Identification of risk areas for arboviruses transmitted by *Aedes aegypti* in northern Brazil: A One Health analysis

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ABSTRACT

Introduction: The complex and growing problem generated by the rapid expansion of unplanned urban areas includes high population density and increased infestation by vectors responsible for the transmission of several diseases. This requires interdisciplinary and intersectoral interventions due to the burden of diseases, especially those caused by arboviruses, which can present severe forms and generate significant pressure on health systems, especially in more vulnerable regions. The **objective** of this study was to analyze the spatial distribution of arboviruses transmitted by *Aedes aegypti* (dengue, Zika, and chikungunya) and assess their correlations with demographic, social, and environmental data from the state of Tocantins, Brazil.
Methods: This was an ecological time series study of the dengue, Zika, and chikungunya arboviruses in the state of Tocantins. Local Moran's indices were used to observe the spatial autocorrelation of cases and to delimit clusters of high and low risks, correlating them with socioenvironmental indicators, in addition to analyses to detect case clusters.
Results: The state reported a mean incidence of 591 annual cases of arbovirus infections per 100,000 inhabitants and a stationary trend with seasonal pattern. Female Pardo individuals aged 20–39 years, with an education level of below college education, were the most affected; Palmas and Araguaína, the two largest cities in the state in terms of economy and population, were the most affected.
Conclusion: A better understanding of the interaction between social characteristics, the environment, and ecology of wild animals and vectors is important for the development of mechanisms to predict outbreaks as well as to develop strategies to reduce and/or mitigate recurring arboviral epidemics and other diseases.

1. Introduction

Arboviruses represent a major challenge to public health in Brazil. This is due to its association with abrupt climate and environmental changes, deforestation, population migration, disorderly occupation of urban spaces, and precarious sanitation conditions, among others. There are currently 545 known species of arboviruses, of which 150 cause disease in humans [1,2].

Arboviruses are arthropod-borne viruses; transmission to humans occurs through the bite of hematophagous arthropods, the arbovirus vector. In the current epidemiological scenario, Brazil is facing a triple viral epidemic with a high number of dengue, Zika, and chikungunya cases, transmitted mainly by the *Aedes aegypti (A. aegypti)* mosquito.

This is in addition to the transmission yellow fever, which, despite the eminently wild cases, remains endemic and enzootic in several tropical regions of the Americas, Asia, and Africa [1–3].

The state of Tocantins has a favorable environment for the proliferation of *A. aegypti* due to its urban and environmental characteristics. The hot and humid climate, vast network of rivers and streams, disorderly occupation of urban spaces, and low percentage of basic sanitation, along with the seasonal distribution of rainfall, significantly correlate with the high incidence of the arbovirus vector fauna [4,5,6].

Regions with low or few health services favor the worsening of this scenario, since non- or late diagnosis hinders the implementation of measures to combat and control these diseases [7–9].

Considering this perspective, the proposed One Health strategy acts

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as an integrated approach to understand and manage animal, social, and environmental determinants of complex problems such as arbovirus infections [10].

This implies the need to integrate knowledge in the fields of social, economic, biomedical, and ecological studies, among others, in addition to actions with the community and professionals working in the territory, to achieve greater effectiveness and coordination between stakeholders in the development of new surveillance, prevention, and mitigation approaches for multifactorial problems focused on One Health [11,12].

Given this scenario, the objective of this study was to analyze the trend of dengue, Zika, and chikungunya arbovirus infections and their relationship with socioeconomic and environmental determinants in the state of Tocantins, northern region of Brazil.

2. Materials and methods

This was an epidemiological and ecological study on the prevalence of confirmed cases of dengue, Zika, and chikungunya in the state of Tocantins. The inclusion criterion was a confirmed case of the disease, by place of residence, recorded between January 1, 2015 and December 31, 2019.

The study was conducted in the state of Tocantins in the northern region of Brazil, Legal Amazon, between the Parallels 5° e 13°, longitude 46° 00′ and 51° 00′ of Greenwich, and latitude 5° 00′ and 13° 00′ S. It has an estimated population of 1,515,126 and an area of 277,720.567 km², totaling 139 municipalities with a demographic density of 4.98/km². The state is subdivided into eight health microregions and two mesoregions [13].

The laboratory, epidemiological, and sociodemographic data analyzed in the research were exclusively those described in the patient databases provided by the GAL, the System of the Central Public Health Laboratory of Tocantins; there was no contact between the researcher and patient.

Data on building infestation index (BII) and percentage of primary health care coverage were collected from the State Secretariat of Epidemiological and Environmental Surveillance and from online epidemiological bulletins.

Climatological and rainfall data were collected from the National Meteorological Institute (INMET) database.

Socioeconomic information such as social vulnerability index (SVI), GINI coefficient, and GDP per capita were obtained from the Institute for Applied Economic Research (IPEA). Other socioeconomic indicators such as fertility rate, poverty rate, infant mortality rate, and illiteracy rate were collected from the Informatized Health System (DATASUS).

The annual population estimates used as denominators to calculate incidence and mortality coefficients for the disease, population density, and percentage of sanitary sewerage were obtained from the Brazilian Institute of Geography and Statistics (IBGE) and the National Sanitation Information System (SNIS). All dengue, Zika, and chikungunya cases with clinical/epidemiological and laboratory diagnosis in people residing in Tocantins in the period 2015–2019 were included in the study.

The study sample was composed of 100% of the population reported with dengue, Zika, and chikungunya with data duly registered in the database of the State Secretariat of Health of Tocantins.

Epidemiological data (sex, age group, and zone of residence) were represented by descriptive statistics using the Excel 2010 software (Microsoft Office) and statistically analyzed with the Minitab 19 software. The one-way ANOVA test was used to identify differences between the means of epidemiological and demographic variables. The Tukey's HSD post hoc test was performed to determine which mean differences were significant. Significant values were identified as those with $p < 0.05$.

The Prais-Winsten generalized linear analysis model was used for time series and trend analysis. This model is used to correct serial autocorrelation in time series. The confidence intervals of the estimates were calculated, and time series can be classified as increasing, decreasing, and stationary. Non-significant p-values (≥ 0.05) were interpreted as a stationary trend (accepting the null hypothesis that arboviruses did not change throughout the study period). Significant p-values (< 0.05) were interpreted as increasing (positive annual change) and decreasing (negative annual change) trends. The Prais-Winsten test was performed in Stata SE software 14.0 to test the statistical significance of the hypotheses at a 95% confidence level [14].

The statistical tools Variogram and bivariate local Moran (LISA) by queen-type contiguity neighborhood matrix generated with first order neighbors were used to analyze the spatial dependence of the incidence of arboviruses with environmental and social aspects, as these are spatialized variables that admit "negative" or "inverse" autocorrelation ($I < 0$), "randomness" ($I = 0$), and "positive" or "direct" ($I > 0$) hypotheses. This study considered a correlation as weak when the index value was close to 0 (-0.5–0.5) and strong when the value was close to -1 (< -0.5) and 1 (> 0.5), with spatial statistical significance determined by $p < 0.05$. Spatial autocorrelation measures the relationship between observations with spatial proximity, assuming that spatially close observations have similar values. The GeoDa 1.8 software was used to create a conditional "Map Matrix" that conjugates bivariate choropleth maps, combining the variables in pairs. The initial concept of the maps was based on the use of an analysis variable and one or two conditioning variables divided into groups, in this case division by quantile. Thus, each set of conditional maps was created using a socioeconomic and/or environmental indicator with the mean incidence rate of dengue, Zika, and chikungunya in the period.

This study was approved by the Research Ethics Committee (REC) of the School of Sciences of Tocantins (FACIT), TO, under approval no. 3,656,469.

3. Results

The state reported a mean incidence of 591 annual cases of the dengue, Zika, and chikungunya (CKG) arboviruses per 100,000 inhabitants, highlighting the years 2016 with 9902 cases (636 per 100,000/population) and 2019 with 13,954 cases (897 per 100,000/population), which was 300% more than that in the previous year (2018) with 3802 cases. Dengue was the most prevalent, representing 84.8% of the total cases. All four serotypes of the disease were identified in the period, with the most prevalent being DEN 2 (84%) and DEN 1 (13%), in relation to the total number of tests performed (SESAU/TO, 2020).

The analysis of the annual growth rate (AGR) and incidence trend of cases per health region in the state of Tocantins highlights that all regions showed a stationary trend, that is, the mean, variance, and auto correlation were constant over time. The state presented incidences above the number designated by WHO as high risk (> 300 cases per 100,000 inhabitants) in all years except 2018, highlighting the year 2019 with an incidence of approximately 900 cases (Table 1). (See Fig. 1.) (See Table 2.)

The epidemiological profile showed that women had a higher incidence, mainly of Zika (66%). The highest percentage of cases occurred in Pardo individuals (73.4%) in the age group of 20–39 years (43.5%) with a maximum 9–12 years of education (29.2%).

The analysis of absolute case clusters showed a strong spatial influence in the central and northern regions of the state, where the two largest cities in the state are located, the capital city of Palmas and Araguaína respectively. The analysis of incidence showed that the points of higher concentration presented more variability. According to the Kernel estimator, points of higher concentration intensity were located in the health microregions of Bico do Papagaio, in the northern region of the state, and Amor Perfeito and Capim Dourado regions in the center and southeast region, respectively. All these clusters showed a statistical significance $>95\%$ (Fig. 2).

Table 1

Incidence coefficient (per 100,000 inhabitants), annual growth rate and trend of dengue, Zika and chikungunya arboviruses by health region in the state of Tocantins (2015–2019).

| | 2015 | 2016 | 2017 | 2018 | 2019 | AGR% | CI 95% | | P | Tendency |
							IL	UL		
DENGUE										
Médio Norte Araguaia	310.0755	374.3432	471.07619	144.7681	630.7518	−4.28	−93.47	84.89	0.85	stationary
Bico do Papagaio	95.80736	294.5719	165.39877	27.16925	150.1459	−33.31	−108.65	42.03	0.25	stationary
Sudeste	278.9132	596.367	312.38273	65.92493	904.6928	−21.09	−301.01	258.8	0.77	stationary
Cerrado Tocantins Araguaia	61.18589	94.56002	88.379624	32.13805	147.0934	−1.24	−27.38	24.9	0.85	stationary
Ilha do Bananal	217.6308	383.1605	87.377956	96.6042	640.4099	19.94	−163.3	203.3	0.75	stationary
Capim Dourado	1183.629	588.2149	334.90386	335.1705	1441.473	16.92	−518.3	552.1	0.92	stationary
Cantão	336.602	540.2539	74.544281	47.64686	725.4619	−20.94	−268.2	226.3	0.8	stationary
Amor Perfeito	163.3826	184.9275	57.453207	342.0261	1380.672	251.8	−139.3	643.1	0.13	stationary
Total	443.2037	401.1785	241.47003	158.2462	789.4506	3.99	−169.1	177.1	0.94	stationary
ZIKA										
Médio Norte Araguaia	2.650218	108.9902	56.648402	3.312772	3.644049	−14.65	−55.82	26.51	0.34	stationary
Bico do Papagaio	5.243189	115.3501	28.599211	16.68287	53.38519	−8.25	−38.75	−22.24	0.45	stationary
Sudeste	0	5.071148	5.0711482	2.028459	13.18499	1.28	−1.4	3.97	0.17	stationary
Cerrado Tocantins Araguaia	11.12471	618.6574	72.310602	11.12471	6.180393	−100.5	−267.6	66.47	0.15	stationary
Ilha do Bananal	0.54272	46.67394	4.884482	0.54272	6.512643	−6.63	−19.32	6.05	0.19	stationary
Capim Dourado	2.133146	17.59845	0.7999296	0.79993	2.933075	−271	−7	1.56	0.13	stationary
Cantão	0	16.90695	1.5369955	2.305493	0.768498	−2.32	−6.48	1.83	0.17	stationary
Amor Perfeito	0	41.29449	31.419723	4.488532	4.488532	−3.82	−22.49	14.84	0.56	stationary
Total	2.924598	114.25	25.558439	4.895522	11.12619	−16.12	−48.46	16.2	0.21	stationary
CHIKUNGUNYA										
Médio Norte Araguaia	0.331277	0	264.69049	26.83345	9.938316	5.36	−107.9	118.6	0.89	stationary
Bico do Papagaio	0	1.429961	286.94541	29.55252	19.54279	7.37	−113.3	128.06	0.85	stationary
Sudeste	0	3.042689	75.052993	14.19921	19.27036	5.02	−23.27	33.33	0.61	stationary
Cerrado Tocantins Araguaia	0.618039	20.3953	708.89111	17.92314	12.97883	1.91	−303.8	307.7	0.98	stationary
Ilha do Bananal	0	1.628161	122.11205	9.768964	11.93984	3.28	−47.08	53.65	0.84	stationary
Capim Dourado	0	0	13.33216	4.532934	3.466362	1.24	−3.85	6.34	0.49	stationary
Cantão	0	0.768498	51.489349	6.91648	15.36995	3.61	−15.14	22.37	0.58	stationary
Amor Perfeito	0	0.897706	91.566049	16.15871	9.87477	3.85	−34.04	41.74	0.76	stationary
Total	0.127156	2.797441	194.93078	15.7674	11.25334	3.78	−78.59	86.16	0.89	stationary

CI: confidence index.
AGR: Annual growth rate.
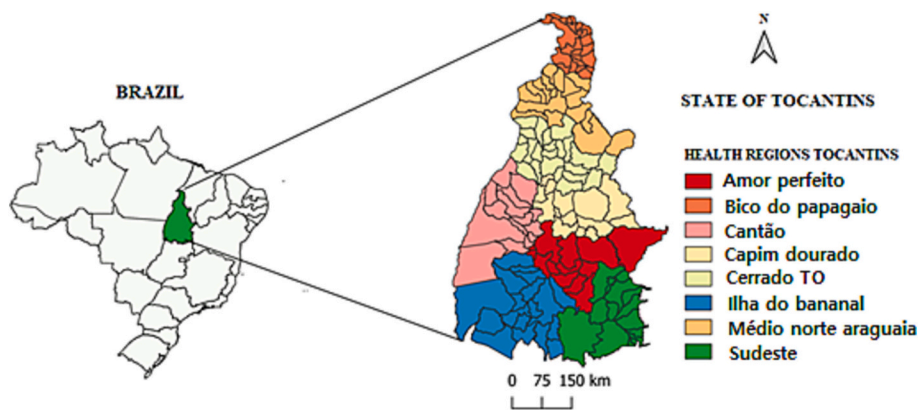IL: Inferior limit.
UL: Upper limit.

Fig. 1. The state of Tocantins, Brazil and health regions.

The analysis of the correlogram by the indicators that specifically represent the income distribution of the population studies, such as the case of the per capita salary, poverty rate, GINI coefficient, and GDP per capita, identified some important characteristics. Cities with high demographic density and good economic indicators, including low poverty rate, moderate per capita GDP, and low GINI index, such as Palmas, Araguaína, and Porto Nacional, presented high incidence of arboviruses. The other cities showed a strong influence of low economic indicators related to the distribution of the population's income on the incidence of arboviruses in those regions (Fig. 3).

This is demonstrated by social indicators, such as illiteracy rate, social vulnerability index, HDI, fecundity rate, and infant mortality, in which most cities presented a strong relationship between the occurrence of these diseases and a poor evaluation of these indicators, except for Palmas and Araguaína. All the cities presented an inverse correlation between the incidence of arboviruses and the coverage of primary health care, that is, the higher the level of coverage, the lower the incidence of the diseases in the city.

Table 2

Quantification and frequency of arbovirus cases in relation to the main epidemiological and demographic variables (2015–2019).

Variable	Dengue	Zika	Chikungunya	Total	%	*p*-value
Sex						
M	17,308	1182	1330	19,820	44.8	0.68
F	19,897	2266	2207	24,370	55.1	
Age groups (years)						
< 5	1760	295	176	2231	5.0	
5–9	2293	227	191	2711	6.1	
10–19	7826	614	571	9011	20.4	0.005
20–39	15,255	1517	1271	18,043	40.8	
40–59	7693	654	915	9262	21.0	
> 60	2380	137	413	2930	6.6	
Education (years)						
0	332	18	57	407	0.9	
< 9	9872	808	894	11,574	26.2	
9–12	11,261	1143	1156	13,560	30.7	< 0.001
> 12	4028	494	265	4787	10.8	
Ignored	11,718	985	1225	13,928	31.5	
Race/color						
White	5647	652	496	6795	15.4	
Black	1760	79	197	2036	4.6	
Pardo	27,379	2474	2744	32,597	73.8	< 0.0001
Asian	1046	68	78	1192	2.7	
Indigenous	127	17	22	166	0.4	
Total cases	**37,211**	**3448**	**3537**	**44,196**	**100**	
Hospital admissions	1979	119	177	2275	100	–
Deaths	20	1	3	24	100	–

The analysis of environmental indicators in relation to the incidence of arboviruses and factors related to urban infrastructure such as basic sanitation, represented by the level of distribution of treated water, sewage collection and treatment network, solid waste management and collection, and drainage of urban rainwater, showed an inverse relationship in most cities with a high incidence of arboviruses and low sanitation levels, except in Palmas, Araguaína, and Tocantinópolis. These cities showed a strong relationship between arbovirus indices and rainfall levels in millimeters and BII (Fig. 4).

The health regions of Bico do Papagaio and Médio Norte Araguaia, located in the northern part of the state, demonstrated a strong influence of the percentage (%) of territory deforestation in the cities on the incidence of arboviruses. The analysis by total deforested territory per square kilometers (km²) makes this relationship more heterogeneous in Tocantins, since the state has cities with considerable differences in territorial areas.

The region with the highest correlation between the deforested area in km² and the incidence of arboviruses also demonstrated the highest cluster level by the Kernel estimator for the incidence of the diseases in the state of Tocantins (Figs. 2 and 4).

The characteristics of the socioeconomic, environmental, and vector indicators of the study area compared with those of the states with the highest (Mato Grosso do Sul) and lowest (Rio Grande do Sul) incidence show that these indicators somehow influence the occurrence of arboviruses, as the states with more satisfactory indicators showed better dengue, Zika, and chikungunya incidence rates (Table 3).

4. Discussion

The state of Tocantins has historically presented favorable conditions for the dissemination of arboviruses, especially those transmitted by *A. aegypti*. Recurrent epidemics have been devastating to the state, such as those recorded in 2002, 2007, 2008 and 2012. This is a fact that corroborates the study by Böhm et al. [15] which shows that all Brazilian states showed a decreasing or stable trend between 2000 and 2010, except Tocantins and Alagoas, which showed an increasing trend for the disease. Despite having presented a stable tendency in the period studied, it is still not possible to consider a significant advance in the
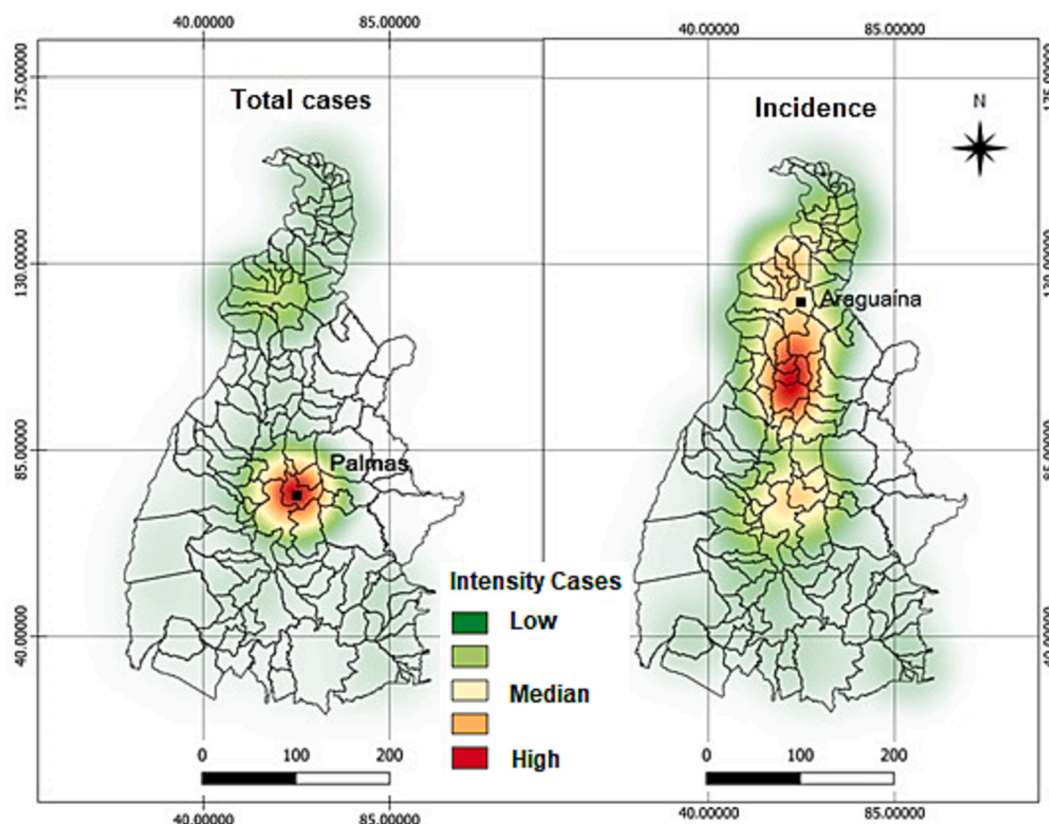

Fig. 2. Spatial distribution by the Kernel estimator of absolute cases and the mean incidence of arboviruses (2015–2019; TO, Brazil).
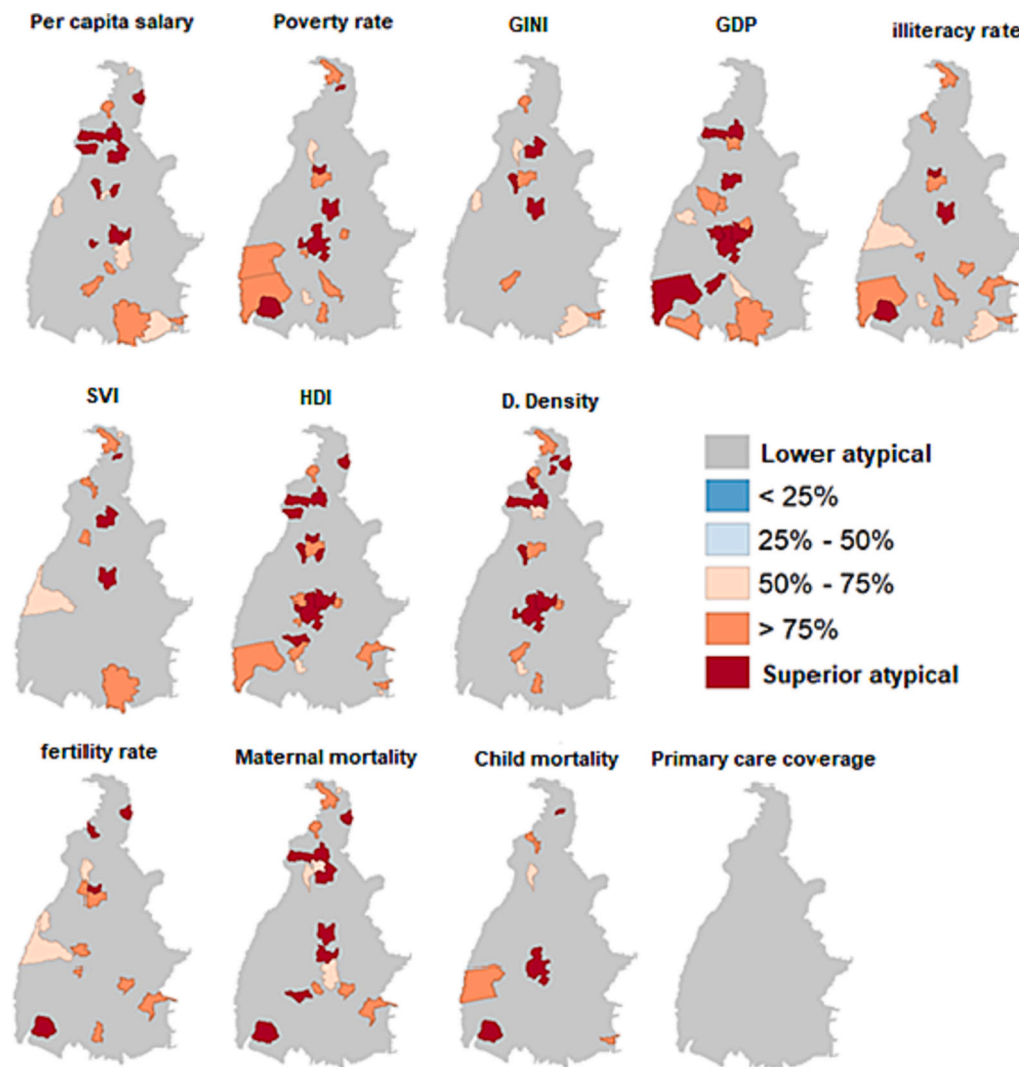
Fig. 3. Conditional maps of analyses of the level of correlation between socioeconomic factors and the incidence of arboviruses by city in the state of Tocantins (2015–2019).

combat of arboviruses, since the indices are stationary at a high-risk coefficient, with a mean incidence close to 600 cases per 100,000 inhabitants [3].

In the period studied, the occurrence of these diseases presented heterogeneous characteristics for each sub-region and period, with dengue having the highest incidence and reaching the highest recorded incidence of the decade in 2019, with epidemic levels with predominance of serotypes DENV-2 and DENV-1, respectively, followed by Zika in 2016 and chikungunya in 2017.

These variations in the occurrence of epidemic outbreaks were directly related to the insertion of a new specific viral serotype in the epidemiological cycle, with no significant group immunity to that serotype, presenting an ideal scenario of vertebrate susceptibility to the virus. The detection of simultaneous infections between DENV and CHIKV in clinical samples analyzed in the state should be highlighted [16–20].

The phenomenon described as "feminization of poverty" and the prevalence of infectious diseases corroborates several studies on the profile of the occurrence of arboviruses, a fact well described in the studies by Freitas [21] and Coutinho [22]. These studies clearly present the profile of mothers of children with congenital Zika syndrome, a worrisome and aggravating incidence for the social pattern of women as the incapacitating sequels caused by this syndrome directly impact the

reinsertion of these mothers in the labor market.

On the other hand, Johansen et al. [23] described that despite the fact that most reported cases are in women, they have greater health care and seek health services more often, suggesting the hypothesis of a possible greater underreporting in men, especially of acute diseases, aligned with the vector characteristic of having higher intra and peri-domicile prevalence, an environment often frequented by women [24].

A well-defined characteristic regarding incidence clusters in the state occurs in cities along the highway that connects Belém to Brasília. This is another important risk factor in the region, since the main means of intercity travel in the state is by land, bringing to light the problem of traveler's disease since the state geographically acts as an epidemiological corridor between different ecosystems (Amazon and Cerrado), each with its biotic and abiotic pattern of disease distribution [25]. The same phenomenon was also reported in the studies by Almeida [26] and Sá [27], who reported that human mobility and cargo flow contributed to vector dispersion and to the occurrence of endemic and non-endemic diseases in the region.

As cities advance and deforestation increases, preexisting viral species, with an eminently wild circulation, start to circulate in the urban environment, and a new transmission chain may emerge. Other factors such as intensification of agriculture, cattle ranching, mining, and large hydroelectric developments increase deforestation, and are associated
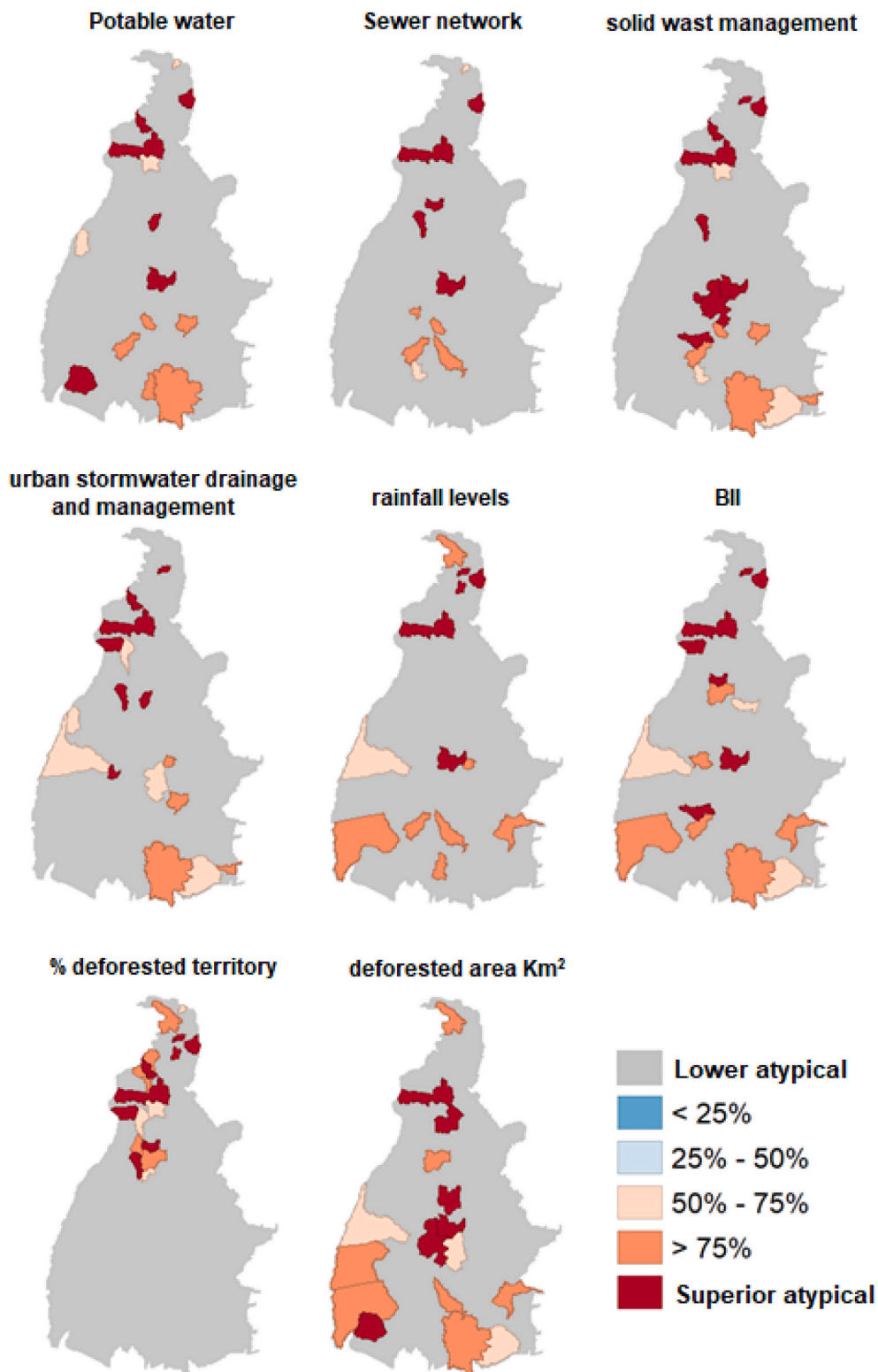
Fig. 4. Conditional maps of analyses of the level of correlation between environmental factors and the incidence of arboviruses by city in the state of Tocantins (2015–2019).

with people mobility and human density, thereby changing the ecological pattern of virus-vector-host interaction, providing a scenario completely favorable to the spread of diseases such as dengue, Zika, and chikungunya [28].

The complex phenomenon of the occurrence of infectious diseases, especially those with multicausal characteristics, comes to light when analyzing the socioeconomic characteristics of cities, with quite convergent findings in several of the studies analyzed. Souto-Marchand [29] and Cordeiro et al. [30] emphasized that regions with greater economic potential tended to have higher population density and high population migration, generating social problems such as disorderly growth with points of high social vulnerability and greater inequality.

Table 3

Socioeconomic and environmental indicators for the states of Tocantins, Mato Grosso do Sul, and Rio Grande do Sul and for Brazil.

Socioeconomic indicators	Tocantins	Brazil	Mato Grosso do Sul	Rio Grande do Sul	p-value
Salary per capita	1.1	1.56	1.53	1.84	
Poverty rate[1] (%)	21.83	16.2	10.11	7.26	
GINI index	0.531	0.544	0.481	0.486	
GDP per capita	25,021	35,161	38,482	42,406	
Illiteracy rate (%)	9.7	6.6	5.1	2.4	
SVI	0.251	0.241	0.192	0.207	
HDI	0.69	0.77	0.76	0.78	
Population density	4.98	23.8	7.7	40.3	0.988
Fertility rate	2.7	1.89	2.04	1.76	
Maternal mortality rate[2]	83.8	59.1	62.9	39.1	
Infant mortality rate[3]	15.3	11.5	13.6	9.3	
Primary care coverage (%)	95.4	74.6	73.04	73.3	
Environmental indicators					
Treated water (%)	76.6	97.1	85.8	86.6	
Sanitary sewerage (%)	26.3	55	55.7	33.5	
Solid waste management (%)	83.2	90.5	87.9	92.5	
Rainwater management and drainage	10.6	21	7.4	21.5	0.440
Rainfall levels (mm)	264	1460	1288	1229	
Deforested territory (%)	75.2	39	75.3	71.6	
Deforested area (km^2)	30,663	1,160,634	60,446	56,018	

1 Poverty rate: income of up to ¼ of the minimum wage per capita.
2 Maternal mortality rate per 100,000 live births.
3 Number of deaths of residents under one year of age, divided by the total number of live births multiplied by one thousand.

Such phenomena characterize the richest cities as those with the highest burden of infectious diseases, similarly to what occurred in Tocantins, where the cities with better economic indicators and higher population concentration showed high prevalence of the diseases analyzed [13,31,32].

Considering the continental size and the heterogeneity of Brazilian regions, and in several situations, socioenvironmental divergences in municipal boundaries, most studies demonstrated a strong correlation between socioeconomic indicators (GDP per capita, HDI, GINI, SVI, and poverty rate) and high levels of arboviruses. This situation is well demonstrated in large cities with high economic power, but with outbreaks concentrated in peripheral areas with low urban/health structure and high social vulnerability [29,33,34].

Greater effectiveness of public policies on the environment and health in integration with the community are necessary, since discoveries involving sanitary issues and the adaptability of *A. aegypti* regarding reproduction and of larva and pupa contamination have brought forth new hypotheses about the vector. A study by Chitolina et al. [35] suggests that *A. aegypti* can adapt to new places and lay eggs in polluted water such as raw sewage. Du et al. [36], on the other hand, identified that mosquito larvae and pupae could acquire ZIKV from contaminated aquatic systems, resulting in ZIKV infection in adult females.

In recent years, humans have been challenged with epidemics. In the last decade, several public health emergencies have shown that humans and health systems are poorly prepared for these events. The intriguing fact of this situation is that most of these episodes are known events, and their emergencies and re-emergences are the result of historical

negligence from the co-responsible public and private agencies [37].

Despite advances in the dissemination of scientific and practical knowledge on successful One Health actions, the implemented proposals are still very limited, either by institutional and/or corporativist resistance or by the low inclusion of this interdisciplinary method in the professional training process [38,39].

In several different regions of the world, successful approaches have been adopted to fight against arboviruses with a One Health approach, such as the Early Warning and Response System for Dengue Outbreaks (EWARS) in Mexico, which processes epidemiological, meteorological, and entomological alarm indicators to predict dengue outbreaks and trigger early response activities [40]. In the Mediterranean region, the "EpiSouth" stands out as a project that creates a collaborative framework on epidemiological issues to improve communicable disease surveillance, communication, and training in the Mediterranean and Balkan countries [41,42].

In Brazil, the robust implementation of this strategy is still very discrete. In the scenario of public policies, isolated actions such as the inclusion of veterinarians as a part of primary health care (PHC) teams is already underway; however, with the immense challenges posed by socioenvironmental characteristics and the high burden of communicable zoonotic diseases, the inclusion of other areas of knowledge working in an integrated and targeted social, environmental, faunal, and epidemiological specificity regarding the region of operation, it would be possible to glimpse an effectiveness closer to the ideal of what is proposed in One Health [43].

Another bottleneck for an effective and proactive One Health action is the disarticulation between the potential tools for health, environmental, and animal surveillance, in addition to inequities in investment and supply of health services to meet needs related to the heterogeneous profile of Brazilian regions. It is possible to cite the extreme urgency in the expansion of high-tech laboratory and biomedical network in the Amazonian context, a region with a high need for constant environmental, animal, human, and vector surveillance [43,44].

Despite the challenges, successful experiences with One Health approaches have already been described in several regions, such as the elimination of canine visceral leishmaniasis in the city of Palotina, Paraná. In addition, the investment and preparation of professionals working with zoonosis, vector-borne diseases, and venomous animals to form a highly qualified and skilled team within the One Health approach has resulted in satisfactory results in Foz do Iguaçu, Paraná [45].

The advanced and efficient surveillance and control method by the stable introduction of *Wolbachia* bacteria (strain *w* Mel) in *A. aegypti* in Niterói, RJ, should be highlighted, which reduced dengue rates by 69%, proving to be an effective and sustainable method to control dengue and other diseases transmitted by *A. aegypti*, even in large and complex urban environments [46].

Tocantins presented a high prevalence for arboviruses (dengue, Zika, and chikungunya) in the period studied (2015–2019). Arboviruses showed a stationary trend with high-risk incidence levels, that is, above 300 cases per one-hundred thousand population, with emphasis on the cities of Palmas and Araguaína, the most populous and economically influential in the state.

5. Conclusions

The results showed a heterogeneous presentation of disease occurrences in the territory, and places with a high social vulnerability index and high population density should be monitored due to their association with an increased occurrence of arbovirus infection. Several cities showed a high correlation between the incidence of arboviruses and socioeconomic and environmental factors, especially Palmas and Araguaína.

Thus, an interdisciplinary approach, with a One Health focus aimed at integrating different fields of knowledge, will improve the understanding of the important social and environmental obstacles faced by

control services, especially in the complex urban areas of Brazilian cities. The dialogue with other forms of knowledge will allow the definition of more viable strategies according to different political, social, environmental, and wildlife realities.

The use of secondary data is a limitation of this study, given that asymptomatic and oligosymptomatic patients choose not to visit health services, as well as individuals living in cities with lower health service provision, which can generate underreporting. Another challenge is the triple burden of the arboviruses, DENV, ZIKV, and CHIKV, which present similar signs and symptoms that can influence the differential diagnosis. This situation can lead to possible notification errors.

New studies are necessary to more accurately analyze the role of each indicator described in this study in the occurrence of arboviruses in specific regions. A better understanding of the interaction between social characteristics, the environment, and ecology of wild animals and vectors is important for the development of mechanisms to predict outbreaks and to develop strategies to reduce and/or mitigate recurring arboviral epidemics and other diseases.

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Authors' contribution

Gomes H, De Jesus AG and Quaresma JAS contributed to the conception and design of the study, data collection, image processing, analysis and interpretation of results, writing and critical review of the manuscript's content. All authors have approved the final version of the manuscript and are responsible for all aspects of it, including ensuring its accuracy and integrity.

Author statement

I, Helierson Gomes, declare, for the purposes of submission to One Health journal, that the article "Identification of risk areas for arboviruses transmitted by *Aedes aegypti* in northern Brazil: A One Health analysis", is original, unpublished and has not been submitted to another journal, as well as express consent regarding the Submission and Editorial Policy, Guidelines for Publication and Declaration of Copyright, which will apply in case of publication of the aforementioned work. I also declare, as the author of the manuscript, that I participated in the construction and formation of this study, and I assume public responsibility for its content.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.onehlt.2023.100499

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