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Environmental influence on arboviruses emerging and reemerging infectious

Influência ambiental em doenças infecciosas emergentes e reemergentes

Elfany Reis do Nascimento Lopes*; Felipe Micali Nuvoloni; Gioncarlos Silva Moreno

[1] Centro de Formação em Ciências Ambientais. Universidade Federal do Sul da Bahia. Campus Sosígenes Costa, Porto Seguro, Bahia, Brasil.
E-mail: felipe.nuvoloni@ufsb.edu.br (FMN); gion_enfermagem@yahoo.com.br (GM)
*Email para correspondência: elfany@csc.ufsb.edu.br

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Resumo: Esta pesquisa aborda a relação entre variáveis ambientais e a incidência de dengue, zika e chikungunya, doenças transmitidas por arbovírus e consideradas emergentes e reemergentes. Analisamos as mudanças no uso e cobertura da terra, a ocorrência de focos de incêndio e as condições socioeconômicas, relacionando-as com a incidência dessas doenças entre 2009 e 2019 em 70 municípios do sul do Estado da Bahia, no nordeste do Brasil. Modelos lineares generalizados mistos, regressão parcial múltipla e análise de redundância foram utilizados para testar a hipótese da influência ambiental na incidência das doenças, avaliando as relações entre meio ambiente e saúde. Identificamos uma relação positiva entre o uso e cobertura da terra, os focos de incêndio, as condições socioeconômicas e o clima com a incidência de dengue, zika e chikungunya. A variável mais influente para explicar a incidência é o clima. Temperaturas entre 20,9 ºC e 28 ºC são favoráveis ao desenvolvimento do vetor. A incidência é agravada em cidades com maiores áreas urbanas e baixa qualidade de vida.

Palavras-chave: Epidemiologia; Geoprocessamento; Mata Atlântica; Saúde pública.

Abstract: *This research addresses the relationship between environmental variables and the incidence of dengue, zika, chikungunya, diseases transmitted by arboviruses which are considered emerging and reemerging diseases. We analyzed changes in land use and land cover, the occurrence of fire outbreaks, and socioeconomic conditions and related them to the incidence of diseases between 2009 and 2019 in 70 cities in the south of the State of Bahia, northeastern Brazil. Mixed linear generalized models, multiple partial regression, and redundancy analysis tested the hypothesis of environmental influence on the incidence of diseases to assess environmental and health relationships. We identified a positive relationship between land use and land cover, fire outbreaks, socioeconomic conditions, and climate with the incidence of dengue, zika, and chikungunya. The most influential variable to explain the incidence is climate. Temperatures between 20.9 ºC and 28 ºC are conducive to the development of the vector. The incidence is aggravated in cities with larger urban areas and low quality of life.*

Keywords: *Epidemiology; Geoprocessing; Atlantic Forest; Public health.*

1. Introduction

Changes in the natural environment and agricultural systems induced by economic and industrial development, including population dynamics (growth, urbanization, migration), are the main causes that result in the persistence, emergence, and resurgence of infectious diseases in developing countries (YANG *et al.* 2015).

There currently is a considerable increase in cases of neglected tropical diseases (NTDs) caused by infectious agents or parasites in populations of Africa, Asia, and Latin America, prevailing in 149 tropical and subtropical countries. Such diseases affect more than one billion people worldwide and accounted for 4.4 million deaths in 2016 (1.7 million women and 2.7 million men), mainly in low- and middle-income countries (WHO, 2020).

In Brazil, between 2010 and 2017, there were 10,578,337 cases of illnesses due to infectious diseases, while in the State of Bahia, in 2017 alone, there were 24,584 recorded cases of infectious and parasitic diseases (BRASIL, 2019; SOUZA *et al.* 2020a). Among these rates are emerging and reemerging infectious diseases such as dengue, chikungunya and zika. They have in common the viral infection transmitted by a mosquito, the vector *Aedes aegypti*. It occurs mainly in urban areas of tropical countries due to ecological, climatic and social conditions, characterizing a public health challenge (GENOUD *et al.* 2018; ZICKER *et al.* 2019; SOUZA *et al.* 2021).

The challenge arises as these diseases do not have an effective cure and control strategies continue to be chemical and biological controls. Although the investment in resources for the development of antiviral drugs and vaccines (GENOUD *et al.* 2018; WILDER-SMITH *et al.* 2019) is also recognized, it requires a continuous understanding of how health and the environment are related. Studies have identified the environmental effect on the spread of diseases and a tendency to increase the number of pathologies when degradation of natural resources occurs (PIENKOWSKI *et al.* 2017; HAMMEN & SETTELE, 2019).

The reduction and fragmentation of native vegetation has increased the emergence of diseases transmitted by vectors, wild animals, viruses, fungi, bacteria (ALHO, 2012; BROCK *et al.* 2019; PRIST *et al.* 2020; JOHNSON *et al.* 2020). Urbanization and expansion of cultivated areas also contribute to the emergence of predisposition to virus mutations and transmission of pathogens from natural populations to human populations (HAMMEN & SETTELE, 2019; ALTIERI & NICHOLLS, 2020). Climate change may cause changes in disease occurrence and in genetic or metabolic resilience to pathogens due to heat stress (SEHGAL, 2010; JOHNSON *et al.* 2020; SOUZA *et al.* 2021). The increase in fires in natural areas also enables pathogens present in wild animals to approach human beings (ALHO, 2012; WHO, 2021; HAMMEN & SETTELE, 2019; CDC, 2021).

This study identifies the need for further analysis in the context of the relationship between health and the environment in order to answer central questions, such as what is the influence of environmental variables on the dissemination of emerging and reemerging pathologies? How does changing in land use and land cover favor the occurrence of emerging and reemerging diseases? We investigate the hypothesis that changes in land use and land cover associated with climatic conditions and low socioeconomic quality in cities increase the occurrence of the infectious diseases dengue, zika and chikungunya in the south of the State of Bahia, northeastern Brazil.

2. Methodology

2.1. Study area

This study was carried out in seventy municipalities in the southern coastal region of the State of Bahia, Northeast Brazil. The territorial area is 54,723 km², with a population density of 37.9 inhabitants/km², and cities with a population ranging from 3,000 to 230,000 inhabitants. The municipalities assessed here are inside the Atlantic Forest Biome and have natural areas relevant to environmental quality. However, they also promote the exploitation of natural resources driven by an economy based on agriculture, forestry, and tourism.

2.2. Epidemiological profile of infectious diseases

The epidemiological profile was prepared by accessing the TABNET (BRASIL/DATASUS, 2020) health database of the Bahia State Health Department and the Disease Information and Notification System (SINAN, 2020) of the Brazilian Ministry of Health between 2009 and 2019. Confirmed cases and incidence rates were considered per 100,000 inhabitants and for each municipality, based on the ratio between the total number of cases of the diseases and the population of the municipality, according to data of the Brazilian Institute of Geography and Statistics (IBGE, 2010). The following equation was used (**Eq. 1**):

$$DIR = (Nb / Pb) \times 100{,}000 \text{ inhab.} \qquad \text{Eq.1}$$

Where: DIR - disease incidence rate per municipality;
Nb - number of cases of the disease;
Pb - total population of the municipality.

Cases were considered confirmed if they underwent a laboratory test or clinical evaluation with a diagnosis made by a physician. The incidence rate, standard error, maximum and minimum values of incidences per year and per disease were calculated using the software R (R Core Team, 2020) and spatialized using the software QGIS, version 3.12 (QGIS.org, 2020), for the plotting of thematic maps.

2.3. Environmental characterization

A database was built with environmental variables of the cities studied here. Variables were from free-of-charge and secondary databases of government agencies and research institutes and contained the following information: land use and land cover, climate variation (temperature and precipitation), outbreaks of fires, Municipal Human Development Index (MHDI), and Gini Index.

Land use and land cover was taken from an annual matrix format (2009, 2014 and 2019) available at the Map Biomas Project - collection 6 (SOUZA *et al.* 2020b), and the amounts in hectares of land use categories were calculated per year and city. The data on outbreaks of fires between 2009 and 2019 were obtained from the Burning Program of the National Institute for Space Research (INPE, 2022) for each city and organized according to the number of occurrences per year.

Precipitation and temperature data were obtained monthly from WorldClim, with a spatial resolution of 2.5 minutes (~ 21 km²), in matrix format, between 2009 and 2018 (FICK & HIJMANS, 2017). The minimum (°C) and maximum (°C) values of monthly temperatures and precipitation were extracted for the centroid of the urban area of each city, and the annual averages of temperature, average and accumulated precipitation were obtained per city and year.

The MHDI scores of each city were obtained from the database of the United Nations Development Program in Brazil for 2010, while the Gini index was obtained from the TABNET health database of the State Department of Health of Bahia for each city (BRASIL/DATASUS, 2020).

2.4. Statistical analyses

The effects of land use and land cover, fires, climate (temperature and precipitation), and social (MHDI and Gini) variables were tested separately for the incidence rates of each disease using multiple regression analyses seeking to assess the influence of these variables on disease incidence rates by municipality and year, in software R (R CORE TEAM, 2023).

To assess the relative contribution of each set of predictors on cases, partial redundancy analyses (RDA) were conducted. The RDA allows partitioning these effects into cases based on abundance and incidence data (presence/absence) (BEISNER *et al.* 2006; BORCARD *et al.* 2011; LEGENDRE & LEGENDRE, 2012). The following fractions were evaluated: change in land use and land cover [A], fire outbreaks [B], climate [C], social [D], considering them independently, partials integrated between each set of factors, and the unexplained component [R]. The importance of each fraction was obtained considering the adjusted R^2 (LEGENDRE & LEGENDRE 2012; BEISNER *et al.* 2006; PERES-NETO *et al.* 2006).

3. Results

Between 2009 and 2019, there was a predominant incidence of dengue in the region. The notification of infectious diseases prevailed until 2016, when there were reports of zika and chikungunya. **Table 1** and **Figure 1** show in detail the spread of diseases in southern Bahia which includes the cities of Itabuna, Ilhéus, Porto Seguro, Teixeira de Freitas, and Eunápolis as the most populous, all with over 100,000 residents.

There were 180,816 cases of Dengue recorded between 2009 and 2019, making it the disease with the highest number of cases and incidence in this study. In 2010, the highest average incidence of Dengue was observed, reaching 4,010 cases per 100,000 inhabitants in southern Bahia. The highest number of cases occurred in the municipality of Itabuna in the years 2009 and 2016, with the same total of cases (19,405). However, the highest incidence rate was recorded in the municipality of Ibicaraí (10,572 cases per 100,000 inhabitants). For Zika, there were 37,117 cases in 97.14% (68 municipalities), and the highest number of cases (18,444) and incidence were recorded in the municipality of Itabuna. In 2016, the highest average incidence of cases per 100,000 inhabitants was recorded (740 cases), with the highest occurrence reported in the municipality of Itabuna (18,444 cases) in that year. Chikungunya was recorded in 92.86% (65 municipalities) from 2015, and the highest incidence peak was in 2018 (1,500 cases).

Table 1: Variation in the incidence rate of cases of dengue, zika and chikungunya in southern Bahia

Diseases	**Dengue**		**Zika**		**Chikungunya**	
Year	**Average (± EP)**	**Min/Max**	**Average (± EP)**	**Min/Max**	**Average (± EP)**	**Min/Max**
2009	1,136 ± 182	0 – 7,863	0	0	0	0
2010	2,381± 75	0 – 4,010	0	0	0	0
2011	218 ± 33	0 – 1,759	0	0	0	0
2012	656 ± 110	8- 41,733	0	0	0	0
2013	993 ± 148	0 – 6,345	0	0	0	0
2014	118 ± 19	0 – 709	0	0	0	0
2015	582 ± 116	0 – 4,602	99 ± 24	0 – 1036	12 ± 4	0 – 241
2016	1,462 ± 243	0 – 10,572	740 ± 146	0 – 8,370	1,208 ± 307	0 – 13,618
2017	319 ± 127	0 – 8,845	22 ± 4	0 – 217	199 ± 54	0 – 2,067
2018	65 ± 20	0 – 1,090	4 ± 2	0 – 116	44 ± 25	0 – 1.500
2019	164 ± 31	0 – 1463	5 ± 1	0 – 55	15 ± 4	0 – 253

Caption: SE= Standard Error; Min = Minimum incidence\recorded; Max = Maximum incidence recorded. Incidence per 100,000 inhabitants. Source: SINAN, 2020.

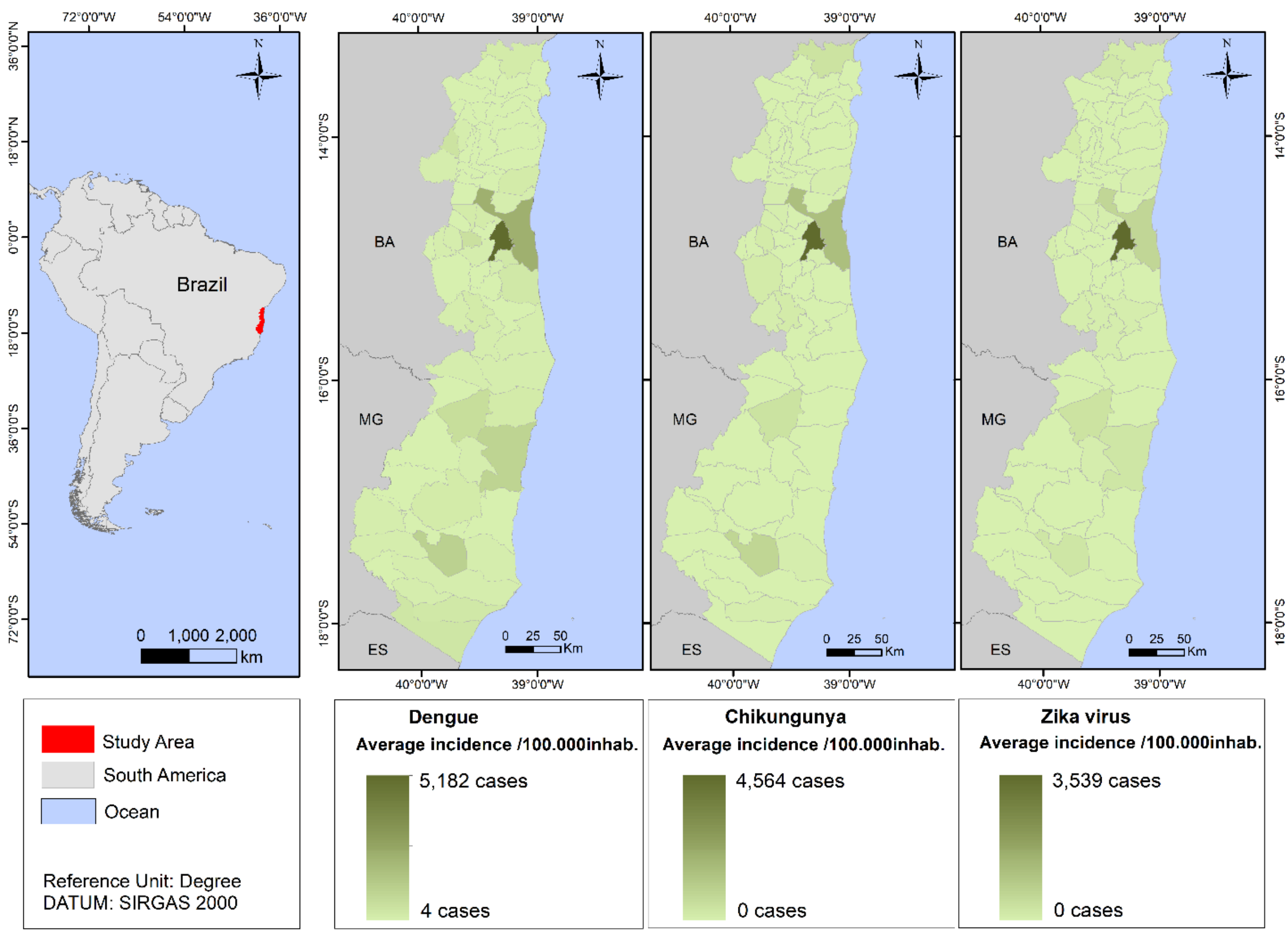

Figure 1: Spatial distribution of the average incidence per 100,000 inhabitants of dengue, chikungunya and zika in the south of Bahia.

In the period (2009-2019), the area had 7,079 fires; the main occurrences were in 2015 (1,326 cases) and 2019 (1,061 cases), which recorded twice as many occurrences as in 2009. For dengue, zika, and chikungunya, there was a positive relationship between the number of cases and the outbreaks of fires (dengue: estimated 0.51, t= 5.24, p<0.001, R^2=0.16; zika: estimated 0.34, t =3.16, p<0.001, R^2=0.36; chikungunya: estimated 0.28, t=-4.06, p<0.001, R^2=0.28), although the effect of fires is null in certain years (**Figure 2**).

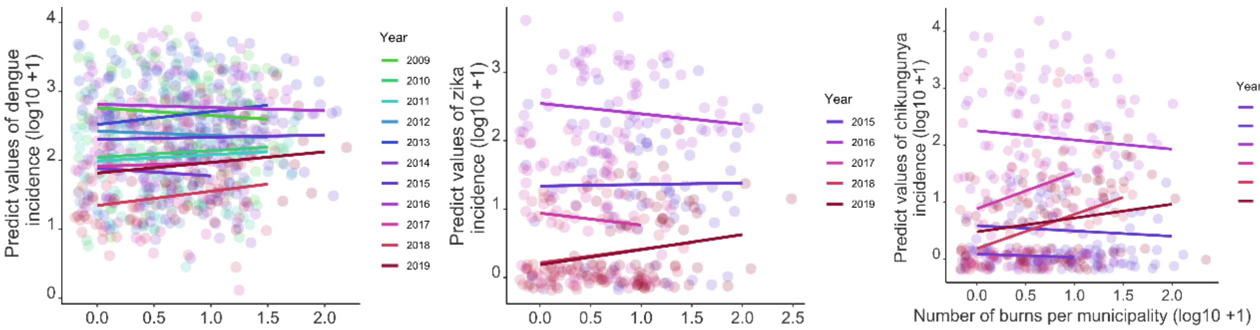

Figure 2: Relationship between fires and the incidence of disease cases in municipalities in southern Bahia between 2009 and 2019.

The relationship between the number of fires and incidence was more evident in 2019 for zika (2019: R^2= 0.08, p< 0.001) and in 2017 and 2018 for chikungunya (2018: R²= 0.17 and p< 0.001 and 2019: R^2= 0.05, p= 0.02).

The social indicators show that these cities have a socioeconomic condition close to or higher than the average MHDI in Brazil. High MHDIs are associated with municipalities that have an economy based on services, tourism and industry. The highest income *per capita* is that of the city of Maraú (R$ 11,351.44), with a life expectancy of 73 years, MHDI of 0.593 and the Gini of 0.713, which suggests a greater territorial inequality. The opposite was verified for Firmino Alves, which is considered the city with the lowest social inequality, with an MHDI of 0.578 and a Gini of 0.4375; the income of the poorest is closer to that of the richest people.

We observed a relationship between the increase in MHDI and the increase in the incidence of dengue (p<0.001, R^2=0.26), zika (p=0.003, R^2=0.08), and chikungunya (p<0.001, R^2=0.11) in general. The relationship was specially marked among cities of Porto Seguro region and dengue incidence (p<0.001, R^2=0.31), and also between the incidence of zika and chikungunya and Ilhéus-Itabuna region (p<0.001, R^2=0.20; p<0.001, R^2=0.37). The cities of the micro-region of Ilhéus-Itabuna, which have the most populous and urbanized cities (**Figure 3**). GINI index did not prove to be an important indicator of the occurrence of the emerging and reemerging diseases studies here.

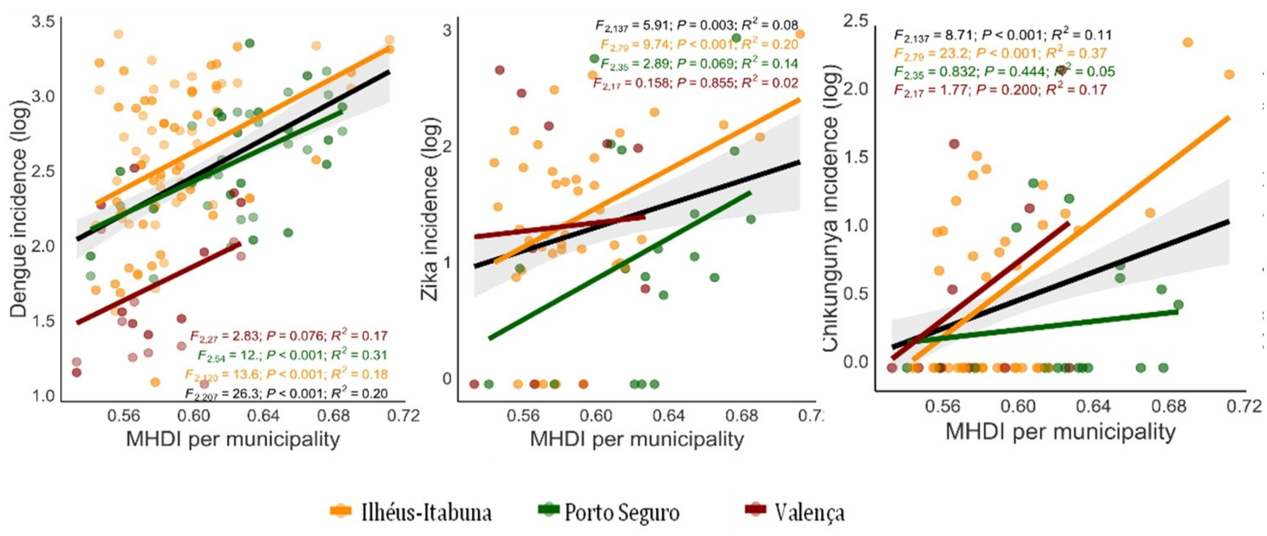

Figure 3: Relationship between MHDI (Municipal Human Development Index) and the incidence of disease cases per micro-regions in southern Bahia between 2009 and 2019. Black lines and dots represent the general model considering micro-regions altogether.

The climate in the region is predominantly tropical, with monthly/annual average temperatures between 20.9°C and 28°C. The highest average temperatures are between November and March and the lowest are between May and August. The historical series indicates the occurrence of precipitation distributed throughout the year; 2011 was the wettest year (1,464 mm) and 2015 was the driest year (1,001 mm). The cities to the north had a higher annual accumulated precipitation.

Climatic factors (minimum temperature, maximum temperature, annual temperature variation, and precipitation) were related to all diseases. Dengue showed a positive relationship with maximum temperature (R^2= 0.07, p<0.01, **Figure 4a**) and annual temperature variation (R^2= 0.02, p< 0.01, **Figure 4b**) and a negative relationship with cumulative precipitation (R^2= 0.02, p<0.01, **Figure 4c**).

For the incidence of chikungunya, maximum temperature (R^2= 0.02, p<0.01, **Figure 4d**) and temperature variation (R^2= 0.02, p<0.01, **Figure 4e**) showed a positive relationship. For zika, precipitation showed a negative relationship (R^2= 0.04, p<0.01, **Figure 4f**) and minimum temperature (R^2= 0.04, p<0.01, **Figure 4g**) showed a positive relationship.

Land use and land cover is heterogeneous in the region and promotes a fragmented landscape. More modified than natural areas predominate with higher rates of pasture, forestry, and agriculture. The temporal growth (2009-2019) of forestry was equivalent to 116,157 ha, of agriculture to 215,114 ha, and of natural forests reduced to 75,188 ha.

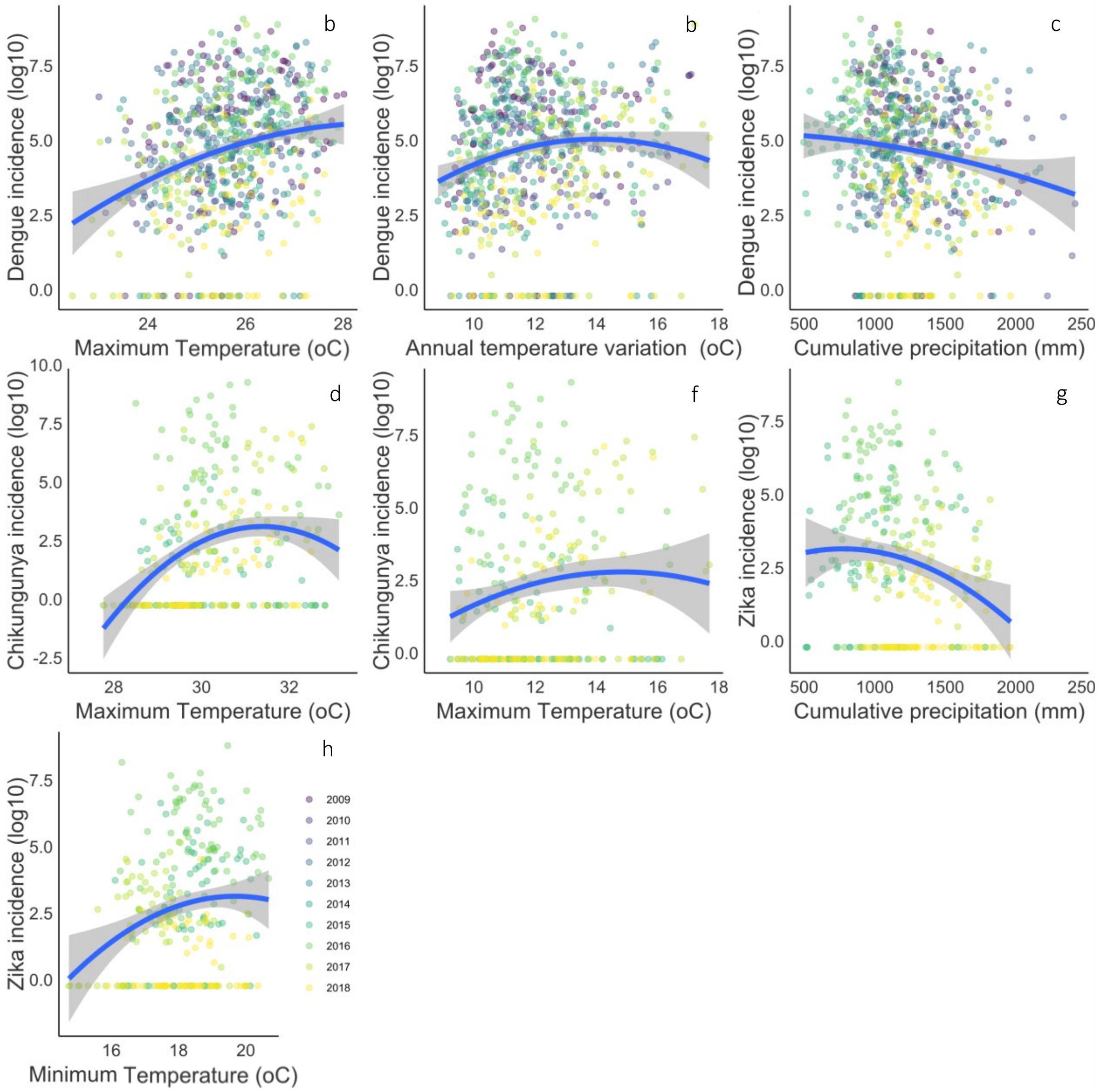

Figure 4: Relationship between climatic factors and the incidence of dengue, zika, and chikungunya in municipalities between 2009 and 2019 considering significant interactions.

We identified a relationship between the incidence of dengue and the increase in urban infrastructure, with emphasis on the cities in the microregion of Valença (R^2=0.08 p<0.01, **Figure 5a**). The incidence of zika related to the increase in pastures (R^2=0.08 p<0.01, **Figure 5b**), with emphasis on the cities of the microregion of Porto Seguro. The other cities do not show important influences.

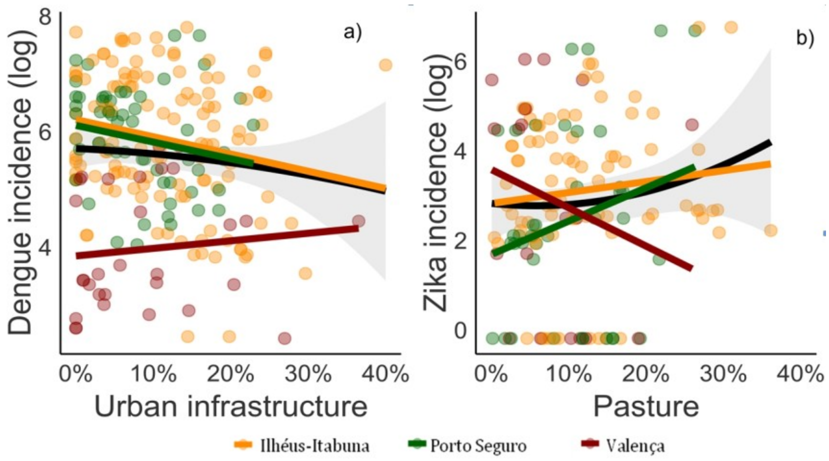

Figure 5: Relationship between land use and land cover and the incidence of dengue and zika according microregions between 2009 and 2019 considering significant interactions, urban infrastructure (a) and pasture (b).

Considering the integrated analysis of environmental variables (climatic, social, fires, and land use and land cover), we observed that the set explained about 38% of the variation in the incidence of dengue cases, 22% of zika cases, and 27% of chikungunya cases. Climate alone was the most relevant to the incidence of diseases, explaining about 20% of the incidence of dengue and chikungunya and 16% of the incidence of zika in the municipalities evaluated (**Figure 6**). Considering the intersection of climate and other factors, the whole explanation achieve 30% for dengue incidence.

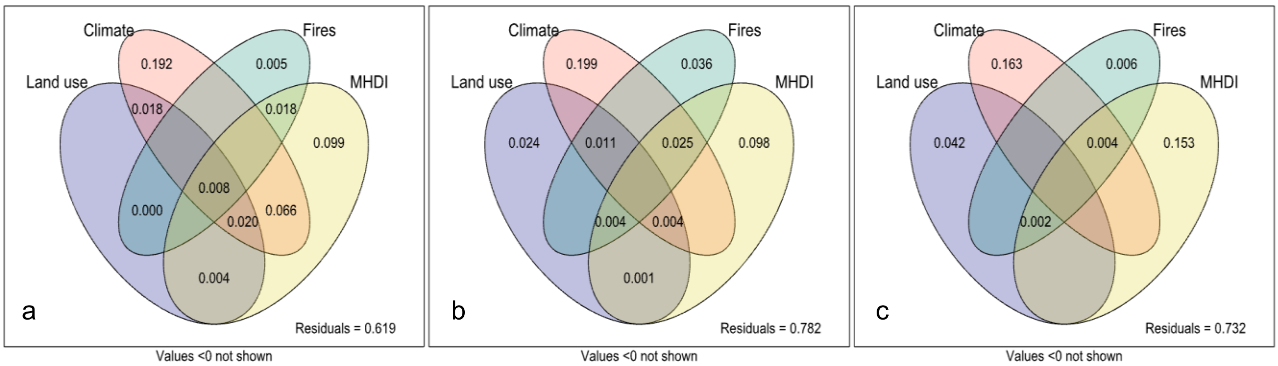

Figure 6: Multivariate analysis and incidence of dengue (a), chikungunya (b) and zika (c) cases in southern Bahia from 2009 to 2019.

The MHDI alone explained about 10% of the incidence of dengue and chikungunya and 15% of zika in the region, while land use and land cover integrated with other factor explained about 5% of the incidence of dengue, 3% of zika and 4% of chikungunya. The outbreaks of fires have a low influence.

4. Discussion

The evaluation of environmental variables that influence the incidence of diseases in the municipalities of southern Bahia showed that climate is the most influential for the occurrence of zika, chikungunya and dengue. Climate change is pointed out as one of the main predictors of the spread of disease when considering the potential impact of mobility, population growth, trade and globalization (BRATTIG *et al.* 2021).

The incidence of dengue, zika, and chikungunya suggest a similar geographic pattern recorded in the central region in more populous cities. We seek to investigate the hypothesis that changes in land use and land cover associated with climatic conditions and low socioeconomic quality in cities increase the occurrence of the infectious diseases dengue, zika and chikungunya in the south of the State of Bahia, northeastern Brazil.

Changes in land use and land cover, outbreaks of fires and MHDI can be considered secondary factors that vary in importance according to the evaluated disease. However, the alteration of activities on the Earth's surface and the occurrence of fires are closely related to temperature and precipitation, revealing synergistic and cumulative factors for the spread of diseases and suggesting a joint evaluation of these characteristics. Daszak and Hyatt (2001), emphasized that the loss of biodiversity derived from environmental changes is also a direct factor in the increase of emerging diseases.

The statistical models satisfactorily explained the environmental effect on the incidence of dengue, chikungunya and zika, reaching more than 30% of explanation for dengue and more than 20% for zika and chikungunya. The occurrence of dengue in all municipalities in the region and similar geographical pattern for zika and chikungunya results from climate adaptability and sharing the same vector, the mosquito *Aedes aegypti* (VALLE *et al.* 2016).

The abundance of this vector is partially regulated by temperature and precipitation. These factors affect mosquito viability and development and reproduction rates, which justifies the incidence of pathologies in the cities studied (Ajuz and Vestena, 2014; Lima *et al.* 2018). This perception was also recorded in Colombia, where climatic factors such as temperature and wind showed a significant correlation between average temperature and wind speed with disease transmission, reinforcing that an increase in minimum temperature leads to a decrease in disease incidence (MORGAN *et al.* 2021).

The reproduction of vectors increases as the temperature increases (25°C to 32°C); conversely, it decreases with temperatures below 20°C and is interrupted from 16°C and below. For Faria *et al.* (2016), in Bahia, transmission is only interrupted when it reaches 15ºC, as it affects the entomological structure of the vector. This study sheds light on the discussion that temperatures from 20ºC and up favor the transmission of the vector and not only 25ºC, which makes the south of Bahia a propitious area for the dissemination of these diseases confirmed by the epidemiological bulletins of the health agencies as the region most affected by these diseases in 2016, concentrating 42.2% of cases in the State of Bahia (BAHIA, 2017).

This dissemination is aggravated when favored by the high viral circulation of the diseases in the region and by the negligence of the population in contributing to campaigns to eliminate reproduction foci or public agencies in regularizing the basic sanitation service, predominantly the collection and correct disposal of solid waste (PAIXÃO *et al.* 2018). In the region, Silva and Lopes (2021) showed that eight cities do not have sufficient coverage for waste collection and deposit in open-air dumps. There is an impact on the health of the population, considering that Brazilian municipalities present a deficit in the treatment of water, effluents, waste, and the decrease of natural areas has been evident throughout Brazil, with high rates of loss of natural areas (YANG *et al.* 2015; SOS MATA ATLÂNTICA, 2019; 2021; 2022; RAMOS *et al.* 2022).

The association between the incidence observed and environmental degradation is promoted by changes in land use and land cover, specifically by the reduction of forests for urban expansion, pasture, forestry and agriculture. Land-use change, particularly forest fragmentation and the conversion of natural habitats into agricultural and urban areas, directly influences mosquito biodiversity and the emergence of arboviruses (IZQUIERDO-SUZÁN *et al.* 2024). A study conducted in the Arc of Deforestation in the Southern Amazon demonstrated that the richness and abundance of arbovirus vectors increase in more fragmented landscapes, characterized by smaller forest remnants with irregular shapes and high edge density (VIEIRA *et al.* 2022). Vector species showed a higher probability of occurrence in areas with medium to high levels of disturbance, suggesting that environmental degradation favors vector proliferation and potentially increases the risk of arbovirus transmission in that region (VIEIRA *et al.* 2022). Similar results were observed in the land use change and Dengue dynamics in China (GAO *et al.* 2021) and considering the mosquito biodiversity and contamination with Dengue and Zika virus in disturbed landscapes in Mexico (IZQUIERDO-SUZÁN *et al.* 2024).

In the south of Bahia, in 35 years, 59% of the territory was modified to accommodate human activities, reducing 328,595 ha of native Atlantic Forest (RAMOS *et al.* 2022). The association of the increase in urbanization and agriculture with the incidence of dengue (HORTA *et al.* 2013) and with the occurrence of outbreaks of fires and criminal burnings induced by rudimentary practices of agricultural management, land cleaning, disposal of solid waste, and unauthorized conversions, contributing to reproduction of arboviral vectors (SILVA *et al.* 2018).

The greater number of these outbreaks and the positive relationship with dengue, zika, and chikungunya show an association with municipalities where real estate speculation occurs and with the influence of the pulp and paper sector, concentrating an average of 7.64 outbreaks per municipality/year. Its relationship with the loss of native vegetation area encourages the proximity between constructed and natural areas, exposure of new hosts to a diversity of pathogens, and contact between humans and the viral vector, culminating in disease outbreaks in humans (DASZAK, 2001; MEENTEMEYER *et al.* 2012; MCGINNIS & KERANS, 2013; MURRAY & DASZAK *et al.* 2013; ALMEIDA, 2016). These numbers are also affected by a change in Brazilian environmental policy between 2018 and 2022, with a reduction in inspections and a marked drop in the number of assessments and environmental infractions (BARBOSA *et al.* 2021).

Although our results show that the increase in the MHDI reflects a higher incidence of diseases, it should be noted that the average MHDI in the evaluated region is 0.59, below the average for Brazil and the world, indicating that the region is in development. Cities with expanding urban areas and high population density favor the occurrence of the vector and spread of the disease, and when sanitary structures are deficient they increase the spread of diseases among the population. The investigation of the incidence of chikungunya associated with socioeconomic factors in the world has also shown that less developed countries have a higher incidence of the diseases (WHITEMAN *et al.* 2020).

Similarly, when assessing the risk of infection by Zika, dengue, or chikungunya in vulnerable adolescent populations, it was observed that living in less favorable socioeconomic conditions, attending school in the morning, and having a high building infestation index in the school region could contribute to an increase in cases (MORGAN *et al.* 2021; DALVI *et al.* 2023). These findings reinforce that precarious socioeconomic conditions, combined with ecological factors, serve as key indicators to be monitored for the spread of arboviruses, especially in developing regions where urban infrastructure deficiencies persist considering are diseases of global health are transmitted by the mosquito *Aedes aegypti*, which is of worldwide circulation.

We ratify the importance of public management to reflect on the factors that affect quality of life and planning to ensure the environmental quality of cities and the individuals who inhabit them, since the greater the social inequality, the greater the environmental degradation (JALAN *et al.,* 2000; RABELO *et al.* 2020). SilviaTortosa-La Osa *et al.* (2022) reinforces the importance of looking at epidemiological, ecological, and sociodemographic factors in an integrated manner, given that mosquito density is one of many factors that influence virus transmission. In the case of dengue, Adnan (2021) addresses that environmental factors play an important role in the abundance of *Aedes* mosquitoes and local dengue control measures. For climatic variables, there is evidence that these, in addition to their relationship with disease incidence, can be used as predictive models for outbreaks to act in health education, epidemiological surveillance, and expand public policy efforts to reduce vulnerability to disease (ZHU *et al.* 2019; JAYARAJ *et al.* 2019).

The strategy implemented in Singapore, with the establishment of a Vector Control Unit (VCU), can serve as an example to be observed as a regional public policy. The program is characterized by four main features: (i) proactive surveillance and control between outbreaks, intensified during epidemic periods; (ii) risk-based prevention and intervention strategies, supported by advanced data analytics; (iii) coordinated inter-sectoral cooperation between the public, private, and community sectors; and (iv) the adoption of new tools and strategies based on evidence (HO *et al.* 2023). This program has provided evidence of accurate diagnostics and ongoing actions for monitoring and effective response during outbreaks. Morgan *et al.* (2021) also emphasize that establishing consistent knowledge about the city is an effective measure to combat diseases.

It should not be forgotten that a comprehensive approach requires integrating social, ecological, and economic factors, along with effective vector management and vaccination efforts, which are essential for reducing arbovirus transmission and alleviating the strain on healthcare systems.

5. Conclusions

This study analyzed the influence of environmental variables on the spread of emerging and reemerging diseases, specifically dengue, Zika, and chikungunya. We found a direct relationship between environmental factors and the incidence of these diseases, explaining 20% to 30% of their spread. Our findings confirm the hypothesis that climate, particularly average temperatures between 20.9°C and 29°C, plays a key role in the proliferation of the Aedes aegypti mosquito, the primary vector. While changes in land use, land cover, and fire outbreaks are secondary factors, they are significant as they bring vectors and hosts closer to human populations. The expansion of urban areas, especially when it encroaches upon native vegetation, increases the risk of habitat disruption and creates favorable conditions for mosquito breeding. The incidence of fires, which often follows urban sprawl and deforestation, further exacerbates environmental imbalances.

Additionally, the spread of these diseases is aggravated by increasing population density and low municipal human development index (MHDI).

Given these findings, urban governance must prioritize sustainable development policies that balance urban growth with environmental conservation. Strategies should include strengthening vector control programs, integrating climate-adaptive urban planning, and preserving native vegetation to mitigate the risks of disease spread. Furthermore, promoting fire prevention and control measures in urban expansion areas is essential to prevent the negative impacts of land degradation. A multidisciplinary and integrative approach that combines urban development, environmental protection, and community health will be critical in reducing the incidence of these diseases and improving quality of life in affected regions.

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