rev Soc Bras Med Trop. 2011 Aug;44(4):471–4. https://doi.org/10.1590/S0037-86822011000400014

29. Barreto-Neto AA, Cometti RR. Sensoriamento remoto como ferramenta auxiliar no combate à ocorrência de dengue na cidade de Vitória-ES . Anais XIII Simpósio Brasileiro de Sensoriamento Remoto. 2007 Apr;3733–8. Disponível em: http://ri.uepg.br:8080/riuepg/bitstream/handle/123456789/943/LIVRO_ManualdeNormaliza%C3%A7%C3%A3oEstiloVancouver.pdf?sequence=1

30. Machado, LS; Sobrinho, AFM; De Jesus, AG; Quaresma, JAS; Gomes, H. Analysis of Morbidity and Mortality Due to Yellow Fever in Brazil. *Viruses* 2025, (*17)*, 443. https://doi.org/10.3390/v17030443.

31. Lima Junior, F. de A., Rocha, L. de A., Gomes, H., & Ferreira, R. G. (2025). Epidemiology of Zika Virus in the State of Tocantins. *Revista De Gestão Social E Ambiental*, *19*(3), e011720. https://doi.org/10.24857/rgsa.v19n3-113.

AUTHOR’S CONTRIBUTIONS

Nicolas Kevyn Cavalcante Fernandes contributed to bibliographic research, data collection, processing and analysis, writing, content development and critical review of the manuscript. **Helierson Gomes** contributed to the conception and design of the study, methodology, interpretation and description of results, statistics, image processing, relevant critical review of the manuscript and approval of the final version to be published.

All authors approved the final version of the manuscript and are responsible for all its aspects, including ensuring its accuracy and integrity.