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Papers

Household Water Insecurity and Social Vulnerability in the Municipal Context of the Semi-Arid Region of Ceará

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Keywords
Human development
Water security
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Abstract
Household water insecurity refers to difficulties accessing water of sufficient quality and quantity to maintain human well-being. Although this fundamental right is a premise for survival, it is not always guaranteed. This article aims to verify whether there is a correlation between household water insecurity and social vulnerability in the semi-arid region of Ceará. For this purpose, the "Household Water Insecurity Experiences – HWISE" protocol was applied to households to investigate the various problems related to water and household water supply problems. Statistical exploratory data analysis techniques were used through factor analysis, clusters, and spatial correlation to verify the spatial relationship between water insecurity and social vulnerability. The main results show that although there is a situation of household water insecurity, its connection with social vulnerability is more pronounced in urban areas. In rural areas, where vulnerability is higher, the presence of multiple water supply sources such as cisterns and water tankers conveys a higher sense of water security to the population, both in terms of access and availability of water for household consumption. Based on the achieved results, it is evident that household water insecurity requires the consideration of a wide range of factors, and its assessment cannot be accomplished solely through the use of a synthetic indicator of social vulnerability.

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INTRODUCTION

Access to water is a universal right and essential to life, yet an estimated 663 million people worldwide face some form of water scarcity (UNICEF; WHO, 2015). Several elements lead to difficult access, which is commonly associated with climatic conditions, the level of technological development, and social inequalities.

In Brazil, difficulties in access to quality water are related to social and environmental conditions and existing water infrastructures. Despite having one of the world's largest river basins in the country's northern region, there is a deficit in the water supply system in various locations, in addition to water quality problems. In the Southeast, in addition to the urban population's demand for access to water, in some cases, there are significant quality problems (RIBEIRO, 2017). In turn, the Brazilian northeast is historically known for annual water scarcity and constant droughts that generate negative social and economic impacts and influence water insecurity (GUTIÉRREZ et al., 2014; MARENGO; et al., 2017; JEPSON et al., 2021).

In the State of Ceará the 2012-2016 drought was considered the worst in the last 100 years (CEARÁ, 2016), triggering widespread water insecurity throughout the state. Although the entire territory was affected, the most severe circumstances occurred in the small urban centers in the semi-arid region, where water insecurity was associated with other existing social problems.

The resulting problems reflect the plans and actions developed since the nineteenth century to mitigate the impacts of droughts and guarantee water security for the Northeast of Brazil through different governmental spheres. The primary mark of these interventions was the construction of reservoirs and, more recently, the incorporation of channels and pipelines. This perspective was ratified by the National Water Security Plan – Plano Nacional de Segurança Hídrica (BRAZIL, 2019), which essentially addresses the execution of infrastructure works and neglects those aspects inherent to human development, especially among the most vulnerable groups.

Amid the targeting of approaches focused on infrastructure and climate conditions, initiatives have emerged to understand water security based on the human development perspective (JEPSON, 2014; DAPAAH; HARRIS, 2017; JEPSON et al., 2017; MEHTA, 2014), going beyond attempts concentrating on the availability and supply of infrastructure. Fundamentally, these seek to address cultural and social issues taking as reference the context of families in their homes.

This new analytical perspective broadens the understanding of the theme by bringing hydrosocial issues to the fore, revealing the different contexts of water insecurity. As highlighted by Subbaraman et al. (2015), these approaches enable a conception of water insecurity as deficiencies in water quality, quantity, access, reliability, accessibility, and equity in the provision of services.

Recent research by authors such as Jepson and Brown (2014), Jepson (2014), Mehta (2014), and Schur (2017) show that water insecurity is not exclusive to developing countries. However, the problems are more intense in the Global South, where populations face acute water scarcity (WORKMAN; UREKSOY, 2017; MEHTA, 2014), as has been verified in Bolivia (WUTICH, 2009; HADLEY; WUTICH, 2009) and in Brazil (COÊLHO et al., 2004; JEPSON et al., 2021), where conditions of social vulnerability tend to be more pronounced, magnifying water insecurity.

Given the above, this article aims to verify whether a relationship exists between household water insecurity and social vulnerability to verify the possibility of establishing a spatial distribution pattern between these two indicators. The municipality of Forquilha, state of Ceará, Brazil, is used as a case study to validate the results.

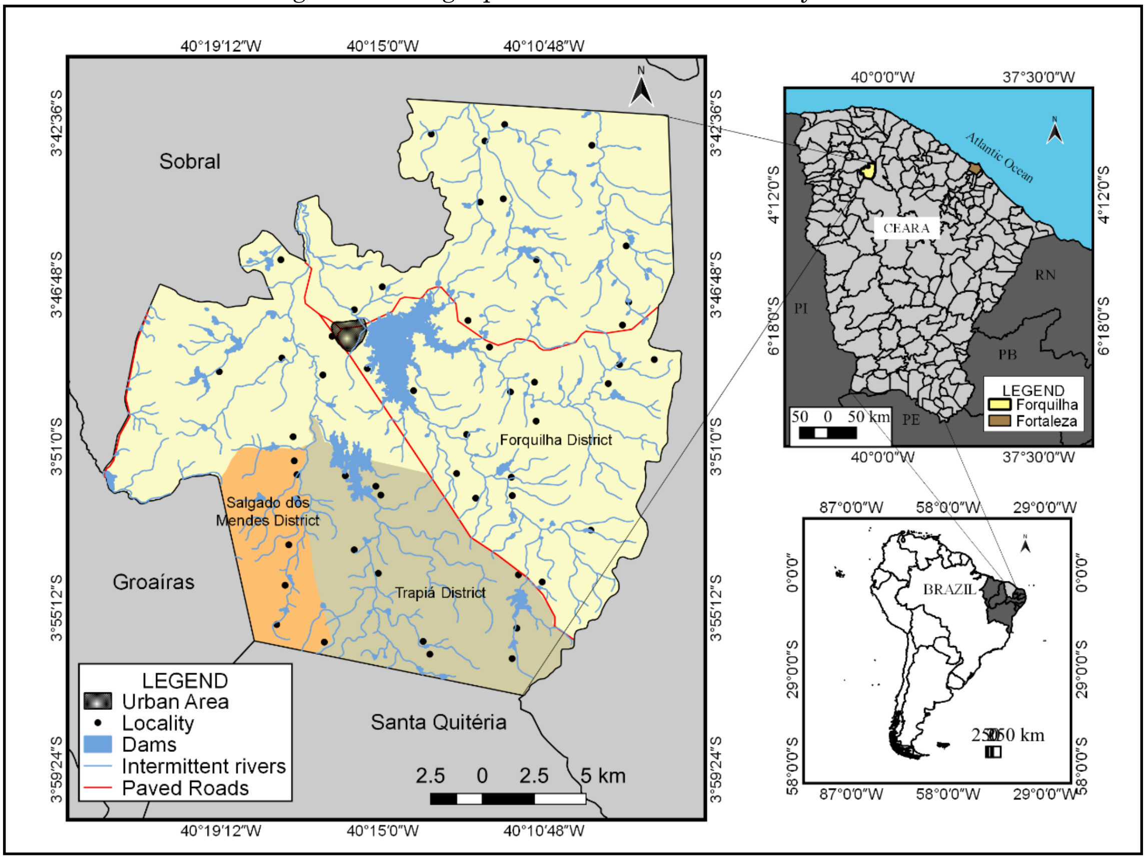
METHODOLOGY

Study area

The study area covers the municipality of Forquilha, located in the State of Ceará, northeastern Brazil (Figure 1). The municipality has a territorial extension of 516.99 km² and a population of 21,786 inhabitants, of which 71.02% reside in the urban area (CEARÁ, 2017).

It is shaped by semi-arid geoenvironmental conditions, characterized by high temperatures and evapotranspiration rates, along with relatively low rainfall rates, concentrated both in time and space (CEARÁ, 2017). The region is inserted in the Sertaneja Depression, with shallow, stony soils with a low water storage capacity in the subsoil, due to its crystalline composition (CEARÁ, 2016; CEARÁ, 2017; TOMAZ, 2020).

Figure 1 - Geographical location of the study area



Source: The authors (2023).

According to IBGE data (2010), the municipality of Forquilha's water supply has a coverage rate of 98.86% in the urban area and 74.16% in the rural area. However, households without access to this supply system often obtain water from wells and small reservoirs.

The 2012 to 2016 drought had severe consequences for the municipality. From 2015, during the peak of the water crisis in Ceará, several alternative supply solutions were implemented to serve the population since the public supply system could not supply water continuously and with adequate quality for consumption. At the same time, residents tried to find complementary water sources, like buying bottled water from private companies.

Classification of Household Water Insecurity

The assessment of water insecurity is based on constructing the Household Water Insecurity Index - HWISI (TOMAZ et al., 2020). A research instrument (protocol) developed by the group of researchers from the collaboration network *Household Water Insecurity Experiences - HWISE* (https://hwise-rcn.org/) published in Young et al. (2019). This protocol was created to facilitate the collaborative and multinational collection and analysis of data related to water problems (YOUNG *et al.*, 2019).

The HWISE protocol variables were organized into dimensions that enable the assessment of water insecurity (availability, quality, accessibility, stress) and cover sociodemographic and economic issues. The protocol has about 110 items (variables) with subjective and objective questions.

The sample calculation for finite populations was applied to define the sample size, with a confidence level of 90% and a sampling error of 0.5, resulting in a sample of 258 (n). In total, 321 (n) protocols were applied to obtain a greater confidence margin.

Social Vulnerability Indicator

The social vulnerability index (SVI) is a valuable tool that identifies territories that sometimes harbor large population segments with unfavorable socioeconomic conditions because it encompasses aggregating variables that approximate certain social groups' living conditions. Precisely for this reason, the construction of an SVI requires carefully choosing the variables that will be used, including data availability.

A synthetic vulnerability index established social vulnerability – SVI constructed through factor analysis and grouping statistical techniques to cover and relate indicators of infrastructure and basic sanitation, education, social situation, and income. The SVI Calculation followed the precepts established by Kaztman (2001), Medeiros et al. (2014), and Tomaz (2019).

The variables used to form the social vulnerability database refer to census data. Table 1 presents a synthesis of authors who studied social vulnerability and indicated variables and dimensions to group the variables. The indicators used to compose the SVI - Forquilha study were mainly based on Chart 1.

Chart 1 - Example of Indicators used to form the index.

AUTHOR	INDICATORS or DIMENSION
KAZTMAN (1999; 2001)	Physical (housing, basic infrastructure services, durable goods, and income-related variables) Human (involving occupational structure and employment) Social (comprise the interpersonal and reciprocal relationships that can be in the family, community, religion, etc.)
IPEA (2015)	Urban infrastructure Human Capital Income and work
MEDEIROS (2014)	Housing and Sanitation Income Education Social Status

Source: KAZTMAN (1999; 2001); IPEA (2015); MEDEIROS (2014).

Establishing the Correlation Between Water Insecurity and Social Vulnerability

Factor analysis (FA) was used to cover as many variables as possible but grouped for better data analysis and applied to a comprehensive database related to water insecurity. However, when the results were evaluated, only twenty-two items were retained by the model, representing the correlatable dimensions of water insecurity. The variables segmented in this study followed the methodology presented by Tomaz et al. (2020). Using the results of the Factor Analysis (AF), both vulnerability data and water insecurity data were classified into clusters to understand the levels of the analyzed phenomena. For the formation of clusters, the non-hierarchical K-Means method was applied, which employs measures of Euclidean distance (geometric distance between two points in space), involving the definition of cluster centers from which observations are allocated based on their proximity to these centers (FÁVERO, 2017).

The results enabled four classes of water insecurity to be established: very low, low, medium, and high, which aligns with the categories commonly used for vulnerability assessments, as presented in Souza and Zanella (2010), Santos (2015), and Dantas et al. (2016).

As a result of the factor analysis proportion rule, eight variables were used for the vulnerability database. The number of variables and observations must be at least 1:5 (HAIR JR et al., 2009); in the case of this analysis, the observations refer to Forquilha's 38 census tracts.

The tests to verify whether the data supported a factor analysis were satisfactory. Bartlett's test was significant (p-value = 0.000) for both databases. In the *Kaiser-Meyer-Olkin* test (KMO), 0.668 was obtained for vulnerability and 0.707 for water insecurity, values above the critical point (HAIR JR et al., 2009). In the anti-imaging matrix, the measure of sample adequacy (MSA) exceeded the value of 0.50, which signals the appropriateness of applying the factor analysis. The Commonality value of the data was > 0.50.

The "Principal Component Analysis" (PCA) extracted the factors, considering only those with eigenvalues greater than 1. The eight factors obtained for water insecurity explained 71% of the variance. The PA model for vulnerability considered three factors and explained 85.68% of the total variance. Chart 02 presents the factors regarding social vulnerability extracted for the databases.

Chart 2 - Extracted factors and the dimensions that make up the SVI-Forquilha

FACTORS	DESCRIPTION OF DIMENSIONS
Factor 01 - Low educational level and income	Percentage of the population aged 15 years or older who are not literate Percentage of non-literate heads of households Proportion of households with per capita family income less than half a minimum wage
Factor 02 - Social conditions and lack of basic sanitation	Percentage of residents in households that are not connected to the general sewage system or with a septic tank Percentage of residents in households without garbage collected by cleaning service Percentage of female responsible persons with an income below one monthly minimum wage
Factor 03 - Insufficient water supply and household infrastructures	Percentage of residents in households that are not connected to the general water supply network Percentage of residents in households without bathrooms or toilets for the exclusive use of residents

Source: The authors (2023).

The Household Water Insecurity Index and Forquilha's Social Vulnerability Index were created by aggregating indicators (factors) in the mathematical model described in Kubrusly (2001).

The formula used for calculating the index consists of $IA_j = \sum_{i=1}^{n} w_i f_{ij}$, where IAj = Aggregated Index of the j-th observation; wi = weight assigned to the i-th factor (wi = percentage of variance explained by component i / percentage of variance explained by all factors); fij = factor score of the i-th component for the j-th observation; i = 1; p (principal components) and j = 1; n (observations).

The index was standardized (Min-Max), with the best performance acquiring a value of 0 and the worst a value of 1. Subsequently, the values were grouped using the Euclidean distance and the non-hierarchical K-mean agglomeration method to identify aggregates with similar behavior patterns.

Exploratory Analysis of Spatial Data (AEDE) techniques were used to establish spatial correlations between the water insecurity index and vulnerability. The AEDE verified the hypothesis of spatial randomness; that is, a variable in a given region does not depend on the values of this variable in neighboring regions (ALMEIDA, 2012).

Contiguity matrices of the "Queen" and "Rook" types were tested to insert the spatial effect (ALMEIDA, 2012). Subsequently, the Global Moran *I* coefficient was applied, which uses the measure of autocovariance in the form of a cross-product and tests the null hypothesis of spatial randomness (ALMEIDA, 2012). Once the spatial correlation had been confirmed, the next step verified the formation of spatial patterns of the analyzed indices and whether social vulnerability influenced water insecurity. To this end, the *I* Moran Local Bivariate index was used, with the local spatial non-association as a null hypothesis (H0) (ANSELIN, 1995).

RESULTS

Household Water Insecurity in the Municipality of Forquilha

The Household Water Insecurity Index for the municipality of Forquilha expresses the water security assessment. The resulting grouping of four clusters is classified as Very Low Water Insecurity; Low Water Insecurity; Medium Water Insecurity; and High Water Insecurity. Table 1 shows the groups formed with the threshold values of the index.

Table 1 - Classes of the Household Water Insecurity Index - HWISI

Water Insecurity Classes	IIHD	Households (%)	
		Urban	Rural
Very Low Water Insecurity	0.00 ≤ 0.19	38.01	61.38
Low Water Insecurity	0.20 ≤ 0.39	37.10	26.73
Medium Water Insecurity	0.40 ≤ 0.63	18.10	7.92
High Water Insecurity	0.64 ≤ 1	6.79	3,96
Total		100	100

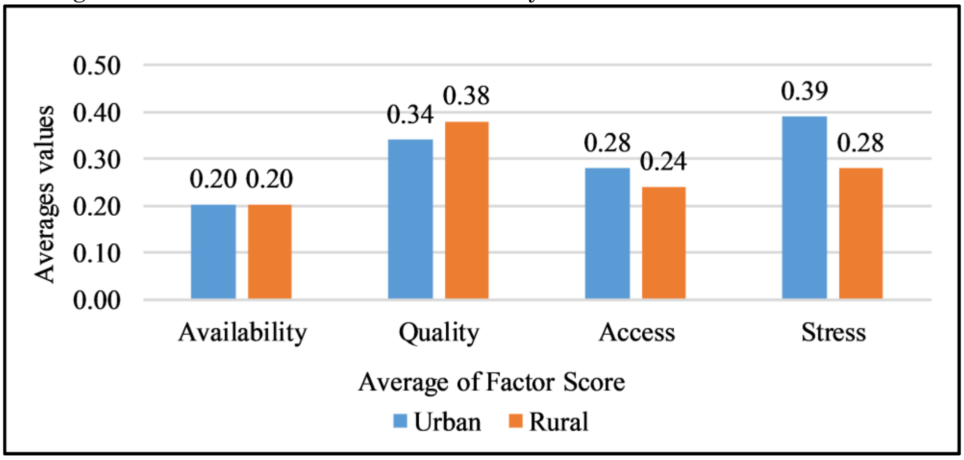
Note: ANOVA (p-value = 0.000); for the significance level adopted (p<0.05), the null hypothesis is rejected. The mean values of the variables differ in at least one of the clusters. Source: The authors (2023).

A significant part of Forquilha's population has problems with household water supply. For Medium and High Water Insecurity, the proportion of households is higher in the urban area (24.89%) compared to the rural area (11.88%). Families in this situation have availability and access problems, including economic difficulties in obtaining water of acceptable quality.

The *Student's T-test* for mean comparison evidenced a statistically significant difference in areas (urban and rural) (*p-value* = 0.001), showing that the urban area has more significant problems in the acquisition of water (mean = 0.27) for domestic consumption compared to the rural area (mean = 0.20).

The main differences were found in the variables that address stress due to problems with water, the most cited being feelings such as fear, discomfort, and worry. Figure 2 shows the average of the values obtained by analyzing the factor scores distributed according to the dimensions of water insecurity, showing the difference between rural and urban areas in the municipality of Forquilha.

Figure 2 - Difference in water insecurity in the evaluated dimensions



Note: Availability: Test T for independent samples (p-value= 0.611); Quality: Test T for independent samples (p-value= 0.014); Access: Mann-Whitney Test (p-value= 0.090); Stress: Mann-Whitney Test (p-value=0.000). Source: The authors (2023).

The dimension of "quality" also obtained evidence of a mean difference between areas (p-value = 0.014). Residents described the water's unpleasant characteristics, such as a yellowish, dark color and an unpleasant smell, which was more frequent in the rural area.

Problems with availability and access to water are similar in both areas. With the constant interruptions in the water supply, families need to acquire alternative sources, often unreliable and difficult to access. Some situations were more critical in the urban area, such as the time needed to obtain water. The results indicate that the residents spent an average of 30 minutes acquiring water. This time was due to the queues at public water fountains and water tankers. In other situations, residents expressed concern about their own safety or that of the person responsible for fetching water due to robberies and fights in these queues. Women avoid fetching water at night because they feel more vulnerable.

Social Vulnerability In Forquilha

The results reveal that social vulnerability in Forquilha is a striking characteristic in the municipal reality since just under 27% of the population can be considered in a situation of low vulnerability.

Unlike water insecurity, social vulnerability in Forquilha was more intense in rural areas. Table 2 presents the data related to the Social Vulnerability Indicator – SVI.

Table 2 – Classes of the Social Vulnerability Index in the municipality of Forquilha

Vulnerability Classes	IVS	Census Tracts (%)
Low	0.00 ≤ IVS ≤ 0.17	23.68
Medium	0.18 ≤ IVS ≤ 0.41	36.84
High	0.42 ≤ IVS ≤ 0.79	36.84
Very High	0.80 ≤ IVS ≤ 1	2,64

Note: ANOVA result (p-value = 0.000); for the significance level adopted (p<0.05), the null hypothesis is rejected. It is defined that the average values of the variables differ in at least one of the clusters in relation to the others. Source: The authors (2023).

The medium vulnerability reached the highest number of residents (8,271), followed by high vulnerability (7,373). Most of the population lives in precarious conditions; 76.32% of residents are between medium to very high vulnerability.

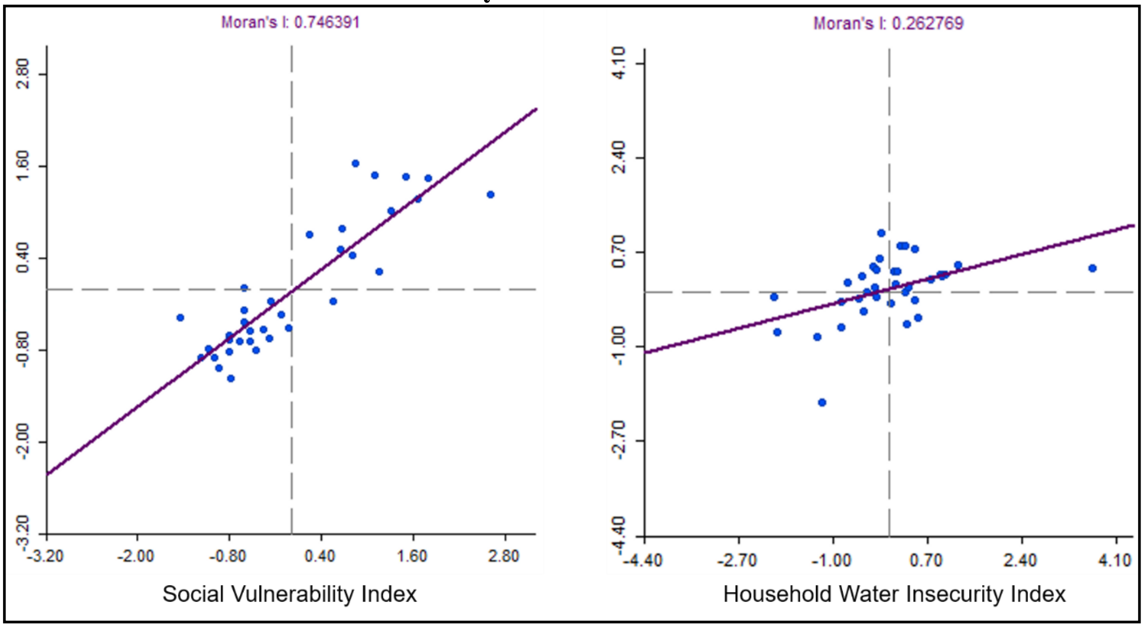
The rural area's infrastructure, basic sanitation, education, and income indicators had the worst results. The vulnerability for this area ranged from high to very high; most of the rural area has high vulnerability reaching 6,374 residents.

The high vulnerability in rural sectors confirms the low opportunity structures for this population. Most residents of rural Forquilha live from subsistence agriculture. This activity depends on geoenvironmental aspects that limit food production, so rural producers are caught in intractable cycles of low productivity, seasonal unemployment, and low wages and are thus particularly vulnerable (UN, 2014).

Spatial Interactions Between Water Insecurity and Social Viability

Applying the Global Moran *I* to verify the spatial correlations of social vulnerability and water insecurity resulted in positive values with a significance of 5%, showing indications of spatial autocorrelation of each index separately (Figure 3).

Figure 3 - Dispersion diagram of Global *Moran measure I* (univariate) for HWISI and SVI, according to Queen conventions



Source: The authors (2023)

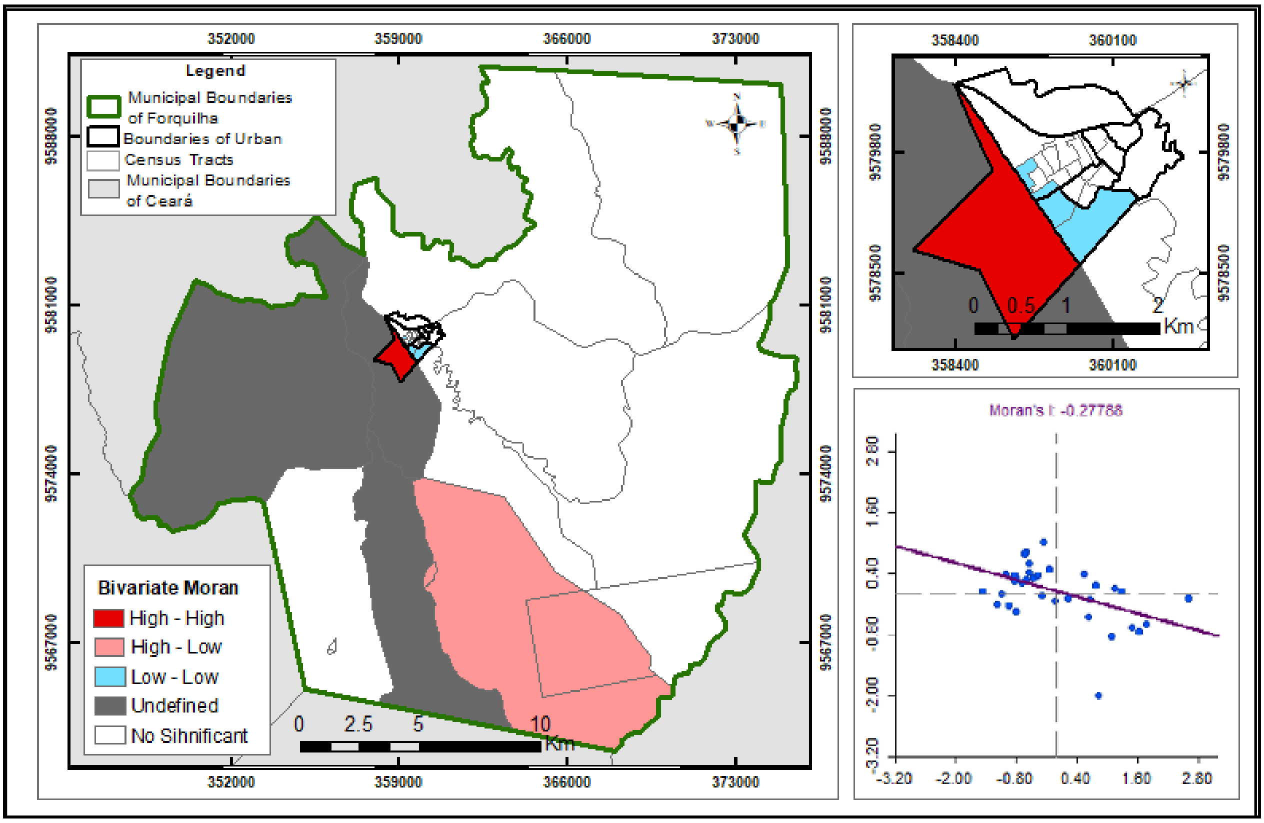
The two indices have spatial correlations of the High-High and Low-Low type, implying that sectors with high values are neighbors of sectors with the same characteristics. Likewise, it indicates that sectors with low values have neighbors that, on average, also have low indexes.

Once spatial correlation was proven, the *I* Moran Local Bivariate was used to identify spatial correlation patterns between social vulnerability and water insecurity, aiming to explain the relationships between the phenomena and their spatial understanding. The result identified statistically significant values (at the 5% level). Figure 4 presents the results of the spatial correlation between the phenomena that were classified as statistically significant.

The water insecurity index positively associates the High-High type with the social vulnerability index in the urban area. Evidence shows that peripheral neighborhoods have water supply problems due to the municipality's insufficient supply system.

The Low-High grouping demonstrated a negative correlation between the phenomena. In these cases, water insecurity cannot be explained by vulnerability. The negative correlation indicates that the level of social vulnerability does not cause high water insecurity rates in these sectors. In this case, the problems may be related to undersizing or the need to expand the public water supply network.

Figure 4 - Significance and Cluster Map - *I* Bivariate Local Moran for the Household Water Insecurity Index and the Social Vulnerability Index, emphasizing the urban area in the upper right corner.



Source: The authors (2023)

In the last significant quadrant of the High-Low type, formed by sectors of the rural area, there was a negative correlation where regions with high social vulnerability neighbor regions that, on average, have low water insecurity. These locations have a higher proportion of households at the most extreme level of low water insecurity. In these places, adversities do not seem to influence the residents' perception of their water insecurity. So, the results indicate that the vulnerability indexes, widely used to explain various social problems and exclusion from basic services, cannot cover all the established dimensions and social situations. In this scenario, water insecurity seems to have been influenced by aspects that could not be scaled in constructing the vulnerability indicator.

In the meantime, there is an urgent need to conjecture about the factors that explain or influence greater water security in rural areas at the expense of urban areas. It is essential to list some observations that go beyond quantitative methods and permeate the subjectivity of a vulnerable group, as may be the case with the rural population of Forquilha.

The rural population proved to be more adapted and able to maintain access to water in times of crisis, mainly due to the coexistence of policies to deal with water scarcity. The construction of plate cisterns and the implementation of rural supply systems are notable in this context. The combination of these actions may have contributed to expanding the communities' perception of the degree of water security compared to the scenario before these structures were installed. Explaining household water (in)security in these situations is more complex than merely describing the installed infrastructures or collecting quantitative data.

Even with low household water insecurity, the rural area of Forquilha has the highest number of vulnerable people, concentrating low income, education, and environmental sanitation indicators.

FINAL CONSIDERATIONS

Water insecurity in Forquilha was analyzed to identify how unsafe the households are. The results show that most residents have low incomes and difficulties accessing basic sanitation and education services. On the other hand, the water supply infrastructure is flawed regarding the availability and quality of water.

The results herein reinforce the concept that more socially vulnerable populations have more significant difficulties in dealing with adversities, as in the case of the droughts that affect the semi-arid region of Ceará, causing the most vulnerable to have greater water insecurity (SCHUR, 2017; HADELY; WUTICH 2009).

The exploratory spatial data analysis identified correlation patterns between water insecurity and social vulnerability in some sectors. The water insecurity index positively correlates with the SVI in the urban area, precisely in neighborhoods with high social vulnerability.

Despite the relationship established for underprivileged neighborhoods in the urban area, statistically, the data set (sample) and the results obtained do not state a direct relationship between water insecurity and social vulnerability since this relationship was inverted in rural area sectors. In situations where precariousness is the rule, such as rural communities, a water tanker supply or the need for short walks to obtain water (e.g., plate cisterns) may not be perceived as a difficulty. In this context, historically constructed perspectives on access to water are reinforced. Going out to fetch water is often not a hindrance as long as the displacement is not too far.

In such situations, social groups' perception of their vulnerability is masked, reinforcing their condition of vulnerability. This fact demonstrates the study's main limitation, the ability to capture the interviewees' perception of their water insecurity. This aspect should be mitigated with research development in new areas and incorporating analytical variables that can statistically associate these two dimensions. These gaps are being addressed within the scope of the investigations developed by the HWISE Brasil network (*Household Water Insecurity*).

Household water insecurity is a challenge to be faced in the semi-arid northeast, especially in periods of drought, as was made explicit in one of the most extensive droughts that affected the Brazilian northeast from 2012 to 2016. Several problems related to water supply were identified in the municipality of Forquilha. The situation has negative results for families, reflected in strenuous efforts to obtain water, impacting hydrosocial relations and affecting the full development of human capacities.

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AUTHORS CONTRIBUTION

Paula Tomaz collected primary data, performed statistical analysis and textual production. Jader Santos guided the work and helped with the analysis and textual construction. Wendy Jepson conceived the collection instrument, helped with the analysis and carried out the construction of the text.