e-ISSN:2316-9834

GeAS

Revista de Gestão Ambiental e Sustentabilidade
Journal of Environmental Management & Sustainability

Received: 25 Mar. 2024 - **Approved:** 25 Mar. 2024
Responsible Editor: Andreza Portella Ribeiro
Evaluation Process: Double Blind Review
https://doi.org/10.5585/2024.25071

Proposition of an human vulnerability index to the insufficiency of basic sanitation: the context of the small paraibanos municipalities

Yuciara Barbosa Costa Ferreira[1] **Andrea Carla Lima Rodrigues**[2] **Francine Modesto dos Santos**[3] **Yáscara Maia Araújo de Brito**[4] **Dayse Luna Barbosa**[5] **and Sahara Guimarães da Cruz**[6]

[1] Master's degree in Civil and Environmental Engineering. Federal University of Campina Grande – UFCG. Campina Grande, Paraíba – Brazil. yuciara.barbosa@gmail.com

[2] PhD in Civil and Environmental Engineering. Federal University of Campina Grande – UFCG. Campina Grande, Paraíba – Brazil. andrea.carla@professor.ufcg.edu.br

[3] PhD in Demography. Campinas State University – Unicamp. Campinas, São Paulo – Brazil. franmodesto@gmail.com

[4] PhD in Natural Resources Engineering and Management. Federal University of Campina Grande – UFCG. Campina Grande, Paraíba – Brazil. yascaramaiaa@gmail.com

[5] PhD in Natural Resources. Federal University of Campina Grande – UFCG. Campina Grande, Paraíba – Brazil. dayse.luna@yahoo.com.br

[6] Civil Engineering. Federal University of Campina Grande – UFCG. Campina Grande, Paraíba – Brazil. sahara.guimaraes@estudante.ufcg.edu.br

Authors' notes'

The authors have no conflicts of interest to declare.

Correspondence regarding this article should be addressed to Sahara Guimarães da Cruz.

Cite como - American Psychological Association (APA)

Ferreira, Y. B. C., Rodrigues, A. C. L., Santos, F. M., Brito, Y. M. A., Barbosa, D. L., & Cruz, S. G. (2024). Proposition of an human vulnerability index to the insufficiency of basic sanitation: the context of the small paraibanos municipalities. *J. Environ. Manag. & Sust., 13*(1), 1-30, e25071. https://doi.org/10.5585/2024.25071

Abstract

Objective: Develop an index that synthesizes socioeconomic, institutional and human health aspects regarding the lack of basic sanitation in small municipalities, based on the three dimensions of vulnerability – risk, susceptibility and adaptive capacity.

Methodology: The method for constructing and validating the index consisted of three stages: the development of the theoretical framework using data from IBGE (2010), MUNIC (2017), the Atlas Esgoto (2017), and SUS from the period 2010-2014; weighting and standardizing the indicators through multivariate statistical techniques; and validation, through the application and analysis within the context of the municipalities of Paraíba.

Originality/Relevance: The literature lacks indices that integrate the social dimension with housing characteristics, access to basic sanitation and epidemiological indicators in small municipalities. This study is relevant because it understands factors that increase the vulnerability of populations and territories, allowing it to identify the most critical areas and direct actions to improve the quality of life of affected populations.

Results: The results revealed the geographic influence of large urban centers on the surrounding small municipalities. It was found that vulnerability is a strong indicator of inequity and social inequality present in municipalities. In the state's panorama, it was found that the Agreste Paraibano mesoregion presents scenarios of high vulnerability, due to its economic, health and sociodemographic characteristics.

Social/management contributions: It is expected to contribute to the identification of factors that require immediate welfare actions and public policies, in benefit of better quality of life for the most vulnerable populations.

Keywords: vulnerability, basic sanitation, human health, small municipalities

Proposição de um índice de vulnerabilidade humana à insuficiência de saneamento básico: o contexto dos municípios paraibanos de pequeno porte

Resumo

Objetivo: Desenvolver um índice que sintetiza aspectos socioeconômicos, institucionais e de saúde humana diante da insuficiência de saneamento básico em municípios de pequeno porte, a partir das três dimensões da vulnerabilidade – risco, susceptibilidade e capacidade adaptativa.

Metodologia: O método para construir e validar o índice se configurou em três etapas: concepção do framework teórico com dados do IBGE (2010), da MUNIC (2017), do Atlas Esgoto (2017) e do SUS do período de 2010-2014; ponderação e padronização dos indicadores por meio de técnicas estatísticas multivariadas; e validação, com a aplicação e análise dentro do contexto dos municípios paraibanos.

Originalidade/Relevância: A literatura carece de índices que integrem a dimensão social às características das habitações, acesso ao saneamento básico e indicadores epidemiológicos em municípios de pequeno porte. Este estudo é relevante por compreender fatores que elevam a vulnerabilidade de populações e territórios permitindo identificar as áreas de maior criticidade, e direcionar ações para melhorar a qualidade de vida das populações afetadas.

Resultados: Os resultados revelaram a influência geográfica dos grandes centros urbanos sobre os municípios de pequeno porte circunvizinhos. Constatou-se que a vulnerabilidade se configura como um forte indicador da iniquidade e da desigualdade social presente nos municípios. No panorama do estado, verificou-se que a mesorregião do Agreste Paraibano apresenta cenários de vulnerabilidade elevada, em virtude de suas características econômicas, sanitárias e sociodemográficas.

Contribuições sociais/para a gestão: Espera-se contribuir na identificação dos fatores que exigem ações e políticas públicas assistencialistas imediatas, em benefício de melhores qualidades de vida para as populações mais vulneráveis.

Palavras-chave: vulnerabilidade, saneamento básico, saúde humana, municípios de pequeno porte

Propuesta de un índice de vulnerabilidad humana ante la insuficiencia del saneamiento básico: el contexto de los pequeños municipios en paraíba

Resumen

Objetivo: Desarrollar un índice que resuma los aspectos socioeconómicos, institucionales y de salud humana relacionados con la insuficiencia de saneamiento básico en municipios pequeños, basado en las tres dimensiones de la vulnerabilidad: riesgo, susceptibilidad y capacidad de adaptación.

Metodología: El método para construir y validar el índice se configuró en tres etapas: concepción del marco teórico con datos del IBGE 2010, MUNIC (2017), Atlas Esgoto (2017) y SUS del período 2010-2014; ponderación y estandarización de indicadores mediante técnicas estadísticas multivariadas; y validación, con aplicación y análisis en el contexto de los municipios de Paraíba.

Originalidad/Relevancia: La literatura carece de índices que integren la dimensión social con las características de la vivienda, el acceso a saneamiento básico e indicadores epidemiológicos en municipios pequeños. Este estudio es relevante porque comprende los factores que aumentan la vulnerabilidad de las poblaciones y territorios, permitiendo identificar las áreas más críticas y dirigir acciones para mejorar la calidad de vida de las poblaciones afectadas.

Resultados: Los resultados revelaron la influencia geográfica de los grandes centros urbanos sobre los pequeños municipios circundantes. Se encontró que la vulnerabilidad es un fuerte indicador de la inequidad y desigualdad social presente en los municipios. En el panorama estatal, se encontró que la mesorregión Agreste Paraibano presenta escenarios de alta vulnerabilidad, debido a sus características económicas, sanitarias y sociodemográficas.

Aportes sociales/de gestión: Se espera contribuir a la identificación de factores que requieren acciones de bienestar y políticas públicas inmediatas, en beneficio de una mejor calidad de vida de las poblaciones más vulnerables.

Palabras clave: vulnerabilidade, saneamento, salud humana, pequeños municípios

Introduction

The complexity of society, combined with the intensification of environmental impacts, particularly regarding the inadequacy of basic sanitation infrastructure, directly affects the promotion of health and the quality of life of the population (Heller, 1998, Teixeira, Gomes & Souza, 2012, Silva et al., 2017). From this perspective, access to basic sanitation services has been a topic of worldwide concern, and the report Progress on Drinking Water, Sanitation and Hygiene (World Health Organization [WHO], 2017) highlights the increased vulnerability of rural populations.

Nationally, Heller (2018) considers that the asymmetry in access to sanitation in Brazil is intensified due to social inequality and exclusionary public policy patterns in the sector. Among the greatest challenges faced by Brazilian society, equitable social inclusion in sanitary and environmental issues can be considered a primary factor.

When analyzing the reality of most Brazilian municipalities, there are significant deficits in the coverage of basic sanitation services and in the effective planning of these services (Lima Neto & Santos, 2012). Such practices result in social, economic, and environmental impacts, especially in less favored regions, such as small localities in the semi-arid northeast.

Of the 5,570 municipalities in Brazil, about 88% are considered small, with populations of up to 50,000 inhabitants (Instituto Brasileiro de Geografia e Estatística [IBGE], 2017). Although they do not suffer from the same urban problems as large cities, most of these municipalities face operational difficulties in planning and managing sanitation due to a lack of institutional and administrative structure.

To provide greater visibility to municipalities of this type, analyzing the population's vulnerability to inadequate sanitation is essential. The term vulnerability expresses the multidimensionality of concepts used in various fields of knowledge, highlighting its application in social sciences, natural sciences, and engineering (Cutter, 2011).

The concept of vulnerability addressed in this study is based on the proposal presented by the Intergovernmental Panel on Climate Change (Intergovernmental Panel on Climate Change [IPCC], 2007), explained through three elements: risk, susceptibility, and adaptive capacity. However, it was necessary to contextualize these components for the specific theme and reality analyzed.

To understand and quantify the various types of vulnerability, indices and indicators have been widely disseminated by the scientific community to measure, characterize, and identify the vulnerability of individuals, groups, or communities (Alcântara et al., 2013). In Brazil, there are some studies that measure vulnerability through indicators developed to support public policies specifically aimed at regions and population groups considered most vulnerable (Instituto de Pesquisa Econômica Aplicada [IPEA], 2015, Malta, Costa & Magrini, 2017, Santos et al., 2019). However, the literature still lacks indices that integrate the social dimension with housing characteristics, access to basic sanitation, and epidemiological indicators, particularly in the context of small municipalities.

The relevance of this study lies in identifying factors that require immediate actions to reduce the vulnerability of populations and territories, serving as a useful tool for policy formulation, decision-making in public spheres, and promoting the use of indicators in regional, national, and international public policy agendas.

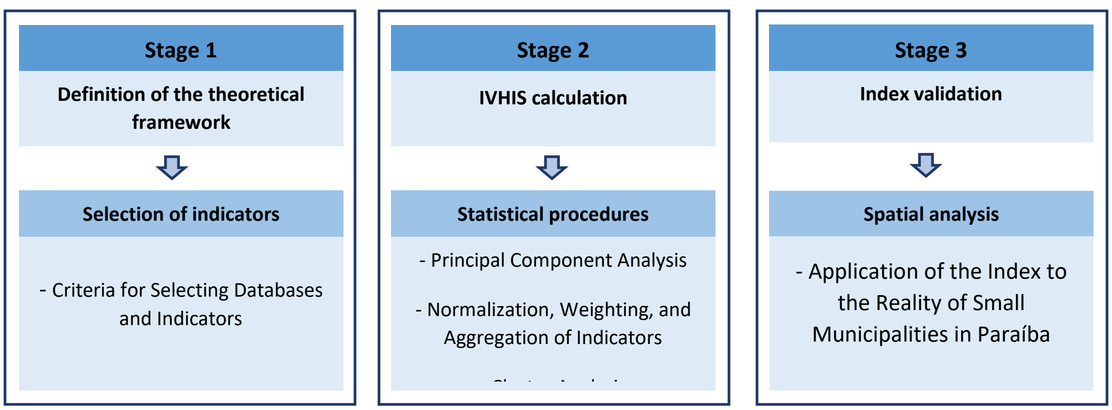
The choice was made to analyze and apply the research to municipalities in Paraíba with populations of up to 50,000 inhabitants, as small municipalities predominate throughout the state of Paraíba, representing 96% of its total. Among these municipalities, there are different management models despite the similarity in population size and geographic proximity, including those that, despite natural limitations, find alternatives to deal with situations such as water scarcity. Given this scenario, the present study aimed to propose a human vulnerability index to inadequate basic sanitation in the context of small municipalities in Paraíba.

Methodology

The objective of this paper is to develop an index to support studies on the vulnerability of populations and territories to insufficient basic sanitation. Thus, the methodology for its construction was divided into three stages, as shown in Figure 1.

Figure 1

Methodological stages of the research



Source: Author.

Stage 1: Theoretical Framework

According to Hammond et al. (1995 as cited by Silva 2015), the construction of indicators for public policy purposes must explicitly state both the adopted metric and the underlying conceptual model inherent to the indicator. In this context, to obtain a metric of municipal vulnerability for comparative purposes, the development of a composite (or synthetic) index was chosen, as it encompasses different indicators. Composite indices integrate and synthesize multidimensional aspects, acting as complexity reducers and providing a means for comparing units of analysis (Barata et al., 2014).

In view of this, the developed index follows the same approach as the IPCC (2007) and is composed of three sub-indices that correspond to the fundamental elements of vulnerability: risk, susceptibility, and adaptive capacity. Together, these components form the Human Vulnerability Index to Insufficient Sanitation (IVHIS), which depicts the vulnerability conditions of each municipality.

The risk sub-index (IR) can be interpreted as the direct hazard, as well as the nature and extent of the problems related to inadequate sanitation services. Therefore, it is understood that a household with inadequate sanitation combines the most degrading forms to health and the environment simultaneously. Additionally, information related to the incidence of environmental impacts resulting from the lack of sanitation is also grouped.

The susceptibility sub-index (IS) demonstrates the sociodemographic characteristics, poverty levels, and occurrence of Diseases Related to Inadequate Sanitation (DRIS), which can make the population more susceptible to the impacts of poor sanitary conditions. The constructed poverty indicators aggregate information on access to basic sanitation, recognized as an influential factor in the well-being of the population and a fundamental element in analyzing the living conditions of families.

In this sense, if, in addition to low monetary income, households have poor access to minimum health and sanitation conditions, they are in a situation of extreme vulnerability and thus constitute the primary target group for public policies aimed at improving quality of life (IBGE, 2011).

The adaptive capacity sub-index (ICA), in addition to integrating information directly related to improving the population's quality of life, also evaluates the presence of planning and management instruments for sanitation services that benefit the population, mitigating the impacts caused by insufficient or inadequate sanitation.

The theoretical foundation for the construction of the index was based on both international and national scientific literature focused on the assessment of socio-environmental and health vulnerability, as well as its impacts (Kienberger, Lang & Zeil, 2009, Mavhura, Manyena & Collins, 2017, Carmo & Guizardi, 2018).

Selection of Indicators

The selection of indicators to compose the index primarily referenced a study in the area of environmental health surveillance by the Ministry of Health (Brasil, 2012). However, some suggested indicators did not align with the particularities of small municipalities and were therefore not included in the construction of the index. The data used in this research were sourced from the 2010 Demographic Census (IBGE, 2012), the Basic Municipal Information Survey – MUNIC (IBGE, 2017), and the Sewage Atlas (Agência Nacional de Águas e Saneamento Básico [ANA], 2017), constituting a set of socioeconomic, demographic, and sanitation infrastructure data. For diseases and basic health coverage, data provided by the Department of Informatics of the Unified Health System (DATASUS) for the period 2010-2014 were used. In total, 30 indicators were used, allocated across the three sub-indices (Table 1).

It is considered that the presence of indicators comprising the Risk Sub-Index (IR) contributes to increasing human vulnerability to insufficient basic sanitation, i.e., high values of the IVHIS; this line of thought also applies to the nine indicators of the Susceptibility Sub-Index (IS). Conversely, to evaluate the Adaptive Capacity Sub-Index (ICA), the higher the value of its indicators, the lower the value of the IVHIS.

Table 1

Proposed indicators for obtaining IVHIS

Sub-index	Indicators
RISK	• Percentage of households with inadequate water supply; • Percentage of households with inadequate sanitation; • Percentage of households with improper waste disposal; • Percentage of households without exclusive use bathrooms and without toilets; • Percentage of the population in households without sewage collection and treatment; • Occurrence of environmental impacts due to lack of sanitation; • Concentration of pollutants in water requiring expansion of water intake and treatment during drought periods.
SUSCEPTIBILITY	• Under-5 mortality rate; • Dependency ratio; • Illiteracy rate (15 years and older); • Percentage of population vulnerable to poverty; • Hospitalizations due to Diseases Related to Inadequate Sanitation (DRSAI) from 2010 to 2014; • Proportional mortality due to DRSAI; • Hospitalizations due to Acute Diarrheal Disease (ADD) in children under 5 years old; • Occurrence of drought between 2014-2017.
ADAPTIVE CAPACITY	• Life expectancy at birth; • Municipal Human Development Index (IDHM); • Per capita income; • Urbanization rate; • GDP per capita. Existence of: • Municipal Basic Sanitation Policy; • Municipal Basic Sanitation Plan; • Municipal Council of Basic Sanitation; • Municipal Basic Sanitation Fund; • Municipal Housing Plan; • Integrated Solid Waste Management Plan; • Environmental management instrument for basic sanitation; • Legislation on watershed management; • Environmental management instrument for selective collection of domestic solid waste.

Statistical Procedures for Calculating the IVHIS

The formulation of the methodology based solely on statistical criteria aimed, among other factors, to reduce the subjectivity present in participatory methods that incorporate expert opinions, for example. To assess vulnerability, aggregating various indicators has been a widely used technique due to the advantage of incorporating a wide range of variables, leading to a more comprehensive model of reality. Therefore, a widely disseminated solution is the use of multivariate statistical techniques for data reduction, with minimal loss of information during the process. Due to the complexity of the calculations performed, the XLSTAT statistical software version 2019.3.2 was used to process techniques involving Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA).

Before starting the statistical procedures, it was necessary to observe the criteria that must be met for the chosen multivariate technique, as it can be affected in various ways if it does not meet its inherent conceptual premises (Tabachinick & Fidell, 2007). The planning of a PCA comprises three initial stages: verifying the adequacy of the database, determining the extraction technique and the number of factors to be extracted, and deciding on the rotation of the factors (Figueiredo Filho & Silva Júnior, 2010).

First, the adequacy of the database was verified. Regarding the level of measurement, the literature recommends prioritizing the use of continuous or discrete variables. Concerning the correlation pattern between the variables, the correlation matrix should display a substantial number of values above 0.30 (Hair et al., 2009). The Kaiser-Meyer-Olkin (KMO) test, whose values range from 0 to 1, was used to assess the suitability of using factor analysis. The closer to 1, the more suitable the technique. Favero et al. (2009) suggest the following scale to interpret the KMO statistic: between 0.90 and 1, very good; between 0.80 and 0.89, good; between 0.70 and 0.79, average; between 0.60 and 0.69, reasonable; between 0.50 and 0.59, poor; and below 0.5, inadequate.

After verifying the adequacy of the database, the next step was choosing the factor extraction technique, which, for this study, refers to the use of principal components. Although there is no consensual criterion for defining the number of factors to be extracted, the literature points to some methods that can assist researchers in making decisions, such as the Kaiser criterion, a priori criterion, percentage of variance criterion, and Scree plot criterion. This study uses the Kaiser criterion, which suggests extracting only factors with eigenvalues above one. If the factor has a low eigenvalue, it will contribute little to explaining the variance in the original variables.

The extracted factors are usually rotated to make the empirical result easily interpretable while maintaining their statistical properties. There are two main types of rotation: orthogonal and oblique. Orthogonal rotations are easier to report and interpret, and for this reason, this type of rotation was chosen in this work. For this, it was assumed that the principal components (Fi) are independent, determined from linear combinations of the initial variables Xi, according to the mathematical model of Equation 1:

$$Xi = ai_1F_1 + ai_2F_2 + ai_3F_3 + ... +Ai_kF_k \quad (1)$$

Each of the k observed variables is described linearly in terms of the “k” uncorrelated components (Fi); aik are the weights or factor loadings that compose the linear combination. The factor loadings aik express the correlation coefficients between each variable and their respective components.

Finally, the last step for performing PCA involved the interpretation and naming of the factors through the factor loadings. In each principal component, the most representative variables are those with the highest factor loadings (aik > 0.30), as established by Hair et al. (2009).

To develop the proposed vulnerability index, the orthogonality property was used, testing whether the factor scores were orthogonal and observing the variance-covariance matrix among them. The scores associated with the municipalities had a symmetrical distribution around the mean zero, i.e., half of the factor scores had positive signs while the other half had negative signs. Thus, municipalities with the lowest IVHIS presented negative factor scores.

To prevent high negative factor scores from increasing the magnitude of the indices associated with the municipalities, the factor scores were transformed to bring them to the first quadrant, standardizing them according to Equation 2.

$$I_p = \frac{I_o - I_{mín}}{I_{máx} - I_{mín}} \quad (2)$$

Where: Ip is the standardized index value, Io is the observed value of the indicator to be standardized, and Imín and Imáx are the minimum and maximum values observed for the factor scores among all municipalities, within the closed interval between zero and one.

Qualitative variables that could assume two values were qualified as dichotomous; that is, to make them quantifiable, the variables were coded as follows: Yes=1 and No=0.

Finally, the IVHIS was calculated using Equation 3:

$$IVHIS = \frac{I_R + I_S + (1 - I_{CA})}{3} \qquad (3)$$

PCA is generally used as an intermediate step for the application of other multivariate techniques. With the results obtained up to this stage, it was necessary to decide the vulnerability intervals for classifying the municipalities, considering that differentiating the localities is an important factor. A solution to this impasse was the use of the multivariate technique called cluster analysis.

Recurrent studies, as well as multivariate analysis manuals, have suggested applying HCA to the component scores, i.e., to each IVHIS value generated (Macedo & Bassani, 2010).). Thus, municipal information was grouped using hierarchical clustering techniques, with the main objective of classifying municipalities into groups, so that there is homogeneity of IVHIS values within the same group and heterogeneity between different groups (clusters).

Clustering techniques aim to reduce subjectivity, as they quantify the similarity or dissimilarity between individuals (Guimarães, Asmus & Burdorf, 2013). In this work, the partition was made according to a clustering function based on Euclidean distance, known as the most commonly used measure of dissimilarity in clustering. Central points (centroids) were established, and the members of each group were identified by the method of least squares.

Validation of the Index

This article's basic unit of analysis, processing, and spatialization of information includes all municipalities with up to 50,000 inhabitants in the state of Paraíba, located in Northeast Brazil, covering a territorial area of 56,467.239 km². Its estimated population is 4,018,127 people, making it the 14th most populous federation unit in the country (IBGE, 2019). The state comprises 223 municipalities distributed across 23 microregions and four mesoregions, namely: Agreste Paraibano, Borborema, Mata Paraibana, and Sertão Paraibano.

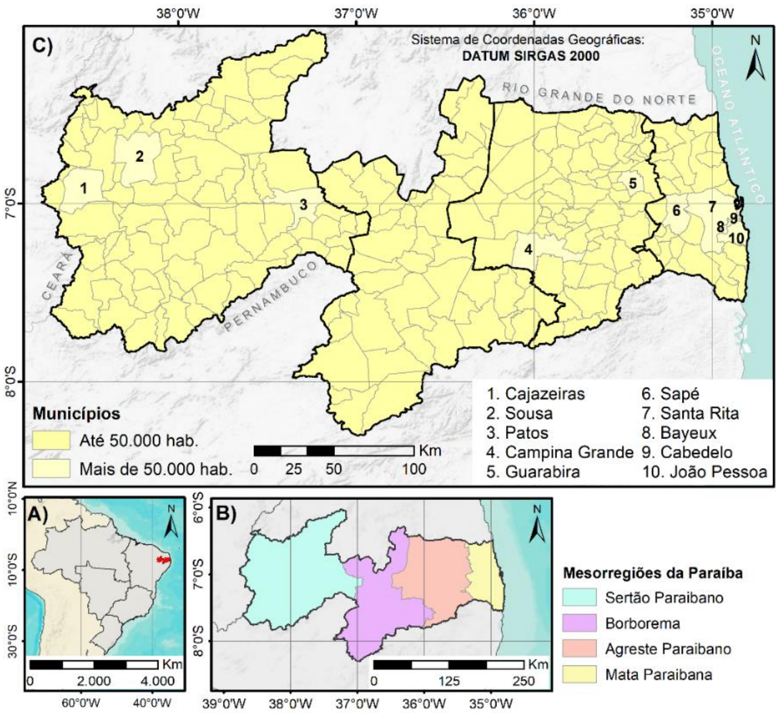
In terms of population, the mesoregion with the highest number of small municipalities relative to its total is Borborema (100%), followed by Agreste Paraibano (97%), Sertão Paraibano (96.4%), and Mata Paraibana (83%). Another relevant piece of information is that according to the last Demographic Census of 2010 (IBGE, 2012), about 42% of these 213 municipalities under analysis are predominantly rural.

Regarding the spatial cutout of the research (Figure 2), out of the total municipalities in the state of Paraíba, 213 (95.5%) are considered small according to the IBGE classification (2011). Only ten municipalities have populations exceeding 50,000 inhabitants and will therefore be disregarded in this study.

To validate the developed index, the distribution of factor scores for each selected municipality was evaluated, followed by the mapping of the Human Vulnerability Index to Insufficient Sanitation (IVHIS). To facilitate the understanding of the vulnerability distribution and the spatial relationship between the municipalities, geoprocessing techniques were used in a GIS environment (ArcGIS Desktop 10.6) to represent the values of the IVHIS and each subindex.

Figure 2

Geographical location, mesoregional division and population characteristics of the state of Paraíba



Source: Author.

Results and Discussion

Multivariate analysis techniques, including principal component analysis (PCA) and clustering, were applied to the set of 30 variables from small municipalities in Paraíba. The statistical results from the PCA for each subindex of the IVHIS are presented in Table 2.

Table 2

PCA Results for the Risk, Susceptibility, and Adaptive Capacity Subindices

Sub-index	KMO Test	PCA	Equations
RISK	0,682	▪ F1=46,6% a) Households with inadequate water supply; b) Households with inadequate sanitation; c) Households with improper waste disposal; d) Households without a bathroom exclusively for residents or without a toilet. ▪ F2=22,1% e) Population in households without sewage collection or treatment.	$IR_{quant}=\frac{f_1 \times 0,466+f_2 \times 0,221}{0,687}$ (4) $IR_{quali}=\frac{\sum_{i=1}^{2} fi}{2}$ (5) Where: fi represents the municipal code for the occurrence of environmental impacts due to the lack of sanitation and the presence of high concentrations of pollutants in the water during drought periods, which can be either 0 or 1. $IR_{final}=\frac{IR_{quant} \times 5+IR_{quali} \times 2}{7}$ (6)
SUSCEPTIBILITY	0,660	▪ F1=29,7% a) Dependency ratio; b) Gini index; c) Illiteracy rate (15 years or older); d) Percentage of population vulnerable to poverty. ▪ F2=18,9% e) Hospitalizations due to Diseases Related to Inadequate Basic Sanitation (DRIBS) and f) Hospitalizations due to Acute Diarrheal Disease (ADD) in children under 5 years old. ▪ F3=12,5% g) Mortality rate for children under 5 years old and h) Proportional mortality due to DRIBS.	$IS_{quant}=\frac{f_1 \times 0,297+f_2 \times 0,189+f_3 \times 0,125}{0,611}$ (7) $IS_{final}=\frac{IS_{quant} \times 8+IS_{quali}}{9}$ (8)
ADAPTIVE CAPACITY	0,660	▪ F1=49,5% a) Life expectancy at birth; b) HDI; c) Per capita income; and d) Urbanization rate. ▪ F2=20,3% e) GDP per capita	$ICA_{quant}=\frac{f_1 \times 0,495+f_2 \times 0,203}{0,698}$ (9) $ICA_{quali}=\frac{\sum_{i=1}^{9} fi}{9}$ (10) Where:fi represents the municipality code regarding the existence of management instruments related to sanitation. $ICA_{final}=\frac{ICA_{quant} \times 5+ICA_{quali} \times 9}{14}$ (11)

The correlation analysis applied to the variables of each sub-index showed significant correlations, reinforcing the adequacy of the PCA technique. The KMO test for the three sub-indices resulted in reasonable values for the application of the statistical technique.

Each sub-index was divided according to the typology of its variables based on Equations 4, 5, 7, 8, 9, and 10 in Table 2. The final values for IR, IS, and ICA were represented by the weighted average of the quantitative and qualitative variables present in each dimension of vulnerability, as shown in Equations 6, 8, and 11 described in Table 2.

Subsequently, ACH was carried out to group the values of each sub-index into distinct classes. In order to analyze the hierarchical structure formed by the union between the elements and to visualize the clustering process, dendrograms were used, which is the most usual way of representing the results of hierarchical methods. This diagram represents a hierarchical tree of links in which the vertical axis shows the loss of information (dissimilarity) as the clustering stages progress. A good decision point for the final clustering, i.e., the choice of the number of groups, is where the distance values change considerably. The results of this technique demonstrated that the values of IVHIS and its sub-indices (IR, IS, ICA) should be grouped into three classes (low, medium, and high).

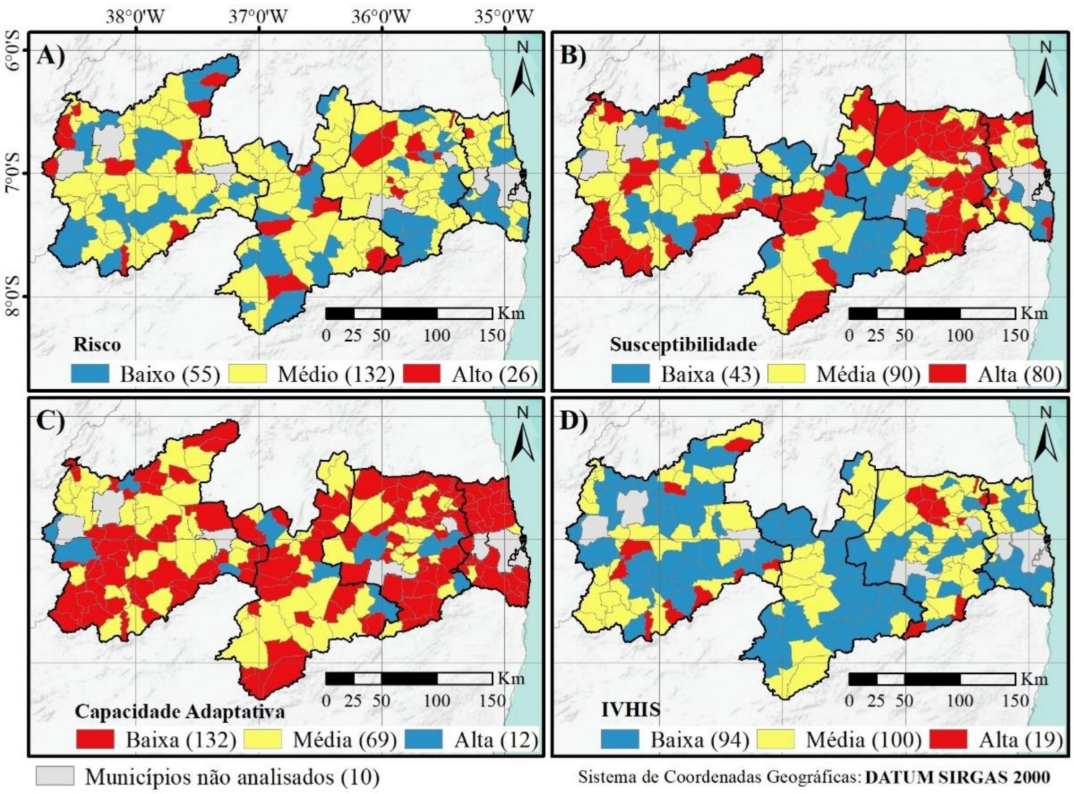
After performing the statistical procedures, the IVHIS values were obtained for each small municipality in Paraíba, according to the three dimensions of vulnerability (Figure 3).

The Risk sub-index (IR) (Figure 3a) reflected that approximately 62% of small municipalities in Paraíba showed a medium risk. Values closer to 1 indicate high risk, while those closer to 0 indicate low risk. Among all 213 municipalities, 26 showed more significant inadequacy averages. The mesoregions that stand out in relation to municipalities with a higher incidence of sanitation problems were the Sertão, with a percentage of 42.3%, and the Agreste with 34.6%.

In the mesoregion of Sertão Paraibano, municipalities with more critical situations are well distributed. However, it is noted that the main factor contributing to the elevation of risk in these 11 municipalities is related to high levels of inadequate sanitation.

Figure 3

Spatial analysis of performance of small municipalities in Paraíba for: a) risk sub-index; b) susceptibility sub-index; c) adaptive capacity sub-index; d) Human Vulnerability Index to Insufficient Sanitation (IVHIS)



Source: Author.

On the other hand, the Agreste region is home to the city of Campina Grande, the second largest in the state by population. The municipalities immediately south of this city showed low risk. The most significant values, characterized as the most concerning for the Agreste, are situated north of Campina Grande, indicating that the presence of a large urban center may reduce the risk for the small municipalities located around it.

Solânea was the municipality in the Agreste region with an extreme risk index value (1.0). It is important to highlight that the final score obtained is for comparative purposes, and therefore, a score of zero does not indicate the absence of vulnerability, just as a score of one does not mean extreme vulnerability. Rather, it indicates that a particular municipality in the state is more or less vulnerable compared to others (Santos, 2016). The indicators contributing to this critical situation in Solânea were the high percentage of households with inadequate sanitation (approximately 100%) and improper waste disposal (around 80%). According to Oliveira (2018), the urban expansion process in the municipality has led to socio-spatial segregation, where a significant portion of the population occupies precarious housing without access to urban sanitation infrastructure.

In summary, the scenario in Paraíba points predominantly to a low to medium risk classification, with 25.8% of localities showing low risk situations, 62.0% falling into the median category, and 12.2% registering significantly high levels of inadequate sanitation services.

Regarding susceptibility (Figure 3b), the results showed that about 80% of municipalities had medium to high susceptibility, among which 47% exhibited more significant values.

It is observed that the region most affected by population vulnerability is the Agreste Paraibano. Among its 66 municipalities, more than 50% recorded a high susceptibility index, while only 10.6% indicate better quality of life for the population. In these latter municipalities, actions to increase population resilience, considering the parameters analyzed in susceptibility, should be the focus of planning and appropriate public policies to reduce social inequalities and the incidence of DRSAI.

Areas of greater criticality can be identified, such as municipalities located in the extreme north of the Agreste, characterized by higher poverty rates and deficiencies in basic sanitation. In these municipalities, the importance of the Bolsa Família Program is notably high, indicating not only the key role of policies and public services that mitigate the effects of poverty and lack of economic opportunities, but also corroborating the high degree of vulnerability of this population (Paraíba, 2018).

Paiva & Souza (2018) have also found, based on secondary data from all Brazilian states, that hospitalizations due to waterborne diseases are associated with basic sanitation conditions, education levels, and coverage by basic care services, while Viana, Freitas & Giatti (2015) revealed a direct relationship between high hospitalization rates for DRSAI, high levels of extreme poverty, and poor sanitation conditions in the Legal Amazon. Therefore, the clear interface between disease spread and sanitation service coverage indicates a structural explanation for a profound public health crisis in Brazil.

The Mata Paraibana, the mesoregion with the highest recorded population density in the state, includes medium and large cities to the south, among which is the capital João Pessoa, which showed low vulnerabilities in this aspect, with the exception of Pitimbu. Despite this municipality having low risk, Costa, Gadelha & Filgueira (2019) found that the presence of open-air landfills and consumption of water outside potability standards in the locality reflect health hazards, making the population more susceptible to DRSAI.

In the hypothetical development of action plans to reduce the vulnerability of small municipalities in Paraíba, where susceptibility characterizes the priority factor for investment, the Agreste would be the region for urgent intervention. Thus, it is suggested that integrated adoption of sanitation policies, education, and health care that consider intramunicipal inequalities can contribute to improving the health conditions of the most affected population.

Although risk and susceptibility represent the fragility of municipalities, the absence of planning and management tools for basic sanitation services can accentuate the impacts generated by existing sanitary problems. Thus, the ICA differs from the other sub-indices in that the closer its value is to 1, the lower the vulnerability. When analyzing the general state panorama, as shown in Figure 3c, it is observed that 62% of Paraíba's municipalities have low adaptive capacity, i.e., they lack public policies and services that promote improvements in the population's quality of life.

Among the variables analyzed in this sub-index, it is noted that only 5.2% of municipalities have legislation related to watershed management. However, effective planning of basic sanitation actions requires intersectoral cooperation with other areas, especially those related to water resources management, where the interaction factor between sanitation and the preservation of water bodies is concentrated in the context of watershed management.

The mesoregion with the highest prevalence of municipalities with low adaptive capacity was the Mata Paraibana, where 23 of its 25 selected small municipalities showed an unfavorable scenario. This situation is mainly due to the absence of instruments and policies related to basic sanitation.

In relation to extreme cases, the municipalities of Gado Bravo and Cacimbas, located in the Agreste and Sertão of Paraíba, respectively, revealed an attention-grabbing picture. When analyzing the indicators that strongly contributed to a low adaptive capacity in these municipalities, it was found that both had no basic sanitation management tools, and more than 75% of the population lived in rural areas. On the other hand, the municipalities of Teixeira and Santa Cruz, both located in the Sertão, presented positive scenarios with high adaptive capacity indices.

It is important to emphasize the differences between these municipalities, considering that Teixeira is more urbanized and has approximately twice the population of Santa Cruz. However, there is a similarity in the fact that both are close to medium-sized municipalities: Patos, the third most important municipality in the state considering economic, political, and social aspects; and Sousa, the main pole of the state's northwest. Therefore, although these small municipalities belong to the same mesoregion, each has inherent particularities.

The results also showed that the absence of Municipal Plans for Basic Sanitation (PMSB) strongly interferes with the other variables. If there is no PMSB, it is unlikely that other management tools associated with basic sanitation will exist in the municipality. In light of this, the existence of PMSB is a condition for accessing federal resources. Lisboa, Heller & Silveira (2013) identified in their studies the main difficulties for the elaboration and implementation of PMSB in small municipalities: the unavailability of financial resources, limitations regarding professional qualification and municipal technical capacity, lack of integration of agencies linked to sanitation areas, and political will.

Adapted systems are more stable in variations, so government actions aim to promote socio-economic development of the community; on the other hand, vulnerable systems have development strategies compromised by the impacts of insufficient basic sanitation, which reduce the effectiveness of social, economic, and health promotion policies. This means that before investing in education and health, it is necessary to promote the universalization of basic sanitation services, so that everyone has access to a healthy and balanced environment.

Finally, municipalities were analyzed according to their vulnerabilities to insufficient basic sanitation (Figure 3d), integrating the three factors discussed above (risk, susceptibility, and adaptive capacity).

Most of the municipalities analyzed were concentrated in the medium vulnerability range (46.9%). Agreste Paraibano concentrated 52.6% of the most vulnerable municipalities. In this scenario, it is possible to identify a group of neighboring municipalities with high vulnerability indices, namely: Damião, Arara, Solânea, Casserengue, and Cacimba de Dentro. It is worth noting that the homogeneity presented by these localities is due to the peculiarities of the microregion in which they are inserted, characterized by river intermittency, water scarcity, poor water quality in underground aquifers, low job supply by the agricultural sector, high poverty rates, inadequate water supply and sanitation systems, and the absence of planning and management tools related to the basic sanitation sector (Paraíba, 2018).

On the other hand, Borborema includes municipalities with lower vulnerability indices, despite all being considered small-sized. The Mata Paraibana mesoregion also presented a more favorable situation, since Pedro Régis was the only municipality with a critical vulnerability situation.

The Sertão, in turn, encompasses the second and third most vulnerable municipalities in all of Paraíba: Água Branca and Cacimbas, respectively. It is noted that both are located south of the mesoregion, specifically on the border with the state of Pernambuco. These situations of high criticality are justified by the fact that the two municipalities had high risk and susceptibility indices, and almost no strategy aimed at improving the quality of life for the population.

Moreover, this general view also allowed for the visualization of the geographic influence of medium and large municipalities on small municipalities, given that the surrounding municipalities to large urban centers showed lower vulnerability indices. This finding indicates the high dependency and vulnerability of these locations and can be explained by circumstances in which a large part of the population benefits from the services offered by larger municipalities.

Therefore, this dependency relationship serves as a warning, because in situations where large urban centers begin to reveal major infrastructure problems and continuous failures in welfare and health promotion public policies, the population of small municipalities will be highly affected.

Conclusions

This study demonstrated that the use of indices and indicators can facilitate the evaluation of implemented public policies, as well as the more appropriate direction of actions and programs aimed at populations facing vulnerabilities.

The IVHIS integrated and synthesized a wide range of variables, represented by a single value, which allowed the analysis of different dimensions around the issue of inadequate sanitation and its impacts on society.

The theoretical-conceptual framework defined in this study highlighted that vulnerability is complex to measure, given its multidisciplinary nature encompassing social, economic, demographic, institutional, and human health aspects. Thus, the developed methodology emphasized aspects of an integrated, multifaceted, and multidimensional view.

Regarding the validation of the proposed index, the use of geoprocessing techniques favored the visualization of important aspects of vulnerability processes, emphasizing the geographic influence among municipalities in Paraíba, the priority areas for intersectoral policy articulation, and promoting the monitoring of specific policy cycles in the development of territorialities. Another notable issue was the fragility of small municipalities. Based on the results of the IVHIS for the reality of Paraíba, a possible dependency relationship between these municipalities and large urban centers was explicitly described.

It is noteworthy that situations of vulnerability are not permanent; they are dynamic and can change. Understanding vulnerability as an evaluation parameter involves analyzing various factors with the intention of revealing how exposed, susceptible, and incapable a population may be to the impacts of inadequate sanitation services.

In conclusion, for public policy purposes, identifying municipalities where high socioeconomic, demographic, and sanitary vulnerabilities coincide helps to decide where the greatest efforts should be directed to improve the quality of life of the most affected populations. Furthermore, in the current context of the expansion of Brazil's urbanization trajectory, identifying, measuring, and characterizing the vulnerability of population groups and their territories is fundamental to inform the design of public policies within the new scenarios that are beginning to emerge.

References

Agência Nacional de Águas e Saneamento Básico. (2017). *Atlas esgotos: despoluição de bacias hidrográficas.* Brasília: ANA. Recuperado de https://metadados.snirh.gov.br/geonetwork/srv/api/records/1d8cea87-3d7b-49ff-86b8-966d96c9eb01

Alcântara, V.S., Strauch, J.C.M, & Ajara, C. (2013). Metodologia para análise da vulnerabilidade socioambiental: estudo de caso na macrorregião da Costa Verde. *Revista Brasileira de Cartografia*, *65*(3), 555-570. https://doi.org/10.14393/rbcv65n3-44805

Barata, M.M.L., Confalonieri, U., Marinho, D.P., Costa N., C., Luigi, G., Oliveira, F.T. ... Pereira, C.A.R. (2014). *Mapa de vulnerabilidade da população dos municípios do estado do Rio* *de Janeiro frente às mudanças climáticas:* Relatório Final. Recuperado de https://www.arca.fiocruz.br/handle/icict/64216

Bernardes, C., Bernardes, R. S., & Gunther, W. M. R. (2018). Proposta de índice de salubridade ambiental domiciliar para comunidades rurais: aspectos conceituais e metodológicos. *Engenharia Sanitária e Ambiental*, *23*(4), 697-706. https://doi.org/10.1590/S1413-41522018141631

Brasil. (2012). *Vigilância em Saúde Ambiental: dados e indicadores selecionados*. Brasília: Ministério da Saúde.

Carmo, M.E., & Guizardi, F.L. (2018). O conceito de vulnerabilidade e seus sentidos para as políticas públicas de saúde e assistência social. *Cadernos de Saúde Pública*, *34*, e00101417. https://doi.org/10.1590/0102-311X00101417

Costa, S.G.F., Gadelha, C.L.M., & Filgueira, H.J.A. (2019). Saneamento básico e salubridade ambiental em cidades do litoral do estado da Paraíba. *Revista DAE*, *67*(219). https://doi.org/10.4322/dae.2019.041

Cutter, S.L. (2011). A ciência da vulnerabilidade: modelos, métodos e indicadores. *Revista Crítica de Ciências Sociais*, (93), 59-69. https://doi.org/10.4000/rccs.165

Doni, M.V. (2004). *Análise de cluster: métodos hierárquicos e de particionamento* (Monografia de Bacharelado). Universidade Presbiteriana Mackenzie, São Paulo, Brasil. Recuperado de http://meusite.mackenzie.com.br/rogerio/tgi/2004Cluster.PDF

Favero, L., Belfiore, P., Chan, B., & Silva, F. (2009). *Análise de dados: modelagem multivariada para tomada de decisões.* Rio de Janeiro: Elsevier. Recuperado de https://repositorio.usp.br/item/001769290

Figueiredo F., D.B., & Silva Jr., J.A. (2010). Visão além do alcance: uma introdução à análise fatorial. *Opin. Publica*, *16*(1), 160-185. https://doi.org/10.1590/S0104-62762010000100007

Guimarães, R.M., Asmus, C.I.R.F., & Burdorf, A. (2013). Caracterização da exposição de população a organoclorados: uma aplicação da análise de cluster. *Revista brasileira de epidemiologia.*, *16*(2), 231-239. https://doi.org/10.1590/S1415-790X2013000200001

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E, & Tatham, R. L. (2009). *Análise Multivariada de Dados* (6a ed.) Porto Alegre, RS: Bookman.

Heller, L. (1998). Relação entre saúde e saneamento na perspectiva do desenvolvimento. *Ciência & Saúde Coletiva, 3*(2), 73-84. https://doi.org/10.1590/S1413-81231998000200007

Heller, L. (2018). Política de saneamento vis–à-vis à política de saúde: encontros, desencontros e seus efeitos. In: R. D'Albuquerque, A. L. Brito, F. Sarti, F. Ultremare, & L. Heller. (Org.). *Saneamento como política pública: um olhar a partir dos desafios do SUS* (pp. 133-143). Rio de Janeiro, RJ: Centro de Estudos Estratégicos da Fiocruz. https://doi.org/10.1590/0103-11042019S718

Instituto Brasileiro De Geografia e Estatística. (2011). *Indicadores Sociais Municipais*. Rio de Janeiro: IBGE.

Instituto Brasileiro De Geografia e Estatística. (2012). *Censo Demográfico 2010: Resultados gerais da amostra.* Rio de Janeiro: IBGE.

Instituto Brasileiro De Geografia e Estatística. (2017). *Pesquisa de Informações Básicas Municipais (MUNIC).* Recuperado de https://www.ibge.gov.br/estatisticas/economicas/financas-publicas/19879 suplementos-munic2.html?=&t=downloads

Instituto Brasileiro de Geografia e Estatística. (2019). *Cidades.* Recuperado de https://cidades.ibge.gov.br/brasil/pb/panorama

Instituto De Pesquisa Econômica Aplicada. (2015). *Atlas da vulnerabilidade social nos municípios brasileiros* (77 pp.). Brasília, DF: Costa, M. A. & Marguti, B. O. Recuperado de https://repositorio.ipea.gov.br/handle/11058/4381

Intergovernmental Panel on Climate Change. (2007). *Climate change 2007: impacts, adaptation and vulnerability: technical summary.* Cambridge: IPCC. Recuperado de https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf

Kienberger, S., Lang, S., & Zeil, P. (2009). Spatial vulnerability units--expert-based spatial modelling of socio-economic vulnerability in the Salzach catchment, Austria. *Natural Hazards & Earth System Sciences*, *9*(3), 767-778. https://doi.org/10.5194/nhess-9-767-2009

Lima N, I.E., & Santos, A.B.D. (2012). Planos de Saneamento Básico. In: A. Philippi Jr., & A. C. Galvão Jr. (Org.), *Gestão do Saneamento Básico: abastecimento de água e esgotamento sanitário* (323-363). Barueri: Manole.

Lisboa, S.S., Heller, L., & Silveira, R.B. (2013). Desafios do planejamento municipal de saneamento básico em municípios de pequeno porte: a percepção dos gestores. *Engenharia Sanitária e Ambiental*, *18*(4), 341-348. https://doi.org/10.1590/S1413-41522013000400006

Macedo, C.E.G., & Bassani, V.D.S. (2010). Vulnerabilidade socioeconômica em Porto Alegre: uma abordagem com base em análise multivariada. In: *Anais XVII Encontro Nacional de Estudos Populacionais*, Caxambu, MG. Recuperado de https://proceedings.science/abep-2010/trabalhos/vulnerabilidade-socioeconomica-em-de-porto-alegre-uma-abordagem-com-base-em-anal?lang=pt-br

Malta, F.S., Costa, E.M., & Magrini, A. (2017). Índice de vulnerabilidade socioambiental: uma proposta metodológica utilizando o caso do Rio de Janeiro, Brasil. *Ciência & Saúde Coletiva*, *22*(12), 3933-3944. https://doi.org/10.1590/1413-812320172212.25032017

Mavhura, E., Manyena, B., & Collins, A. E. (2017). An approach for measuring social vulnerability in context: The case of flood hazards in Muzarabani district, Zimbabwe. *Geoforum*, *86*, 103-117. https://doi.org/10.1016/j.geoforum.2017.09.008

Oliveira, F. L. B. (2018). *Vulnerabilidade socioambiental e expansão urbana: análise do município de Solânea – PB* (Dissertação de Mestrado). Universidade Federal de Campina Grande, Campina Grande, Brasil. Recuperado de http://dspace.sti.ufcg.edu.br:8080/jspui/handle/riufcg/1700

Paiva, R.F.P., & Souza, M.F.D.P.D. (2018). Associação entre condições socioeconômicas, sanitárias e de atenção básica e a morbidade hospitalar por doenças de veiculação hídrica no Brasil. *Cadernos de Saúde Pública*, *34*(1). https://doi.org/10.1590/0102-311X00017316

Paraíba. (2018). *Projeto Segurança Hídrica da Paraíba – PSH/PB: Plano gestão ambiental e social da primeira fase do ramal do Curimataú - sistema adutor transparaíba*. Paraíba: Secretaria de Estado da Infraestrutura, dos Recursos Hídricos, do Meio Ambiente e da Ciência e Tecnologia. Recuperado de https://paraiba.pb.gov.br/diretas/secretaria-de-infraestrutura-e-dos-recursos-hidricos/programas/projeto-de-sustentabilidade-hidrica

Piccoli, A. S., Kligerman, D. C., & Cohen, S. C. (2017). Políticas em saúde, saneamento e educação: trajetória da participação social na saúde coletiva. *Saúde e Sociedade*, *26*(2), 397-410. https://doi.org/10.1590/S0104-12902017160043

Santos, R. B., Menezes, J. A., Confalonieri, U., Madureira, A. P., Duval, I. B., Garcia, P. P. ... Margonari, C. (2019). Construção e aplicação de um índice de vulnerabilidade humana à mudança do clima para o contexto brasileiro: a experiência do estado do Espírito Santo. *Saúde e Sociedade*, *28*(1), 299-321. https://doi.org/10.1590/S0104-12902019180431

Santos, R.B. (2016). *Vulnerabilidade socioambiental e de saúde dos municípios do estado do Espírito Santo frente aos impactos das mudanças climáticas* (Dissertação de Mestrado). Centro de Pesquisas René Rachou, Belo Horizonte, Brasil. Recuperado de https://www.arca.fiocruz.br/handle/icict/15089

Santos, R.B., Menezes, J.A., Confalonieri, U., Madureira, A.P., Duval, I.B., Garcia, P.P. ... Margonari, C. (2019). Construção e aplicação de um índice de vulnerabilidade humana à mudança do clima para o contexto brasileiro: a experiência do estado do Espírito Santo. *Saúde e Sociedade*, *28*(1), 299-321. https://doi.org/10.1590/s0104-12902019180431

Silva, A.A. (2015). *Indicadores para avaliação de efeitos de intervenções de saneamento básico: a questão da sustentabilidade* (Dissertação de Mestrado). Faculdade de Saúde Pública da Universidade de São Paulo, São Paulo, Brasil. https://doi.org/10.11606/D.6.2016.tde-30052016-132007

Silva, S.A., Gama, J.A.S., CALLADO, N.H., & SOUZA, V.C.B. (2017). Saneamento básico e saúde pública na bacia hidrográfica do Riacho Reginaldo em Maceió, Alagoas. *Engenharia Sanitária e Ambiental*, *22*(4), 699-709. https://doi.org/10.1590/s1413-41522017146971

Siqueira, M.S., Rosa, R. S., Bordin, R., & Nugem, R. C. (2017). Internações por doenças relacionadas ao saneamento ambiental inadequado na rede pública de saúde da região metropolitana de Porto Alegre, Rio Grande do Sul, 2010-2014. *Epidemiologia e Serviços de saúde*, *26*(4), 795-806. https://doi.org/10.5123/S1679-49742017000400011

Tabachnick, B., & Fidell, L. (2007). *Using multivariate analysis.* Needham Heights: Allyn & Bacon.

Teixeira, J.C., Gomes, M.H.R., & Souza, J. A. (2012). Associação entre cobertura por serviços de saneamento e indicadores epidemiológicos nos países da América Latina: estudo com dados secundários. *Revista Panamericana de Salud Pública*, *32*(6), 419-425. Recuperado de https://iris.paho.org/handle/10665.2/9233

Viana, R.L., Freitas, C.M., & Giatti, L.L. (2016). Saúde ambiental e desenvolvimento na Amazônia legal: indicadores socioeconômicos, ambientais e sanitários, desafios e perspectivas. *Saúde e Sociedade*, *25*(1), 233-246. https://doi.org/10.1590/S0104-12902016140843

World Health Organization. (2017). *Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines*. Geneva: WHO. Recuperado de https://www.who.int/publications/i/item/9789241512893