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# Vulnerability caused by the lack of sanitation in slums of the Rio de Janeiro, Brazil


## Abstract

This study used a multi-criteria index to assess vulnerability due to lack of sanitation at the microscale of the territory of Complexo do Alemão slums, in Rio de Janeiro, Brazil, comparing different microareas and establishing which of them need priority public action and which have less sanitary risk. The index was built using the method developed by the Jones dos Santos Neves Research and Development Support Institute to score the indicators and determine the comparative aspects in the Complexo do Alemão slums, using comparative spatial analysis. This methodology made it possible to assess that within a territory considered vulnerable in terms of sanitation, there are regions that are more fragile due to basic sanitation problems, and that this data is correlated with socio-economically more unfavorable areas, making it possible to structure the assessment of this type of vulnerability. On average, the partial index of lack of access to water was 0.34, the partial index of sewage collection was 0.28 and the glocal index was 0.31, classifying the Complexo do Alemão slums in the extreme lack range. This approach corroborated the validation of the sanitation deprivation index with information on the territorial scale of communities faced with the risk caused by unequal access to the human right to sanitation.


**Keywords:** basic sanitation, sewage collection, water supply, sanitation deficiency index, slums

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## Introduction

The main text must be clearly paragraphed. State the objectives of the work and provide an adequate background, comprehensive insight on the purpose of the study and its significance, avoiding a detailed literature survey or a summary of the results.

Water scarcity affects more than 40% of the world's population and is expected to increase due to climate change and the lack of proper water management. Sustainable Development Goal (SDG) number 6 - Drinking Water and Sanitation, states that we must ensure the availability and sustainable management of water and sanitation for all. To achieve this goal, springs, rivers and basins must be protected, and water treatment technologies must be shared.[1] Regardless of socio-economic situation, everyone should have access to drinking water, which favors collective health, reduces the number of deaths and illnesses, especially among the elderly and children. Deaths from diseases related to inadequate environmental sanitation (in Portuguese we use the acronym DRSAI) can be prevented with adequate basic sanitation.[2–4] In addition, water security has a positive impact on people's quality of life, with the ability to make communities more resilient to adverse conditions, reducing socio-environmental inequalities.[5]

The term vulnerability has become a buzzword in studies on environmental risk,[6] and is a very diffuse term.[7] Various definitions of vulnerability have emerged and are used in different disciplinary contexts, whether related to sustainability,[8] natural and environmental risks,[9–10] or in social and economic areas.[11] Therefore, the concept of vulnerability can be adapted to each area of knowledge.[6,12] The construction of indicators to assess living conditions and monitor public policies are used successfully thanks to their simplicity, ease of understanding and the more holistic and comprehensive way of measuring a given characteristic, such as the Human Development Index (HDI), which is a summary measure of long-term progress in three basic dimensions of human development: income, education and health.[13] Although the HDI broadens the perspective on human development, it does not cover or exhaust all aspects of development, including the issue of vulnerability. As a result, new indices have been developed to measure a variety of issues.[6]

The Basic Sanitation Deficiency Index (BSDI) was created in 2004 by the *Instituto de Apoio à Pesquisa e ao Desenvolvimento Jones dos Santos Neves* (IJSN),[14] so that the Espírito Santo state government could check the population's access to basic sanitation services. This index consists of determining, by means of indicators that are grouped into categories, the sanitation deficiency index of each territorial area. In the case of the IJSN, the indicators used were microdata from the municipalities in the 2000 Census sample of the Brazilian Institute of Geography and Statistics, which were categorized as "adequate" and "inadequate". The indicators adopted by the study took into account water supply and sewage disposal. According to the study itself, "100" corresponds to the worst value observed (100% absolute deficiency) and "0" corresponds to the best value (0% deficiency). To obtain the final index, which was the sum of the weighted averages of each of the partial indices, weights were assigned to each category. In these studies, the proponents adopted different weights for the partial indicators: 3 (ICwater); 2 (ICsewage).

In order to implement sanitation in locations with difficult access in areas of socio-environmental vulnerability, the use of social technologies is recommended, such as the treatment of water from springs and the use of evapotranspiration systems that are appropriate to the reality of the areas, without having to remove residents from their locations and improving the quality of life for people and the environment.[15] Given the problems of public water shortages, which mainly affect the regions where the most socioeconomically vulnerable population lives, in the upper parts of the slums, it is desirable to identify the regions that could be priorities for the implementation of social technologies in sanitation.[16]

The aim of this study was to propose the use of basic sanitation indicators for slum areas, making it possible to evaluate them on a micro sub-basin scale, in order to indicate priority areas for the installation of social sanitation technologies. This will help support the formulation and implementation of public policies, since it is essential for these actions to spatially locate the areas that concentrate the most vulnerable population segments in the dimensions considered.

## Material and methods

### Database analysis

Based on the institutional project "Social Technologies in Sanitation and Health", which aimed to define where filter systems for spring water treatment and sewage treatment would be installed, a survey of the conditions of access to water and sewage collection was carried out through a descriptive cross-sectional study with a random sample of 369 residents of the Complexo do Alemão slums in Rio de Janeiro, Brazil, in which a structured questionnaire was applied in the action research stage of the project, from November 2021 to May 2022. The study was approved by the Research Ethics Committee (CEP) of the Sergio Arouca National School of Public Health (ENSP), of the Oswaldo Cruz Foundation under CAAE number: 52504621.5.0000.5240, and the information was provided directly in the structured questionnaires, covering 1% of the households in the slum area.

### Study area

The study region is similar to other slum areas, where sewage is mostly discharged directly into the ground, ditches and rivers,[17] and is located in the northern portion of the Guanabara Bay Sub-Basin of the Canal do Cunha, in Complexo do Alemão, a region that was divided into seven microareas, taking into account the influence of the Timbó River drainage microbasin and its confluence with the Faria River (Figure 1). The term Complexo do Alemão was used in a more general way than the neighborhood boundary, because of the portions of subnormal agglomerations that relate to the neighborhoods of Bonsucesso, Inhaúma and Engenho da Rainha in this large complex of favelas located in the Sub-Basin of the Cunha do Canal, made up of 183 census tracts described by the IBGE (2010).[18] Residents in 166 census tracts in this region were consulted.

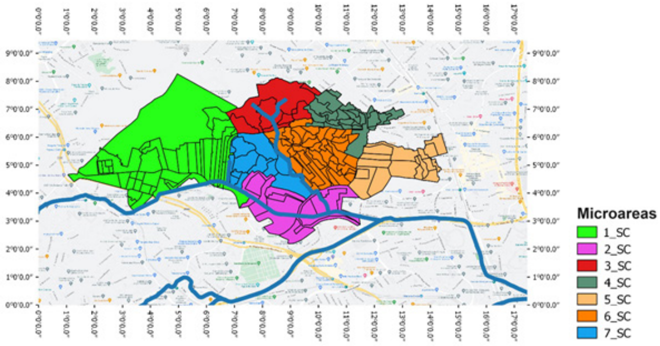


**Figure 1** Microareas of the Complexo do Alemão region covered by the study, smaller polygons corresponding to the census tracts (SC) described by the IBGE (2010).[18]

**Source:** The authors.

### Calculation of the Basic Sanitation Deficiency Indicators (BSDI)

The method used to evaluate sanitation indicators was the Basic Sanitation Deficiency Index (BDSI), a methodology created in 2004 by the Instituto de Apoio à Pesquisa e ao Desenvolvimento Jones dos Santos Neves (IJSN).[14] The aim of the ICSB was to assess access to sanitation services using indicators for water supply and sewage disposal, according to data provided by the IBGE, 2010.[18] However, in this study we adapted it to take into account the data obtained from the residents who answered the questionnaires. In order to indicate the lack of each sanitation component, were considered questions that allowed us to evaluate two partial indices: the Water Deficiency Index ($ID_{WATER}$) and the Sewage Deficiency Index ($ID_{SEWAGE}$). Initially, a Percentage of Deprivation (PD) was established for each component. To this end, for each of the indicators evaluated, households with precarious access were considered (for water, they had access to the network, but also needed to use water from another source; for sewage, when they declared that they were outside the collection network), as expressed in Equation 1.

$$PD = \frac{(No.\ precarious\ access\ households)}{(No.\ total\ households)} \times 100 \qquad \text{(Equation 1)}$$

where,

**PD:** Percentage of deprivation.

Subsequently, $ID_{WATER}$ and $ID_{SEWAGE}$ were calculated using the following Equation 2:

$$Partial\ ID = \frac{(PD - Lowest\ Value)}{(Highest\ Value - Lowest\ Value)} \times 100 \qquad \text{(Equation 2)}$$

where,

**Partial ID:** Basic sanitation deficiency index, referring to each of the indicators (water as $ID_{WATER}$ and sewage as $ID_{SEWAGE}$)

**PD:** Percentage of deficiency in the given attribute;

**Highest value:** Corresponds to the worst value, when there was the highest percentage of deficiency;

**Lowest value:** Corresponds to the best value, when there was the lowest percentage of deficiency.

This calculation took into account the "lowest value" among all the percentages of the microareas under analysis for this same indicator. Consequently, the "highest value" field was filled in with the highest value among them. After defining the $ID_{WATER}$ and $ID_{SEWAGE}$ partial indices, the global basic sanitation deficiency index (BDSI) was calculated using the weighted averages for each partial index, according to Equation 3:

$$BDSI = \sum \frac{(Partial\ ID \times Category\ Weight)}{(Category\ Weight)} \times 100 \quad \text{(Equation 3)}$$

where,

**BDSI:** Basic sanitation deficiency index;

**Partial ID:** Referring to the $ID_{WATER}$ and $ID_{SEWAGE}$ indicators;

**Category weight:** In this study, weight 1 was adopted for the two sanitation indicators.

The weights for each category are adopted according to the criteria and adjustment needs of each author, as described in the 2004 Ministry of Health book.[19] The deprivation index was categorized into 3 levels, ranging from 0 to 1, where 0 represents the highest degree of deprivation and 1 the lowest degree of deprivation.[20] Thus, the classification of microareas with regard to sanitation services considering the index was determined in three intervals[14]: (a) Low deprivation index: ID ranging from 0.8 to 1; (b) High deprivation index: ID ranging from 0.5 to 0.8; (c) Extreme deprivation index: ID ranging from 0 to 0.5.

### Association and correlation of indicators

In order to assess vulnerability due to sanitation deficits in comparison with socio-economic indicators (income ratio below 1300.00 BRL; percentage of black and brown people; demographic density in households; schooling only up to primary level; receiving water every day) in microareas in slum areas, descriptive and bivariate analyses (Spearman's correlation) were carried out using Jamovi® 2.3.21 software. Statistical significance was set at 5% (p-value <0.05). The QGIS 2.18.4 program was used to create the thematic maps.

## Results

The seven microáreas slums in Complexo do Alemão differed in their position in the Timbó Watershed (Figure 1). The microareas located in the highest parts, close to the Serra da Misericórdia Forest were: microarea "3_SP" - highlighted in red (the Morro do Alemão region, with the Morro dos Mineiros and Relicário slums), which comprised only 9 census tracts in the Complexo do Alemão neighborhood; and micro-area "4_SP" - highlighted in gray (the Morro do Alemão region, with the Morro Esperança and Morro da Baiana slums), which comprised 29 census tracts in the Complexo do Alemão neighborhood. On the right side of the Timbó River are the microareas: "5_SP" - highlighted in pink, comprising the slums of the Morro do Adeus and Morro do Piancó communities, with 44 census tracts in the Complexo do Alemão and Bonsucesso neighborhoods; and microarea "6_SP" - highlighted in coral, comprising the slums of the Joaquim Queiroz (Grota), Nova Brasília and Itararé communities, with 40 census tracts in the Complexo do Alemão and Inhaúma neighborhoods.

On the left side of the Timbó River are the microareas: "7_SP" - highlighted in blue, with the slums of Morro das Palmeiras, Parque Alvorada and Cruzeiro, with 11 census tracts in the Complexo do Alemão and Inhaúma neighborhoods; and microarea "1_SP" - highlighted in green, with the Vila Matinha communities, with 39 census tracts in the Engenho da Rainha and Inhaúma neighborhoods. In the lower part of the Timbó river basin, and at the junction with the Faria river in the Inhaúma neighborhood, there is microarea "2_SP" - highlighted in lilac, comprising only 9 census tracts in the Inhaúma neighborhood, with the Parque Everest community slum.

The Organization of the United Nations (ONU) has recognized, through the Sustainable Development Goals, that access to drinking water and basic sanitation is a universal right.[21] In order to verify access to these rights in the slum areas of Complexo do Alemão, in the municipality of Rio de Janeiro, the population's water supply and sewage collection rates were assessed. On average, 96.48% of households had access to mains water, but 98.64% answered that they had access to mains water, but also had access via another system, off the mains, indicating intermittent supply. On average, 79.67% of households reported having mains sewage collection; this figure was around 1.2 times lower than that described for the municipality of Rio de Janeiro, which was 92.08%.[22]

In general, the region of slums of the Complexo do Alemão in terms of socioeconomic data was characterized by having an average of 68.6% (SD = 12.3) of the population of black ethnicity (declared black or brown); with 56.10% (SD = 14.60) of the population having up to elementary school education; 65.10% (SD = 9.82) with an income below one minimum wage; with a population density of 18.4 (SD = 11.50) inhabitants per square kilometer; and 45.90% (SD - 28.70) of the households do not receive water every day, so they also declared having other forms of access to water. The average water deficiency index (IDWATER) was 0.34 (SD 0.43), classified as an "extreme" shortage index, as was the average sewage deficiency index (IDSEWAGE), which was 0.28 (SD 0.40) and the global basic sanitation deficiency index (BDSI), which was 0.31 (SD 0.39).

In order to implement sanitation in locations with difficult access in areas of socio-environmental vulnerability, the use of social technologies is recommended, such as the treatment of water from springs and the use of evapotranspiration systems that are appropriate to the reality of the areas, without having to remove residents from their locations and improving the quality of life for people and the environment.[23] Given the problems of public water shortages, which mainly affect the regions where the most socioeconomically vulnerable population lives, in the upper parts of the slums, it is desirable to identify the regions that could be priorities for the implementation of social technologies in sanitation.[16]

The correlation between the indices of poor sanitation in the seven slum microareas of Complexo do Alemão was significant between BDSI (general) and IDWATER (partial); and between BDSI (general) and IDSEWAGE (partial), was around 99% statistical significance (Table 1). Although the correlation between IDWATER and IDSEWAGE was positive, it was not statistically significant, $p > 0.05$.

The socio-economic variables did not have a significant correlation above 95% with the sanitation deficiency indices, but those that did have a positive correlation were considered in the comments: (i) correlation between IDWATER and ethnicity, highlighting the structural racism observed in slum areas: it is black people who suffer most from the lack of water supply, and households with higher population densities; (ii) correlation between people of black ethnicity and population with income below 1 minimum wage ($rho = 0.714$; $p = 0.088$), characterizing social vulnerability in access to water, marking those with health vulnerability; (ii) in contrast, there were positive correlations between the variable "high proportion of inhabitants per area" with the three indicators of lack of sanitation (Table 1).

**Table 1** Correlation between the indices of lack of partial and overall basic sanitation and the socioeconomic characteristics of the population of the slum microareas of Complexo do Alemão, Rio de Janeiro, RJ, Brazil

| **Variable** | **$ID_{WATER}$** | | **$ID_{SEWAGE}$** | | **BDSI** | |
|---|---|---|---|---|---|---|
| | **rho** | ***p*** | **rho** | ***p*** | **rho** | ***p*** |
| Schooling up to primary level | 0,371 | 0,413 | -0,143 | 0,783 | 0,036 | 0,963 |
| High proportion of inhabitants per area | 0,445 | 0,317 | 0,571 | 0,200 | 0,571 | 0,200 |
| Proportion does not receive water every day | 0,630 | 0,129 | -0,036 | 0,963 | 0,250 | 0,595 |

**Source:** Authors elaboration.

Water supply was the sector with the lowest deficiency indices (IDWATER). The spatial distribution of the shortage index of the water supply network, separated by microarea, shows that micro-areas SC-2, SC-4 and SC-5 had the worst conditions, in the classification of the extreme range (value = 0.0), none were in the high shortage index range, However, microareas SC-1 and SC-3 were in the low sanitation deficiency index range, although SC-3 had IDSEWAGE in the extreme range (value = 0.40), so the overall BDSI for this microarea was in the high index range (value = 0.70), which can be explained by the righer vulnerability in this location.

Dividing the Timbó River watershed into microareas in the Complexo do Alemão made it possible to comparatively assess the microareas in the sanitation vulnerability system, and how a socio-environmentally vulnerable territory has regions with a greater lack of public basic sanitation services, Through the Basic Sanitation Deficiency Index (BDSI), the SC_1 area had a low BDSI, SC_3 had a high BDSI and the other areas had an extreme BDSI (Figure 2), so it was possible to see from the calculation of the BDSI which territories have the greatest vulnerabilities in terms of sanitation.

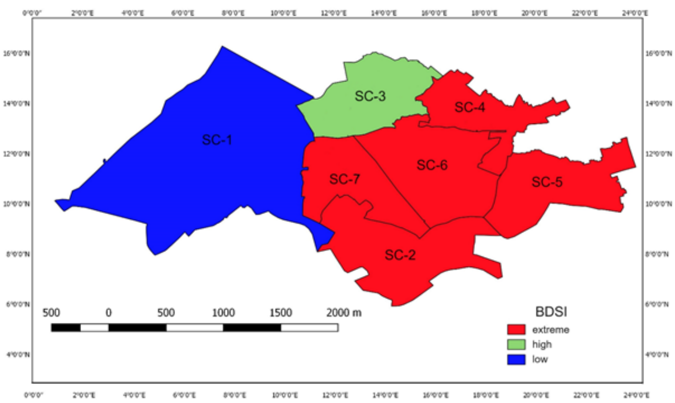


**Figure 2** Thematic map for the global basic sanitation deficiency index (BDSI) of the microareas of Complexo do Alemão, Rio de Janeiro, Brazil.

## Discussion

The growing use of multi-criteria analysis methodology in territorial and urban planning is increasingly used, with considerable advances in spatial analysis compared to conventional map overlay approaches. Currently, multi-criteria analysis is being integrated into Geographic Information Systems (GIS), creating a robust tool to support spatial analysis processes through modeling and to provide decision support on issues with spatial distribution and consequences.[6]

The methodology of integrating GIS analysis and multi-criteria analysis using indicators corroborates the studies of Santos et al.,[24] in the analysis of the social fragility of the urbanized area of the municipality of Viçosa - MG; Oliveira et al.,[25] to determine the Sustainability Index for the Expansion of the Sugar-Alcohol Sector; and Gomes and Lins,[26] in the analysis of the quality of urban life of the population of the municipality of Rio de Janeiro.

In this way, the methodology of analyzing indicators integrated into the GIS has been consolidated as an extremely useful resource in public management and decision-making. It is therefore necessary to understand that the tool offers resources for reflecting on the various vulnerability problems in the territories.[27] In the specific case of this article, the integration of the methodologies aimed to help the process of identifying the areas with the greatest sanitation shortages, in order to identify places where the universalization of sanitation in the territory should begin.

Urbanization, concentrated in areas of the massifs and in the few green areas left in the cities, has further aggravated the need for infrastructure, which has not kept pace with the growth of the cities. This rapid and disorderly process of urbanization has had a series of consequences, most of them negative, such as the unplanned occupation of hillsides. The lack of urban planning and a less concentrated economic policy has contributed to the problems of poor basic sanitation. One of the main problems resulting from accelerated urbanization is the concentration of wealth in planned areas of cities, and as a consequence the increase in inequalities.[6]

The fight for the right to the city and the right to housing emerged as a counterpoint to an exclusionary model of urbanization, which over decades of accelerated urbanization absorbed large contingents of poor people, without ever effectively integrating them into cities.[28] In addition to socio-economic problems, one of the dimensions of the fight for the right to the city is the right to a healthy environment, which requires access to sanitation, housing, security, infrastructure and health policies,[29] and as in the favela areas, urban infrastructure is precarious, without decent housing conditions and basic sanitation - water supply, sewage treatment, waste collection and drainage, and where there is frequent water shortage, added to the high population density, number of households and low per capita income are common characteristics of communities, favoring the incidence of diseases, especially those associated with social vulnerability.[2]

From the results found in this article, it can be seen that the highest BDSI values are found in the regions of the Complexo do Alemão slums where people of black ethnicity (blacks and browns) predominate, confirming that it is the black and underprivileged populations that bear most of the negative effects of urbanization, confirming studies by Cutter et al.,[30] where the authors discuss the variation of vulnerability in time and space, between different social groups.

The methodology and results obtained for the BDSI can serve as support for sanitation policies in slum areas, contributing to the minimization of socio-spatial segregation and, consequently, a change in the current urbanization model, so that all residents have the same right to the city.

## Conclusion

The methodology for integrating the analysis of the basic sanitation deprivation index and GIS data provides an important tool for defining and validating micro-areas in situations of vulnerability. In this way, it was possible to identify priority areas in need of basic sanitation policies and facilitate their monitoring. In order to apply this methodology in other regions, it is suggested that indicators be included and/or replaced according to the reality of the region to be analyzed. In this way, spatial knowledge of the most vulnerable areas can be used to help draw up preparedness and response plans to tackle problems and, consequently, mitigate them.

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## Conflicts of interest

The authors have no conflicts of interest to declare.

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