DOI: 10.17058/f9same25

Urban socio-environmental vulnerability in the Immediate Geographic Region of Brejo Santo – CE

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Resumo
Estudos sobre vulnerabilidade socioambiental têm se destacado no contexto em que a análise dos sistemas econômicos e sociais é cada vez mais repensada a partir de suas conexões ambientais. Esse ensaio se propõe a identificar o padrão de vulnerabilidade socioambiental urbana da Região Geográfica Imediata de Brejo Santo - CE, a partir da construção de um Índice de Vulnerabilidade Socioambiental Urbana (IVSA), composto por seis dimensões: econômica (VEC), educacional (VED), políticas de saúde (VPS), habitacional (VH), infraestrutura urbana (VIU) e pressão sobre o ambiente natural (VPN). Como resultados, as dimensões que registram padrões de alta vulnerabilidade são a econômica (0,625), a educacional (0,562) e a de infraestrutura urbana (0,525). Níveis intermediários de vulnerabilidade foram observados em políticas de saúde (IVPS de 0,436, próximo do limite superior da faixa de vulnerabilidade moderada) e habitacional (IVH de 0,354). A dimensão pressão sobre o ambiente natural apresenta os melhores resultados, com baixa vulnerabilidade e IVPN de 0,118. Esse conjunto de resultados aponta para vulnerabilidade socioambiental média (IVSA de 0,437) na Região Geográfica Imediata de Brejo Santo - CE,

com padrão de vulnerabilidade superior ao da Região Imediata de Juazeiro do Norte (0,436), ao de Fortaleza (0,351) e à média cearense (0,427).

Palavras–chave: Dinâmicas urbanas. Vulnerabilidade socioambiental. Políticas públicas.

Urban socio-environmental vulnerability in the immediate geographic region of Brejo Santo - CE

Abstract
Studies on socio-environmental vulnerability have stood out in a context in which the analysis of economic and social systems is increasingly rethought based on their environmental connections. This paper aims to identify the pattern of urban socio-environmental vulnerability in the Immediate Geographic Region of Brejo Santo - CE, based on the construction of an Urban Socio-Environmental Vulnerability Index (IVSA), composed of six dimensions: economic (VEC), educational (VED), health policies (VPS), housing (VH), urban infrastructure (VIU) and pressure on the natural environment (VPN). As a result, the dimensions that register patterns of high vulnerability are the economic (0.625), the educational (0.562) and the urban infrastructure (0.525). Intermediate levels of vulnerability were observed in health policies (IVPS of 0.436, close to the upper limit of the moderate vulnerability range) and housing (IVH of 0.354). The dimension of pressure on the natural environment presents the best results, with low vulnerability and IVPN of 0.118. This set of results points to average socio-environmental vulnerability (IVSA of 0.437) in the Immediate Geographic Region of Brejo Santo - CE, with a pattern of vulnerability higher than that of the Immediate Region of Juazeiro do Norte (0.436), Fortaleza (0.351) and the Ceará average (0.427).

Keywords: Urban dynamics. Socio-environmental vulnerability. Public policy .

Vulnerabilidad socioambiental urbana en la región geográfica inmediata de Brejo Santo - CE

Resumen
Los estudios sobre vulnerabilidad socioambiental se han destacado en un contexto en el que el análisis de los sistemas económicos y sociales se replantea cada vez más a partir de sus conexiones ambientales. Este ensayo tiene como objetivo identificar el patrón de vulnerabilidad socioambiental urbana en la Región Geográfica Inmediata de Brejo Santo - CE, a partir de la construcción de un Índice de Vulnerabilidad Socioambiental Urbana (IVSA), compuesto por seis dimensiones: económica (VEC), educativa (VED), de políticas de salud (VPS), de vivienda (VH), de infraestructura urbana (VIU) y de presión sobre el medio natural (VPN). Como resultado, las dimensiones que registran patrones de alta vulnerabilidad son la económica (0,625), la educativa (0,562) y la de infraestructura urbana (0,525). Se observaron niveles intermedios de vulnerabilidad en las políticas de salud (IVPS de 0,436, cercano al límite superior del rango de vulnerabilidad moderada) y en la vivienda (IVH de 0,354). La dimensión de presión sobre el medio natural presenta los mejores resultados, con baja vulnerabilidad e IVPN de 0,118. Este conjunto de resultados apunta a una vulnerabilidad socioambiental media (IVSA de 0,437) en la Región Geográfica Inmediata de Brejo Santo - CE, con un patrón de vulnerabilidad superior al de la Región Inmediata de Juazeiro do Norte (0,436), al de Fortaleza (0,351) y al promedio de Ceará (0,427).

Palabras clave: Dinámica urbana. Vulnerabilidad socioambiental. Políticas públicas.

1. Introduction

One of the important movements in the urban system in Brazil in recent decades has been the consolidation of regional centers and the affirmation of hub cities, based on connections through the flow of people, goods, capital, and information, with broad territorial influences.

Considering the changes in Brazilian economic, demographic, political, and environmental dynamics, it became necessary to recognize new spheres and scales of social, cultural, and economic influence among municipalities, leading to the classification of Immediate and Intermediate Geographic Regions by the Brazilian Institute of Geography and Statistics (IBGE). Immediate Geographic Regions have the urbanized network as their most relevant reference, consisting of structures in nearby urban centers with dynamics to meet the need for goods, employment, and specialized public services. Each region has an articulating pole within its territory, generally the pole with the highest urban hierarchy, responsible for defining the region (IBGE, 2017).

In parallel, studies on socio-environmental vulnerability have become prominent in a context where the analysis of economic and social systems is increasingly being rethought from the perspective of their environmental connections. Amidst discussions of a new development model, where the environmental dimension guides the actions of different sectors (public sector, business organizations, third sector, society in general), the field of interest that attempts to reconcile development with environmental balance and social equity now encompasses: environmental management and planning; environmental policies and practices; sustainability and protection; socio-environmental risk and vulnerability, etc. Urban environmental vulnerability, therefore, becomes an important topic for considering the quality of life and well-being of populations.

Furthermore, the vulnerability of environmental, social, and economic systems does not stem solely from the risk of disasters or inadequate management practices, nor is it limited to climate change, globalization, or trade agreements. It results, above all, from the way these systems relate to one another. In this sense, according to Aquino, Paletta and Almeida (2017), the analysis of environmental vulnerability can constitute a path to be followed by governments, both to improve the management of natural resources and to implement effective measures to solve the structural problems present in various societies.

It is within this context that the present essay is situated, whose objective is to identify the pattern of urban socio-environmental vulnerability in the Immediate Geographic Region of Brejo Santo - CE. To this end, the methodological strategy adopted is the construction of an Urban Socio-environmental Vulnerability Index (IVSA), which seeks to synthesize, in an integrated way, the multiple dimensions that condition vulnerability in the region.

2. Methodological approach

Located in the far South of Ceará, the Immediate Geographic Region of Brejo Santo – CE encompasses the municipalities of Abaiara, Barro, Brejo Santo, Jati, Mauriti, Milagres, Penaforte, and Porteiras, with Brejo Santo as its articulating hub and dynamic regional center. The municipality occupies the position of Zone A Center (4A) in the urban hierarchy and integrates the Population Arrangement of Juazeiro do Norte/CE - Regional Capital B (2B), which demonstrates its insertion in a regionally influential urban network. Brejo Santo has a territorial area of 654.658 km² and a population of 51,090 inhabitants, with a population density of 78.04 inhabitants/km² (IBGE, 2026a). Economically, the municipality concentrates the greatest expression of the region: in 2023, it registered a GDP of BRL 1,263,862.58 thousand and a GDP per capita of BRL 24,737.96, occupying the 27th position in the state ranking and accounting for 38.90% of the regional GDP. This performance contrasts with that of the other municipalities in the RGIBS, which have significantly lower GDPs and GDPs per capita, such as Jati, whose GDP per capita was BRL 16,531.25, and Abaiara, with BRL 14,318.54, which reinforces the economic centrality of Brejo Santo in the regional context (IBGE, 2026b) .

The Urban Socio-Environmental Vulnerability Index (IVSA) was constructed from six indices representing the following dimensions: economic (VEC), educational (VED), health policies (VPS), housing (VH), urban infrastructure (VIU), and pressure on the natural environment (VPN).

The construction of the IVSA was based on secondary data obtained from IBGE, the Institute for Economic Research and Strategy of Ceará (IPECE), and the National Institute for Space Research (INPE), among other institutions. The definition of the variables used is detailed in Table 1, which is based on the proposition of Alves, Rodrigues and Rodrigues (2021) and incorporates three new dimensions aimed at measuring urban socio-environmental vulnerability.

Table 1 - Urban Socio-environmental Vulnerability Index – Dimensions, indicators and sources

Dimensions and indices	Indicators	Observations on the variables	Source
Economic Vulnerability (EV)	Employed Population – IPO	Percentage of the population employed	IBGE (2022)
	Per Capita Income – IRPC	Percentage of the population with a nominal monthly per capita income of up to half the minimum wage	IBGE (2022)
	Household without Income – IDR1	Percentage of households with no income	IPECE (2021)
	Household with income up to ½ minimum wage – IDR2	Percentage of households with income up to half the minimum wage	IPECE (2021)
Educational Vulnerability (EDV)	School Enrollment Rate – ITE	School enrollment rate for children aged 6 to 14	IBGE (2022)
	Illiteracy Rate – ITA	Percentage of people aged 15 or older who cannot read and write	IBGE (2022)

	Averages for the Initial and Final Years of Elementary and Secondary Education – IDEB	Average of Elementary and High School Grades	IBGE (2022)
Vulnerability in Health Policies (VPS)	Inpatient Beds – ILI	Hospital beds per thousand inhabitants	IBGE (2022)
	Infant Mortality Rate – ITMI	Infant mortality rate - deaths per thousand live births	IBGE (2022)
	Hospitalizations for Diarrhea – IID	Hospitalizations due to diarrhea per thousand inhabitants	IBGE (2022)
	Dengue Case Notification – INCD	Dengue case notifications per thousand inhabitants	IBGE (2022)
Housing Vulnerability (HV)	Property Occupancy Status – ICO	Percentage of households that are not owned or rented; Owned or rented – 0; other condition – 1	IBGE (2022)
	Households with inadequate sanitary conditions – IDCSI	Percentage of households without connection to the general sewage system	IBGE (2022)
	Density of people per bedroom – IDD	Percentage of households with more than two people per bedroom	IBGE (2022)
	Household cladding standard – IPRD	Percentage of households with other types of wall coverings besides masonry	IBGE (2022)
Urban Infrastructure Vulnerability (VIU)	Sanitary sewage – ICES	Percentage of the urban population without sewage coverage	IPECE (2021)
	Water Supply – IAA	Percentage of households that obtain water from a well, spring, or other source	IPECE (2021)
	Waste Collection – ICL	Percentage of households without garbage collection	IPECE (2021)
	Urban characteristics of the surroundings of dwellings – ICUE	Assessment of the existence of urban trees, storm drains or sewers, accumulated garbage in public spaces, and open sewers	IBGE (2022)
	Stormwater Management – IMAP	Assessment of the existence: a) only surface drainage; b) risk areas subject to landslides; c) risk areas without drainage infrastructure; d) risk areas requiring special drainage; e) stormwater attenuation devices	IBGE (2017)
Pressure on the Natural Environment (VPN)	Carbon monoxide emissions – IEMC	Vehicle carbon monoxide emissions (kg/personnel)	Brazil (2011)
	Total Industrial Waste - IRI	Industrial waste (kg/hectare) in 2001 according to the state inventory	Ceará (2004)

	Environmental Degradation due to wildfires - IDAQ	Fire outbreaks (per thousand inhabitants)	INPE (2018)
	Preservation of native forest – IP	Percentage of the area in the municipality reserved for natural forests or woodlands designated for permanent preservation or legal reserve	IBGE (2022)

Source: Prepared by the author.

In analytical terms, the IVSA calculation is based on the equation proposed by Alves, Rodrigues and Rodrigues (2021):

$$IVSA = \frac{1}{k}\sum_{p=1}^{k} I_p (1)$$

Where:

IVSA = Urban Socio-environmental Vulnerability Index;

I_p = value of the p-th index;

p = 1,..., k (index)

Each index is formed from a set of indicators, as shown in Table 1. Although there is a diverse number of variables, it was decided to assign equal weights to the indicators in the composition of this index. The value of the p-th index was calculated as follows:

$$I_p = \frac{1}{S}\sum_{q=1}^{S} C_q (2)$$

$$C_q = \frac{1}{M}\sum_{j=1}^{m}\left[\frac{1}{N}\left(\sum_{i=1}^{n}\frac{E_{ij}}{Emax_i}\right)\right] (3)$$

Where:

Cq = represents the contribution of the q-th indicator to the p-th index of the municipalities;

E_{ij} = score of the i-th variable of the q-th indicator obtained by the j-th municipality;

$Emax_i$ = maximum score of the i-th variable of the q-th indicator;

i = 1,..., n (variables that make up the indicator "q");

j = 1,..., m (municipalities);

q = 1,...,s (number of indicators that make up the p-th index).

The proposed vulnerability index is presented on a scale of 0 to 1, with 0 representing the lowest relative vulnerability among municipalities and 1 representing the highest vulnerability. For classification purposes, the following vulnerability scales were used: low vulnerability, with index values between 0 and 0.200 (inclusive); moderate vulnerability, between 0.201 and 0.499 (inclusive); and high vulnerability, between 0.500 and 1 inclusive (Alves; Rodrigues; Rodrigues, 2021).

3 Theoretical framework

As proposed by Acselrad (2006), understanding vulnerability is contextual, commonly associated with exposure to risks, reflecting the sensitivity of individuals, localities, infrastructures, and ecosystems to different types of adversity.

From the perspective of environmental vulnerability, this phenomenon occurs when natural systems prove susceptible or incapable of responding to external interactions. This condition can result from the inherent characteristics of the natural environment, the pressure exerted by human activities, or even a fragile system with low recovery capacity, that is, with a reduced ability to return to its natural state and overcome critical situations. (Aquino; Paletta; Almeida, 2017).

Figueirêdo *et al.* (2007) defined environmental vulnerability as the fragility of a system in the face of environmental degradation, taking into account factors such as the exposure the system to environmental stresses characteristic of agro-industrial activities. Such fragilities can be measured through indicators that show: (i) the anthropogenic factors that pressure the system; (ii) sensitivity of the system to the pressure exerted; (iii) the physical and biological environmental characteristics of the affected area; and (iv) the response capacity of the impacted environment. From this perspective, the socio-environmental vulnerability of a system is determined by the nature and magnitude of the interactions to which it is exposed, by its susceptibility, and by its capacity to adapt to changes of any kind.

It is worth noting that, as discussed by Alves, Correia and Silva (2024), the constitution of cities subjects the physical environment to demands of the most diverse kinds, altering its dynamics through the creation or acceleration of numerous processes, without considering the limitations imposed on the most fragile environments. According to Garcias and Sanches (2010), continuous urban activities have produced significant changes in the environment, especially in natural processes, making cities progressively more exposed to risks and vulnerabilities in the social and environmental fields. Confalonieri (2003), in turn, points out that the concept of vulnerability has been incorporated into the treatment of urban environmental issues and, given the inseparability of the social question, has been used to characterize the social groups most affected by environmental stresses, including those associated with climate.

Although the definition is primarily focused on vulnerability resulting from natural disasters, it is important to emphasize that vulnerability and urban risks involve a set of social, economic, technological, cultural, environmental, and political factors directly associated with the poverty of a significant portion of contemporary society. In the Brazilian context, the accelerated process of urbanization and the expropriation of rural lands have produced a significant contingent of migrant workers who, lacking income or with insufficient income, have been unable to acquire or rent housing in cities. Consequently, they have come to occupy unsuitable areas, often exposed to risky situations such as landslides and floods, forming a group in a permanent state of vulnerability (Ribeiro, 2010).

Along the same lines, Ximenes (2010) highlights the multidimensional nature of vulnerability, understood as the condition of individuals or groups who, in addition to being exposed to risks, are subject to high degrees of social disintegration. This condition results from processes of exclusion, discrimination, and invisibility, associated with factors such as poverty, economic crises, fragility of social security and protection systems, insecure location, and reduced levels of human, social, or cultural capital.

Thus, vulnerability also takes on a social dimension. In urbanized areas, poverty and income concentration accentuate insecurity, causing a significant

number of individuals from the middle and lower classes to be exposed to risks and difficulties, which makes them more vulnerable (Jatobá, 2011).

In general, as Silva Júnior (2020, p. 16) confirms, social vulnerability manifests itself "mainly in its occurrence in peripheral areas and/or areas with poor infrastructural conditions, which leads to strong negative impacts on the individual and collective reconstruction capacity of communities."

Observing the environmental pressure factors associated with human occupation and the fragility of a territory in suffering damage as a result of these factors highlights its state of environmental vulnerability. Understanding this dynamic helps prioritize public investments, which are usually scarce, in different national regions (Figueirêdo *et al.*, 2007). Such prioritization should consider research on the sensitivity of the environment to changes, as well as studies involving aspects of vulnerability, considered important for sustainability and for promoting improvements in socio-environmental quality (Ribeiro *et al.*, 2016).

It is worth highlighting that the construction of socio-environmental vulnerability indices in regional development contexts constitutes a fundamental analytical tool for understanding territorial inequalities and for formulating more effective public policies. By synthesizing multiple dimensions, these indices allow us to identify not only the most critical areas, but also the interrelationships between the factors that produce and reproduce vulnerability. As Alves, Rodrigues and Rodrigues (2021) point out, measuring vulnerability through composite indices allows for an integrated understanding of the population's living conditions and the pressures on the natural environment, contributing to the prioritization of investments and actions in regions historically marked by structural deficiencies. In this sense, the index is not only a descriptive instrument, but also a subsidy for territorial planning and public management at regional scales.

In the case of immediate geographic regions, such as Brejo Santo - CE, the application of an urban socio-environmental vulnerability index (IVSA) proves particularly relevant, as it allows capturing the specificities of small municipalities that are often overlooked in aggregate analyses of regional development. The construction of the IVSA, by considering dimensions such as economy, education, health, housing, urban infrastructure, and pressure on the natural environment, offers an objective basis for identifying local priorities and for formulating public policies that consider intra- and inter-urban inequalities. Furthermore, by allowing comparison between different territorial divisions, within states, and with the state of Ceará itself, the index contributes to a broader view of regional development processes and the asymmetries that characterize them, reinforcing the need for territorialized and socially inclusive strategies.

4. Results and discussion

Table 1 analyzes the indicators of the economic vulnerability dimension, aiming to verify the economic situation of families in the region and assess the extent to which the pattern of economic growth has exposed populations to conditions of vulnerability that impact their quality of life and well-being. The employed population indicator (IPO) is based on individuals in favorable working and remuneration conditions, protected by registered contracts. It is observed that all municipalities

presented high value for this indicator, demonstrating a marked scenario of informality in the labor market. The average for the RGIBS remains close to the state and RINTER JN averages. The municipalities of Brejo Santo and Mauriti registered the highest number of formal jobs, with 3,571 and 3,629, respectively, which, added together, represent approximately 52.62% of the total formal jobs in the RGIBS. Abaiara and Jati presented the lowest number of formal jobs, totaling 8.84% of jobs in the region.

The per capita income index (IRPC) attempts to relate GDP performance to the demands of the general population, functioning as an indicator of economic development in that region. All municipalities presented high values in the indicator, indicating high vulnerability.

Table 2- Economic Vulnerability Index (IVEC) and indicators of the RGI of Brejo Santo – CE

Municipalities	IPO	IRPC	IDR1	IDR2	IVEC
Abaiara	0.973	0.968	0.116	0.404	0.615
Barro	0.971	0.961	0.266	0.513	0.678
Brejo Santo	0.878	0.890	0.299	0.208	0.569
Jati	0.939	0.887	0.034	0.479	0.585
Mauriti	0.980	0.958	0.174	0.680	0.698
Milagres	0.969	0.958	0.093	0.428	0.612
Penaforte	0.940	0.907	0.190	0.344	0.595
Porteiras	0.960	0.936	0.182	0.519	0.649
RGIBS AVERAGE	**0.951**	**0.933**	**0.169**	**0.447**	**0.625**
RINTER JN AVERAGE	**0.943**	**0.941**	**0.182**	**0.520**	**0.647**
FORTALEZA	**0.662**	**0.729**	**0.262**	**0.000**	**0.413**
CEARÁ	**0.932**	**0.918**	**0.249**	**0.506**	**0.651**

Source: Prepared by the author.

The index of households without income (DR1) showed low vulnerability in six of the eight municipalities analyzed, while Barro and Brejo Santo presented moderate vulnerability. Regarding the percentage of households with income up to ½ minimum wage (DR2), 62.5% of the municipalities analyzed registered medium vulnerability, with Mauriti, Porteiras, and Barro standing out, presenting the highest values for this indicator. In these municipalities, the percentage of families with household income up to ½ minimum wage corresponds to 67.24%, 63.33%, and 61.26%, respectively.

This dimension presented an index of 0.625 for the Immediate Geographic Region studied, being classified as having a high level of economic vulnerability, a value quite close to the state average (0.651). Similarly, all municipalities in the RGIBS registered high vulnerability.

Table 2 shows the level of vulnerability in the educational dimension, based on the assessment of school enrollment and illiteracy rates and the Basic Education Development Index (IDEB). Regarding the school enrollment rate (ITE), 62.5% of the municipalities (Abaiara, Barro, Jati, Penaforte, and Porteiras) were classified as having moderate vulnerability. Mauriti and Milagres obtained the best results, being classified as having low vulnerability. The net enrollment rate, the percentage of the population in a given age group enrolled in the appropriate level of education for

their age, ranged from 71.7% to 95.4% in primary education and from 34.9% to 61.1% in secondary education. Brejo Santo, although presenting high vulnerability in this indicator, registers a positive enrollment rate, with 85.59% at the primary level and 44.44% at the secondary level.

Table 3 - Educational Vulnerability Index (IVED) and indicators of the RGI of Brejo Santo - CE

Municipalities	IT	ITA	IDEB	IVED
Abaiara	0,346	0,705	0,725	0,592
Barro	0.296	0.553	0.613	0.487
Brejo Santo	0.864	0.513	0.600	0.659
Jati	0.173	0.630	0.813	0.539
Mauriti	0.173	0.698	0.738	0.536
Milagres	0.407	0.709	0.738	0.618
Penaforte	0.346	0.459	0.675	0.493
Porteiras	0.235	0.716	0.763	0.571
RGIBS AVERAGE	**0.355**	**0.623**	**0.708**	**0.562**
RINTER JN AVERAGE	**0.309**	**0.665**	**0.680**	**0.551**
FORTALEZA	**0.420**	**0.000**	**0.650**	**0.357**
CEARÁ	**0.279**	**0.639**	**0.606**	**0.508**

Source: Prepared by the author.

Regarding the IDEB (Basic Education Development Index), the decision was made to evaluate the average of the initial and final years of elementary school and high school. This index is composed of two elements: the school achievement index (approval rate) and the average performance on tests administered by INEP (National Institute for Educational Studies and Research), with approval rates obtained from the School Census (Barros, 2017), conducted annually. All municipalities showed high vulnerability in this indicator, although the state of Ceará has registered positive progress in education and satisfactory results in the IDEB in recent years.

The average educational vulnerability score for RGIBS was higher than the average for Ceará and RINTER JN, with Brejo Santo standing out as it presented the highest result for this dimension.

Table 3 presents the indicators for the health policy dimension. The ILI corresponds to the number of inpatient beds per thousand inhabitants, and 87.5% of the municipalities studied registered high values in this indicator, with Abaiara and Jati standing out, reaching the maximum value on the scale used. The scarcity of beds leads to delays in elective hospitalizations and long waiting lists, in addition to compromising the flow of hospital beds, affecting external patient transfer rates and hindering internal transfers.

Brejo Santo was the municipality that presented medium vulnerability. Among the available health facilities, the Specialized Hospital, the Ceará Eye Hospital, and two general hospitals stand out: the Casa de Saúde Nossa Senhora de Fátima and the Brejo Santo General Hospital, both under municipal administration. The Brejo Santo General Hospital has a Type I Intensive Care Unit (ICU) and therefore provides highly complex hospital services. With this structure, the municipality has 241 inpatient

beds. The neighboring municipality of Mauriti, classified as a Zone B Center, also has a specialized hospital, the São José Maternity Hospital, with 13 inpatient beds (Fernandes, 2020).

Table 1- Vulnerability Index in Health Policies (IVPS) and indicators of the RGI of Brejo Santo – CE

Municipalities	ILI	ITMI	IID	INCD	IVPS
Abaiara	1,000	0.609	0.201	0.661	0.618
Barro	0.773	0.420	0.127	0.408	0.432
Brejo Santo	0.367	0.314	0.619	0.131	0.357
Jati	1,000	1,000	0.070	0.566	0.659
Mauriti	0.765	0.681	0.082	0.062	0.397
Milagres	0.628	0.707	0.102	0.168	0.402
Penaforte	0.766	0.174	0.135	0.048	0.281
Porteiras	0.821	0.257	0.098	0.202	0.345
RGIBS AVERAGE	**0.765**	**0.520**	**0.179**	**0.281**	**0.436**
RINTER JN AVERAGE	**0.714**	**0.442**	**0.178**	**0.182**	**0.379**
FORTALEZA	**0.649**	**0.369**	**0.057**	**0.927**	**0.500**
CEARÁ	**0.809**	**0.430**	**0.095**	**0.171**	**0.376**

Source: Prepared by the author.

The infant mortality rate (IMR) corresponds to the number of deaths per thousand live births. Jati, Milagres, Mauriti, and Abaiara registered the worst results, indicating high vulnerability in this indicator; Barro, Brejo Santo, Porteiras, and Penaforte, in turn, showed moderate vulnerability. These results reflect the limited presence of public policies aimed at improving economic, demographic, educational, public health, and basic sanitation indicators, since poverty, lack of treated water, and malnutrition are among the main macro-socioeconomic determinants of infant mortality in Brazil (Sousa; Nations, 2011). The IID indicator refers to the number of hospitalizations for diarrhea per thousand inhabitants. It was found that 75% of the municipalities presented low vulnerability in this indicator, while Abaiara and Brejo Santo registered medium and high vulnerability, respectively.

The fourth and final indicator of this dimension concerns the number of dengue cases per thousand inhabitants reported in each municipality. Penaforte, Mauriti, Brejo Santo, and Milagres registered low vulnerability, while Barro and Porteiras presented medium vulnerability. Abaiara and Jati registered the highest values for this indicator. Social, behavioral, economic, and environmental factors influence the proliferation of the disease (Martins, 2020). Another relevant observation is the high variability of this indicator, due to the influence of local outbreaks that can significantly increase the values in certain municipalities. It is noteworthy that the average number of dengue cases in the RGIBS was higher than the state and RINTER JN averages.

The analysis of the vulnerability dimension in health policies revealed that 25% of the municipalities studied (Abaiara and Jati) presented high vulnerability, while the others (Barro, Brejo Santo, Mauriti, Milagres, Penaforte, and Porteiras) registered moderate vulnerability. The RGIBS average is significantly higher than the averages of RINTER JN and the state of Ceará, being surpassed only by that of the capital, Fortaleza.

The analysis of housing vulnerability (Table 4) proves to be particularly sensitive to the social situation of the population. In the housing conditions indicator, the lowest values are observed in the municipalities of Brejo Santo, Penaforte, Abaiara, and Porteiras, which present low vulnerability. Jati, Barro, Mauriti, and Milagres register medium vulnerability in this indicator, suggesting that housing in these municipalities is often irregular and does not offer ideal living conditions, possibly due to the instability of the materials used in construction, difficulty of maintenance, and inadequate ventilation and lighting in small rooms, in addition to precarious sanitary facilities. Furthermore, the housing vulnerability of the RGIBS is lower than that observed in the RINTER JN and Ceará.

The indicator of inadequate sanitation conditions points to medium vulnerability in almost all municipalities; however, Abaiara registers a relatively high index compared to the others, with only about 2.3% of households connected to the general sewage system. Brejo Santo and Penaforte present lower vulnerability, as they have better sanitation conditions and a relatively high percentage, compared to the local reality, of connections to the general sewage system (respectively, 54.7% and 53.52%). The other municipalities present a medium percentage of vulnerable households and fragile and inadequate sanitation infrastructure. Most of these municipalities are small towns with a low percentage of urban population, so the responsibility for sewage disposal falls on the residents, suggesting that, in these cases, the local public authorities have a limited role in providing infrastructure in rural areas.

Table 5 - Housing Vulnerability Index (HVI) and indicators of the RGI of Brejo Santo – CE

Municipalities	ICO	IDCSI	IDD	IPRD	IVH	Urb. Pop. (%)	Pop.
Abaiara	0.186	0.517	0.818	0.106	0.407	43	10,496
Barro	0.289	0.481	0.528	0.164	0.365	61	21,514
Brejo Santo	0.136	0.232	0.735	0.165	0.317	62	45,193
Jati	0.316	0.449	0.513	0.077	0.339	59	7,660
Mauriti	0.240	0.493	0.742	0.205	0.420	53	44,240
Milagres	0.222	0.477	0.656	0.125	0.370	48	28,316
Penaforte	0.141	0.240	0.515	0.209	0.276	78	8.226
Porteiras	0.195	0.420	0.673	0.053	0.335	41	15.061
RGIBS AVERAGE	**0.216**	**0.413**	**0.648**	**0.138**	**0.354**	**56**	**22,588**
RINTER JN AVERAGE	**0.281**	**0.448**	**0.636**	**0.161**	**0.381**	**55**	**978.221**
FORTALEZA	**0.000**	**0.203**	**0.449**	**0.272**	**0.231**	**100**	**2,452,185**
CEARÁ	**0.316**	**0.456**	**0.552**	**0.296**	**0.405**	**75**	**8,452,381**

Source: Prepared by the author.

The density of bedrooms reveals high vulnerability in all municipalities, with the highest result in Abaiara, where the percentage of households with more than two people per bedroom exceeds 31.4%; in the other municipalities, this value ranges between 23.6% and 29.5%. People living in very small houses with poor infrastructure can develop health problems, since the lack of good ventilation and lighting, combined with the reduced space of the homes in relation to the size of the families, favors the emergence of diseases. Some of these can even be caused by

overpopulation in poorly ventilated houses, such as tuberculosis and cholera (Cohen, 2010). Regarding the indicator of the standard of housing cladding, the observed values do not seem to be related to the status of urbanization. Of the eight municipalities in the RGIBS, 75% showed low vulnerability in this indicator, and only Mauriti and Penaforte registered medium vulnerability.

In the housing vulnerability index, it is observed that housing constitutes a highly complex asset and is essential to the well-being of families. From this context, it was found that the insufficiency of decent housing still deserves special attention in the municipalities belonging to the Brejo Santo Regional Development Area (RGI), constituting, among other aspects, a strong indicator of regional underdevelopment. Mauriti and Abaiara registered the highest IVH values, while Penaforte, Brejo Santo, and Porteiras presented the lowest values of this index. The average IVH of the RGIBS was very close to the average of the RINTER JN and lower than the average for the state of Ceará.

The fifth dimension, whose data are presented in Table 5, analyzes infrastructure deficiencies that may directly or indirectly expose populations to environmental risks. In this sense, several aspects are examined, including water supply and sewage systems, the conditions of the housing environment, and stormwater management, the latter being evaluated in terms of drainage and exposure to landslides and/or floods (Alves; Rodrigues; Rodrigues, 2021).

Table 2- Urban Infrastructure Vulnerability Index (IVIU) and indicators of the RGI of Brejo Santo - CE

Municipalities	IES	IAA	ICL	ICUE	IMAP	IVIU
Abaiara	1,000	0.407	0.672	0.379	0.800	0.652
Barro	0.798	0.333	0.463	0.370	0.800	0.553
Brejo Santo	0.170	0.221	0.263	0.301	0.400	0.271
Jati	1,000	0.300	0.460	0.246	0.400	0.481
Mauriti	0.715	0.331	0.466	0.419	0.800	0.546
Milagres	1,000	0.422	0.589	0.338	0.800	0.630
Penaforte	1,000	0.250	0.260	0.266	0.600	0.475
Porteiras	0.813	0.465	0.611	0.263	0.800	0.590
RGIBS AVERAGE	**0.812**	**0.341**	**0.473**	**0.323**	**0.675**	**0.525**
RINTER JN AVERAGE	**0.859**	**0.361**	**0.435**	**0.383**	**0.570**	**0.519**
FORTALEZA	**0.421**	**0.041**	**0.000**	**0.384**	**0.600**	**0.289**
CEARÁ	**0.820**	**0.345**	**0.429**	**0.359**	**0.471**	**0.485**

Source: Prepared by the author.

Regarding sanitation (IES), it is observed that several municipalities are highly exposed to risk due to low urban sewage coverage rates. Abaiara, Jati, Milagres, and Penaforte stand out as being most vulnerable, lacking urban sewage infrastructure. In addition , Mauriti, Barro, and Porteiras also registered high values in this indicator, with rates of 19.2%, 13.3%, and 10.2%, respectively. In this context, Brejo Santo presented the lowest vulnerability among the analyzed municipalities, with a sewage coverage rate of 86.8%. It is important to highlight that the lack of sanitation, besides causing water pollution, is directly associated with health conditions, as the absence

of sewage treatment favors the occurrence of diseases transmitted by waterborne vectors and local contamination (Landim, 2017).

Regarding the water supply service (IAA), the reality faced in the provision of sanitation services is reproduced. Brejo Santo also presents the best water supply index, with an urban coverage rate of 77.1%. Penaforte, although showing significant vulnerability regarding the IES, registers an urban water coverage rate of 74.4%. The other municipalities present marked deficiencies, especially Porteiras, Milagres and Abaiara, which register the worst rates of supply by general network: 44.8%, 40.8% and 39.5% of households, respectively, do not have access to this service.

Regarding waste collection (WC), Brejo Santo and Penaforte also have the highest coverage rates for this service. Conversely, Abaiara and Porteiras registered the highest vulnerability rates for WC, since 59.7% and 55.8% of households in these municipalities, respectively, are not served by waste collection. A likely explanation for this result is that the lower population density, long distances, and poor road conditions in rural areas make waste collection more expensive, rendering the service economically unviable in small towns with these characteristics, resulting in lower coverage rates.

The indicator "Urban Conditions of the Surroundings" (ICUE) refers to tree cover, water drainage (sewers or catch basins), accumulation of waste in public places, and open sewage. Mauriti registered the highest value for this index, mainly due to the absence of drainage (lack of sewers or catch basins) and the presence of open sewage, primarily as a consequence of the low coverage of sanitation services, since most of its households lack basic sanitation, which implies a significant volume of open sewage and significant environmental risks for the population. Jati, Penaforte, and Porteiras have the lowest values for the ICUE.

Stormwater management is particularly relevant as it highlights the role of local public authorities and the existence of infrastructure to handle stormwater drainage in order to prevent or reduce damage and disruption to the population. It is important to note that climatic conditions in the Cariri region vary between hot semi-arid tropical climate and hot sub-humid tropical climate. Although the region is located in the Northeast, whose climate is commonly associated with semi-arid conditions (IPECE, 2022), this variation implies higher rainfall. This characteristic, combined with the topography, favors the occurrence of landslides, floods, and other events during the rainy season. Therefore, all municipalities proved vulnerable due to a lack of underground drainage and buffering mechanisms to reduce the damage caused by rainfall. The populations of the municipalities of Abaiara, Barro, Mauriti, and Milagres are in a more vulnerable situation, as they still have risk areas subject to landslides and other aggravating factors that require special drainage systems.

Given the above, vulnerability in urban infrastructure is greater in the municipalities of Abaiara, Milagres, and Porteiras. It is worth mentioning that Brejo Santo presents low fragility in all indicators of this dimension and registers the lowest IVIU value, while Abaiara was the most vulnerable municipality in the region. The average vulnerability in urban infrastructure in the Immediate Geographic Region of Brejo Santo is very close to that observed in the Intermediate Geographic Region of Juazeiro do Norte.

Table 6 presents the index of pressure on the natural environment, whose purpose is to capture the effects of the different urban agglomerations of the RGIBS

on the natural environment, both in terms of resource extraction and waste deposition, and reduction or preservation of native vegetation and forests.

The carbon monoxide emission indicator (CVEI) is an indirect indicator of air pollution, directly related to the vehicle fleet and, consequently, to the population. It is important to highlight the scale normalization adopted in this study, since, in this case, a scale from zero to one widens the disparity between municipalities due to the low dispersion of the analyzed data (Alves; Rodrigues; Rodrigues, 2021). The highest emission levels are observed in Brejo Santo, Mauriti, and Penaforte, respectively, the two most populous municipalities and the one with the highest urban population rate, while the others show lower values for the indicator. Thus, it is clear that the growth of Brejo Santo, Mauriti, and Penaforte has been accompanied by an increase in the number of vehicles, which entails environmental risks associated with this population and economic growth.

Table 3- Vulnerability Index of Pressure on the Natural Environment (IVPN) and indicators of the Brejo Santo – CE Integrated Management Region.

Municipalities	IEMC	IRI	IDAQ	IP	IVPN
Abaiara	0.164	0.000	0.111	0.080	0.089
Barro	0.137	0.000	0.197	0.111	0.111
Brejo Santo	0.395	0.001	0.147	0.039	0.146
Jati	0.139	0.000	0.125	0.310	0.144
Mauriti	0.187	0.000	0.268	0.045	0.125
Milagres	0.154	0.001	0.270	0.080	0.126
Penaforte	0.370	0.000	0.042	0.027	0.110
Porteiras	0.143	0.000	0.109	0.108	0.090
RGIBS AVERAGE	**0.211**	**0.000**	**0.159**	**0.100**	**0.118**
RINTER JN AVERAGE	**0.233**	**0.004**	**0.220**	**0.092**	**0.137**
FORTALEZA	**0.658**	**0.547**	**0.056**	**0.000**	**0.315**
CEARÁ	**0.2785**	**0.0144**	**0.1462**	**0.1048**	**0.136**

Source: Prepared by the author.

The industrial waste production indicator (IRI) corroborates the concentration of large urban centers as the largest generators of waste, especially industrial waste; however, 75% of the municipalities in the study region did not register values for this indicator. Only Brejo Santo and Milagres presented values, albeit not very significant: both the footwear sector in Brejo Santo and the ceramic artifact manufacturing segment in Milagres are examples of waste-generating activities. It should be noted, however, that the scale is relative and that, when compared to municipalities in the Metropolitan Region of Fortaleza, characterized by high industrial activity and low population, the values of the analyzed municipalities are not very significant. As an example, while Maracanaú produces 6,586 kg/inhabitant of waste, Milagres produces 3.8 kg/inhabitant.

Regarding environmental degradation, the variable "fire outbreaks" was adopted as an indirect indicator. Mauriti and Milagres recorded the highest values for

this indicator, while Penaforte recorded the lowest. In this case, vulnerability stems from the risk of health problems caused by soot and environmental damage to the soil and biodiversity.

Related to the presence of protected areas, the greatest vulnerabilities are in Jati, Barro, and Porteiras, while the lowest values are observed in Penaforte, Brejo Santo, and Mauriti.

In general, the municipalities that exert the most pressure on the natural environment and, consequently, are the most vulnerable are Penaforte, Jati, Brejo Santo, and Milagres. Brejo Santo and Penaforte stand out due to the high pollution associated with economic growth and the advance of urbanization, while the vulnerability of Jati and Milagres is related to environmental degradation, due to the high number of fires and the absence of preserved areas.

Table 7 presents the Urban Socio-environmental Vulnerability Index (IVSA), as well as the partial indices related to each dimension.

Table 8 - Urban Socio-environmental Vulnerability Index (IVSA) of the Brejo Santo – CE Integrated Region

Municipalities	IVEC	IVED	IVPS	IVH	IVIU	IVPN	IVSA	Ranking
Abaiara	0.615	0.592	0.618	0.407	0.652	0.089	0.495	8
Barro	0.678	0.487	0.432	0.365	0.553	0.111	0.438	4
Brejo Santo	0.569	0.659	0.357	0.317	0.271	0.146	0.386	2
Jati	0.585	0.539	0.659	0.339	0.481	0.144	0.458	6
Mauriti	0.698	0.536	0.397	0.420	0.546	0.125	0.454	5
Milagres	0.612	0.618	0.402	0.370	0.630	0.126	0.460	7
Penaforte	0.595	0.493	0.281	0.276	0.475	0.110	0.372	1
Porteiras	0.649	0.571	0.345	0.335	0.590	0.090	0.430	3
RGIBS AVERAGE	**0.625**	**0.562**	**0.436**	**0.354**	**0.525**	**0.118**	**0.437**	-
RINTER JN AVERAGE	**0.647**	**0.551**	**0.379**	**0.381**	**0.519**	**0.137**	**0.436**	-
FORTALEZA	**0.413**	**0.357**	**0.500**	**0.231**	**0.289**	**0.315**	**0.351**	-
CEARÁ	**0.651**	**0.508**	**0.376**	**0.405**	**0.485**	**0.136**	**0.427**	-

Source: Prepared by the author.

As a result, the dimensions that show patterns of high vulnerability are the economic (IVEC of 0.625), educational (IVED of 0.562), and urban infrastructure (IVIU of 0.525). Intermediate levels of vulnerability were observed in health policies (IVPS of 0.436, close to the upper limit of the moderate vulnerability range) and housing (IVH of 0.354), while the dimension of pressure on the natural environment shows the best results, with low vulnerability and IVPN of 0.118.

These results indicate medium socio-environmental vulnerability (IVSA of 0.437) in the Immediate Geographic Region of Brejo Santo - CE, with a vulnerability pattern close to that of the Immediate Region of Juazeiro do Norte (0.436) and higher than that of Fortaleza (0.351) and the average for Ceará (0.427).

Thus, the economic, educational, and urban infrastructure dimensions stand out negatively, registering the highest rates and constituting the main axes of regional fragility. Conversely, the dimension of pressure on the natural environment showed the best relative performance, indicating that, although there are specific pressures on natural resources these do not yet constitute the main vector of vulnerability in the region. Comparison with the reference territorial areas - the Immediate Region of Juazeiro do Norte, Fortaleza, and Ceará - reveals that the RGIBS occupies an intermediate position, although with a vulnerability pattern higher than that of the capital and very close to the state average. This reinforces the need for territorialized public policies that consider the specificities of small municipalities and the interrelationships between the analyzed dimensions, as well as the urgency of actions that prioritize the most critical axes identified, especially those related to the economy, education, and urban infrastructure.

It is important to highlight that Brejo Santo's position as a hub of the RGI (Regional Integration Region) does not exempt it from vulnerabilities; on the contrary, its role as a regional center imposes specific demands that are reflected in the analyzed indicators. The municipality concentrates medium and high complexity health services, educational facilities, and economic activities that attract populations from neighboring municipalities, which generates pressure on urban infrastructure, the health system, and the education network. This phenomenon can be understood as an overload vulnerability: even though Brejo Santo shows the best indices in some dimensions, such as urban infrastructure (IVIU of 0.271) and health (IVPS of 0.357) its function as a hub means that these structures are continuously demanded by a population that exceeds the limits of the municipality itself. A clear example is the educational dimension, in which Brejo Santo registers the highest vulnerability index in the region (IVED of 0.659), despite being the main urban center. This suggests that the supply of services is not keeping pace with the growth in regional demand, which reinforces the need for public policies that consider not only local needs, but also the regional functions performed by the hub municipalities.

5. Final considerations

This study identified the levels of urban socio-environmental vulnerability in the Immediate Geographic Region of Brejo Santo - CE, which, as a whole, presented a pattern of medium vulnerability (IVSA of 0.437). This result, although indicating an intermediate situation in the context of Ceará, reveals relevant internal inequalities among the municipalities of the region, which deserve to be considered in territorial planning and in the formulation of public policies.

Among the municipalities analyzed, Barro, Brejo Santo, Penaforte, and Porteiras presented lower VISA (Index of Social Vulnerability) than the average for the RGIBS (Regional Group of the Southern Bahia). Brejo Santo, as a regional hub, registers the lowest vulnerability in the economic and urban infrastructure dimensions, which may be associated with a higher income level, a greater number of formal jobs, and the concentration of economic activities and public investments in infrastructure. Porteiras, in turn, presents the lowest IVPN (Index of Natural Potential), reflecting less pressure on the natural environment due to its lower population density and lower pollutant emissions.

Regarding weaknesses, Abaiara and Milagres show greater vulnerability in urban infrastructure, associated with deficiencies in rainwater drainage, basic sanitation, and garbage collection. In the dimension of health policies, Abaiara and Jati stand out negatively, reflecting structural and investment limitations in the sector. Milagres, on the other hand, is the most vulnerable municipality in the region, with weaknesses in all dimensions analyzed, highlighting the need for priority and coordinated actions across different areas of public policy.

An integrated reading of the six dimensions analyzed reveals that urban socio-environmental vulnerability in the RGIBS (Regional Integrated Basin of the Southern Region of Ceará) does not stem from isolated deficiencies, but from a combination of mutually reinforcing weaknesses. In this context, urban infrastructure plays a structuring role, as inadequate sanitation, drainage, and waste collection conditions not only constitute a specific dimension of vulnerability but also condition the outcomes of other dimensions, especially health and housing. This chain of events suggests that isolated sectoral interventions tend to have limited effects, reinforcing the need for intersectoral approaches that consider the interdependence between the dimensions analyzed. Furthermore, the intermediate position of the RGIBS in the Ceará context, close to the state average and higher than that of the capital, indicates that socio-environmental vulnerability is not a phenomenon exclusive to large urban centers but also manifests itself in small regions, albeit with distinct configurations.

From a regional development perspective, the results of this study contribute to the discussion on territorial inequalities in immediate geographic regions, especially those composed of small municipalities, often overlooked in aggregate analyses. By highlighting that urban socio-environmental vulnerability manifests itself differently even in small regions, the study reinforces the importance of analytical tools capable of capturing these specificities and guiding the formulation of territorialized public policies. In this sense, the construction and application of the IVSA (Index of Social Vulnerability and Social Vulnerability) can serve as a basis for regional planning, allowing the identification of local priorities and the comparison between different territorial divisions, contributing to more balanced and socially inclusive development strategies.

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Submetido em: 15/08/2024 **Aprovado em: 13/10/2026**

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