https://doi.org/10.5194/nhess-2022-86
Preprint. Discussion started: 4 April 2022

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Water shortage: Assessment and Analysis on a Regional Scale

Yuri M. Macedo[1,2], Adriano L. Troleis[1], and Lutiane Q. de Almeida[1]

[1]Postgraduate Program in Geography (PPGE), Federal University of Rio Grande do Norte, P.O. Box 1524, Natal-RN, 59078-970, Brazil
[2]Federal Institute of Education, Science and Technology of Rio Grande do Norte, Macau-RN, 59500-000, Brazil

Correspondence to: Yuri M. Macedo (yurimmacedo@hotmail.com)

Abstract This paper aims to analyze the risk of municipal urban water shortage in the state of Rio Grande do Norte (RN) through the results of the Index of Water Shortage Risk (IRDH). The theoretical-methodological assumptions are based on Walle and Birkmann (2015); Almeida, Welle and Birkman (2016); Medeiros (2018); Oliveira (2018); Macedo et al. (2020 e 2021). In this context, the IRDH was structured in a systemic perspective, where the territories of water shortage risk were identified through environmental, social and economic, and state planning indicators, using 19 variables as instruments of analysis. The research was conducted qualitatively and quantitatively, evaluating and analyzing the risk of water shortage in RN and the 153 cities that compose the system of supply managed by the Company of Waters and Sewers of Rio Grande do Norte (CAERN), a state concessionaire (representing 92% of the 167 cities of the State), in its seven regions of water supply. The result of the IRDH of Rio Grande do Norte proved the relationship between the indicators in the water shortage problem in the State, classifying 49% of the analyzed cities in the classes of "high" and "very high" risk, which places them in a situation of higher attention regarding the potential damages derived from the water shortage, 40.5% of them being "medium" and 10% "low" risks, with no occurrences of "very low" risk examples. In absolute values, 1 city was classified as "very high"; 74 were classified as "high"; 62 as "medium"; and 16 were considered of "low" risk of water shortage. With the goal of reducing/mitigating the results of the IRDH in the State, a transposition of watersheds, integration of supply systems, hydrogeologic research, among others, were proposed.

1 1 Introduction

The water shortage in Rio Grande do Norte (Brazil) is a recurring problem, potentially affecting the majority of the 167 cities in the State, especially those located in the semiarid weather, which comprises the largest part of the state territory. In this context, the water shortage is characterized as a disaster for promoting "a grave interruption on the functioning of a society, causing general human, material, economic or environmental losses that exceed the capacity of the affected society of dealing with its own resources" (UNESCO, 2010). In this State, due to the drought that happened between 2012 and the first trimester of 2019, the Government renovated 12 times the decree of emergency that comprises 152 of its 167 cities (91%). Related to this, in March of 2017, 23 cities in the State were identified as being in a situation of hydric collapse by the state concessionaire of water supply (CAERN).

The collapse of municipal urban water supply is the objective result of the set of elements that characterize the water shortage: bankruptcy, exhaustion, temporary or permanent interruption of the water supply due to the lack/scarcity of the resource in its fountainhead, or infrastructure problems in the network. Specifically in the context of water shortage, it is vital to discuss the

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water scarcity, which is a problem in several regions in the world, affecting millions of people in all of the continents, as shown by the research Tzanakakis et al. (2020): (a) More than 2 billion people live in regions with high water stress, and this number is likely to increase; (b) more than 1 billion of people do not have access to potable, clean, and safe water; (c) around 3.4 million of people die each year due to the use of contaminated water; (d) millions of women and children spend several hours a day collecting water in an average distance of 6 km; (e) at any time, half of hospital beds in the world are occupied by patients who suffer of diseases associated with the lack of access or low quality of water for consumption. Both the collapse and the water scarcity, in the majority of the affected regions, are related to the periods of prolonged dry weather (drought), as well as the result of contamination of the fountainheads.

Therefore, there is an error of naturalizing the disaster, often intentionally with political aspirations, as denounces Raju, Boyd and Otto (2022), in a recent article titled: Stop Blaming the Climate for Disasters, in a criticism that says that "the disasters continue to be interpreted as an 'act of God' or described as 'natural'". The present article highlights the need of denaturalization of disasters, giving the role of the population/society in the center of the analysis: "Natural dangers such as floods, droughts and heat waves become disasters as a result of the social vulnerability, namely, a propensity of the people, society and ecosystems to be harmed" (Raju, Boyd and Otto, 2022). Furthermore, as pointed out by Pelling (2014), the "disasters are consequences of the sum of the failures in the development of a society", therefore, the studies that aim to evaluate and mitigate the risk of disasters are important tools in the management of this problem by the society.

Acting this way, it will be possible to acquire a proactive posture in the reducing of risk of disaster through the human and material dimension; therefore, aimed to the organized human measure in society and the role of the institutions in the management of the risk of disasters and not just in the reactive management of damages.

The object of discussion in this article is the analysis and evaluation of risk of municipal urban water shortage in a state level, using as case study the State of Rio Grande do Norte, Brazil. The elaboration of the Index of Water Shortage Risk (IRDH) took place through the methodology used by Almeida, Welle and Birkmann (2016) and of the works of analysis of socioenvironmental risk, using a system of indicators with categorized and pondered variables, resulting in a synthesis index, as in Medeiros (2014 and 2018); Macedo (2015); Welle and Birkmann (2015); Almeida, Welle and Birkmann (2016); Oliveira (2018); and Macedo et al. (2020 e 2021).

The production of indexes has configured a fundamental methodology in the evaluation studies of risk of disaster. One index regarding the topic of water resources that is highlighted is the WSI - Water Stress Index (Falkenmark and Lindh, 1974) as "one of the first integrated evaluations among water resources and population in the Third World Population Conference in Bucharest in 1974" (Damkjaer and Taylor, 2017). Subsequently, the organization works were produced, such as the Intergovernmental Panel on Climate Change (IPCC, 2007 and 2012) and the Aqueduct 3.0 platform from World Resources Institute (WRI) "which analyzed several hydrologic models and calculated the amount of water removed from the superficial and underground supplies available in each region of world in comparison to the total of water available" (Cajazeiras, 2020).

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In Brazil, the works regarding climate vulnerability to the drought phenomenon, produced by the National Institute of Spatial Research (INPE, 2007 and 2015), and regarding indicators of vulnerability to the drought (Rosendo, 2014; Rosendo et al, 2017) are highlighted. Regarding water supply, the thesis of Castro (2010) brings a functional analysis of the infrastructure and metropolitan water supply quality of Rio de Janeiro. Also, in Rio Grande do Norte, Troleis and Silva (2018 and 2019) proposed a methodology of territorial vulnerability to the collapse in the water supply. Besides these, Diniz (2019) published a paper regarding the vulnerability to water shortage in Campina Grande (Paraíba), albeit with only 4 variables/indicators. It is important to highlight that the works cited differ from the object of this article for its higher or lower scale of analysis, methodological proposal and focus of analysis.

In turn, in this article, the availability of the underground fountainhead, its vulnerability to contamination and the capacity of municipal water storage are among the variables that compose the IRDH. The index of integrated risks proposed present variables related to the natural environment, technical objects of infrastructure, social and economic characteristics and of institutional planning. The results of this research were directed by the hypothesis that the relationship between environmental, infrastructural, social and economic, and state planning factors, materialized in the space, produce territories with water shortage risk. These factors were analyzed through variables, and, posteriorly, related among themselves in a general index, the IRDH (Index of Water Shortage Risk)

2 Field of Study

The field of study of this research comprises of 153 cities of Rio Grande do Norte (RN) supplied by the concessionaire of water supply of Rio Grande do Norte (CAERN). According to the last census of the Brazilian Institute of Geography and Statistics (IBGE, 2010), the total urban population of these cities is 2,320,149 inhabitants. The remaining 14 cities of RN, which are supplied by autonomous systems ministered by each city hall, totaling 167 cities in the State, were not contemplated in this analysis due to the absence or precariousness of availability of data.

In this context, the State has a total of 3,479,010 inhabitants, being the 16th most populous in Brazil, with a demographic density of 60 inhabitants/km², the 10th densest in the country. Based on the last Brazilian demographic census (IBGE, 2010), the RN population is spread in rural, with 703,036 inhabitants (22%), and urban, with 2,464,991 inhabitants (78%) spaces. According to the classification methodology of IBGE (2010), the population agglomerations in the state territory are located in the urban parts of the cities, and it is observed that Natal, the State's capital, carries out a centrality over the population density of RN. Around the capital, in the East coast and its proximities, the population is denser than the State's average, presenting several areas with more than 100 inhabitants/km². In turn, Natal presents the highest population density in the State, with more than 500 inhabitants/km². It is important to note that this class of demographic density (more than 500 inhabitants/km²) is only observed in the urban areas of few cities of the State, mostly in the most populated ones after the capital, such as Mossoró, Parnamirim, and Caicó.

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Regarding the natural characteristics of the State, Rio Grande do Norte presents a semiarid climate in the largest part of the territory (Diniz and Pereira, 2015), which brings 7 to 8 months per year of dry weather, with a rainfall average of 600mm/year (Figure 1). In this context, a dense technical infrastructure is necessary to be installed in the state territory in order to promote the municipal urban water supply, working continuously throughout the year.

The Figure 1 characterizes RN as having the largest part of its territory with a semiarid climate, which contributed to, between 2012 and 2017, the occurrence of the longest period of dry weather registered in the last 100 years. This climate phenomenon occurs due to different factors. Among them, there is the influence of the continentality of the region and the prominence, which favor the precipitation in the windward and drought in the leeward of the plateau of Borborema, presenting low regular rainfall indexes (Diniz and Pereira, 2015).

Besides the climate condition, the State's countryside is located, in its largest part, above the foundation of igneous and metamorphic crystalline rocks, which limits the access to the underground water by the population due to the characteristics of low availability and quality of the fissure aquifer, classified as "very low" in regards to the hydro and geologic potentiality (Pfaltzgraff et al., 2010), affecting directly the municipal urban water supply.

In this context, the geology in the State of Rio Grande do Norte (RN) has two great geologic structures: the Potiguar Sedimentary Basin (which comprises the whole area of sedimentary rocks in the territory of the State: Potiguar Basin and Pernambuco-Paraíba Basin) and the Crystaline Complex. The former is a sedimentary structure, a product of the marine regression and of events of modern or neotectonic continental elevation, consistent in rocks with low to medium degrees of hardness, with limestone and sandstone of Mesozoic and Cenozoic ages. The latter is a complex of igneous and metamorphic rocks, with medium to high degrees of hardness, being intensely folded with cracks and tilting. This crystalline complex is the geologic foundation of the Potiguar Sendimentary Basin mainly presenting a Precambrian age (Ibdem).

Referring to the relation with the water supply, the crystalline complex with fractured rocks can supply water in the fissure aquifer system, albeit with low outflow and quality. Due to is low general permeability, this is an important structure for superficial water storage, where the largest part of the dams in RN are located. The Potiguar Sedimentary Basin has different characteristics, which presents a lot of potential for water supply through the underground captures. However, because they are porous and permeable sedimentary formations in its majority, they are not very suited for dam usage. At the same time it presents lakes that are propitious for capture, it also has systems of associated water supply networks, such as the Boqueirão de Touros Lake and the lake complex of Bonfim, in Nisia Floresta.

Relating the climate with the geology of RN, the most important elements of the natural dynamic for the IRDH, it is possible to classify the most vulnerable units to this disaster. For example, the Potiguar crystalline aquifer associated to the semiarid climate increases the natural vulnerability to water shortage, which hinders the underground (in quantity and quality) and superficial water usage due to the low volume of rain in 10 months of drought, inherent behavior of this type of climate. In turn, the semiarid climate in the East coast of the State, associated with the Barreiras aquifers (sedimentary basin), increases the possibilities of water capture, both in the underground and superficial fountainhead, since the high level of rainfall (more

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than 1000mm of annual average), permeability and capacity of storage of the Barreiras aquifer reduce the vulnerability to water shortage in this region of the State. The climatic and geologic configuration of RN can be viewed in Figure 2.

3 Methodological and Theoretical Referential

The water shortage can persist even after the reestablishment of normal average rainfall quantitative, since, as cited by Hohenthal and Minoia (2017), “the drought is a creeping phenomenon whose impacts extend to large regions and accumulate themselves while the drought proceeds, in such a way that they might still be felt after the meteorological phenomenon that started the drought disappeared.” Therefore, this problem leads us to differentiate two types of droughts: climatological and hydrological. The former refers to the lower than the normal average rainfall levels of a determined period of a region, and the latter is inherent to the water insufficiency of rivers and/or reservoirs in meeting the existent demand in the region, “possibly resulting in a climatological drought or managing problems of the water resources” (Campos and Studart, 2001).

As a solution and/or mitigation of the water scarcity, a discussion emerges regarding the water safety in the studies of this kind of risk of disaster. As Paungartten and Costa (2020) explain, this topic presents multiple aspects: measurable approaches, such as those that measure the water stress; water safety through alimentary needs – alimentary safety; and planning and management policies of the water resources (governance of water). They also associate water safety to the natural risks. Therefore, this last approach is more applicable to the research of this article, especially due to the importance of the climatological drought in the context of water shortage in a semiarid region of Brazil, climate condition of the largest part of the territory of Rio Grande do Norte.

Conceptually, this article discusses risks of disasters (risk of water shortage), understood as a function between danger and vulnerability. In this way, the concepts of risk, danger and vulnerability were defined as starting point for the theoretical and methodological conception of this work.

The study of this topic in Geography has its first highlighted works around the 1920 decade, with Gilbert F. White, alongside Ian Burton and Robert W. Kates, geographers of the traditional School of Chicago (USA), through the production of studies, conceptions and concepts around the “Natural Hazards”, (Marandola Jr. and Hogan, 2004). In the beginning, the studies were focused in the understanding and control of the natural phenomenon related to the disasters. A problem derived from this perspective is the naturalization of the disasters. As Quarantelli (1998, apud Sales and Almeida, 2019) points out, they are put as a product of the dynamic of the environment, where the disaster is seen as a punctual event, but the risk and its management are a procedural condition, in other words, it is connected to the human accountability. In turn, for Saavedra and Marchezini (2020), the disaster is a result of a process of risky social production. The risk (and its management) is the dimension that is somewhat possible to be known, analyzed and controlled through the measures of mitigation.

In this context, the concept of Risk used in this article is defined through a function between social vulnerability and the natural dangers of a local: $R = f(P, V)$ - R = Risk; P = Danger; V = Vulnerability. Therefore, it is important to keep in mind that the

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need to understand both the dynamic of the environmental elements – natural and artificial (the water infrastructure also applies here) – that compose a territory, as well as the social conditionings that expose the individuals to a risky situation.

According to Veyret (2007), the risk is a social construction and it is directly connected to the conception of the population in regards to some potential danger of physical damages and/or material loss of great amount. In turn, danger is a potential threat to the people and their goods, while risk is a probability from the occurrence of a danger and of generating loss. (Smith, 2001, p. 392). Regarding vulnerability, it results from the capacity of each individual when it comes to "the resistance or capacity of dealing and recovering oneself from the impact of a natural danger" (Blaikie *et al.*, 1994, p. 9). In this perspective, the vulnerability is understood as a condition of susceptibility to some event that potentially causes physical and material damages to the resident population.

In this context, the environmental, state planning, and social and economic indicators that compose the IRDH were defined through the studies of risk of disaster such as the Intergovernmental Panel on Climate Change (IPCC, 2012), United Nations International Strategy for Disaster Reduction (UNISDR, 2009); Macedo (2015); Medeiros (2018); Oliveira (2018), as well as through the propositions of managers and technicians connected to the water supply of the State. They allowed for the production of a systematic index that comprised 19 variables inherent to the exposition, capacity of coping and adaptation of the population of the studied region in what concerns the municipal urban water shortage in RN.

The definition of the weights for each variable was adjusted through a technical consultation carried out both with engineers and technicians of the Water Resources Secretary of RN (SEMARH), as well with the water supply concessionaire (CAERN), professionals responsible for the sectors of state water supply. The weighting in studies of risk of disaster is present in works such as: Welle and Birkmann (2015); Almeida, Welle and Birkmann (2016); Medeiros (2018); Oliveira (2018).

3.1 Methodological Procedures

After establishing the weight of each variable and indicator in the sample, the weighted arithmetic average was applied, which allowed for two indexes, one that specifically represents the Average per Indicator (MI), and another one that represents the general result of the Index of Water Shortage Risk (IRDH). The acquisition of two indexes can be identified in the Equations 1 and 2. In Equation 1, we have the Average per Indicator (MI):

$$MI = \frac{\sum_i^n (V_i \cdot PV_i)}{\sum_i^n PV_i}$$

Where i – First variable; n – Last variable; V_i – Result obtained for the ith variable of a specific indicator; PV_i – Weight that refers to the respective variable obtained in the data collection of the research.

The categorization of the variables was associated with the weight of each one inside an indicator in a way that the sum of the weights of each variable is equal to the quantity of variables of the indicator. The Average per Indicator (MI) has the goal of establishing an index, giving a diagnostic of the situation of the referring city to each indicator. Furthermore, this value will be used to determine the general index of the IRDH, using the Equation 2.

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$$IRDH = \frac{\sum_j^n (MI_j \cdot PI_j)}{4}$$

Where j – First indicator; n – Last indicator; MI_j – Result of the Equation 1 for the jth indicator; PI_j – Specific weight of the respective indicators. The result of the IRDH consolidate in a single parameter the risk of water shortage in each city, since it considers all of the variables and indicators collected in the study. Another important aspect in the composition of the index was the categorization of data of each variable in five categories: Level 1 – Very Low Risk; Level 2 – Low Risk; Level 3 – Medium Risk; Level 4 – High Risk; and Level 5 – Very High Risk.

The process of spatialization of the IRDH was possible through the urban city data collection referring to the indicators that compose the index (Environmental; Infrastructural; State Planning; and Social and Economic) attached to the city polygonal georeferenced in a S.I.G environment. – System of Geographical Information, which allowed for the production and analysis of the IRDH results. In this context, it is necessary to detail the indicators and its variables, its weighting and basis.

Respecting the sequence of organization of variables, there is the environmental indicator, with the second highest weight inside the Index of Water Shortage Risk of Rio Grande do Norte, with a value of 1.0. Its importance resides, especially, in the exposition and susceptibility of cities to water shortage, and, therefore, affects directly in the increase or reduction of the municipal risk for this disaster.

The variables that compose this indicator are, in order of importance in the weighting: V1) Average outflow of the wells; V2) Natural superficial water bodies in the city; V3) Predominant climate type in the city, and V4) General vulnerability of the underground fountainhead of municipal water supply (GOD index). The categorization of the variables, its weighting and justification can be viewed in the Tables 1, 2, 3 and 4, representing, respectively, the following indicators: Environmental, Infrastructural, State Planning, and Social and Economical. Where (P) – Weight of the Variable; and P (I) – Weight of the Indicator

The V1 and V2 variables have more importance in the environmental indicator, both with weight 1.25, since both the underground and superficial fountainheads are immediate alternatives to water supply in case of shortage by water pipelines (transposition of river sheds) with capture in fountainheads outside the city. In sequence, there are the V3 and V4 variables, with weight of 0.75, and even being the strong semiarid climate (N5), the city can have availability in the underground fountainhead or large dams resistant to long periods of dry weather. In regards to the vulnerability to contamination of the underground fountainhead, it can be high (N4) or extreme (N5) and not have large sources of contamination in the city, or even have Water Treatment Stations (ETA) with methodologies capable of improving the quality of the water to adequate levels of potability based in the decree of the Health Ministry nº 2,914 of December of 2011, and CONAMA 357/2005 and 396/2008 resolutions.

In turn, there is the infrastructural indicator, with the highest weight of the IRDH (1.75). In this indicator, the “way of municipal urban water supply (type of capture)” variable is a fundamental parameter for the evaluation of risk of water shortage, having the largest weighting in the indicator. The variables that compose this indicator are, in order of importance in the weighting: V5) Type of capture; V6) Capacity of the cities’ reservoirs; V7) Time of installation of the urban water supply network; V8)

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Constructive material of the network of water supply; V9) Existence of sewage treatment and waste collection in the city; V10) Percentage of households supplied by piped water in an urban environment. The categorization of the variables, its weighting and justification can be viewed on Table 2.

The variable V5 has the highest importance in the infrastructural indicator, with a 1.5 weight. In sequence, there are the V6, V7, and V8 variables with 1.0 weight. The V9 and V10 come next with 0.75 weight in the indicator. In this hierarchy, there are three scales of importance of the variables, where the type of capture is highlighted, since it is fundamental for the safety of the municipal water supply, reducing directly the IRDH (or increasing, depending on the result). The variables with 1 weight have secondary importance, since they interfere in the availability of the structures of urban storage and distribution of water, which can hamper or preclude the water supply. In turn, the variables with 0.75 weight respond to the existence (or not) of structures of sewage and waste treatment that increase the possibility of contamination and to the proportion of households supplied by piped water reflecting directly in the vulnerability of water shortage of the population.

The indicator State Planning has intermediate weight in the IRDH, with a value of 0.75 The variables that compose this indicator are: V11) Occurrences registered in the collapse of the city's urban supply in the last 6 years of drought; V12) Existence of a municipal plan referring to the water supply; V13) Structural measures for the reduction of risk of shortage; and V14) Risk management of shortage in the city. The categorization of the variables, its weighting and justification can be viewed on Table 3.

The variable V11 has higher importance in the State Planning indicator, with 1.5 weight, followed by variables V12, with 1.0 weight, V13 and V14, both with 0.75 weight. Of the three levels of importance of the variables, the occurrence of the collapse is highlighted, interfering directly in the result of the IRDH. The variable that comprises the existence of a municipal plan of water resources or sanitation is seen as an important instrument of planning in order to mitigate or reduce the risk of type of disaster. Lastly, the variables with the lower 0.75 weight represent the existence, or lack thereof, of structural works for the reduction of risk of water shortage (V13) and of institutional bodies responsible for the management/reduction of this type of risk (V14). These last two variables contributed for the reduction of the risk, since they increase together the capacity of coping and reduce the exposition of the population to the risk of water shortage.

The Social and Economic indicator is the one with the lowest weight in the IRDH, with a value of 0.50. The variables that compose this indicator are: V15) Quantity of urban inhabitants of the cities; V16) IDHM – Income (income per capita of the population, namely, the average monthly income of the individuals in the city); V17) IDHM – Education; V18) Level of coverage of income transfer program (Bolsa Família); and V19) Gini Index. The categorization of the variables, its weighting and justification can be viewed on Table 4.

The variable V15) has higher importance in the Social and Economic indicator, with 1.5 weight. The larger the quantity of urban inhabitants exposed to the water shortage, higher the risk of this type of disaster, which increases the prognosis of material damages, thus affecting directly in the result of the IRDH.

The variables of weight 1 (V16 and V17) have secondary importance in the indicator, since they interfere in the susceptibility, capacity of response, and adaptation from the population in regards to the shortage. The characteristics of income and education of the population exposed to the risk of disaster are very common variables in studies of risk, since they are characteristics that can reduce the risk through the increase of the capacity of coping, recovering and resisting disasters, as well the increase of its resilience.

Lastly, the variables V18 and V19, with lower weight (0.75), represent tertiary characteristics (indirectly affecting the result of the IRDH) in the Social and Economic indicator, since social inequality (V19), the higher it is, the more it reduces the potential of resisting the disasters, as well as it increases the quantity of areas that are susceptible to the dangers. The opposite is true for V18, since, the higher the coverage of assistance programs such as Bolsa Família, the more resistance and capacity of recovery there are from the population in regards to disasters.

4 Results and Discussion

In Rio Grande do Norte, the regions of water supply Seridó and Alto Oeste Potiguar are historically the most problematic when it comes to water safety in the State. In the last period of prolonged dry weather (six years, between 2012 and 2017), these two regions were the ones that presented the highest quantity of cities in water collapse or supply rotation, according to the informative of the situation of supply of the concessionaire (CAERN, 2018 and 2019).

The Figure 3 shows the result of the 19 variables, organized by indicators. They are, in sequence: variables 1 through 4 – Environmental indicator; 5 through 10 – Infrastructural indicator; 11 through 14 – State Planning indicator; 15 through 19 – Social and Economic indicator.

4.1 Environmental Indicator

The further a city is from the coast, the more it finds itself in a semiarid climate. This type of climate increases the vulnerability and the risk of shortage related to the Environmental indicator. In the East coast, aside from the propitious geological conditions to underground water exploration, the climate is humid and tropical, which contributes to the recharge of the aquifer.

The Figure 4 shows the result of this indicator, which, among the 153 analyzed cities, 52 of them presented a “very high” risk level (34%) and a total of 307,995 inhabitants (14%); 51 presented a “high” risk level (33%), totaling 279,102 inhabitants (12%); 21 presented a “medium” risk level (14%) adding up to 136,408 inhabitants (6%); 17 cities presented a “low” risk level (11%) and 190,088 inhabitants (9%); and, finally, 12 cities presented a “very low” risk level (8%) and 1,332,633 inhabitants (59%).

The classification of “very low” risk has the lowest quantity of cities, but the highest quantity of inhabitants. This happens because the most populous cities in the State are in this category, such as Natal, Mossoró and Parnamirim, which have environmental characteristics that are less vulnerable to water shortage. There are in these cities good conditions (quality and quantity) of portability of the underground fountainhead, besides the uncountable superficial water bodies, characteristics that are inherent to two of the four variables that compose the Environmental indicator.

In regards to the “very high” and “high” categories, they have a higher quantity of cities, totaling 103 (67%) and reaching 587,097 urban inhabitants which represents 26% of the population. They reveal some problems in the state territory regarding the environmental characteristics that increase the risk of water shortage.

Specifically, the cities classified as “very high” risk for this indicator presented strong influence of the climate type and presence of the fissure aquifer located over the Potiguar crystalline, which reduces the water availability, both superficially as well as underground. A different situation occurred in the cities that presented “medium”, “low”, and “very low” levels of risk. They presented perennial water bodies (V2) in their territories, a variable with a higher weight in the indicator (1.25), as well as a less severe climate type (V3 – 0.75 weight) in the cities next to the coast, which reduced the general result of the risk for the Environmental indicator.

Through the analysis of the results, it was also possible to conclude that all of the cities with “very high” risk have low outflow of the wells (V1 – 1.25 weight), which put them in the most elevated level of risk for this variable. Another aspect is that the cities with the risk result being “high” and “very high” do not have superficial or just intermittent water bodies (V2 – 1.25 weight). They also have a semiarid type of climate (V3 – 0.75 weight). The vulnerability to contamination of the underground fountainhead (V4 – 0.75 weight) is high or very high in these cities due to the lithology of the crystalline type, which increases the risk of contamination. The cities with less vulnerability (“medium”, “low” and “very low” levels of risk for the indicator), in the majority of the cases, have less water bodies in their territories (V2) and a medium and mild semiarid type of climate (V3), humid or semi humid.

4.2 Infrastructural Indicator

The result of this indicator in the State can be analyzed through the influence of more than a thousand kilometers of water supply networks that permeate Rio Grande do Norte, bringing water to the cities for up to 315 km of extension. One example is the case of the Monsenhor Expedito network, which supplies 30 cities and serves approximately 265,040 inhabitants, with main capture in the Bonfim Lake, city of Nisia Floresta. Besides this water supply network, others that stand out are the Alto Oeste system, with its two subsystems (with capture in the Santa Cruz do Apodi and Açude Pau dos Ferros dams), which will supply 27 cities when their total operations initiate. Another important network system is the Sertão Central Cabugi, which serves 8 cities in the central region of the State, capturing water of the Barragem Armando Ribeiro Gonçalves dam, and serving approximately 47,527 inhabitants. Generally speaking, 81 cities are supplied by water supply networks, either exclusively or mixed (alongside wells), therefore 53% of the analyzed universe and 70% of the population. The Figure 4 shows the configuration of this indicator in the State.

The Infrastructural indicator of the IRDH presented 43 cities with “high risk” (28%), totaling 226,050 inhabitants (10%); with “medium” risk, 79 cities (51%) and 444,661 inhabitants (20%); with “low” risk, 30 cities (20%) and 1,373,059 inhabitants (61%); and with “very low” risk, with only 1 city (1%) and 202,456 inhabitants (9%). It is important to note, however, that the classification of “low” risk has only 30 cities, but the highest number of inhabitants. That is because the two most populated cities in the State are in this category, namely Natal (803,739 inhabitants) and Mossoró (237,241 inhabitants). Next, the “high”

https://doi.org/10.5194/nhess-2022-86
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and "medium" categories have a higher quantity of cities, totaling 122, with 670,711 urban inhabitants in these two categories, in other words, 61% of the cities and 30% of the population, revealing the problems of the state territory regarding the water infrastructure that increase the risk of shortage.

The analysis of the results allowed for the conclusion that the variable V5 – Type of capture is determinant, since a lot of cities of the State are supplied by local dams and by tubular wells in the Potiguar crystalline, in small intermittent alluviums, especially in the regions of Seridó and Alto Oeste Potiguar, which increase the risk of shortage for the Infrastructural indicator. Furthermore, the largest part of the cities of the State presented "very high" and "medium" risks for the city sewage treatment indicator (V9 – 0.75 weight), not having available a sewage treatment station and/or with problems of final destination of the urban solid residues (landfills). This is a fundamental problem for the risk of shortage in the State, since it leads to the increase of vulnerability to contamination of its fountainheads in all of the regions of water supply.

Another variable that contributed for the increase of shortage risk was V7 – Time of installation of the water supply network (weight 1), which presented in 107 cities (of the 153 analyzed in the State) a urban water supply system that is more than 30 years old, putting them as Level 5 risk, namely, the "very high" risk category.

In what concerns the variable V6 – Capacity of the reservoirs (weight 1), the majority of the cities of the State were classified as "high" risk, when there are reservoirs with low capacity, between 50 and 250mm³, in the cities, which reduces the capacity of water storage for the supply of the urban population of the cities in prolonged cases of dry weather or other dangers that affect the water supply. Thus, these three variables, alongside the variable V5, increased the general risk of the cities for the Infrastructural indicator, which, in the scale among the variables, led the result to be "medium" and "high" risk for the majority of the cities in the State.

On the other hand, in the variable V8 – Constructive material of the distribution network, weight 1, the majority of the cities of the State presented "very low" and "low" risks, showing that the network of water distribution of the State presents materials of good quality and resistance, such as PVC tubes, for example. In the variable V10 – Percentage of cities supplied by piped water in an urban environment, weight 0.75, the largest part of the state territory was classified as "very low" risk, which, through the scale between the variables of the indicator, reduced the result of the IRDH for the Infrastructural indicator, not having cities classified as "very high" risk for example.

4.3 State Planning Indicator

The result of the risk of water shortage inherent to this indicator was that the majority of the cities presented "medium" risk in the largest part of the state territory, followed by "high" and "very high" risks, with none being classified as "very low" risk. The Figure 4 also shows the spatial configuration of the State Planning indicator in RN.

In this Figure, it is possible to see that the State Planning indicator presented "very high" risk in 29 cities (19%), totaling 164,223 inhabitants (7%). 61 cities (40%) were classified as "high" risk, totaling 223,879 inhabitants (10%); with "medium" risk, 60 cities (39%) and 614,688 inhabitants (28%); with "low" risk, 3 cities (2%), 1,243,436 inhabitants (55%); and no city with "very low" risk. It is worth noting, however, that the classification of "low" risk has 3 cities only, albeit it also has the largest number of inhabitants. That is because the most populated cities of the State are in this category, namely, Natal, Mossoró, and Parnamirim. In turn, the categories "medium" and "high" have a larger quantity of cities, totaling 121, with 838,567 urban inhabitants in these two categories, showing the problems of the state territory regarding the state planning, which increases the risk of shortage of the general IRDH of RN.

The variable V11 – Occurrences of water supply collapse, weight 1.5, which refers to the last period of dry weather (2012-2017), is the most important for the increase of general vulnerability of the indicator. This variable in the state presented the regions of Seridó and Alto Oeste Potiguar with more occurrences of cities that registered collapse in the last period of prolonged drought.

Furthermore, the variables V13 – Structural measures to reduce the risk of shortage, and V14 – Risk management of shortage in the city (Civil Defense, responsible decree, etc.), both with 0.75 weight, resulted in "high" and "very high" risks for the absolute majority of the cities in this region and in the State as a whole. This result suggests that there are no options of backup fountainheads, construction works in progress or projects of improvement for the supply system (V13) in these cities. There is also no structured civil defense with workers, equipment and alert systems with plans of contingency and/or monitoring for the reduction of risk of disasters (RRD), which leads to the increase of the V14 variable's level of risk. These two variables, alongside the variable V11, taking into consideration the weights in the indicator, were decisive in the State planning and in the general result of the index.

On the other hand, the variable V12 – Existence of municipal plan regarding water supply (sanitation plan, etc.), weight 1, has the largest part of the cities with "medium" and "low" classifications in the State. This result occurs because the cities are either planning their sanitation plans (medium risk) or already counting with a sanitation plan (low risk), with the measures of water supply to be implemented in a short, medium, and long term.

4.4 Social and Economic Indicator

The Social and Economic indicator of the State was built through the level of income transfer program coverage, education and income IDHM, quantity of urban inhabitants, and Gini index variables. The result of this indicator is influences, mainly, by the variables V15 – Quantity of urban inhabitants, which have higher weight in the indicator (1.50), V16 – Income IDHM and V17 – Education IDHM, both with weight 1.0.

Through Figure 4 and the collected data in the research, it is possible to conclude that 52 cities (34%) have "high" risk level for the Social and Economic indicator, totaling 1,624,894 inhabitants (72%), 97 have "medium" risk level (63%) with 613,938 inhabitants (27%), and 4 cities (3%) have "low" risk level, with 7,394 inhabitants (1%), approximately. No city was classified with "very high" or "very low" risk. With this, the higher quantity of inhabitants is in the "high" risk class, showing the influence of the variable V15 – quantity of urban inhabitants in which the most populated cities in the State (Natal, Mossoró and Parnamirim) are located.

In this context, the variables V16 (Income IDHM) and V17 (Education IDHM), both with weight 1, had results of "high" and "very high" risk in the majority of the cities of the State, which contributed for the general result of the indicator. The level of risk of these variables shows that the problems that the State has regarding the access to education and the availability of income of the inhabitants, which is fundamental to resist, cope and recover in case of disaster, such as in a water shortage situation.

Differently, the variable V15 – Quantity of urban inhabitants had risk result classified as "medium" in the majority of the cities, where the urban population is between 2,500 and 60,000 inhabitants. Only Natal fits in the "very high" risk class for this variable for being the city with the largest population of the State (803,739 inhabitants). Due to its larger weight for the Social and Economic indicator, the result of this variable was determinant for the spatialization of the indicator in the State.

Still regarding the results obtained for the State, the majority of the cities presented "medium" social inequality, which was confirmed through the spatialization of the Gini index (V19, 0.75 weight). Lastly, there is the variable V18 – regarding the level of coverage of the program Bolsa Família, weight 0.75, which, in RN, has the largest part of the cities with a "medium" risk, when 25 to 50% of the population is assisted by the program. However, 17 cities, most of them located in the Seridó region, presented a "high" level for this variable, which increased the level of risk for the Social and Economic indicator.

4.5 Index of Water Shortage Risk of Rio Grande do Norte (IRDH-RN)

The IRDH-RN presents a relevant result in the research, since, besides drawing attention to the risk of water collapse in the regions of the State, it also proposes a discussion regarding the measures that must be taken when it comes to the integration of systems, research for underground fountainheads, and investments in water infrastructure, such as construction of larger reservoirs, and renovation of the distribution network and municipal basic sanitation.

When compared to other states, the RN has a good water infrastructure, with more than 1000km of water supply networks distributing treated water to the cities of the semiarid Potiguar, mainly. Even so, a lot of the cities of the State registered a collapse of water supply in the last period of drought, revealing the largest vulnerability of the Environmental indicator, through the predominant climate and geology of the countryside cities, if compared to the coast.

The result of the IRDH-RS did not present a city with a "very low" risk level of shortage. However, 1 city (1% of the cases) was classified as "very high" risk (Almino Afonso), totaling 3,479 inhabitants (0,15% of the analyzed population); 74 cities (48%) had a "high" level of risk in the state IRDH, with a total of 373,702 inhabitants (16,75% of the analyzed population) in this category; 62 cases (41%) of "medium" risk and 426,401 inhabitants (19% of the analyzed population) in this class; 16 cities (10%) were classified as "low" risk of water shortage, totaling 1,442,644 inhabitants (64% of the analyzed population). Thus, the category with most cities, and, consequently, the largest portion of the state territory, is the "high" risk. However, this class is not the one with the most urban inhabitants. That goes to the "low" risk category, where the most populated cities of the State are: Natal, Mossoró and Parnamirim.

In this context, for the Environmental indicator, problems related to the low outflow and availability of the underground fountainhead (V1), as well as the low availability of superficial water bodies (V2) stand out. These variables also present higher weight in the indicator (1.25); Regarding the Infrastructure indicator, the variable that refers to the time of installation of the urban water distribution network (V7) stands out, with the majority of the cities classified as "very high" risk. Another

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variable in highlight is the low capacity of the reservoirs located in the cities (V6), with the majority of them registering "high" risk, since storing water in times of scarcity is fundamental for the resistance to the water shortage. In several cities of the State, there is only one reservoir with up to 50 m³ of capacity.

Still on this indicator, the type of municipal capture (V5), which has higher weight in the indicator (1.5), registered a large part of the cities with "high" and "very high" risk (30% of the cases), followed by the "medium" risk class in 25% of the cases. Therefore, the risk for this indicator in the State increased, since many cities capture water in large or small local dams in the Potiguar crystalline that have low water availability, and, therefore, high vulnerability in times of prolonged dry weather.

In turn, the State Planning indicator had as a highlight the variables that refer to the absence or precariousness of the municipal risk management (V14) and structural measures for the reduction of the risk of shortage, such as structural construction works or projects (V13). Besides these, for the variable regarding occurrences of water collapse in the city (V11), 45 cases of "very high" risk were found, namely, where occurrences registered in the last period of drought (2012-2017) took place. This variable has higher weight in the indicator, which directed its concerning result, with "high" and "very high" risk, especially for the regions of Saridó (87% of the cases) and Alto Oeste (81% of the cases).

Lastly, there is the Social and Economic indicator, where the variables referring to the income (V16) and education (V17) stood out negatively. In these variables, the majority of the cities of the State were classified as "high" and "very high" risk, revealing the problems that the inhabitants would have to face, resist, and adapt in a situation of water shortage disaster. In this context, the Figure 3 shows the configuration of the result of the IRDH in regards to the 19 variables, separately, besides the Figure 4, which shows the general result of the IRDH for the state of Rio Grande do Norte alongside the results of the indicators.

The analysis of the Figure 4 allows us to identify that the State had the majority of the cities with "high" risk of municipal water shortage risk, with distributed cases, especially in the Seridó and Alto Oeste regions. These two regions were also the ones that most had occurrences of cities in collapse of water supply, demonstrating the higher vulnerability to the water shortage of these regions, highlighting the environmental factor, mainly. In this context, the variables related to the climate and availability of superficial water resources are the most determinant for the increase of vulnerability, and, in this way, of the risk of water shortage in these regions. Therefore, after the analysis of the results, it became necessary to propose structural measures for the mitigation of risk of disaster in Rio Grande do Norte, which complements the analysis of the IRDH in this research.

After the "high" risk class, the "medium" risk stood out in the result of the IRDH of Rio Grande do Norte. This class can be characterized by the reduction of the vulnerability of the cities through the reduction of the exposition and increase of capacity of coping from the cities, be it through a higher water infrastructure that they have available, low quantity of people, and/or environmental characteristics that allow for a higher safety for water supply. The regions with more occurrences of "medium" risk were the Agreste[1] and Western regions, where most cities serviced by the water supply networks with capture on the

[1] Agreste is the region of transition between the coast and semiarid;

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Potiguar basin (and Pernambuco-Paraíba basin) are also cities with relatively low population contingent. In what concerns the Environmental indicator, in the Agreste region, the climate is less dry and there is more superficial water availability than in the West, which also contributed for the result.

The integration of systems of water supply can be a solution for the reduction of the problems found in the Seridó and Alto Oeste regions regarding water supply. For example, in the Alto Oeste Potiguar region, a highlight goes to the proposal for a stretch that would connect the Alto Oeste water supply network, a Santa Cruz do Apodi subsystem, to the Médio Oeste network, with capture in the Armando Ribeiro Gonçalves dam in the water supply region of Alto Oeste.

In the Seridó region, the Serra da Santana network can be expanded and integrated with the network system Manoel Torres, in Caicó, and Trairas, in Jardim do Seridó, which was carried out partly by the concessionaire through the emergency express network to Caicó. However, it is necessary for it to be replaced with a larger and more resistant network, as well as supply Currais Novos and be integrated to the network system of Acari/Currais Novos, which would increase its capacity of supply, reducing the vulnerability of these two captures in periods of prolonged drought. In turn, the water supply networks of Boqueirão/Carnaúba dos Dantas, Acari/Currais Novos, Trairas/Jardim do Seridó, and Piranhas/Caicó can be connected through networks with little extension, integrating the systems and making viable the water safety of the region, which would make a connection between the system of the Piranhas river to Serra de Santana with capture in the Armando Ribeiro Gonçalves dam, the largest of the State, and, therefore, the most resistant to prolonged periods of dry weather. This measure would increase the water safety of the region and of its largest city, Caicó, with more than 60,000 inhabitants, still being necessary to expand to smaller cities like São João do Sabugi, Ipueira, Equador, Santana do Seridó, and São José do Seridó, for example.

The interconnection of the water supply network of Médio Oeste with Alto Oeste could make viable the arrival of the waters from the Armando Ribeiro Gonçalves dam to the Alto Oeste region of the State, with emphasis on the city of Pau dos Ferros, the largest of the region. It is also the center of services with a large daily flow of people, besides its 25,551 urban inhabitants. When the waters from the São Francisco River arrive through the Oiticica dam, which is located upstream from the Armando Ribeiro Gonçalves dam, they will form together a high security system of water reservoir, which will highly increase its potential of service, reaching a larger quantity of cities and people, which is another reason for the integration of the systems. The transposition of São Francisco will also benefit from the Alto Oeste region. However, there is no prediction as to when it will operate in the region, differently from the Oiticica dam, which has 91% of its construction complete (as in June of 2021). This signals the advance in the effectuation of the waters for the State, differently from the branch in Alto Oeste, which still is in its initial bidding phase. Through Figure 4, it is possible to visualize the configuration of the system(s) of water supply of RN, besides the proposed integration of water supply network systems for the Alto Oeste region of the State.

Another important measure that increases the capacity of coping with the shortage from the population, whose cost will require smaller investors, is the institutional infrastructure of the city for the reduction of risk of disasters. It is about structuring the municipal civil defense with a Plan of Disaster Risk Reduction (PRRD), alongside material, human, and financial resources, as well as articulation between the cities. It could even be carried out through intercity consortiums, as it is the plan of solid residues, for example. This measure affects in the institutional capacity of the cities to deal and adapt to the water shortage. In

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this way, every city (or in a group of them) would have a body of professionals trained for events of disaster, empowering the population, performing drills, monitoring the areas of risk, carrying out detailed city diagnoses on the population and the most vulnerable sectors, which in turn would reduce the risk of shortage through the reduction of vulnerability of the population.

Besides these measures, it is possible to reduce the vulnerability of the cities with investments in more sewage treatment stations, landfills that would receive the residues in each region of water supply of the State. It will also improve the management of municipal risk, with a structure of civil defense or secretary of water resources, associated with the city plan of sanitation, which is fundamental.

In this context, these proposals lead to the reduction of the regional vulnerability to water shortage, increasing the capacity of coping and adapting to the population, reducing the susceptibility to water shortage in the State, which is very exposed to this disaster due to its environmental characteristics. This exposition is very important for the configuration of territories in risk of shortage in Rio Grande do Norte, which presented the majority of the cities with high risk after the analysis of this research. Therefore, they need more attention, especially the Alto Oeste and Seridó Potiguar regions. For this reason, the mitigating measures can be directed towards improving the organization of these territories through the reduction of the IRDH.

Some of these measures of the agencies responsible for the organization of water resources of the State, such as SEMARH and CAERN, proposed recently in conferences (Neto, 2021), can be fundamental in the mitigation of the risk of water shortage in Rio Grande do Norte. These measures and proposals are in consonance with the ones that were discussed in this research, complimenting them. A few highlights are the proposal for a collection of wells in Baía Formosa, in the Agreste region, in order to reinforce the capture of the Monsenhor Expedito water supply network. It would also make viable the project of Agreste Potiguar integrated water supply network. This large system would amplify the quantity of cities of the Monsenhor Expedito water supply network, integrating it with Pedro Velho and Espírito Santo systems. Another recent and important project, now for the Seridó region, is the project of integration of the smaller cities to the water supply network systems that are already existent in the region, such as the Caicó and Boqueirão-Carnaúba dos Dantas systems. This project ratifies one of the mitigating measures of this research, mentioned beforehand.

5 Conclusion

The hypothesis of this research, that the relationship between environmental, social and economic, infrastructural, and state planning factors promote territories of risk of water shortage was tested through the IRDH, in which the indicators of the index correspond to the factors of the hypothesis. Thus, it was possible to conclude that there is a materialization of this relationship in the space, producing territories of risk in the State.

The results of this research can contribute directly to the management of water resources of the State. diagnosing problems, such as the identification of most vulnerable cities and what indicators must be improved, and suggesting measures for the reduction of the vulnerability of the cities, through the improvement of the capacity of coping, susceptibility and adaptation of the population from the State.

The territories of risk of water shortage identified in Rio Grande do Norte are, mainly, the cities identified as "high" and "very high" risk. The result of the IRDH-RN identified 1 city classified as "very high" risk of water shortage, 74 cases with "high" risk, 62 with "medium" risk, 16 with "low" risk, and none with "very low" risk of water shortage. Therefore, 49% of the analyzed cities have "high" or "very high" risk of urban water shortage, which marks them as requiring immediate attention in regards to this type of disaster.

Generally speaking, this result is largely due to the environmental characteristics that increase the exposition to water shortage, as well as the problems found regarding the water infrastructure (especially related to the type of municipal water capture), state planning (especially occurrences of water collapse and lack of investment in sanitation plans and civil defense), and social and economic indicators (especially problems with education and income of the city population), which affects the vulnerability of the population of these cities that compose the territories of risk of these regions of the State in regards to this type of disaster.

Another indicator used in the geographic studies of risk is the cultural one, which can be inserted in the index in a future expansion of the research. The perception of the city population to the dangers that they are exposed to, as well as the tools they have to cope or adapt to a disaster are important, since they increase or decrease the risk of disaster in a territory.

In this context, the methodology of analysis of risk of shortage showed to be pertinent and efficient in the quantification/qualification of the risk of this type of disaster in a regional level. The intention of using it in other states of Brazil can be carried out, with the variables possibly adapted to the availability of data in each state.

Conflicts of Interest

None.

Acknowledgments

The authors express special gratitude to PPGE/UFRN – Post-Graduate Program and Research in Geography of the Federal University of Rio Grande do Norte, in special to Professor Adriano Lima Troleis for all of the support and always pertinent orientation throughout this research. The authors also thank the Dean of Research and Innovation (PROPI) of the Federal Institute of Education, Science and Technology of Rio Grande do Norte (IFRN) for linking this research in a doctorate level in the panel of research projects of the institution, through the Official Notice nº 09/2018 (3ª call) - PROPI/RE/IFRN. We also thank the reviewers of the magazine Natural Hazards and Earth System Sciences (NHESS) for the very pertinent comments for the improvement of the work.

https://doi.org/10.5194/nhess-2022-86
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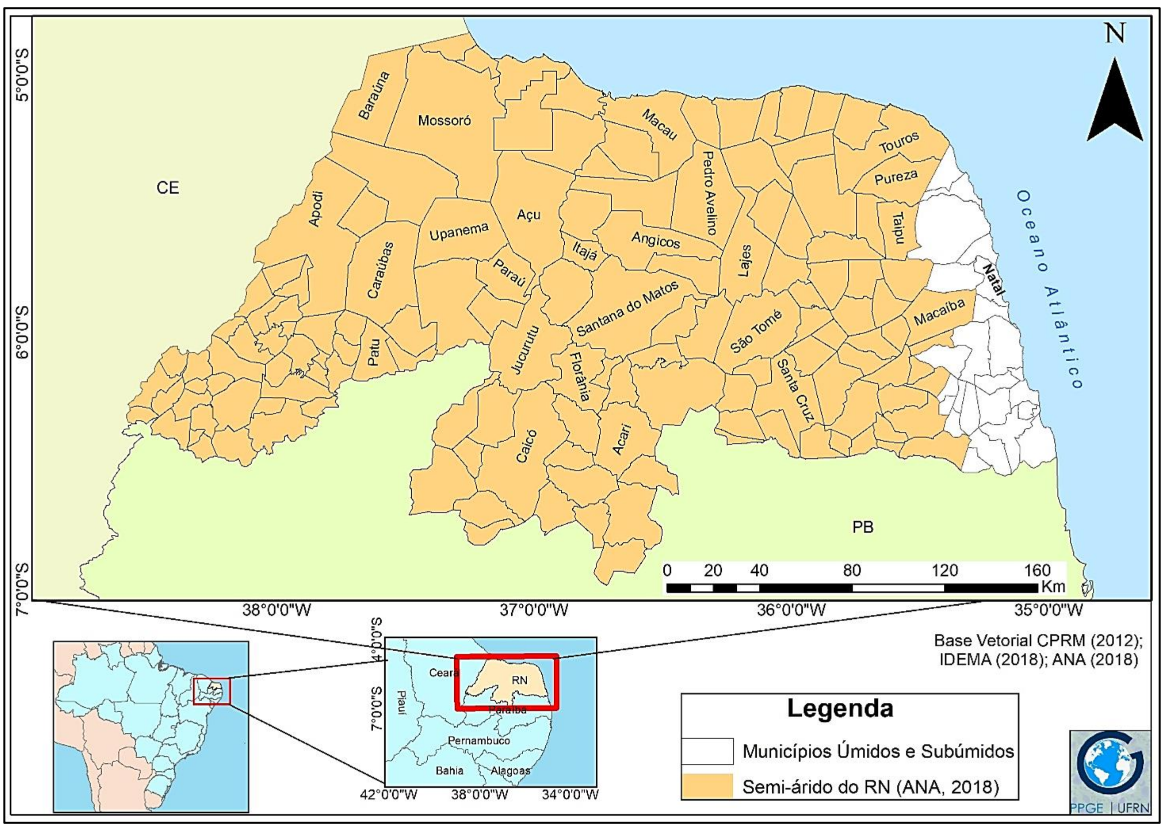

Figure 1 – Rio Grande do Norte and Semiarid Potiguar location. Source: Elaborated by the author. Data base: Pfaltzgraff et a. (2010). CPRM (2019); ANA (2018); IDEMA (2018). Datum Sirgas 2000.

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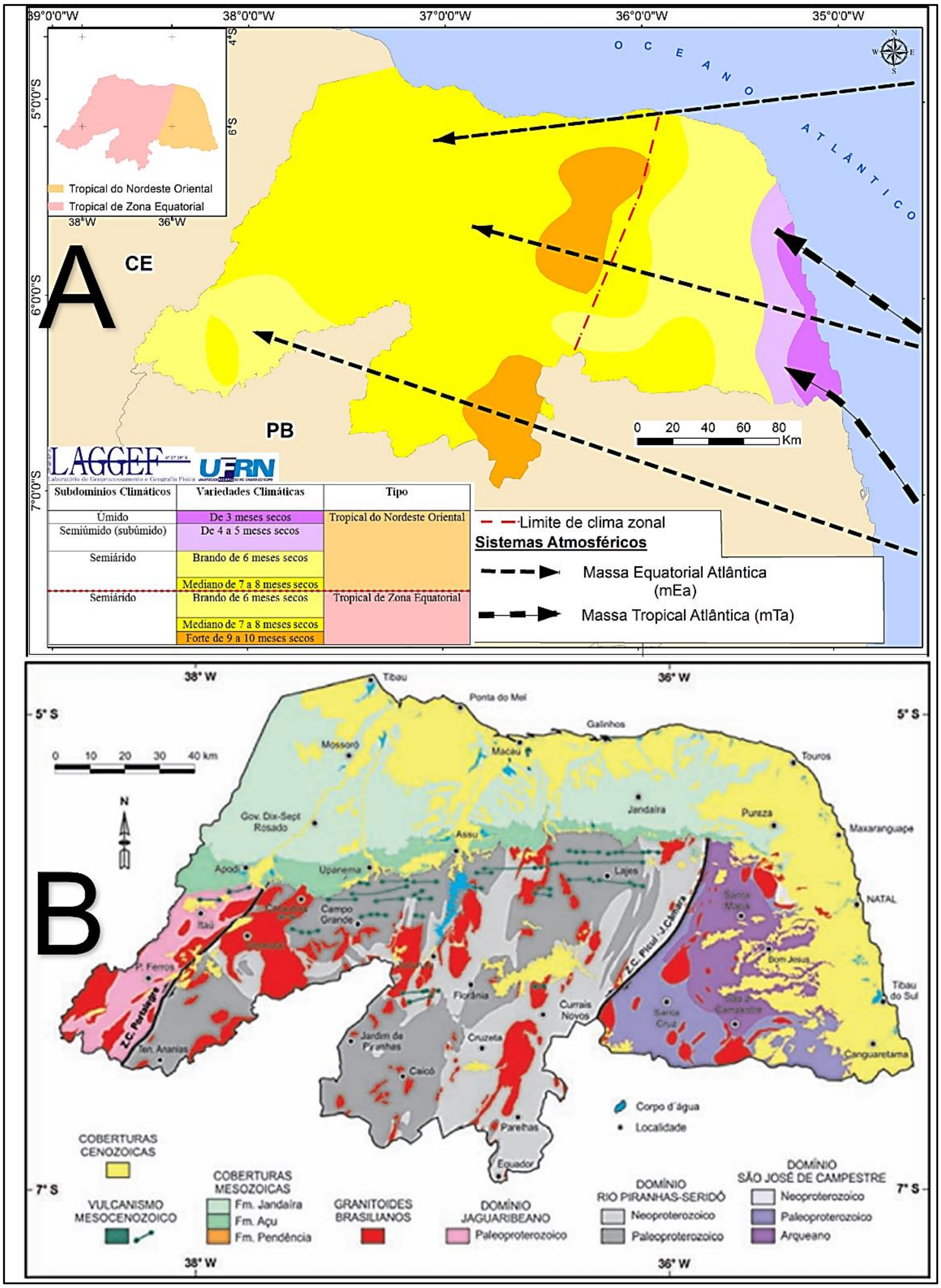

Figure 2 – A) Map of climates of Rio Grande do Norte; B) Geological framework of the State of Rio Grande do Norte. Source: A) Diniz e Pereira (2015); B) Pfaltzgraff et a. (2010).

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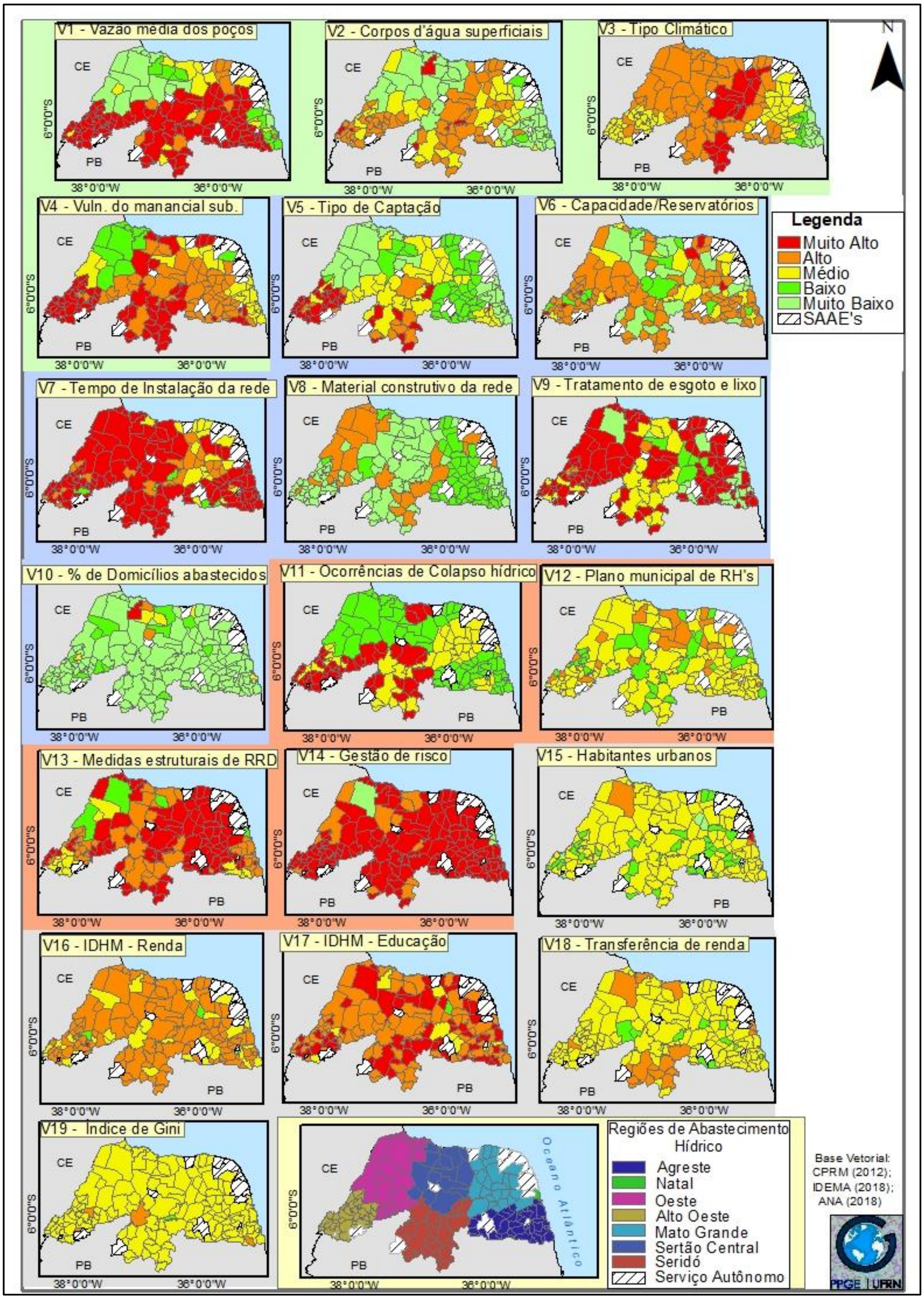

Figure 3 – IRDH – Individualization of the variables. Source: elaborated by the authors (2020). Datum: Sirgas 2000.

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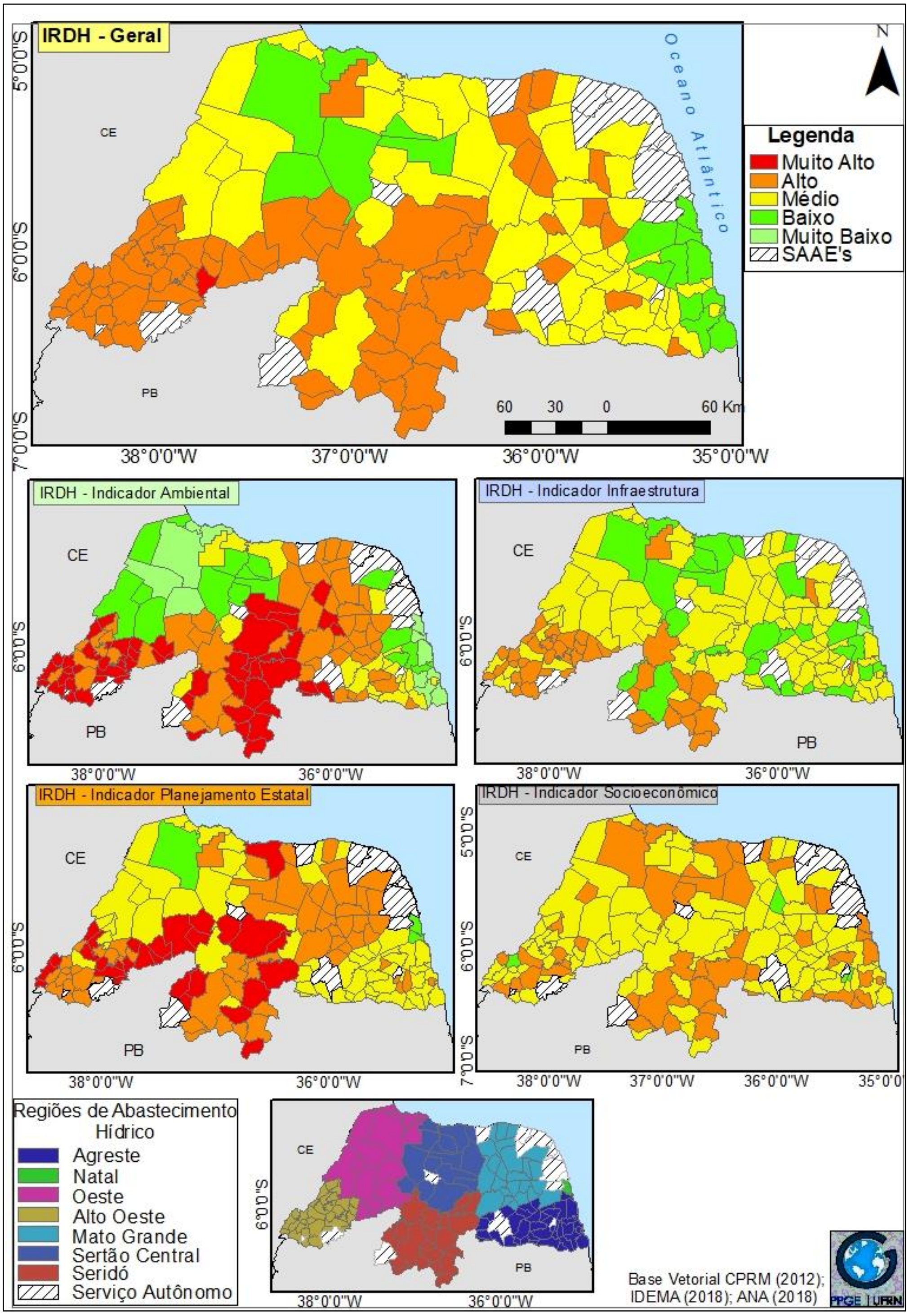

Figure 4 – IRDH – Index of Water Shortage and its indicators. Source: elaborated by the authors (2020). Datum: Sirgas 2000.

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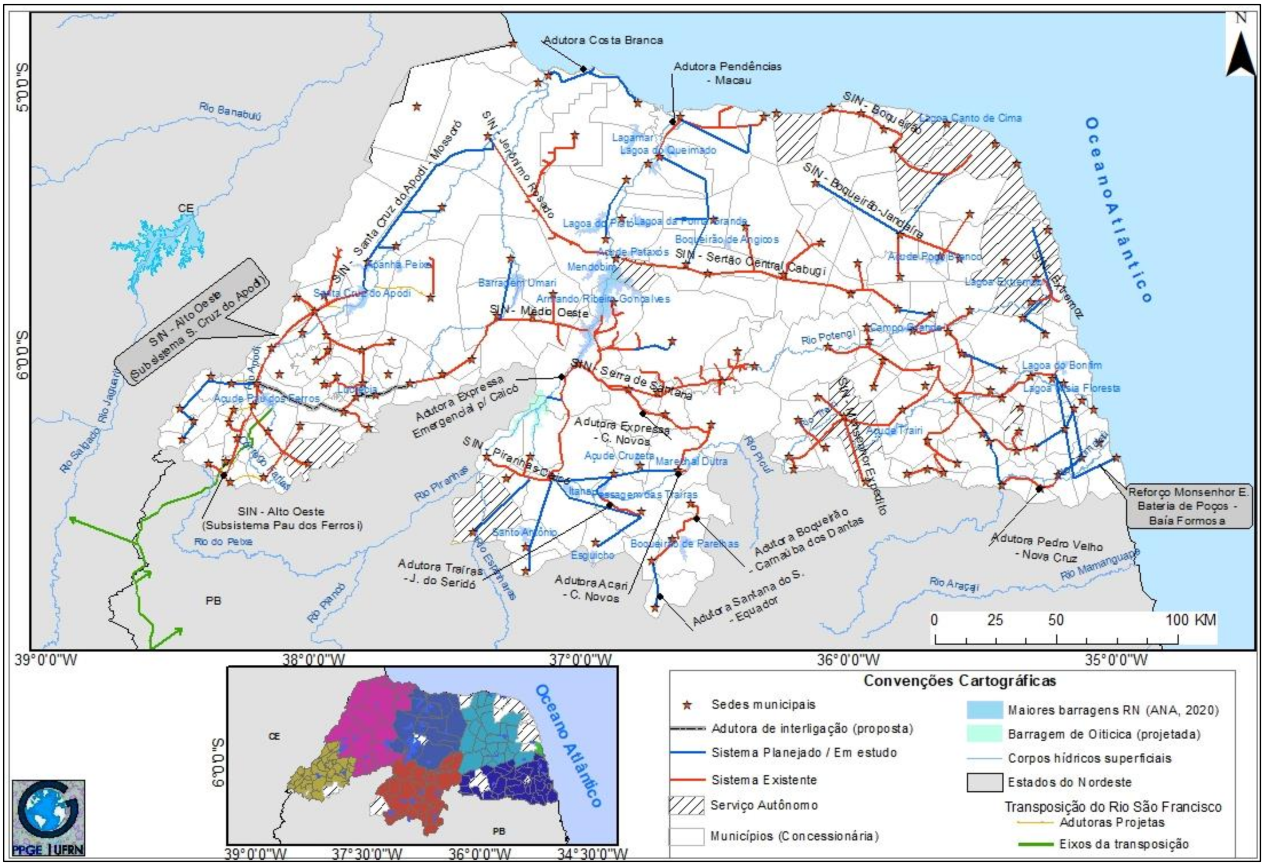

Figure 5 – System(s) of water supply of RN and integration proposal. *SIN: Integrated System. Source: based on ANA (2020), CAERN (2018) and Neto (2021), elaborated by the authors.

Table 1 – Variables of the Environmental indicator of the IRDH. Source: based on Beltrão et al. (2005); SEMARH (2019); Diniz e Pereira (2015); Foster e Hirata (1988).

Variables	Categories	Justification	P (V)	P (I)
(V1) Average outflow of the wells	Superior to 50.1 (N1); 25.1 to 50.0 m3/H (N2); 10.1 to 25.0 m3/H (N3); 5.1to 10.0 m3/H (N4); 0.1 to 5.0 m3/H (N5)	The underground fountainhead is a fundamental alternative to supplying; it is present in the state sanitation plans, such as from RN (SERHID, 1998) and Ceará (SRHCE, 2018), with data regarding wells and outflow (inventory), as well as the data collection from the Geologic Service of Brasil (Beltrão et at., 2005). The data was obtained by the bank of data from the State Secretary of Environment and Water Resources (SEMARH, 2019).	1.25	
(V2) Superficial and natural water bodies in the city.	Perene River (N1); Perene Stream (N2); Intermittent river (N3); Intermittent stream (N4); Absence of water bodies in the city (N5)	Are also an alternative for supply and are present in the state sanitation plans and river basins. The data was obtained through the data bank of SEMARH (2019) of the State Institute of the Environment (IDEMA, 2018) and the National Agency of Waters (ANA, 2018), which were researched in SIG environment.	1.25	1.0
(V3) Predominant climate type of the city	Humid Tropical (N1); Semihumid Tropical (N2); Mild Semiarid Tropical (N3);	The climate is fundamental for the understanding of the territorial dynamic in regards to the water availability. They are also present in the state sanitation and river basin plans. (Data	0.75	

https://doi.org/10.5194/nhess-2022-86
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	Medium Semiarid Tropical (N4); Strong Semiarid Tropical (N5)	collection from CAERN, SEMARH and the Institute of Management of Waters of Rio Grande do Norte [IGARN], among others, which use climate data in their monitoring for water resource management.) The data was obtained through the classification and map generated by Diniz and Pereira (2015).		
(V4) Vulnerability of the municipal underground fountainhead (GOD index)	Imperceptible (N1); Low (N2); Medium (N3); High (N4); Extreme (N5)	Has indirect importance in the Environmental indicator, influencing the contamination of the underground fountainhead. Data of this nature is found in specialized material in Hydrogeology, such as the Hydrogeology manual of the Geologic Service of Brazil (Feitosaet al., 2008). For the acquisition of this data, an analysis was carried out through the GOD methodology (Foster; Hirata, 1988).	0.75	

Table 2 – Variables of the Infrastructural indicator of the IRDH. Source: based on SERHID (1998); ANA (2014); Del Grande (2016); PMBJ (2017); IBGE, (2017); Brazil (2019).

Variables	Categories	Justification	P (V)	P (I)
V5) Type of capture	Supplied by wells of the Potiguar sedimentary basin (granular) (N1); mixed supply - wells and water supply networks (N1); supplied by water supply networks in the Potiguar sedimentary basin (N2); supplied by networks with capture in dams (or other fountainheads) in the Potiguar crystalline (N3); supplied by wells in the Jandaíra aquifer (N3); supplied by wells of the crystalline (N4); supplied by large municipal dams (local) in the Potiguar crystalline (N4); supplied by small dams, with capacity of up to municipal (local) 25 million of m³ (or other captures) in the Potiguar crystalline (N5);	This variable is fundamental inside the system of indicators of the IRDH. The possibility of capture is present in the plans of state and municipal sanitation, besides the diagnosis of several water resources such as the National Agency of Waters (ANA, 2014) and the state agency SEMARH (2014). The data was obtained through the cross of the city water quality reports that contain a type of supply (CAERN, 2018; 2019) associated to the questionnaire applied in the Seridó headquarters of the CAERN.	1.5	1.75
V6) Reservoir capacity in the city	Reservoir(s) with more than 600m³ of capacity (N1); reservoir(s) between 451 and 600m³ of capacity (N2); reservoir(s) between 251 and 450m³ of capacity (N3); reservoir(s) with capacity between 50 and 250m³ (N4); reservoir smaller than 50m³ of capacity or absence of reservoirs/direct distribution in the network (N5)	Equipment of water reservation are fundamental in the coping and resistance to events of collapse or water intermittence (DEL GRANDE, 2016). This information is found in the municipal sanitation plans, in the diagnostic phase (PMBJ, 2017). The data was obtained through a questionnaire applied in the Seridó headquarters of CAERN.	1	
V7) Time of installation of the urban water supply network	Network installed in up to 10 years (N1); network installed from 10 to 15 years (N2); network installed from 15 to 20 years (N3); network installed from 20 to 30 years (N4); network installed in more than 30 years (N5	This variable is an indicator parameter of vulnerability of the supply system. Time promotes abrasion in the structure. This information can also be found in the municipal plans of sanitation. The data was obtained through a questionnaire applied in the Seridó headquarters of CAERN.	1	
V8) Material used in the construction of the water supply network	PVC tube (N1); PVC tube and molten iron (N2); molten iron (N3); PVC tube or molten iron and asbestos cement (N4); asbestos cement (N5)	It is an indicator of vulnerability of the supply system. This information was not found in any other reference. The data was obtained through a questionnaire applied in the Seridó headquarters of CAERN.	1	
V9) Existence of sewage treatment and waste collection in the city	Collection of weekly/regular urban residues (landfills) and sewage treatment (N1); sewage treatment with absence of collection of urban residues and/or destination to landfills (N3); collection of weekly/regular waste and destination	Destination of residues and sewage are agents of pollution of fountainheads, which can make inviable for water supply. It is present in plans of state sanitation or of water resources such as the one of RN (SERHID, 1998). The data	0.75	

	to landfills without sewage treatment (N4); absence of sewage treatment and no ideal destination for urban residues (N5)	was obtained through the questionnaire applied in the CAERN region and cross examined with the National System of Sanitation Information (Brazil, 2019) and the National Research of Basic Sanitation from IBGE (2017).		
V10) Percentage of households supplied by piped water in an urban environment	90 to 100% 9N1); 75 to 90% (N2); 50 to 75% (N3); 25 to 50% (N4); up to 25% (N5)	It is an indication of the lack of infrastructure of the supply network. This information can also be found in plans of municipal and state sanitation plans. It was obtained through the data available in he National System of Information on Sanitation (Brazil, 2019).	0.75	

Table 3 – Variables of the State Planning Indicator of the IRDH Source: Based on Guerra (2009); Macedo (2015); CAERN (2018 e 2019); IBGE (2018); Medeiros (2018)

Variables	Categories	Justification	P (V)	P (I)
V11) Occurrences registered of municipal urban supply collapse in the last six years of drought	No collapse of municipal urban water supply in the period between 2012-2017 (N2); partial collapse in the municipal urban water supply or in the system of rotation in the period between 2012-2017 (N3); collapse of the municipal urban water supply in the period between 2021-2017 (N5)	This variable is important as an indicator of vulnerability and exposition of a city in relation to another. It is an information not found in common references, being obtained through a questionnaire applied in the headquarters of CAERN and cross examination of the supplying of RN (CAERN, 2018 and 2019).	1.5	
V12) Existence of a municipal plan regarding water supply	It exists (N2); it is in planning (N3); it does not exist (N4)	The municipal plan of sanitation of water resources is a fundamental instrument of planning in order to reduce the risk of disaster of this kind. The data of this variable was obtained through the section “MUNIC - General aspects of basic sanitation policy management” (IBGE, 2018)	1	
V13) Structural measures for the reduction of shortage risk	Existence of structural construction works of reservoirs or distribution networks (N2); existence of a project with allocated resources for structural construction works of the municipal SAAA (N3); existence of another option for water supply in case of collapse (N4); absence of options for supply (N5)	Chosen by the studies of risk of disaster such as slides and floods (Guerra, 2009; Macedo, 2015; Medeiros, 2018) in which in-progress projects or construction works that improve the local infrastructural conditions are analyzed with the aim to reduce these disasters. As well as in the plans of state water resources (SERHID, 1998; SRHC, 2018). The data was obtained through a questionnaire applied in the Seridó headquarters of CAERN.	0.75	0.75
V14) Management of risk of shortage in the city.	Existence of a secretary of social security, water resources, environment and public security with a structured civil defense (N1); existence of instruments of control and monitoring for RRD of water shortage (N2); existence of civil defense with interinstitutional structure and a articulation (N3); existence of a municipal plan of RRD or contingency plan (N4); existence of civil defense only (or not) without minimal structure (N5);	It was also chosen through studies of risk of disasters. In the case of water shortage, the secretary of water resources, environment and/or municipal sanitation is also important. This information was obtained through the section “MUNIC - Profile of Brazilian Cities - Management of Risks and Responses to Disasters” (IBGE, 2017).	0.75	

https://doi.org/10.5194/nhess-2022-86
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Table 4 - Variables of Social and Economic Indicator of the IRDH. Source: Based on Welle; Birkmann (2015) e Almeida, Welle e Birkmann (2016).

Variables	Categories	Justification	P (V)	P (I)
V15) Quantity of urban inhabitants of the city	From 100 to 1,000 inhabitants (N1); from 1,000 to 2,500 (N2); from 2,500 to 60,000 inhabitants (N3); from 60,000 to 250,000 inhabitants (N4); more than 250,000 inhabitants (N5)	It was chosen through studies of risk of disasters in Welle; Birkmann (2015) e Almeida, Welle e Birkmann (2016). It is a variable that directly affects the exposition of the population to the dangers of disaster; the more inhabitants are exposed, the higher the danger is. The data of this variable was obtained through the IBGE Census (2010)	1.5	0.50
V16) IDHM – Income	Very high IDHM-R (N1); high IDHM-R (N2); medium IDHM-R (N3); low IDHM-R (N4); very low IDHM-R (N5)	It was chosen through studies of risk of disasters for the world (Welle; Birkmann, 2015) and for Brazil (Almeida, Welle and Birkmann, 2016). It was an important variable for the increase of capacity of coping and adapting to disasters. The data of this variable was obtained through the IBGE Census (2010)	1	
V17) IDHM – Education	Very high IDHM-E (N1); high IDHM-E (N2); medium IDHM-E (N3); low IDHM-E (N4); very low IDHM-E (N5);	It was also chosen through the studies of risk of disasters for the world (Welle; Birkmann, 2015) and for Brazil (Almeida, Welle and Birkmann, 2016). It was also an important variable for the increase of capacity of coping and adapting to disasters. The data of this variable was obtained through the IBGE Census (2010)	1	
V18) Level of coverage of transfer income program (Bolsa Família);	Above 75% of the population (N1); 50 to 75% of the population (N2); 25 to 50% of the population (N3); 10 to 25% of the population (N4); up to 10% of the population (N5)	It was also chosen through studies of risk of disasters. It is an important variable for the increase of capacity of the population in coping and adapting to disasters. The data of this variable was obtained through the single registration of Bolsa Família, available for each city in their own website, connected to the Ministry of Citizenship – National Secretary of Income and Citizenship, with data regarding the year of 2019.	0.75	
V19) Gini index	Very low Gini index - 0,0 a 0,19 (N1); low Gini index - 0,20 a 0,39 (N2); medium Gini index - 0,40 a 0,59 (N3); high Gini index - 0,60 a 0,79 (N4); very high Gini index - 0,80 a 1 (N5)	It was also chosen through the studies of risk of disasters for the world (Welle; Birkmann, 2015) and for Brazil (Almeida, Welle and Birkmann, 2016). It was also an important variable for the increase of capacity of coping and adapting to disasters. The more social equality is available, the less the distance of access to services of health, transport, and proper housing among the rich and the poor. The data of this variable was obtained through the IBGE Census (2010)	0.75	