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Association Between Climate Change and the Occurrence of Microcephaly Due to Congenital Zika Virus Syndrome from 2015 to 2019 in São Luís, Maranhão, Brazil

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ABSTRACT

The number of cases of microcephaly in live-born babies whose mothers were infected with the Zika virus during pregnancy has increased, especially in the northeastern region of Brazil. The objective is to investigate the association between climate change and the occurrence of microcephaly due to Zika virus infection in the city of São Luís, State of Maranhão, from 2015 to 2019. Secondary information was obtained from the Superintendence of Epidemiological Surveillance of the Maranhão State Health Department and climate data from the National Institute of Meteorology - INMET from 2015 to 2019. The average precipitation of >100 mm per month was considered rainy months, and the number of children born with microcephaly during the first trimester of pregnancy was analyzed, comparing those occurring during the rainy season with those corresponding to the non-rainy season. Between 2015 and 2019, n=59 cases of microcephaly due to the Zika virus were reported and confirmed, of which n=43 (72.88%) pregnancies occurred during the rainy season and n=16 (27.11%) pregnancies during the non-rainy season, with a significant difference between the groups p=0.02 (Student t-test). A positive association was observed between climate change and the occurrence of microcephaly due to Zika virus infection.

Keywords: Microcephaly; Zika Virus; Epidemiological Surveillance.

INTRODUCTION

In 1947, the Zika virus was found in monkeys during research on yellow fever viruses. It was named after a forest in Uganda, Africa, called Zika. Subsequently, infection was found in humans, remaining isolated in Africa and Asia until 2014, when cases were reported on Easter Island in Chile, marking its arrival in the Americas (ZANLUCA C et al., 2015).

The Zika virus is an arbovirus belonging to the Flavivirus genus. Its transmission occurs through *Aedes aegypti* and *Aedes albopictus* mosquitoes, with transmission also recorded through bodily fluids such as blood, semen, urine, and saliva (PIELNAA et al., 2020). Symptoms of infection include fever accompanied by headache, rash, malaise, swelling, and joint pain (FREITAS et al., 2017; VASCONCELOS, 2015).

Since its discovery, the virus has remained confined to specific African and Asian regions. Given the low number of cases and the minimal clinical impact compared to other arboviruses, little interest has been shown in researching and developing vaccines and treatments against the Zika virus (FAUCI and MORENS, 2016).

In October 2014, an exanthematic disease accompanied by itching, low fever, and joint pain was reported in the municipalities of Rio Grande do Norte. Initially, chikungunya fever was suspected; however, tests for this disease were negative. Similar cases were then reported in Maranhão and Paraíba (FANTINATO et al., 2016).

Microcephaly

Its etiology is related to genetic and chromosomal factors, environmental exposures of the mother during the prenatal or perinatal period, such as alcohol consumption, illicit drugs, teratogenic medications, contact with chemicals or ionizing radiation, metabolic disorders, and infectious processes like toxoplasmosis, rubella, cytomegalovirus, herpes, and syphilis (MAGNUS et al.; 2018; FERREIRA, 2000).

Microcephaly is associated with intrauterine infections or genetic factors. The most common causes are the syphilis bacteria, the protozoan that causes toxoplasmosis, and viruses like rubella, cytomegalovirus, and herpes simplex virus (BRAZIL, 2017).
Microcephaly is characterized by a reduced head circumference for gestational age, which may lead to brain abnormalities and neurological developmental problems. It is a congenital malformation in which the brain does not develop properly (ALVARADO-ARNEZ et al., 2018; VAGAS et al., 2016).

Children born with congenital malformations such as microcephaly are vulnerable in terms of their health conditions. Most cases are accompanied by motor and cognitive impairments, which may vary according to the extent of brain damage. Some children's neuro-psychomotor development is delayed, and they may experience hearing and vision impairments (MOORE et al., 2017; VAGAS et al., 2016).

Zika Virus and Climate Change

Zika is present in almost all South American countries. The rapid spread of arboviruses has not yet been satisfactorily explained. We know it relates to climate, demographic, social changes, and intrinsic factors in the pathogen’s pathogenesis. During the summer, the rainy season occurs, and due to climate change, the heat becomes more intense, prompting people to store water, which facilitates the more frequent reproduction of the vector (RODRIGUES, 2018).

Brazil is a tropical country, and this condition is present throughout the year, allowing the Zika virus vector to find favorable environmental and climatic conditions for its dissemination. The waste of potable water in reservoirs and homes creates conditions for mosquitoes to breed and proliferate, worsening an already established public health issue (FARIA et al., 2016).

Climate variability is an intrinsic property of the Earth's climate system, responsible for natural fluctuations in climate patterns observed at local, regional, and global levels. Several climatic factors, such as relative humidity and temperature, favor the reproduction and survival of pathogens in the environment, especially vectors of infectious agents, such as the *Aedes aegypti* mosquito (ARAUJO et al., 2019).

Atmospheric conditions strongly influence society, and the health or disease status of the human body is one of the many manifestations of this interaction between climate and health (CAMPBELL-LENDRUM et al., 2023; MENDONÇA, 2005).

Increased migration between countries and regions facilitates the entry of the Zika and Chikungunya viruses into the Americas and Brazil. Poor sanitation, disorganized urbanization, lack of city infrastructure, increasing waste production, inefficient health campaigns, and a lack of preparedness among health professionals to control the disease increase the mosquito-borne endemic. The vector resists control measures (SOARES et al., 2016).

In 2014, an increase in cases of microcephaly in live-born babies was observed, with the highest number in the northeast region. At the time, the cause was unknown in

the literature. Actions developed by national and international health authorities, researchers, and health workers discovered the relationship between the Zika virus and congenital microcephaly syndrome (ALBUQUERQUE, 2018).

Microcephaly Related to Congenital Zika Virus Infection

At that time, the Brazilian Government decided to combat the Aedes aegypti mosquito to control the microcephaly outbreak, even though there was no concrete evidence that Zika infection in pregnant women caused microcephaly. On December 5, 2015, the National Plan to Combat Microcephaly was launched in Recife, Pernambuco (GARCIA, 2020).

Between 2015 and 2019, the Ministry of Health was notified of 18,578 suspected cases of growth and development abnormalities in head circumference, possibly related to Zika virus infection and other infectious etiologies. Of these, 2,265 were excluded after a thorough investigation as they did not meet the current case definitions. (BRAZIL, 2020).

When it occurs during the first trimester of pregnancy, Zika virus infection has a profound impact on fetal development, potentially threatening its viability. It affects cellular proliferation and differentiation, leading to organ malformations and growth limitations (BUENO, 2020).

The information on vertical transmission of Zika from mother to fetus is recent. In 2013, two mothers and their newborns infected with the Zika virus were reported in French Polynesia, where the infection could have occurred either in utero or during childbirth (SHULER-FACCINI L et al., 2016).

We now know that microcephaly is just one of the manifestations of Zika Virus Congenital Syndrome (COSTELLO et al., 2016; EICKMANN, 2016; MOORE et al., 2017).

It is known that climate change affects the spatial and temporal distribution of pathogen vectors, increasing transmission and potentially leading to congenital syndrome caused by the Zika virus (BRITO, 2020).

The severe microcephaly epidemic highlights the urgent need for investments aimed at improving living conditions in urban populations in Brazil. On one hand, the lack of water in homes forces water storage, creating favorable environments for mosquito breeding. On the other hand, rain accumulates in precarious housing or areas

with waste deposits, generating environments conducive to vector development (HENRIQUES, 2016).

The social determinants of health are the social conditions individuals experience, including economic, cultural, ethnic/racial, psychological, and behavioral aspects that influence the incidence of health problems and their risk factors in the population. The Zika epidemic that spread throughout much of the country, propagated by the *Aedes aegypti* mosquito, seems to be directly linked to these determinants (FARIAS, 2016; GONÇALVES, 2018).

As previously mentioned, climate factors favor the reproduction and survival of pathogens in the environment, especially vectors of infectious agents, such as the *Aedes aegypti* mosquito (ARAUJO et al., 2019).

Thus, we raise the following question: Is there an association between climate change and confirmed cases of microcephaly caused by the Zika virus? We hypothesize that the number of children born with microcephaly whose mothers' first trimester of pregnancy coincided with the rainy season (average precipitation above 100 mm) would be higher than those corresponding to the non-rainy season (average rainfall below 100 mm).

Therefore, our objective was to investigate a possible association between climate change and the occurrence of Zika virus-related microcephaly between 2015 and 2019 in the city of São Luís, Maranhão state. The results of this study could contribute to the design of public health policies to protect pregnant women in combating diseases transmitted by the *Aedes aegypti* mosquito.

MATERIALS AND METHODS

Study Population

This cross-sectional study uses secondary information from live-born children with microcephaly between 2015 and 2019 in the city of São Luís, Maranhão state. Only individuals of both sexes with confirmed diagnoses of microcephaly caused by congenital Zika virus infection were included.

The Epidemiological Surveillance Superintendency of the Maranhão State Health Department provided the epidemiological data for reported cases in São Luís of children affected by congenital anomalies caused by the Zika virus. A profile of the sample was then outlined, and relevant information for the study was selected, including the month

and year of the child's birth, the addresses of the mothers for socio-demographic profiling, and the origin distribution of these children.

Climate Data

Climate information was obtained from the National Institute of Meteorology (INMET) website in the form of a climate data spreadsheet for 2015 to 2019. Monthly precipitation was considered either greater than or less than 100 mm to identify rainy or dry months. The child's birth date was used to analyze whether the mother was in a rainy or dry period during the first trimester of pregnancy.

Statistical Tests

The data were analyzed using the Student's T-Test for independent samples to compare the number of children born with microcephaly whose mothers' first trimester of pregnancy corresponded to the rainy season (average precipitation above 100 mm) versus those whose pregnancies occurred during the dry season (average rainfall below 100 mm). Results were considered statistically significant for p-values ≤ 0.05 with a 95% confidence interval.

RESULTS

Through analysis from the Epidemiological Surveillance Superintendency of the Maranhão State Health Department, 59 confirmed and reported cases of Zika virus-related microcephaly were identified between 2015 and 2019 in the city of São Luís. Of these, 52.66% were female. Regarding head circumference, 17% had a head circumference between 30 and 32 cm (Table 1).

Table 1 - Description of gender and head circumference of Zika virus-related microcephaly cases observed between 2015 and 2019.

Variáveis	n	%
Gênero		
Feminino	31	52,54%
Masculino	28	47,46%
Perímetro cefálico		
25 – 27 cm	7	11,8%
27,5 – 29,5 cm	5	8,5%
30 – 32 cm	10	17%
33 – 35 cm	4	8%
40 – 47,5 cm	3	6%
Não informado	30	51%

Regarding the climatic period, 43 mothers (72.88%) were in the first trimester of pregnancy during the rainy season, and 16 mothers during the non-rainy season (27.12%). Comparing these data, we observed a significant difference between these two groups (p=0.0257, Student's t-test) (Figure 1).

Figure 1: Graphical representation of the precipitation period (non-rainy vs. rainy) and the number of pregnant women in their first trimester of pregnancy.

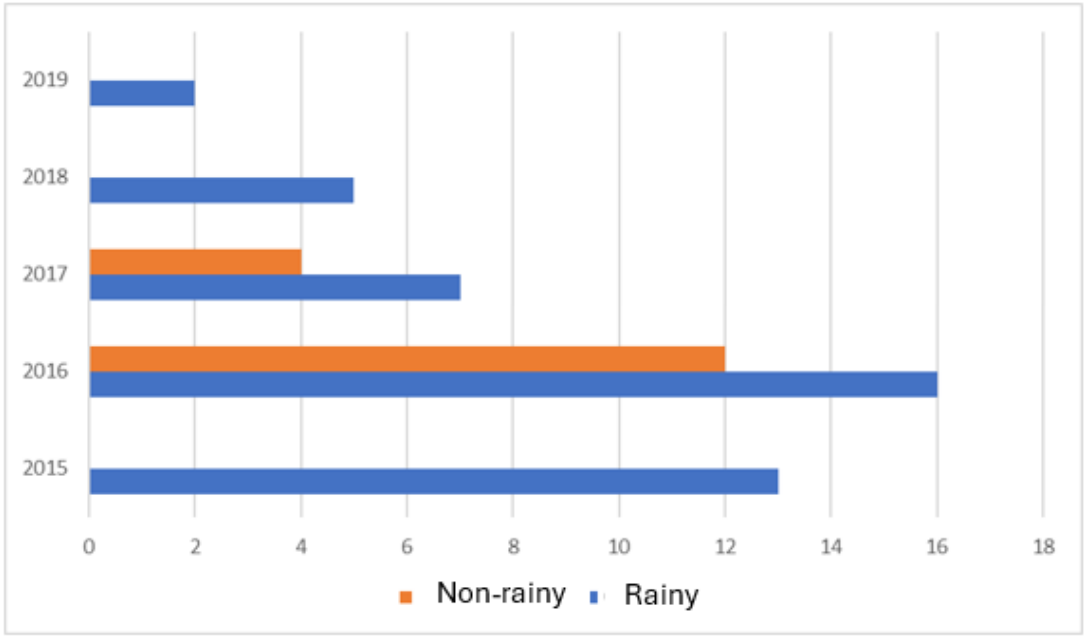
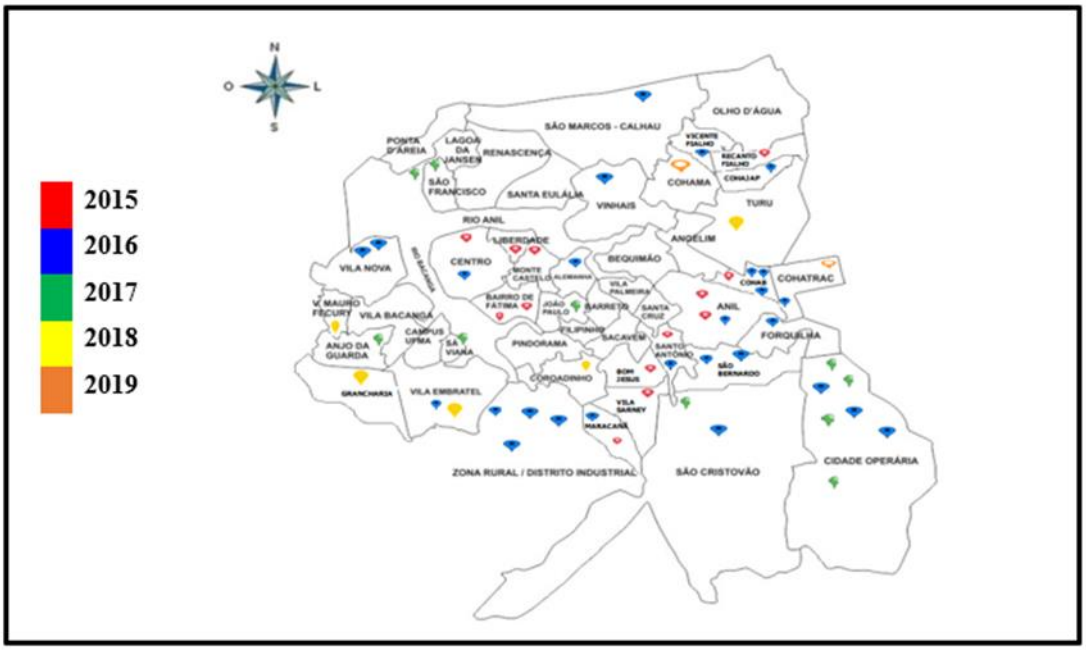


Figure 2 shows the spatial distribution—by neighborhoods—of mothers' locations during the first three months of pregnancy, indicating blue points for the rainy period and red points for the non-rainy period. Interestingly, neighborhoods with low human development indices have a higher density of blue points.

Figure 2: Map of the city of São Luís showing the locations where the mothers lived during the first three months of pregnancy.



DISCUSSION

The results obtained in this study show a higher prevalence (72.88%) of mothers whose children were born with microcephaly resulting from Zika virus infection and who spent their first trimester of pregnancy during the rainy season.

The first trimester of pregnancy is a critical phase for the growth and development of fetal organs and tissues. Mothers infected during this period may transmit the infection to the fetus through the placenta (SOARES et al. 2016). It is also known that the rainy season is more conducive to the reproduction and longevity of *Aedes aegypti* (GOMES et al., 2023; DONALÍCIO, 2002), thus facilitating the mother's infection by the Zika virus.

Considering the above, it is reasonable to propose an association between climate changes and the occurrence of Zika virus-related microcephaly from 2015 to 2019 in the

city of São Luís, Maranhão, where the rainy season is more prone to infections caused by the *Aedes aegypti* mosquito.

Leatte and colleagues (2017) indicate that mosquitoes are more common in urban areas and more intensely infested during the summer due to rising temperatures and increased rainfall.

According to Köppen's climate classification method (ÁLVARES et al., 2013), Maranhão has three climate types: tropical with a monsoon period or humid tropical climate (February to May), characterized by an average precipitation in the driest month of less than 60 mm and a total annual average ≥ 3300 mm, tropical regions with a dry summer, and the tropical zone with a dry winter, covering most of the state, where the most pronounced rainy season occurs in December, January, and February, with a monthly average above 250 mm.

Various factors contribute to the recurring formation of epidemics in tropical and subtropical countries, including the easy proliferation of the *Aedes aegypti* mosquito, rapid demographic growth associated with disordered urbanization, inadequate urban infrastructure, increased production of non-organic waste, urban lifestyles, weaknesses in public health services and campaigns, as well as the lack of preparation among health workers and the population to control the disease (KLAFKE et al., 2023; SUAYA, 2009).

Tropical countries are the most affected by environmental characteristics, especially air temperature and precipitation. Other variables are also important, such as relative humidity, wind speed, vegetation cover, and the presence of breeding grounds. Regarding the climate, Brazil is a tropical country with predominantly hot and humid climates, characterized by average temperatures close to 20ºC. Brazil has the highest incidence of Zika cases in the first months of the year, which typically exhibits the characteristics of a tropical climate (hot and humid) (VASCONCELOS, 2013).

Our data on the spatial distribution of the neighborhoods where the mothers lived during the first three months of pregnancy indicate a higher concentration in neighborhoods with low human development indices (HDI), poor sanitation conditions, and open waste and sewage. These conditions are conducive to the proliferation of bacteria, harmful microorganisms, and viruses, severely affecting the population in these areas through diseases such as dysentery, hepatitis, cholera, arboviruses, etc.

The Zika virus is transmitted by the *Aedes aegypti* vector, which proliferates in areas with stagnant water, waste, and places neglected by health surveillance, the population, and the health department.

On the other hand, there are still issues related to maternal malnutrition, which ends up promoting changes in embryo formation. A malnourished woman already has a higher chance of malformations (in the fetus). The impact of the Zika virus ends up being more intense.

According to the study conducted by Souza (2018), in Brazil, the population most affected by the disease is low-income individuals who live in unhealthy areas.

De Souza and collaborators (2018) examined the spatial distribution of microcephaly cases in Recife (PE) between 2015 and 2016 and their association with socioeconomic conditions through an ecological study. During the study period, 347 cases of microcephaly were reported, of which 142 were confirmed. The authors divided the city into four strata based on the population's living conditions, with the highest stratum having the best quality of life. The research results showed that the highest stratum had the lowest prevalence of microcephaly, with an association found between higher prevalence and poor living conditions. No cases of microcephaly were found in the population of the highest socioeconomic stratum during the first six months of the study.

The research concluded that the population residing in areas with poor living conditions tends to have a higher prevalence of Zika virus-related microcephaly compared to individuals in higher socioeconomic strata. Our results agree with those obtained in this work by De Souza and collaborators (2018).

Susceptibility to Zika virus infection correlates with poverty. Ali and collaborators (2017) state that individuals living in precarious locations generally have limited access to public services, including basic sanitation and healthcare. As the authors describe, about 50% of mosquito breeding in the southeastern region is due to inadequate water storage and poor housing conditions. Thus, individual economic conditions and the lack of essential sanitation services partially explain the disease's progress in Brazil. In the Northeast, the population relies more on their reservoirs for water storage due to scarcity and lack of public supply. Consequently, there is less control over stagnant water, creating conditions for the transmitting vector's proliferation.

In their study, Ali et al. (2017) did not observe cases of microcephaly in the population with better living conditions. Therefore, the research indicated that the population residing in precarious conditions tends to have a higher prevalence of Zika virus-related microcephaly compared to individuals in higher socioeconomic strata.

Our study did not perform a statistical analysis; however, a visual analysis of the spatial distribution of registered cases of Zika virus-caused microcephaly from 2015 to

2019 in São Luís indicates a higher prevalence in neighborhoods with poorer living conditions.

In addition to these variables, favorable climatic conditions contribute to the spreading of the vector responsible for Zika virus transmission. Ali and collaborators (2017) describe that ZIKV transmission becomes favorable in locations with temperatures between 18 and 34ºC. According to data from the Intergovernmental Panel on Climate Change (IPCC, 2013), the 5,570 municipalities in Brazil experience temperatures within this range at some point during the year, which confirms the disease's spread throughout the country's regions. The study also noted that the initial Zika virus outbreaks in the Americas occurred mainly in tropical and subtropical areas.

According to Garbin et al. (2021), the control and proliferation of *Aedes aegypti* occur primarily within a collective framework and require the effort of the entire society. Thus, the population in areas with transmission needs information aimed at changing attitudes, assisting in preventing and controlling this disease. The Zika virus epidemic can be considered one of the leading causes of neuropsychomotor disorders and disabilities in a generation of newborns affected by microcephaly secondary to maternal Zika virus infection. It can be noted, therefore, that the situation studied represents a significant burden for the families involved and a high socioeconomic cost for Brazil.

Brazil is known for its social inequality, although it ranks 9th among the world's largest economies in 2024, with a GDP of US$ 2.17 trillion, ahead of large countries such as Canada, Russia, and Mexico. Its disparity ranks it among the world's most unequal countries. According to data from the UN report, Brazil ranks 14th, sharing the position with Congo, which also has an index of 48.9. According to IBGE data from May 2022, the wealthiest 1% of Brazilians earn an average monthly income 32.5 times higher than the income of the poorest half of the country's population. In 2022, according to the IBGE, the government had its lowest Gini coefficient result since 2012.

Based on the 2022 demographic census, it was observed that the neighborhoods with the highest number of cases are those with the poorest sanitation infrastructure, with homes lacking bathrooms, inadequate or absent waste collection, and no access to piped water. In addition, disordered occupation and segregation are some of the consequences of Zika virus infection and proliferation (TRATA BRASIL, 2022).

Inadequate urban infrastructure creates susceptibility to the reproduction of pests and vectors of various diseases. The vector of arboviruses, *Aedes aegypti*, has its reproduction favored by stagnant water puddles in urban areas.

These environments are typical in areas with accumulated waste in the streets around homes, an inefficient water supply, and a lack of basic sanitation. The population living in regions with such characteristics is consequently more susceptible to infections by the virus transmitted by this vector (MARCONDES and XIMENES, 2016).

This reflects socioeconomic vulnerability, which has health repercussions and makes this group or community more likely to be affected by phenomena or processes such as ZIKA infection (BRASIL et al., 2016).

Thus, the concentration of Zika virus infection cases in the less privileged neighborhoods can be justified by the irregular water supply, as the pressure in the pipes decreases with distance from the distribution centers, which are often far from the periphery. This situation can be aggravated by families being forced to store water in tanks or containers that are often not adequately sealed (LESSER and KITRON, 2016).
In addition to the water supply, there is the issue of waste collection, which does not occur regularly in many neighborhoods of São Luís. After a rain event, plastic bags and disposable containers become breeding grounds for the Zika virus vector.

CONCLUSION

The rainy season is associated with the occurrence of microcephaly due to Zika virus infection in the city of São Luís. Thus, the rainy season appears to be a risk factor for maternal exposure to climatic conditions that favor the proliferation of the virus. Therefore, public policies to protect pregnant women against Zika virus transmission should be in place year-round, with particular attention to periods of higher rainfall.

The results of this study, as well as those indicated by the research, consulted, show that in Brazil, Zika virus-induced microcephaly may be related to the structural and economic conditions of the regions, such as the lack of basic sanitation, the incidence of extreme poverty, high levels of urbanization, among others. Given the above, it can be concluded that combating the disease is not limited to health policies alone, as actions that promote improvements in basic sanitation and regional infrastructure, combined with broader development policies (such as poverty reduction), can have a significant beneficial effect.

Finally, it is hoped that the results of this work can improve public policies to protect pregnant women, who are more susceptible to contamination by vectors such as Aedes aegypti during specific periods of the year.

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