Composition of the social urban water shortage vulnerability index (SUWSVI) applied to São José dos Campos, SP, Brazil

Composição do índice de vulnerabilidade social urbana de falta de água (SUWSVI) aplicado a São José dos Campos, SP, Brasil

Luciana Maria Ferrer [1]

Daniel Andrés Rodriguez [2]

Maria Cristina Forti [3]

Márcio Roberto Magalhães de Andrade [4]

Maria Aparecida de Oliveira [5]

[1] Doctor in Earth System Science, Researcher, Divisão de Impactos, Adaptação e Vulnerabilidades, Coordenação-Geral de Ciências da Terra, Instituto Nacional de Pesquisas Espaciais (Inpe), São José dos Campos, Brazil
E-mail: luciana.ferrer@inpe.br

[2] Doctor in Meteorology, Professor, Instituto de Pós-Graduação e Pesquisa de Engenharia Alberto Luiz Coimbra da Universidade Federal do Rio de Janeiro, Brazil
E-mail: daniel.andres@coc.ufrj.br

[3] Doctor in Geophysics, Professor, Divisão de Impactos, Adaptação e Vulnerabilidades, Coordenação-Geral de Ciências da Terra, Instituto Nacional de Pesquisas Espaciais (Inpe), São José dos Campos, Brazil
E-mail: crisforti@gmail.com

[4] Doctor in Geography, Researcher, National Center for Monitoring and Alerts of Natural Disasters (Cemaden), São José dos Campos, Brazil
E-mail: marcio.geodinamica@cemaden.gov.br

[5] Doctor in Geography, Researcher, Global Public Health Observatory, Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, USA
E-mail: mdeoliv3@jhu.edu

doi:10.18472/SustDeb.v13n3.2022.45523

Received: 25/10/2022
Accepted: 15/012/2022

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ABSTRACT
Mining dams within urban areas are a technological risk because, in the event of an accident, they affect water security. For example, a sand mining dam accident caused an interruption in the water supply in the downstream city of São José dos Campos. Thus, the social vulnerability of the population that suffered from a failure in the drinking water supply was evaluated. A water shortage indicator, the Social Urban Water Shortage Vulnerability Index – SUWSVI, was composed. Variables that best reflect the socioeconomic condition were used: Average Income of Head of Household, Female Head of Household, and Children and Elderly Dependent Ratio. The sensitivity analysis considered the city by geographic regions and zoning classes, considering infrastructure supply and lot size. The results showed that although there are full water supply and sewerage infrastructure (99.6%), the access to water was unequal (39% of the population in the medium SUWSVI range).

Keywords: Social vulnerability. Water shortage indicator. Technological risks. Water security.

RESUMO
As barragens de mineração em áreas urbanas são riscos tecnológicos porque, em caso de acidente, afetam a segurança da água. Um acidente com uma barragem de mineração de areia causou interrupção no abastecimento de água na cidade de São José dos Campos, a jusante. Com isso, foi avaliada a vulnerabilidade social da população que sofreu com a falha no abastecimento de água potável. Um indicador de escassez de água, o Índice de Vulnerabilidade Social Urbana de Falta de Água – SUWSVI, foi composto. Foram utilizadas as variáveis que melhor refletissem a condição socioeconômica: Renda Média do Chefe de Família, Mulher Chefe de Família e Relação de Dependência de Crianças e Idosos. A análise de sensibilidade considerou a cidade por regiões geográficas e classes de zoneamento, que levam em conta a oferta de infraestrutura e o tamanho do lote. Os resultados mostraram que, embora com infraestrutura completa de abastecimento de água e esgoto (99,6%), o acesso à água foi desigual (39% da população na faixa média SUWSVI).

Palavras-chave: Vulnerabilidade social. Indicador de falta de água. Riscos tecnológicos. Segurança hídrica.

1 INTRODUCTION

As depicted in United Nations' Sustainable Development Goal SDG no. 6 (UN, 2015), access to water and sanitation for humankind is a challenge for all and a duty for governments. Water security needs to be guaranteed (GREY; SADOFF, 2007), but the different realities of countries require commitment and different solutions. The high population density added to the demand for water resources, often polluted, turns water supply in cities a challenge, generating conflicts of use due to its quality and quantity (PEREIRA *et al.*, 2020). Water security is water availability and the right to use drinking water for present and future generations. It includes regional and global water availability, environmental issues, access complexity, and water scarcity (HOPE; HOUSE, 2013; VÖRÖSMARTY *et al.*, 2010). Dams are an example of water resources management infrastructure that can increase water security in a region (VÖRÖSMARTY *et al.*, 2010). However, the existence of water-related infrastructure is no guarantee that access to water is equal (LOPES, 2020). Drinking water supply and water security are compromised if water reaches consumption limits, exceeds its carrying capacity, or if there is proven contamination in the distribution system (RAVAR *et al.*, 2020). In addition, solutions for water availability, such as the construction of surface reservoirs, add risks and increase vulnerability, as it causes suppression of vegetation, a decrease of biodiversity, plus the disastrous consequences in case of rupture. (CIONEK *et al.*, 2019; RENN; BENIGHAUS, 2013).

Social vulnerability is a condition that makes people or groups of people more susceptible to harm than others (RECKIEN, 2018). Water-related social vulnerability can be monitored through indices of equality in access to water and sanitation (MUKHERJEE *et al.*, 2020). Studies of indicators to assess non-discrimination and equity in the context of the human right to water and sanitation guide public policy (AMJAD *et al.*, 2014) and understand events that disrupt the normal functioning of communities, putting them at risk (LUNDIN; MORRISON, 2002).

To construct a vulnerability index, it is necessary to use latent variables, intrinsic to some place, not directly observable, and that can only be indirectly measured by statistical procedures. For example, an area's demographic data allow quantitatively defining social vulnerability (SPIELMAN *et al.*, 2020), just as the feature due to abrupt interruption in the water supply is not directly observable. Also, sensitivity analysis (OECD, 2008; TATE, 2012) is needed to choose the variables that had the greatest influence on the expression of the results. These indices are characterized as composite indicators (BECCARI, 2016; MOREIRA *et al.*, 2021; OECD, 2008), of synthetic nature (SPIELMAN *et al.*, 2020) and multidimensional. The latter condition brings complexity to the construction of the index but allows the comparison of various sources and scales and gives alternatives to consider missing data and approximate non-existent information from related data (ANAZAWA *et al.*, 2013; RUFAT *et al.*, 2019). Therefore, as the various existing social vulnerability indices have complex validation because social vulnerability is multidimensional and not directly observable (FEKETE, 2012; RUFAT *et al.*, 2019), the choice of parameters needs to consider both the index configuration and the disaster measure (SPIELMAN *et al.*, 2020; TATE, 2012).

According to Rufat *et al.* (2019), in selecting the variables that lead to the understanding of social vulnerability, it is necessary to analyze which urban population was most affected by the difficulty of access to water and sanitation, relating it to the abrupt interruption of water caused by the dam burst accident. To do so, the variables surveyed need to cover several dimensions: biophysical, socioeconomic, gender-based, and water supply infrastructure (FATEMI *et al.*, 2016). The indices must reflect multidimensionality, interactivity, and causal processes (RUFAT *et al.*, 2019). A socio-hydrological analysis should include socioeconomic water values and aspects relevant to human well-being to assess the sustainability of water resources (SUN *et al.*, 2017).

Risks due to dams in urban areas can compromise water security and need to be taken into account when assessing social vulnerability. Risks cover various agents and causes (FEKETE, 2012; VEIRET, 2007; WOOD *et al*., 2021).

Measuring the social vulnerability of communities near infrastructure that pose water-related risks when an accident occurs is essential. Regardless of size, these infrastructures are embedded in cities, bringing a perennial risk. Brazil has a history of mining dam disasters that have caused incalculable socioeconomic and environmental impacts and can take decades to recover (50 million m³ of iron ore mining tailings released into the Doce River from the collapse of the Fundão tailings dam in Mariana and 13 million m³ of tailings into the Paraopeba River from the Córrego do Feijão tailings dam in Brumadinho, both Minas Gerais State) (CIONEK *et al.*, 2019; VORMITTAG *et al.*, 2018). In the study region (city of São José dos Campos, State of São Paulo, Brazil), the water-related risk is due to the sedimentation dams of ancient sand mines. Over 83 sand mining companies have settled in more than 250 km² along the shores of the Paraíba do Sul River, where the city's water catchment system is located. When the mines are active, the dams are constantly filled with tailings and the risk increases. On the other hand, when inactive or finished, they function as reservoirs and ecosystem services for water supply (FERRER *et al.*, 2021).

From the above, the objective of this work was to consider different indices of social vulnerability (WOOD *et al.*, 2021), to develop the Urban Water Shortage Social Vulnerability Index (SUWSVI), and map the changes in the household dynamics of the population coexisting with dams that represent water-related risks. The intention is to show local public managers the need for water supply planning by city region and neighbourhood to contemplate the most socially vulnerable groups.

2 MATERIALS AND METHODS

2.1 AREA OF STUDY

The city of São José dos Campos is located in the Paraíba do Sul River Basin in the southeast region of Brazil (Figure 1). The southeast is the country's most densely populated and developed region and comprises its three largest metropolitan regions (São Paulo, Rio de Janeiro and Belo Horizonte).

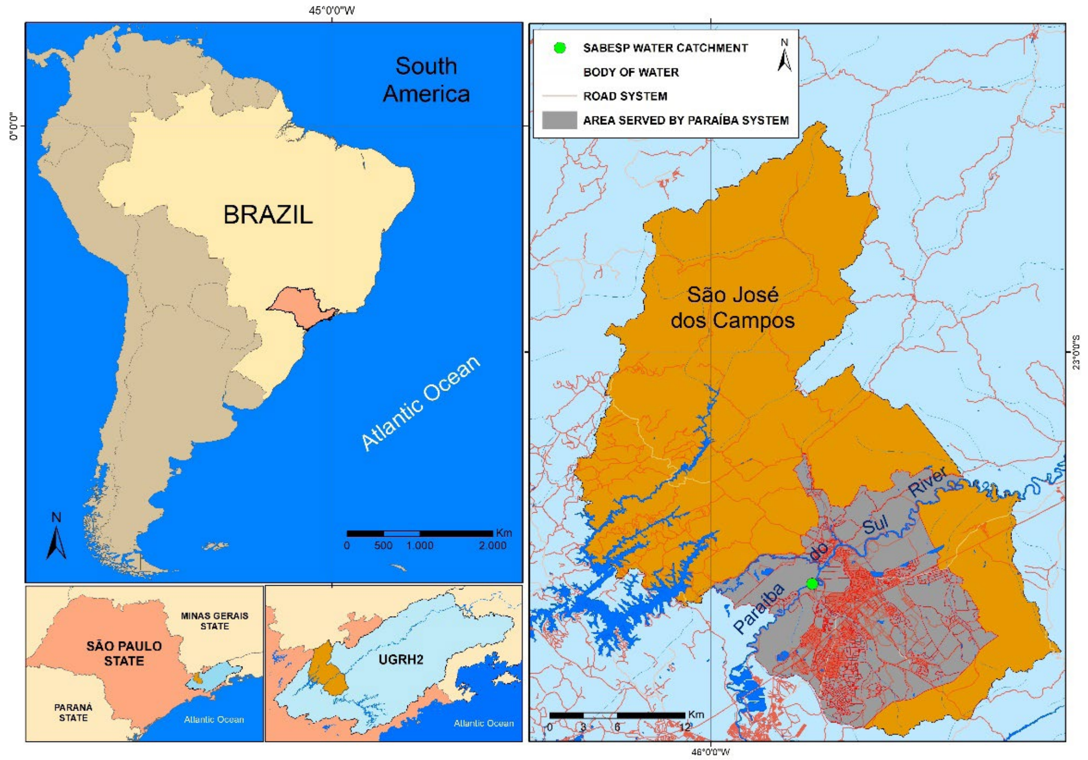

Figure 1 | Location of the study area. Urban area of São José dos Campos and public water supply through the Paraíba Subsystem. Water Resources Management Unit – UGRHI 02

Source: Prepared by the authors, based on Municipal Government of São José dos Campos (2017a), Department of Water and Electricity (DAEE, 2017), and Secretariat of Infrastructure and Environment of São Paulo State Government. Environmental Planning Coordination (2017).

The lowlands of the Paraíba do Sul River Basin, where São José dos Campos is located, have been exploited for more than 70 years for sand mining, leaving dozens of sand pits installed. The city has an estimated population of 729,737 (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, n.d.). These pits have impacted eco-hydrological processes due to hydraulic works, urbanization, and population growth. These infrastructures occur in more than 250 km² of river polders, very close to the water catchment system (FERRER *et al.*, 2021). The sand pits scenario in the river floodplain represents a perennial risk. The municipality of São José dos Campos, SP, had its water catchment system hit by the collapse of an upstream sand pit dam in 2016. Because this water catchment system serves the urban population of this municipality, the water shortage impacted most of the inhabitants. As related in local news and media, the impact was unequally perceived by inhabitants, which suggests different capacities for dealing with disaster in the city.

The studied population is located in an urban area with a full water supply and sewage infrastructure (MUNICIPAL GOVERNMENT OF SÃO JOSÉ DOS CAMPOS, 2017a). Of the 28 municipalities that collect water from the Paraíba do Sul River Basin, São José dos Campos has the largest served population (99,6% of de urban population). The water supply system is designed for approximately 750,000 inhabitants and divided into three subsystems: Paraíba (or Sede), the main tributary, Eugênio de Mello and São Francisco Xavier. The Paraíba Subsystem, the object of this study (Figure 1), has a yield capacity of 2,626 l/s, of which 1900 l/s originate from the Paraíba do Sul River, 12 l/s from the Couves River and the remaining 714 l/s from 48 deep tubular wells. It has approximately 1,699 km of pipelines and distribution networks and serves 172,573 active drinking water connections (MUNICIPAL GOVERNMENT OF SÃO JOSÉ DOS CAMPOS, 2017a). During the last decades, the increase in urban population density required an increase in individual water connections per household (HOPE; ROUSE, 2013).

In 1949, sand mining was installed in the Paraíba do Sul River to supply the local construction sector and the Metropolitan Region of São Paulo (SECRETARIAT OF INFRASTRUCTURE AND ENVIRONMENT OF SÃO PAULO STATE GOVERNMENT, 2017). Although subsidies for environmental planning are consolidated around the Vale do Paraíba river basin (SECRETARIAT OF INFRASTRUCTURE AND ENVIRONMENT OF SÃO PAULO STATE GOVERNMENT, 2017), impacts such as agricultural area expansion, deforestation, changes in river channel morphology, and mining in protected areas (SANCHÉZ; SANTO, 2002) have become permanent elements of the territory and affected ecosystem services supply, especially water provisioning (FERRER *et al.*, 2021).

Sand mining in São José dos Campos was eradicated in 1991; however, in 2016, a mining dam in an upstream town broke up. This was due to the improper discharge of effluent by a neighbouring mining company, which exceeded the retention capacity of the dam (long out of operation) and affected the city's water catchment system. The accident caused the interruption of piped water supply for 75% of the population for more than 30 hours (G1, 2016) because of increased turbidity, iron and aluminium values above safe threshold (GEOGRAPHIC AND GEOENVIRONMENTAL INFORMATION SYSTEM OF THE PARAÍBA DO SUL RIVER BASIN, n.d.). As a result, 94% of the urban area population was affected (approximately 695,992 inhabitants in 2016), with 97.65% of this total served by the Paraíba Subsystem (MUNICIPAL GOVERNMENT OF SÃO JOSÉ DOS CAMPOS, 2017a).

Differences in urbanization processes in the inner city can help to understand the unequal distribution of social vulnerability. Costa and Mello (2010) described the urbanization process of different regions of São José dos Campos describing different subdivisions. The urban region was classified into five classes according to the average land lot size and the existence of essential infrastructures such as running water supply, electricity supply and paved streets:

- Classes were named A, B, C, D, and small farms, where Class A is the subdivision with the largest land lot size and the best infrastructure availability, and class D has the smallest land lot size and poor infrastructure;

- Class A includes properties in high-standard closed condominiums, both vertical and horizontal, that offer strong security and leisure amenities. This class predominates in the West and Central regions of the city;

- Class B includes intermediate - to high-standard vertical gated communities and predominates in the West and Central regions;

- Class C and D are located far from urban centres, usually in high-slope areas for social housing programs. These areas are characteristic of socio-spatial and economic segregation. This class predominates in the South, Southeast, East, and North regions, where urban density was low at implementation, with a predominance of vertical gated communities and low-income housing;

- Farms occur mainly in the West, North and Southeast regions. They are adequately served in infrastructure, security, and leisure needs.

2.2 GEOREFERENCED DATABASES

The cartographic databases of the municipality used for this work were obtained from the 2010 Brazilian Institute of Geography and Statistics Census data (IBGE, 2017). The location of public water supply connections was obtained from the Department of Water and Electricity (DAEE, 2017). The socioeconomic indicators were prepared from information in 871 census sectors in São José dos Campos provided by the 2010 Census (IBGE, 2017). We also supplementarily analyzed over 1,300 citizen comments made on the *Facebook* profile of the Municipality of São José dos Campos (PREFEITURA DE SÃO JOSÉ DOS CAMPOS, 2016). The data were considered to reinforce how the decisions made in composing the isolated SUWSVI variables affected the final results and correlated to the local sensitivity analysis (TATE, 2012). This social media is often used creditably by public authorities for quick communication. Besides being a popular and easily accessible application for citizens, the data are stored with a temporal record. For example, social media can serve to debate the water crisis or even to stimulate social awareness and mobilize social organizations against public management (FISCHER *et al.*, 2018). The emotional content of the manifestations was disregarded, seeking only the count and geolocation of the comment. Risk perception and facing are complex aspects to be reflected in social vulnerability indicators (FEKETE, 2012).

Evaluating pre-existing social, cultural, economic, and political conditions allows the assessment of the formation of value judgments about the severity and acceptability of water-related risks based on psychological, social, and cultural factors (FEKETE, 2012; RENN; BENIGHAUS, 2013; RUFAT *et al.*, 2015).

For the index's composition, we selected the census variables that best reflected the socioeconomic condition of the population and the subdivision into zoning classes in the region (COSTA; MELLO, 2010). The vulnerability was analyzed beyond the population's exposure and resilience to risk (ANAZAWA, 2012). This approach considers the dynamics of the territory and its social relations, treating the place of residence as a common resource, indivisible and highly relevant for the security and well-being of families. In other words, it is a social-ecological analysis in which territory is considered an enhancer of social inequalities. Examples are the occupations of protected natural slopes of the Atlantic Forest in the Serra do Mar and mangroves (ANAZAWA *et al.*, 2013). Social vulnerability is assessed as a result of the interactions between the availability of infrastructure, attributes of poverty and health risk, and factors related to environmental risk (BROUWER *et al.*, 2007; TELLMAN *et al.*, 2020).

We categorized variables to describe economic and social dimensions based on the Census data and elaborated variables and formulas for developing the SUWSVI index, presented in Table 1. To describe the economic dimension of vulnerability, we defined the variable "Average Income of Head of Household" (VEC1), which allows us to understand the impact of water purchasing on family income when the public network does not provide it. The lower the household income, the more difficult it is to face interruptions in the supply of public services since the purchase of water and containers significantly impacts household budgets. On average, a 20-liter gallon of water was R$ 5.00 (or US$ 1.28 2016/February). This price does not include the container's value which is returnable. According to the United Nations, each person needs 3,300 litres of water per month (about 110 litres of water per day) to meet consumption and hygiene needs; in Brazil, consumption per capita can reach more than 200 litres/day (MUNICIPAL GOVERNMENT OF SÃO JOSÉ DOS CAMPOS, 2017a). This translates to R$ 50.00/day/person, which is an expensive cost for a low-income family when it is considered that the national minimum wage was R$ 880.00 (US$ 225.82) per month at the time of the incident (BRAZIL, n.d.). To represent the importance of household income for vulnerability to shortages, we used the ratio between the census variable "Average Monthly Income Value of Persons Responsible for Permanent Private Households (with and without income)" (CENSUS1) and the census variable "Persons Responsible for Permanent Private Households" (CENSUS2), both obtained from Census data. The value of three times the national minimum wage in effect in 2010, R$ 1,530.00 (US$ 392.62) (BRAZIL, n.d.), was used as a reference to classify households in the low- and very-low-income brackets.

For the social domain, we define two variables. The first, called “Female Head of Household” (VSOC1), was estimated as the rate between the census variables “Woman Head of Family” (CENSUS3) and “Head of household, total and men” (CENSUS4). VSOC1 allows us to understand gender inequality in society and the labour market when an incident impacts the paid working day and burdens the woman’s daily domestic life. The second variable, called “Children and Elderly Dependent Ratio “ (VSOC2), was estimated as the proportion of the sum of the Census variables “Under 10 Years Old” (CENSUS5) and “Elderly People - Over 60 Years Old” (CENSUS6), with the “Total Number of Residents” (CENSUS7). VSOC2 allows us to understand the difficulty of the head of the family in obtaining water to supply the number of dependents (children and the elderly), and there is an interruption in the public water supply.

The selection of variables to calculate the SUWSVI attempted to understand the urban distribution of populations most affected by water scarcity in São José dos Campos. The variable “Female Head of Household” - VSOC1 was chosen considering women’s onerous and unequal social role in society and the labour market. The premise of the obligation of domestic work and childcare, insufficient public policies to facilitate the management of conflicting demands between home care and employment, combined with the low male participation in the division of unpaid work, had an impact on employment opportunities for women and mothers with dependent children and reinforced gender inequalities in the labour market (ANAZAWA *et al*., 2013; SORJ *et al*., 2007; TELLMAN *et al*., 2020). The variable “Children and Elderly Dependent Ratio” - VSOC02, reinforces the importance of VSOC01 because women are overburdened when an accident occurs. They stop their paid activities to normalize the situation at home and care for dependents. The dependents are the ones who spend most of the time inside the house and have a direct impact on the family’s ability to find water sources because, besides the need for greater volume and extra cost per person, they have the less physical strength and accessibility (in the elderly the mobility difficulty is implicit) to help in the transportation and loading (ANAZAWA *et al*., 2013; SORJ *et al*., 2007; WOOD *et al*., 2021). The justification for the variable “Average Income of Head of Household” - VEC01 is that it reflects the ability of the head of household to cover the household budget (ANAZAWA *et al*., 2013; SORJ *et al*., 2007; TELLMAN *et al*., 2020; VORMITTAG *et al*., 2018; WOOD *et al*., 2021).

Table 1 | Components used to calculate the Social Urban Water Shortage Vulnerability Indicator (SUWSVI)

Domain	*Variable*	*Indicator Estimate*
Economic	Average Income of Head of Household (VEC1)	CENSUS2 / CENSUS1
Social	Female Head of Household (VSOC1)	(CENSUS3 / CENSUS4).100
	Children and Elderly Dependent Ratio (VSOC2)	(CENSUS5 + CENSUS6) / CENSUS7

Source: Prepared by the authors (2018) based on 2010 Brazilian Institute of Geography and Statistics (IBGE, 2017) Demographic Census Universe data

We applied a linear transformation (Equations 1 and 2) to each defined variable (VEC1, VSOC1 and VSOC2), forcing a scale variation between 0 and 1 (ANAZAWA, 2012). This scaling allows the aggregation of the variables for estimating the Social Urban Water Shortage Vulnerability Index (SUWSVI). Linearly transformed variables were estimated so that values close to 1 represent larger vulnerability than values close to 0. Thus, as both social domain variables, VSOC1 and VSOC2, are directly related to vulnerability, the larger the variable, the greater the vulnerability, and linear scaling was applied directly (Equation 1). However, the economic variable, VEC1, is indirectly related to vulnerability, so the scale was inverted (Equation 2)

$$\mathrm{eV} = \frac{V_{ob} - V_{mn}}{V_{mx} - V_{mn}} \qquad \text{Equation (1)}$$

$$eV = 1 - \frac{V_{ob} - V_{mn}}{V_{mx} - V_{mn}} \qquad \text{Equation (2)}$$

Where:

eV = vulnerability scale

V_{ob} = Value obtained for the sector

V_{mn} = Minimum value observed between sectors for the indicator

V_{mx} = Maximum observed value between sectors for the indicator

After normalization (TATE, 2012), the SUWSVI value was obtained by calculating the average of the variables “Average Income of Head of Household” (VEC1), “Female Head of Household” (VSOC1), and “Children and Elderly Dependent Ratio” (VSCO2), thus establishing equal weights for each. Then, the spatial distribution of SUWSVI was obtained considering the polygonal geographical limits of each census sector. Seeking a product that allows simple and objective communication to decision-makers and the general public, the vulnerability ranges were estimated based on the distribution of SUWSVI values as follows: Very High (> 80), High (80-60), Medium (60-40), Low (40-20) and Very Low (<20).

3 RESULTS AND DISCUSSION

The estimated number of people per SUWSVI range revealed that 39% of the total population is in the SUWSVI Medium range, 24% are in low, 5% very low, 24% high, and 8% very high. Pondering the total result (FEKETE, 2012; TATE, 2012), most of the urban population of São José dos Campos suffered from water shortage within a context of ample water supply infrastructure. Although the interruption lasted only 30 hours, the vulnerability to the danger posed by perennial dams in the landscape is significant. The environmental recovery of closed mines has been limited to the simple stabilization of the physical environment, and these dams are permanently subject to the deposition of waste, which can reach the waters and endanger the surrounding population (MECHI; SANCHES, 2010). Like Sherbinin *et al*. (2019), who consider that vulnerability analyses highlight the underlying factors that put people and infrastructure at risk, mining dams were considered an ongoing risk in the region for the SWISVI study.

Spatial analysis of SUWSVI highlights the city’s unequal distribution of social vulnerability (Figure 2).

ISSN-e 2179-9067

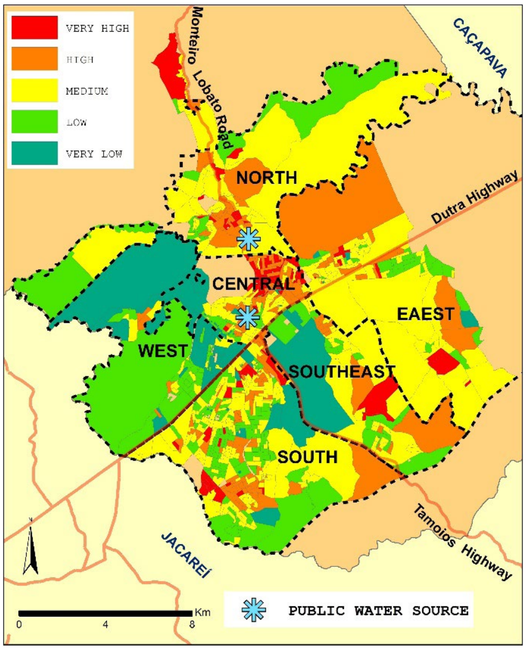

Figure 2 | Range Brackets of the SUWSVI – Social Urban Water Shortage Vulnerability Indicator, São José dos Campos, 2010

Source: Prepared by the authors (2018), based on 2010 Brazilian Institute of Geography and Statistics, Demographic Census Universe data (IBGE, 2017) and Municipal Government of São José dos Campos (2017a,b).

The distribution of the population by SUWSVI range in the administrative regions of the city (Figure 3) reveals that the South and Center regions have the largest number of people in the Very High SUWSVI range (> 14000), followed by the North region (> 7000). Approximately 80% of the population living in the South region are in the Low and Very Low SUWSVI range. The South region is the most populous. Input variables can be subjective and weighted, interfering with the result of vulnerability indicators (WOOD *et al*., 2021). To re-signify and validate the perception of social vulnerability by the distribution of census data, SWISVI was aggregated with the population density variables and occupation patterns by region. This is because social vulnerability is not a directly observable phenomenon, and since there is no device to measure it, its validation requires proxies (DE SHERBININ *et al*., 2019; TATE, 2012).

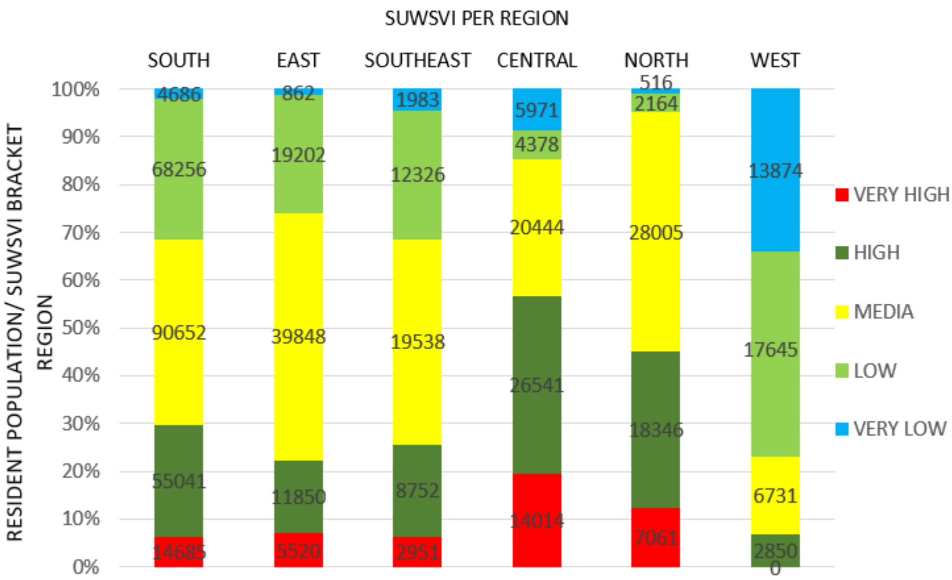

Figure 3 | Populational distribution by city region and SUWSVI

Source: Prepared by the authors (2018) based on Municipal Government of São José dos Campos (2017a).

SUWSVI shows significant differences between ranges and their regions of predominance. We sought to better understand this relation in the most affected census sectors by associating results with testimonies on the *Facebook* social network (PREFEITURA DE SÃO JOSÉ DOS CAMPOS, 2016). Quintslr (2018) also used media data to observe the social construction of the hydric crisis and demonstrate how the hegemonic discourse on the risk of shortages has contributed to keeping the issue of inequality out of decision-making spheres. It must be acknowledged that it was not possible to apply an appropriate multi-criteria analysis method (e.g. analytical hierarchy process AHP) (DE BRITO *et al*., 2018). However, this supplementary consultation was maintained to consider all intermediate manifestations around the accident and its intercurrences that would assist in interpreting the results.

The Central region has three isolated sectors with Very High SUWSVI (Figure 4). These sites are close to public parks that provide free access to potable groundwater sources. The deep wells of public parks helped with logistics in the Center region by supplying water from public sources (MUNICIPAL GOVERNMENT OF SÃO JOSÉ DOS CAMPOS, 2016).

At these places in the Central region, the “Female Heads of Household” (Figure 4a) and “Children and Elderly Dependent Ratio” (Figure 4c) are the most influent variables, meanwhile “Average Income of the Head of Household” (Figure 4b) has a low influence. These sectors comprise A- and B-class urbanization (COSTA; MELLO, 2010). Despite being relatively close geographically to the previous one, a second sector in the Central Region was more influenced by the “Average Income of the Head of Household” variable, which was the main driving influence (Figure 4b) for vulnerability. This is an Environmental Protected Area, named Banhado Permanent Preservation Area (MUNICIPAL GOVERNMENT OF SÃO JOSÉ DOS CAMPOS, 2017b), which has been occupied by a very low-income community living in non-regularized housing (MUNICIPAL GOVERNMENT OF SÃO JOSÉ DOS CAMPOS, 2017b).

Another Very High SUWSVI region appears in an agglomeration of sectors in the Central region (Figure 4), where B-type urbanization is identified (COSTA; MELLO, 2010). Units here are predominantly multifamily residences and commercial spaces, and the variable “Children and Elderly Dependent Ratio” (Figure 4c) is the dominant influence.

In comments on the social network *Facebook*, business establishment owners reported that they were without water all day after February 05, 2016 (the day of the dam collapse accident). They also said they had to close and suffered losses (PREFEITURA DE SÃO JOSÉ DOS CAMPOS, 2016). The development of new indices increasingly involves target populations with participatory approaches (DE BRITO *et al*., 2018).

In the South region (Figure 4), Very High SUWSVI values are found for a sector with the irregular occupation of private property by a very low-income community (BRAZILIAN INSTITUTE OF GEOGRAPHY AND STATISTICS, n.d.; MUNICIPAL GOVERNMENT OF SÃO JOSÉ DOS CAMPOS, 2017a). These values do not reflect conditions at the time of the study since census data was collected in 2010, and the area was unoccupied and returned to owners in January 2012, before the dam collapsed in 2016.

The area of Very High vulnerability located between the most important highways in the region, President Dutra and Tamoios routes (Figure 4), includes C-type urbanization and a mixed zoning area with the greatest diversity of uses in the municipality (MUNICIPAL GOVERNMENT OF SÃO JOSÉ DOS CAMPOS, 2017b). In this area, the vulnerability was chiefly influenced by the “Average Income of the Head of Household” (Figure 4b) and “Children and Elderly Dependent Ratio” (Figure 4c) variables. These are isolated sectors between fast-traffic roads and a planning zone which comprises empty plots and require a master plan for urban occupation in order to improve local mobility and territorial integration conditions. It also borders the Airport Zone, which makes access to the site difficult.

The South region has the highest number of comments on the *Facebook* social network about water shortages (PREFEITURA DE SÃO JOSÉ DOS CAMPOS, 2016). There, water supply for the local municipal school was used to aid the region during the crisis ("VAZAMENTO DE REJEITO DE MINERAÇÃO NO RIO PARAÍBA É CONTIDO EM JACAREÍ, SP", 2016).

The North, East and Southeast regions (Figure 2) have isolated pockets in the Very High SUWSVI range. In the North region, Very High SUWSVI values are found in one sector at the extreme end of the Monteiro Lobato State Highway and in C- and D-class urbanization in areas bordering rural area farms. At these places, the Average Income of the Head of Household (Figure 4b) is the most influential variable for high SUWSVI values. In the East region, the four sectors with Very High SUWSVI values were geographically dispersed but all close to the Presidente Dutra Interstate Highway. The "Average Income of the Head of Household" variable was also the chief contributor to the high SUWSVI values. A network of deep wells installed almost 30 years ago ensured no local shortages occurred in a planned neighbourhood, with A-class urbanization, built in the 1970s (COSTA; MELLO, 2010; PREFEITURA DE SÃO JOSÉ DOS CAMPOS, 2016), as reported in comments on *Facebook*. In the Southeast region, Very High SUWSVI areas are found in three recently expanded sectors located on a back-roads with C- and D-class urbanization (COSTA; MELLO, 2010). In the West region, where urbanization is mostly comprised of A-class and farms (COSTA; MELLO, 2010), no sector shows Very High SUWSVI values.

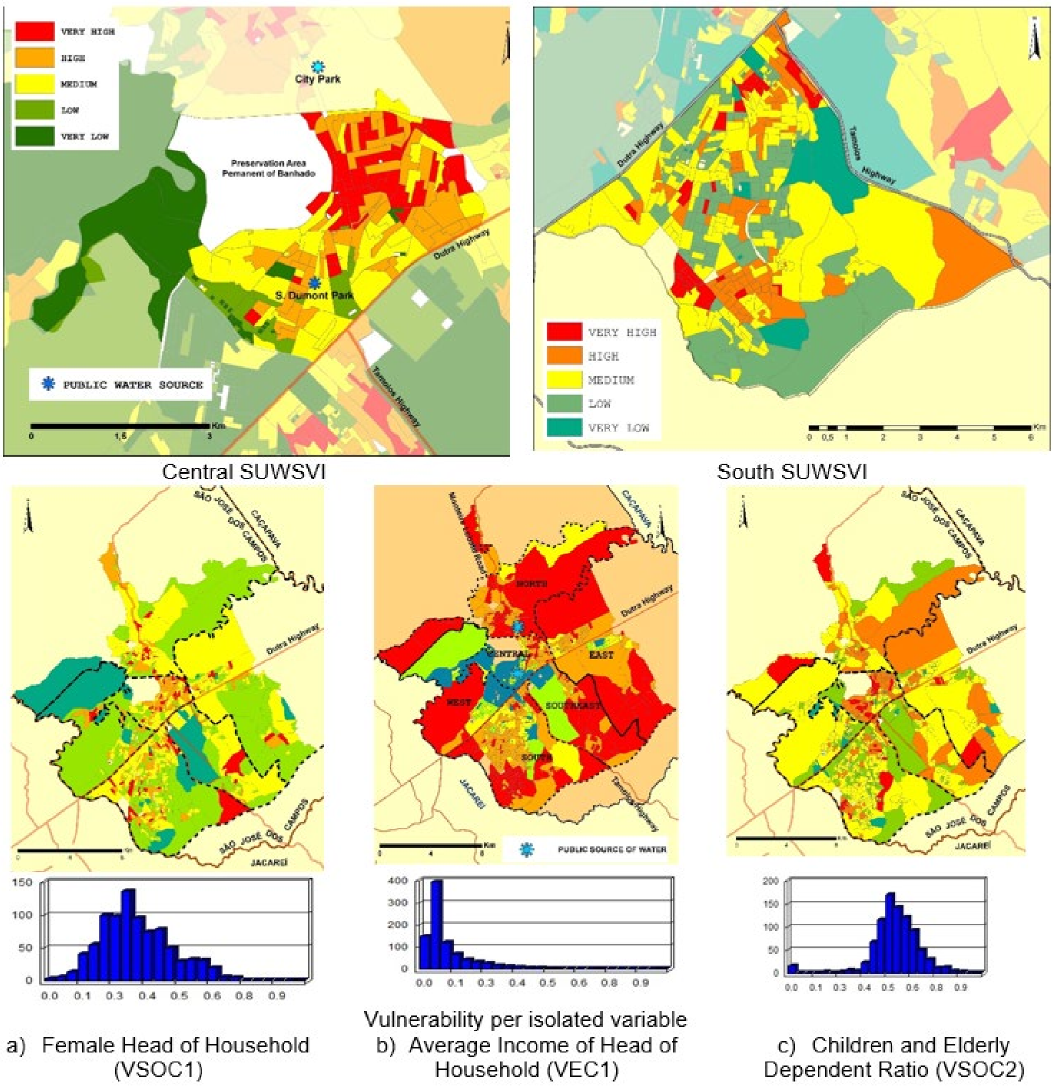

Figure 4 | Central and South urban regions and vulnerability per isolated variable

Source: Prepared by the authors (2018), based on 2010 Brazilian Institute of Geography and Statistics, Demographic Census Universe data (IBGE, 2017.) and Municipal Government of São José dos Campos (2017a,b).

Results show that "Average Income of the Head of Household" is the variable most likely to contribute to Very High SUWSVI values, followed by "Children and Elderly Dependent Ratio". The "Female Heads of Household" variable plays a secondary role. On the other hand, we do not overlook the importance of two other variables (Figure 4 a, c). Gender invisibility is evident because women solve the incompatibilities between the labour market and family responsibilities (SORJ, 2013). Moreover, the historical discrepancy in the sexual division of housework caused by difficulties in accessing water has resulted in public programs implementing cisterns prioritizing female-headed households, as they view them as better managers in water use (MEZA, 2017; NOGUEIRA, 2017).

4 CONCLUSIONS

The Social Urban Water Shortage Vulnerability Indicator (SUWSVI) was developed to analyze the social vulnerability of urban populations to occasional water shortage incidents. Our case study reveals that SUWSVI can capture the heterogenous vulnerability distribution in the city. The results show that 39% of the population has a medium vulnerability, mainly characterized by the lowest incomes and a larger number of dependents on this income. At the public management level, it helps the municipality to plan in which areas of the city it needs to act more quickly to reduce the impacts caused by water shortages. SUWSVI could be applied to the other adjacent municipalities with sand mining pits. Strategies to minimize vulnerability to water scarcity could be taken jointly among the municipalities, promoting public governance.

Besides this result, SUWSVI allows us to assess vulnerability distribution in the city and its relation to the population and the unequal urbanization process. It identified and mapped groups that faced challenges accessing water since it was not provided via public supply.

SUWSVI highlighted the city's social vulnerability to water shortages by plotting the combined values of social and economic variables. Because of its ability to identify economic, household, and mobility vulnerabilities of the populations, SUWSVI serves as a tool for planning and managing risks in accidents that interrupt the supply of drinking water for a long time in the city.

The Paraíba do Sul river valley has more than 200 km of sand mining dams, installed more than 70 years ago, which present a perennial risk for all the municipalities nearby. The perception of risk is contextualized in the scenario of urban social vulnerability to water shortage caused by the collapse of these dams because, in the acceleration of mining production, failures in the drainage of the dams or extreme rainfall accumulations could lead to an accident.

Inequalities within the city's territory affect water security differently. Areas of cities with greater and lesser access to services can present an important gradient in water security. Differences in social conditions and infrastructure lead to inequalities in quality of life, vulnerability, and social exclusion/inclusion. These inequalities must be identified to highlight vulnerability drivers and better guide public policies within the city.

Infrastructure accidents that interfere with collecting water for public supply are a potential risk for municipalities that coexist with sand mining dams. Notwithstanding the low severity of the accident, it served as a case study to evaluate local socio-environmental impacts and can be reproduced for cities in similar urban conditions. Economic rises can lead to increased mining activity, with consequent decreases in water security. SUWISVI sought to provide a holistic view of the system to give suitable alternatives for local public policies.

The multi-criteria approach and sensitivity analysis, combined with the use of GIS technologies and remote sensing, sought to collaborate in developing social vulnerability studies that assist in water security and benefit the population.

ISSN-e 2179-9067

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