Revista Brasileira de Ciências Ambientais
Brazilian Journal of Environmental Sciences

Model of integrated territorial assessment for environmental justice applied to sanitation

Modelo de avaliação territorial integrada da justiça ambiental aplicada ao saneamento

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ABSTRACT

Equitable access to water and sanitation is still a challenge worldwide and in Brazil. In this sense, the concept of environmental justice was used in this paper as a basis for establishing an Integrated Territorial Assessment Model for Environmental Justice Applied to Sanitation. This research aims to give scientific support for the State Government to improve public policies and promote the universalization of water and sanitation services as established by the Sustainable Development Goals (SDGs). This study was based on a quali-quantitative methodology. Secondary data were selected as key information to analyze environmental justice in sanitation, including the following: hydric vulnerability (IV), water supply (WS); untreated sewage collection (SC); sewage collection with treatment (ST); water supply investments (WSI); sewage system investments (SSI); municipal per capita income (MPI); and municipal human development index (MHDI). The data were presented in maps by overlapping the State official regional division and the discussion was carried out based on regional differences and similarities. The repetition of a pattern was noted, in which unfavorable rates were concentrated in the North and Jequitinhonha-Mucuri regions: water vulnerability, sewage system with collection and without treatment, total investment, average investment, per capita income and municipal human development index. Both also have low rates of the sewage system and water supply when compared to others. On the other hand, Zona da Mata and Triângulo regions have favorable rates for hydric vulnerability, sewage system with collection and without treatment and water supply. The Triângulo Mineiro region also presented favorable

RESUMO

O acesso equitativo ao saneamento básico ainda é um desafio no mundo e no Brasil. É nesse sentido que o conceito de justiça ambiental foi utilizado no presente trabalho como base para estabelecer um Modelo de Avaliação Territorial Integrada da Justiça Ambiental Aplicada ao Saneamento. Pretende-se apoiar os estados no aprimoramento de políticas públicas de promoção à universalização dos serviços de saneamento, conforme estabelecido pelos Objetivos do Desenvolvimento Sustentável (ODS). Para o desenvolvimento do trabalho, foi elaborada metodologia quali-quantitativa em duas etapas, com base nos seguintes dados secundários selecionados: vulnerabilidade hídrica (VH); os seguintes índices: abastecimento de água (AA), coleta de esgoto sem tratamento (CE), coleta de esgoto com tratamento (TE), investimento em abastecimento de água (IAA), investimento em esgotamento sanitário (IES), renda per capita municipal (RPM); e desenvolvimento humano municipal (IDHM). O modelo proposto foi aplicado no estado de Minas Gerais. Os dados foram apresentados em mapas com sobreposição da divisão regional oficial do estado, e a discussão foi realizada com base nas divergências e semelhanças regionais. Notou-se a repetição de um padrão, em que índices desfavoráveis concentraram-se nas regiões Norte e Jequitinhonha-Mucuri para vulnerabilidade hídrica, atendimento com coleta e sem tratamento de esgoto, investimento total, investimento médio, renda per capita e IDHM. Ambas também apresentam valores baixos de índice de atendimento com coleta e com tratamento de esgoto, e abastecimento de água quando comparadas às demais. Por outro lado, as regiões Zona da Mata e Triângulo apresentam índices favoráveis para vulnerabilidade hídrica, atendimento com coleta e

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Conflict of interest: the authors declare there are no conflicts of interest.

Funding: None.

Received on: 06/06/2020. Accepted on: 01/09/2021.

https://doi.org/10.5327/Z21769478828

rates of total investment, average investment, per capita income, and municipal human development index. It is concluded that the inequality between the regions is, initially, of natural origin, and reinforced by the social context and inequality in sanitation investments in the different regions.

Keywords: sanitation access; socioeconomic conditions; human right; investment; water vulnerability.

sem tratamento de esgoto e abastecimento de água. A região do Triângulo Mineiro apresentou ainda índices favoráveis de investimento total, investimento médio, renda per capita e IDHM. Dessa forma, a desigualdade entre as regiões mineiras no tema estudado é claramente influenciada por condições naturais, assim como pelo contexto social.

Palavras-chave: acesso ao saneamento; condições socioeconômicas; direito humano; investimento; vulnerabilidade hídrica.

Conceptualization

Brazil concentrates 12% of all freshwater on the planet. However, this scenario does not mean the absence of conflicts or broad access to water for all (ANA, 2019). It is contradictory, but there are populations in a situation of serious water vulnerability in the country that concentrates 30% of the water in the American continent; there are almost 35 million people who are not served by water supply in Brazil (Trata Brasil, 2019). In the different Brazilian regions, there is a great difference in water supply between population groups. In increasing order, these are the following percentage rates per region: North, 57.49%; Northeast, 73.25%; South, 89.68%; Midwest, 90.13%; and Southeast with 91.25% of the population supplied by treated water (Trata Brasil, 2019).

In the State of Minas Gerais the situation is not different, since 13.9% of the households do not have access to the general water network, and 24.7% to the general sewage network (Rodrigues et al., 2019b). After evaluating the historical trend, no significant advances were observed (Costa et al., 2016). When analyzing the Economic Ecological Zoning of the State of Minas Gerais (Minas Gerais, 2008), it is possible to notice that the regions with lower water availability are also the ones with greater social vulnerability, where the human component is in a precarious or very precarious state (SISEMA, 2019).

Rodrigues et al. (2019a), when analyzing the evolution of the spatial distribution of access to basic sanitation services (water supply, sanitary sewage and garbage collection) in Brazilian micro-regions, concluded that the growth in sanitation rates was uneven among the studied areas, showing that the lack of access to these services was predominant in the less populated and lower-income regions in the North and Northeast of the country. The authors also identified spatial concentration in sanitation access rates in regions with large urban agglomeration and higher per capita income.

The National Basic Sanitation Policy — NBSP (Act nº 11.445/2007) includes universal access to sanitation (the concept embraces water supply, sewage collection and treatment) as one of its principles (Brasil, 2007). The new regulation mark for sanitation, Act No. 14.026/2020, reinforces the principle of universalization, establishing the year of 2033 as a limit for achieving universalization. It also presents the need to prioritize plans, programs and projects that aim at the implementation and expansion of services and basic sanitation actions in areas occupied by low-income populations, including informal consolidated urban centers as a guideline (Brasil, 2020). In fact, access to drinking water and basic sanitation is an essential human right, recognized by the United Nations (UN, 2010) and by the Brazilian constitutional system, in which it is intrinsically related to citizenship (art. 1, II), to the dignity of the human person (art. 1, III), to the rights to life (art. 5), health, food, housing (art. 6) and an ecologically balanced environment (art. 225), whose guarantee is part of the primacy of the prevalence of human rights (art. 4, II, all of the Federal Constitution).

In Minas Gerais, State Law no. 11.720/1994 introduced the State Policy on Basic Sanitation, providing the right to sanitation for all and establishing the State System on Basic Sanitation, responsible for the creation of policies, definition of strategies and execution of sanitation actions (Minas Gerais, 1994).

The main sanitation policy planning instrument in the country is the Sanitation Plan, applied to the three existing federal spheres (municipalities, State governments and federal government). Marchi (2015) explains that this Plan should gradually seek for equitable and sustainable progress, so that sanitation services be inserted in the criteria of welfare and social equity, as well as environmental risk reduction. However, according to Ventura and Albuquerque (2020), a lack of social participation and content unrelated to the local reality is observed in these plans.

Among the 853 municipalities in Minas Gerais, only 28.5% had this Plan ready by 2014, and another 48.1% were preparing their respective plans (FJP, 2017). The regions with the highest rates of municipalities that do not have a Municipal Basic Sanitation Plan are Jequitinhonha, South, Southeast, North and Northeast (FJP, 2017), which means that they cannot receive transfers of funds from the Union and the State to execute sanitation actions, since the Plan is a *sine qua non* condition for the investment of these resources.

Heller and Castro (2007) state that it is necessary to understand the access to sanitation as a human right, rather than a market asset, i.e., observe the premises of environmental justice, understood as a set

of principles and practices as defined in the Manifesto for the Launching of the Brazilian Environmental Justice Network. These are about the isonomy of social groups to absorb the environmental liabilities inherent to the political and socio-economic system in which we are inserted; fair and equitable access to the country's environmental resources; principles of publicity and social participation in environmental matters of relevant interest; and the encouragement of social protagonism in the construction of alternative models for development (Brasil, 2001).

Environmental justice is defined as the fair treatment and significant involvement of all people, regardless of race, color, national origin or income, concerning the development and enforcement of environmental laws, regulations and policies (USEPA, 2016). In a section about the specific concept of water, Perreault et al. (2018) advocate that water justice should integrate the economic, cultural, political and socio-ecological aspects of justice.

Other authors reinforce the relationship between environmental justice and sanitation. Menton et al. (2020) and Hurlbert (2020) establish a correlation between environmental justice and the Sustainable Development Goals (SDG), including universalization of sanitation. Corroborating this thesis, Ezbakhe et al. (2019) state that the SDGs help overcome inequality in access to sanitation among social classes and vulnerable groups, especially SGDs 6 and 10. Ataide and Borja (2017) further reinforce that sanitation is an inducer of social justice. Finally, it is important to note that the U.S. Environmental Justice Action Agenda defines the provision of water as a structural axis (USEPA, 2016).

Correlation between access to sanitation and social and economic conditions has been the object of several analyses. Jongh et al. (2019), when evaluating the correlation between access to water and sanitation and social and economic variables in the Sedibeng region (South Africa), concluded that both access to water and sanitation seem to play a significant role in the region's economic and social well-being. Another study in Africa relates access to sanitation to social and demographic variables (Mosimane and Kamwi, 2020). Luh and Bartram (2016) evaluated the correlation of sanitation progress with socioeconomic indicators in 73 countries, and concluded that national socioeconomic characteristics may not be primary determinants of progress in access to water and sanitation. Therefore, it is expected that isonomy and equity, two concepts related to environmental justice, should be the basis for the guidelines of sanitation provision policies.

Thus, the present work aims at proposing a Model for Integrated Territorial Assessment of Environmental Justice Applied to Sanitation. The intention is to support the State Government to improve public policies that promote universalization of sanitation services as established by the SDGs, especially SDG 6 (UN, 2015). The proposed model was applied in the State of Minas Gerais, Brazil.

Methodology

The research was based on a qualitative and quantitative methodological approach, using secondary data. It was divided in two methodological moments. In the first stage, an Integrated Territorial Assessment Model for Environmental Justice Applied to Sanitation was proposed; and in the second, the proposed model was applied for the State of Minas Gerais.

An explanatory perspective on water supply and sanitary exhaustion distribution over a State territory was presented, seeking to evaluate compliance with the principle of isonomy in the delivery of these services, and evaluating reasons for the distribution pattern found; and finally, whether there is environmental justice in access to services.

The integrated territorial assessment model for environmental justice applied to sanitation

The proposed model considered two main dimensions: "access to sanitation" and "socioeconomic conditions", involved in the concept of environmental justice and its relationship with the integrated variables "water vulnerability" and "investments in environmental sanitation" (for water and sewage). For the first dimension, the primary variables were: water supply and sanitation; for the second: per capita income and human development index.

The dimensions, with their respective primary variables and the integrated variables, are described in Table 1. The integrated territorial analysis model, which involves all of them, is presented in the flowchart of Figure 1.

The integrated variable "water vulnerability", which represents a natural condition, is an intervening factor in the provision of water services and was adopted in the study to identify its influence on the model of environmental justice. The integrated variable "investments in environmental sanitation" is in line with the concept of environmental justice and human rights, since it allows the evaluation of whether there is equality in the priority of investments regardless of the social and economic condition of the region.

Treatment of variables and integrated analysis

The primary variables that characterize the access to sanitation and to social and economic conditions are systematized by municipality and by State administrative regions. Therefore, for each variable, a layer was elaborated with the ArcGIS® software, considering both divisions.

To evaluate the territorial correlation in the administrative regions, the local Moran's I coefficient was used. According to Neves et al. (2000), the local Moran's I coefficient is considered a Local Spatial Association Index (LISA) and hence produces a specific value for each object, allowing the identification of groups with similar attribute values (clusters), anomalous objects (outliers) and more than one spatial regime.

Table 1 – Dimensions and variables of the Integrated Territorial Analysis Model of Environmental Justice in Sanitation.

Variables		Abbreviation	Variable classes	Description
Sanitation access	Water supply coverage	WS	-	It considers the number of buildings served by the system and the number of people supplied with water. It allows assessing the degree of supply systems coverage and the service deficit.
	Sewage without treatment	NT	-	Index of people served with collecting network.
	Sewage with treatment	TR	-	Index of collected wastewater that is sent for treatment.
Socioeconomic conditions	*Renda* per capita (*Per capita* income)	PCI	Classes: * 1 – from 0 to R$ 461.40; 2 – from R$ 461.41 to R$ 690.80; 3 – from R$ 690.81 to R$ 920.20; 4 – from R$ 920.21 to R$ 1149.60; 5 – from R$ 1149.61 to R$ 1379.00.	Index that measures the income of each individual component of the municipal population.
	Municipal human development index	MHDI	Classes: ** Very low – 0 a 0.499; low – from 0.500 to 0.599; average – from 0.600 to 0.699; high – from 0.700 to 0.799; very high – from 0.800 to 1.000.	Numerical index that varies from 0 (zero) to 1 (one), based on the Global HDI, considering the same three dimensions - longevity, education and income.
Integrated variables	Water vulnerability	WV	-	Factor composed by three indicators: availability of surface water, groundwater and potential contamination of aquifers. Each with a weight: 50% for the natural availability of surface water and 25% for each of the others (IGAM, 2018).
	Water supply investment	WSI	-	Investments: i) made by service providers; ii) made by municipalities; and iii) made by States.
	Sanitary sewage investment	SSI	-	

*Income classes were obtained by subtracting the lowest value from the biggest one and then dividing the result by five (number of desired groups);
**IDHM varies from zero (0) to one (1).

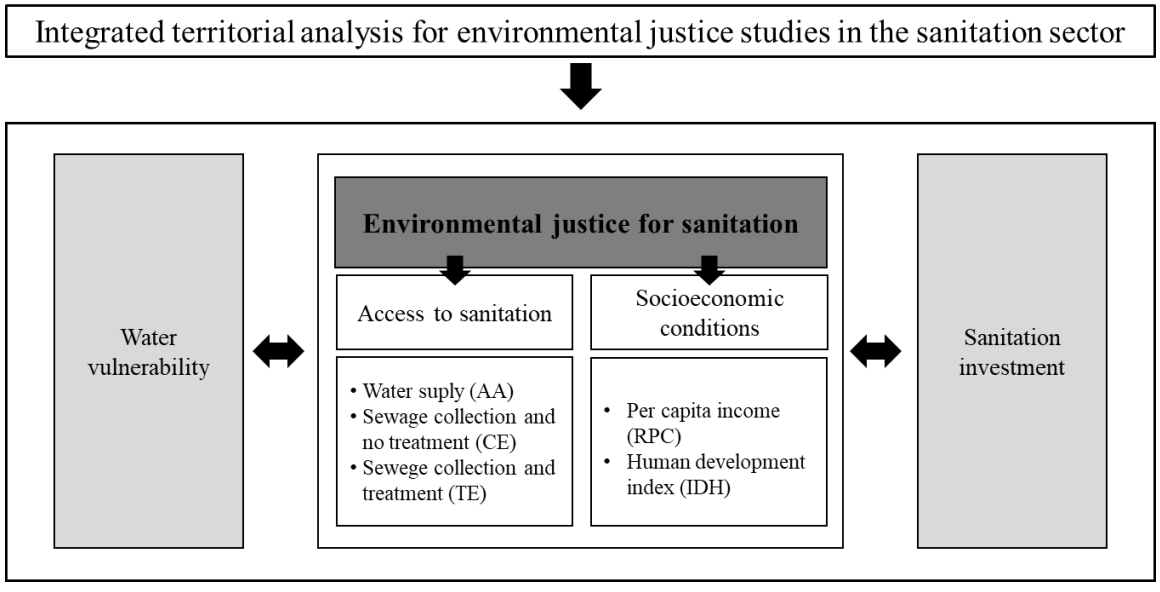

Figure 1 – Flowchart of integrated territorial analysis for environmental justice in the sanitation sector.

The local index was chosen because it allows to understand the spatial correlations considering a more detailed scale (Krempi, 2004). With the application of this index, it is possible to observe the relationship between municipalities and to understand the local and regional dynamics of the entire State in relation to the evaluated parameters. The results are presented as maps and must be interpreted according to Table 2.

Different procedures were adopted to work with the integrated variables. Water vulnerability was analyzed through a map which overlapped this variable and the Minas Gerais planning regions, allowing the visualization of inter-regional similarities and divergences. For investments in sanitation, the following were considered:

- the sum of the investments made by the different entities (sanitation service providers, municipality and State government) in all municipalities of each region in each year – called total investment (TI);
- the average amount invested in the region, obtained by dividing the total investments by the number of municipalities of each region – called average investment (AI).

The relationship between invested values, water supply and sanitary indexes was evaluated by the Pearson's correlation coefficient (r), which allowed us to understand if the increase or decrease of a unit in one of the variables generates the same impact on the other one.

Pearson's coefficient (r) is a measure of variance shared between two variables, whose distributions are linear, and indicates the association between them. Pearson's (r) values vary from -1 to 1, in which the closer to 1 (one), regardless of the sign, the higher the level of linear statistical dependence between the variables. On the other hand, the closer to 0 (zero), the weaker the strength of this relationship (Figueiredo Filho and Silva Júnior, 2009). According to those same authors, a perfect Pearson's correlation, which means values equal to -1 or 1, indicates that the variable score can be predicted by knowing the correlated variable score. If r equals 0 (zero), there is no linear relation between variables.

Finally, an integrated analysis was established among all of the analyzed variables to find the answer to the question presented: is there environmental justice in sanitation?

Case study: Minas Gerais State

At this stage, the model was applied to the State of Minas Gerais. Table 3 shows the sources and respective evaluation period for the considered variables.

The primary variables that characterize the access to sanitation and socioeconomic conditions were systematized by municipality, with the overlapping of the official regional division of Minas Gerais (Minas Gerais, 2019), in a layer elaborated with the ArcGIS® software. This allowed an evaluation of the regional spatial correlation, based on the divergences and similarities, as presented in the previous methodological items.

In conclusion, an argumentative discussion was carried out based on all the data collected to seek answers to the presented question: is there environmental justice for the Minas Gerais State's population regarding access to sanitation?

Validation and formal analysis

Water vulnerability evaluation

Figure 2 shows a map created from the overlapping of water vulnerability and the planning regions of the State of Minas Gerais.

The Northwest, North and Jequitinhonha-Mucuri regions concentrate the areas of high and very high vulnerability, whereas the other regions contain the less vulnerable zones (Figure 2). Thus, it is possible to say there is naturally lower surface and underground water availability, as well as greater potential for aquifer contamination (or a combination of the three factors) in the Northwest, North and Jequitinhonha-Mucuri regions.

The northern part of the central region presents an area with high water vulnerability, which includes all or part of the 110 municipalities, with 85 of them inserted in the basin of São Francisco River (Upper São Francisco), and the others in Rio Doce Basin. Of this total, Belo Horizonte and the municipalities of its metropolitan region, Diamantina and Três Marias, stand out. The same is true for a portion of the Midwest region and other areas in the São Francisco River Basin, but in a more fragmented way.

Table 2 – Spatial analysis results interpretation – local Moran coefficient.

Result	Interpretation
Not significant	No spatial association between the municipality and its neighbors
High-High cluster	Positive spatial association between the municipality and its neighbors
High-low outlier	Atypical situations in which the municipality has the variable value higher than the average while its neighbors have values lower than the average
Low-high outlier	Atypical situations in which the municipality has the variable lower than the average while its neighbors have values higher than the average
Low-Low cluster	Negative spatial association between the municipality and its neighbors

Source: adapted from Neves et al. (2000).

Table 3 – Variables considered for the case study in the Minas Gerais State.

Variable	Type	Abbreviation	Evaluation period/Year	Source
Water vulnerability	Integrated	WV	-	Zoneamento Ecológico e Econômico – ZEE (SISEMA, 2019)
Water supply coverage	Primary	WS	2014	SEIS (FJP, 2017)
Sewage without treatment	Primary	NT	2013	SNIRH Atlas Esgoto: Agência Nacional de Águas – ANA (ANA, 2017)
Sewage with treatment	Primary	TR	2013	SNIRH Atlas Esgoto: Agência Nacional de Águas – ANA (ANA, 2017)
Water Supply Investment	Integrated	WSI	1995 e 2017	SNIS: série histórica (SNIS, 2018)
Sanitary Sewage Investment	Integrated	SSI	1995 e 2017	SNIS: série histórica (SNIS, 2018)
Per capita income	Primary	PCI	2010	Censo 2010 (IBGE, 2010)
Municipal human development index	Primary	MHDI	2010	Atlas do Desenvolvimento Humano no Brasil 2013 (Brasil, 2013).

SEIS: *Sistema Estadual de Informações sobre Saneamento*. The FJP work was selected for this study due to the scope and accuracy of the data and since it is not self-declaratory data; SNIS: *Sistema Nacional de Informações sobre Saneamento*; IBGE: *Instituto Brasileiro de Geografia e Estatística*.

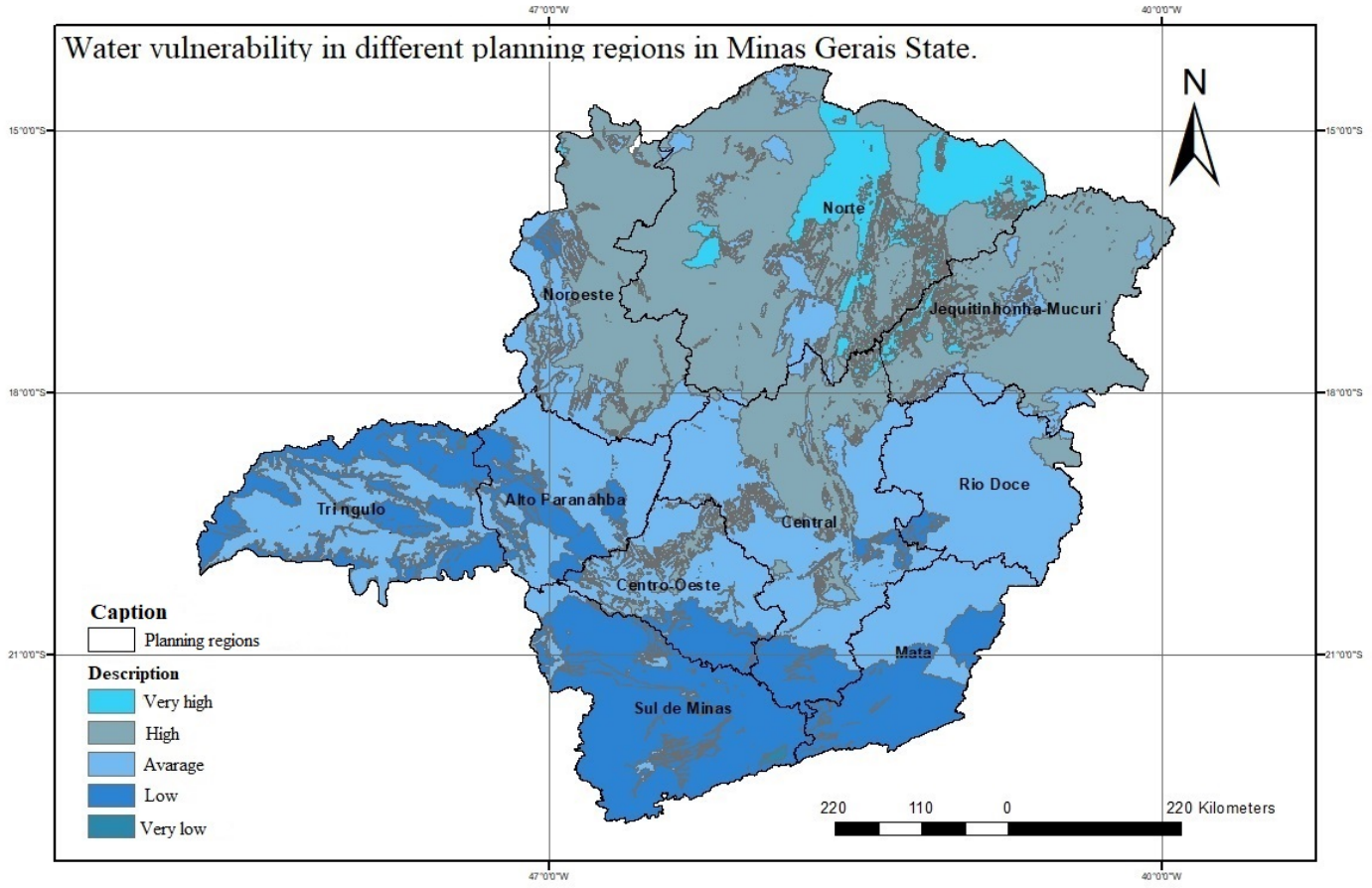

Figure 2 – Water vulnerability in the different planning regions.

Assessment of water supply coverage and sewage disposal

Based on data provided by Fundação João Pinheiro (FJP) and by the Brazilian National Water and Sanitation Agency (ANA), the rates of water and sewage coverage of the urban population in the planning regions of Minas Gerais for 2013 were surveyed, as shown in Table 4.

Regarding water supply, the regions present very close numbers, all of them above 95%, which means there is no evidence of a difference in distribution. Triângulo Mineiro and Alto Paranaíba regions present the highest rates of water supply, very close to 100%. The limitation of the available analyzed data is owed to the fact that they refer only to the urban population, that live a reality known to be different from that of rural areas, thus not providing a more comprehensive analysis of the inequality related to access to water (Silveira, 2013; Agra Filho et al., 2010; Metha et al., 2014).

With these results, it is also possible to observe that the regions of Jequitinhonha-Mucuri, Northwest and North have low rates of sewage without treatment in common, lower than 60%, highlighting the lowest value of 29.04% in the North region.

For the water supply indexes per municipality, the local Moran coefficient was analyzed and presented in Figure 3.

Although regional water supply average rates are homogeneous, the spatial correlation analysis shows some inter and intraregional discrepancies. Especially in the Triângulo Mineiro, Alto Paranaíba and Zona da Mata regions, it is possible to see groups of municipalities that show water supply rates above the general average (high-high relation).

The low-low relationships, which are groups of cities with below-average rates, are prevalent in the North and Northwest regions, as do the high-low outliers. In these regions there are cities with above-average rates surrounded by cities with below-average rates.

Regarding the sewage without treatment index in the municipalities of Minas Gerais, a map showing the local Moran coefficient was also prepared, as shown in Figure 4.

It is possible to identify high-high clusters concentrated in the South, Rio Doce and, in a smaller area, Zona da Mata regions, indicating there is a group of cities within the same region with similar sewage without treatment rates and above the average value for the State.

At the same time, the low-low associations are concentrated in the North, Central (especially in the São Francisco River Basin) and, to a lesser extent, Jequitinhonha-Mucuri region. The Central region has intraregional discrepancies in relation to sewage collection.

The North and Central regions are the ones with the most high-low outliers, i.e., cities with discrepant values from their neighbors. The South, Zona da Mata and Rio Doce regions concentrate the opposite condition.

Finally, the local Moran coefficient for sewage with treatment in the municipalities of Minas Gerais is presented in Figure 5.

The Zona da Mata, Sul de Minas and Rio Doce regions concentrate the low-low clusters, i.e., they present groups of municipalities with below-average sewage with treatment rates. The North and Jequitinhonha-Mucuri regions concentrate the high-high clusters, followed by the Midwest and Triângulo Mineiro regions.

The low-high outliers are dispersed in the South, Triângulo Mineiro, Northwest, Central, Midwest, Rio Doce, Jequitinhonha-Mucuri and North regions. The high-high outliers prevail in the Central and Zona da Mata regions and in smaller groups, in Alto Paranaíba, South and Northwest.

The spatial correlation analyses for the three evaluated indexes (water supply, sewage without treatment and sewage with treatment) demonstrate, considering the concentration of clusters and outliers, there are differences between the North and Jequit-

Table 4 – Distribution of water and sewage service rates among the planning regions of Minas Gerais.

Region	Sewage (urban population)		Water (urban population)
	Average coverage index with collection and without treatment	Average coverage index with collection and treatment	Average service index of water supply network
North	29.04%	24.76%	96.85
Northwest	30.27%	34.88%	96.53
Jequitinhonha-Mucuri	54.21%	18.08%	96.70
Midwest	56.73%	27.62%	96.91
Central	60.30%	14.54%	96.74
Rio Doce	62.49%	16.53%	97.36
Zona da Mata	66.02%	11.28%	97.54
South	66.63%	14.99%	95.68
Alto Paranaíba	67.45%	20.22%	98.10
Triângulo Mineiro	67.67%	18.09%	99.38

Source: Adapted from *Agência Nacional de Águas* (2017) and IBGE (2013) *apud* FJP (2017).

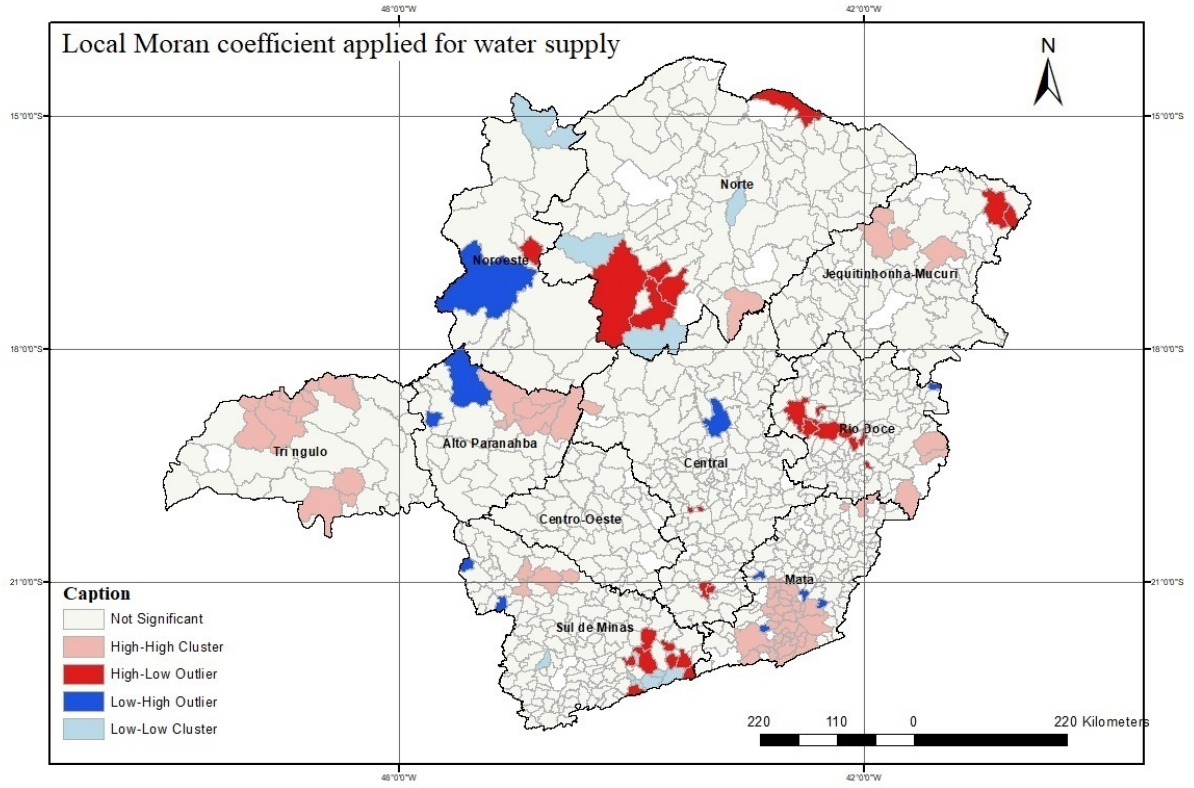

Figure 3 – Spatial correlation map for water supply index in the State planning regions of Minas Gerais.

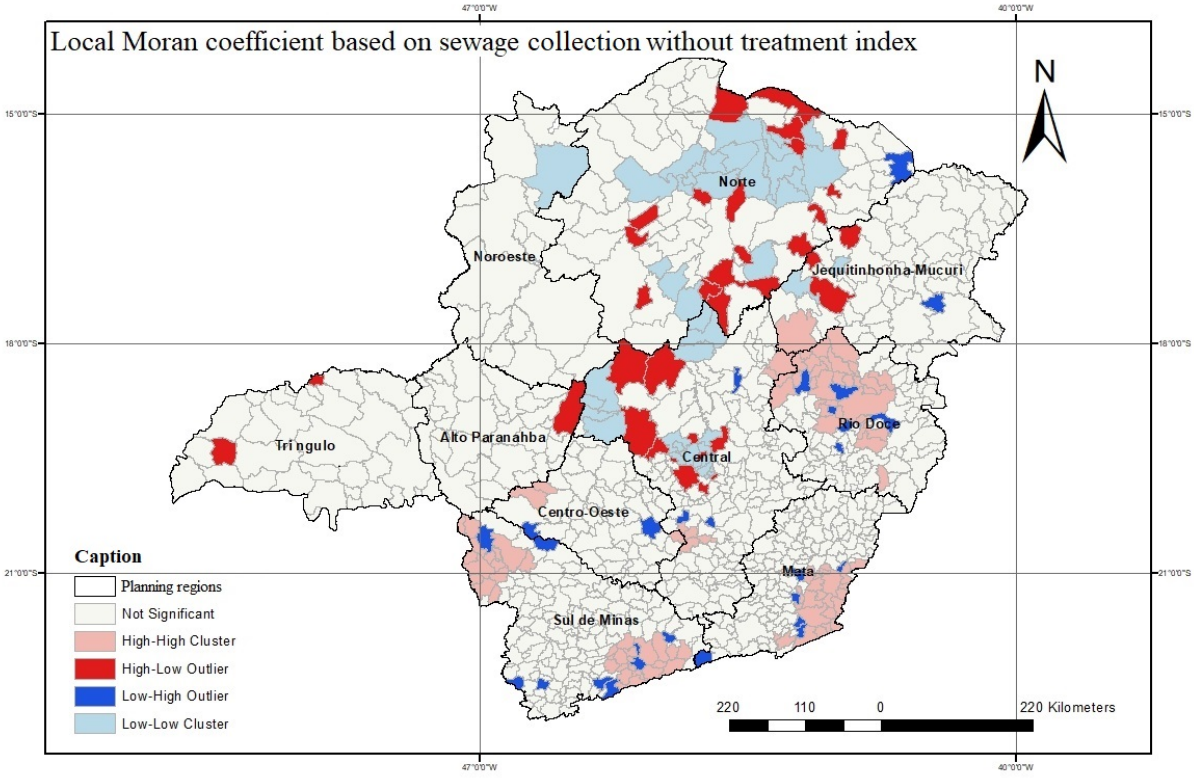

Figure 4 – Spatial correlation map for sewage without treatment index in Minas Gerais.

inhonha-Mucuri regions and the other ones. In the North and Jequitinhonha-Mucuri, low-low clusters are prevalent, indicating a concentration of municipalities with below-average water supply and sewage without treatment rates, while in the others, high-high clusters are prevalent.

The biggest difference occurs between the North and Jequitinhonha-Mucuri *versus* the Rio Doce, Zona da Mata and Sul de Minas regions. The Central region represents a mixture of high and low rates, with highs predominating in its southern portion, and lows in its northern portion.

This analysis also allowed us to understand that even regions with high-high clusters concentration and with high mean indexes in comparison to the others, according to Table 1, present intraregional discrepancies, with low-high outliers. The results show that access to water supply and sewage is unequal among the municipalities and between the planning regions of Minas Gerais.

Correlation with social indicators - per capita income distribution and IDHM

At this stage, per capita income and IDHM data were evaluated in order to identify a possible correlation between water and sewage rates and regional social conditions.

The North region presents a little more than 75% of its cities with average IDHM and approximately 19% with low IDHM; Jequitinhonha-Mucuri has 42% of the cities with low IDHM, and 52% average; and in the Rio Doce region, 70% of the cities have average IDHM, with only 13% presenting low index. The Alto Paranaíba and Triângulo Mineiro regions have 62% of their cities with high IDHM, followed by the Midwest region, where 50% of the cities have high index and Sul de Minas, with 41%. In Zona da Mata, the average indexes appear in almost 78% of the municipalities.

The North and Jequitinhonha-Mucuri regions present a higher concentration of municipalities with the lowest per capita income

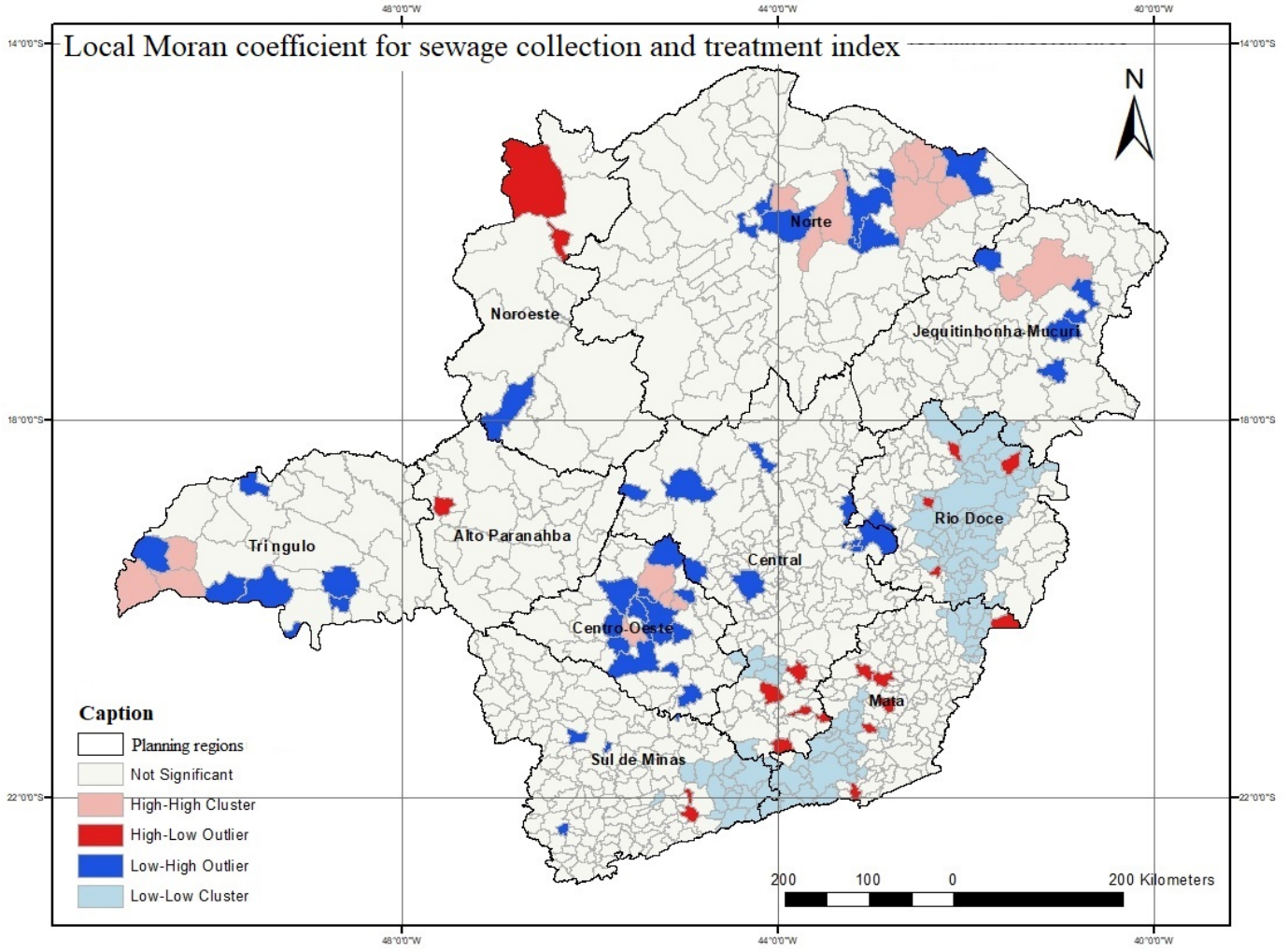

Figure 5 – Spatial correlation map for sewage with treatment index in the planning regions of the State of Minas Gerais.

and IDHM values in the State, reinforcing a possible divergence of standards between these and the other regions of Minas.

The result presented in Figure 6 is similar to that observed in Figure 7, both showing that municipalities of the North, Jequitinhonha-Mucuri, Rio Doce regions, and the northern portion of the Central region, are predominantly in the low and average IDHM ranges, whereas most of the cities in Sul de Minas, Centro-Oeste and especially Alto Paranaíba and Triângulo Mineiro have high IDHM. Only Belo Horizonte and Nova Lima, in the Central region, are in the very high range.

The local Moran correlation coefficient was calculated for the per capita income and IDHM data, whose results are in Figures 8 and 9, and show the existing heterogeneity between the different planning regions of the state of Minas Gerais.

We observed a higher concentration of low-low clusters of IDHM data in the North of the State of Minas Gerais. Part of the regions of Zona da Mata and the North of Rio Doce displays the positive spatial association between a city and its neighbors (high-high cluster). High-low outliers are also observed in the central region.

Regarding income distribution, in the North and Jequitinhonha-Mucuri regions, besides the Northern extremities of the Rio Doce and Central regions, there is a greater concentration of low-low clusters. In these, there is a predominance of municipalities with income values below-average. In the same regions, the high-low outliers are concentrated, demonstrating that some municipalities have above-average per capita income values, with neighbors having below-average values. The opposite happens with the Sul de Minas, Midwest, Alto Paranaíba, Northwest, Triângulo Mineiro and Central regions, where there is concentration of high-high clusters, but occurrence of low-high outliers.

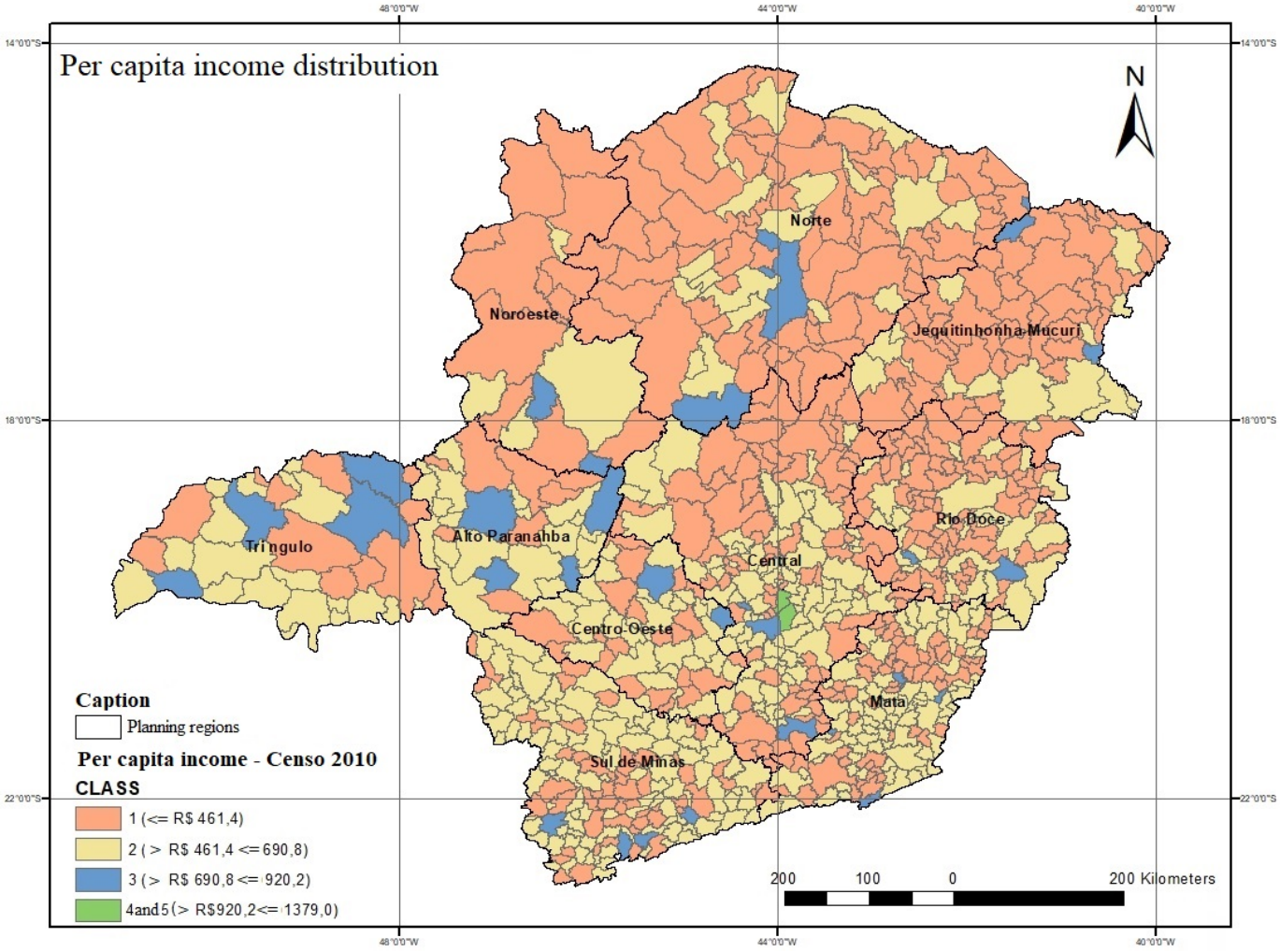

Figure 6 – *Per capita* income data in the municipalities and planning regions of Minas Gerais.

Investments' evaluation in water and sewage

At this stage, data regarding regional investments were evaluated by measuring the total amount of investments made between 1995 and 2017 in Minas Gerais, in water supply and sewage per region, whose results are presented in Table 5.

The total amount invested in water supply and sewage in the cities of Minas Gerais by the municipalities' administrations, providers and the State in the last 20 years was R$24.76 billion. Analyzing the data presented in Table 5, Zona da Mata, Rio Doce, Triângulo, and Central are the regions with the highest total and where the average investment amounts stand out. The Central region concentrated almost 80% of the total investment in Minas Gerais, of which more than 95% went to the city of Belo Horizonte.

Jequitinhonha-Mucuri has the lowest average investment value, followed by the North, both of which are in the semiarid climate region — according to SUDENE (2017a), this region is characterized by an annual average rainfall of 800 mm or less; SUDENE (2017b) also says this region covers 1,262 Brazilian municipalities (and 91 from Minas Gerais). These same regions present 54.21% and 29.04% of sewage without treatment, and 18.08% and 24.76% of sewage with treatment, respectively.

It is important to point out that some of these regions present a concentration of investment in only one municipality. In the Jequitinhonha-Mucuri region, Teófilo Otoni received more than 97% of the investments; and in the Northwest, Unaí received 76.7% of them. One factor that may have contributed to the concentration of investments is the centralization of regional populations in these municipalities. Forty percent of the population of the Central region and 14% of the entire population of the State lives in Belo Horizonte; in Teófilo Otoni, this number drops to 13.5% in relation to Jequitinhonha-Mucuri, and to 0.65% concerning to the State; and in Unaí, to 21.19% of the inhabitants of the Northwest region and 0.37% of the State.

The correlation between the average investment variables and sewage index per region was evaluated by the Pearson's correlation index (r), which generated a value of approximately 0.21, indicating a weak positive relationship (as one variable grows, the other also grows) among them. This can be observed in real life in Central region data, which despite having received almost 80% of the investments in the State, presents a water supply index smaller than the Rio Doce, Zona da Mata, Alto Paranaíba and Triângulo Mineiro regions. About sewage index, this region is still behind Sul de Minas (Table 4).

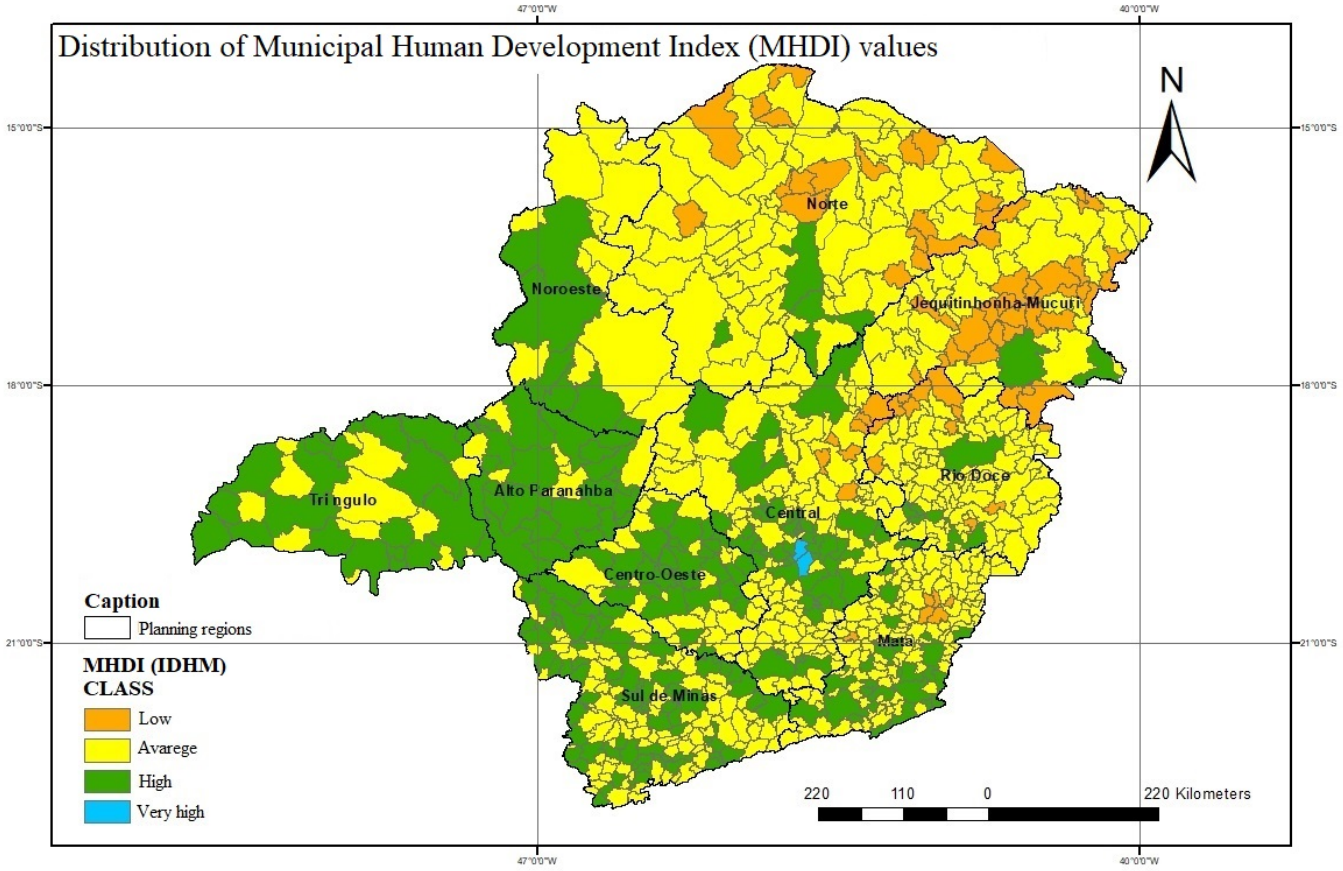

Figure 7 – MHDI data map by municipalities and planning regions of Minas Gerais.

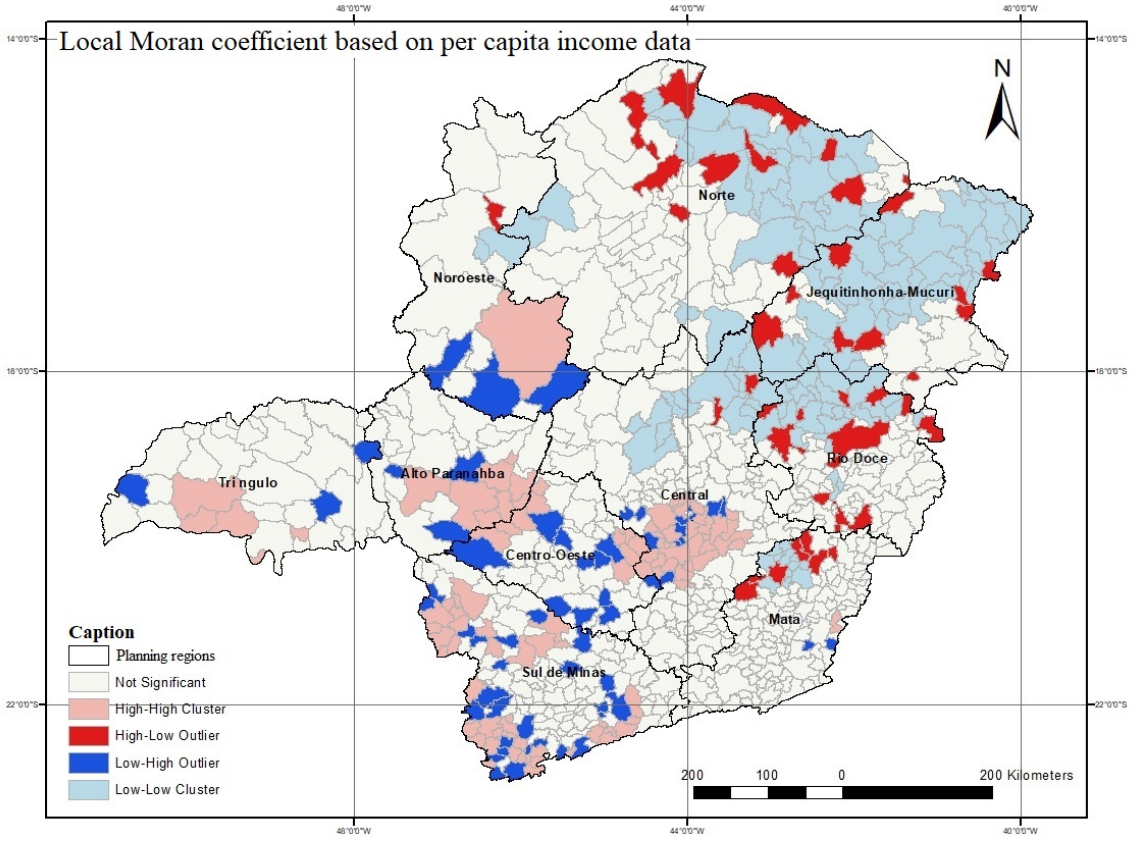

Figure 8 – Spatial correlation map for *per capita* income in the planning regions of Minas Gerais.

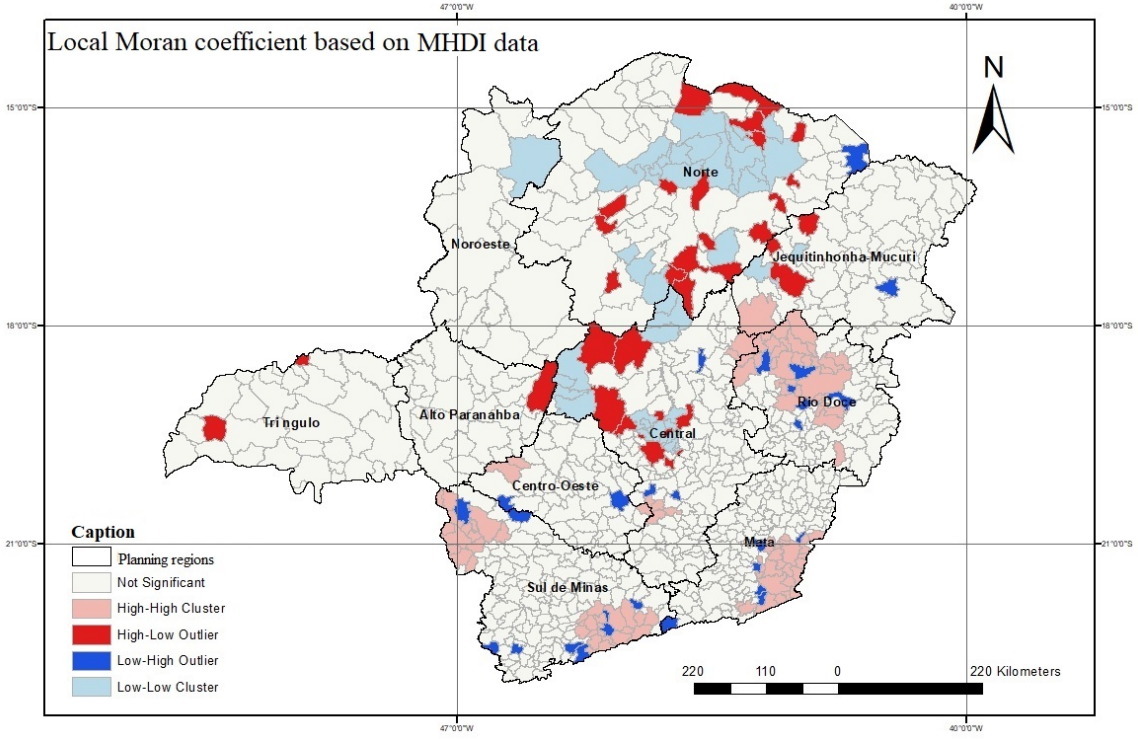

Figure 9 – Spatial correlation map for MHDI through the planning regions of Minas Gerais.

Table 5 – Investments in water supply and sewage by region in Minas Gerais.

Region	Total investment (R$)*	Average investment (R$)**
Jequitinhonha/Mucuri	523,356,236.76	1,466,942.41
North	31,479,926.26	3,497,769.58
Alto Paranaíba	91,788,358.78	4,830,966.25
South	448,449,454.14	5,214,528.54
Midwest	276,314,253.68	7,467,952.80
Northwest	62,041,045.33	7,755,130.67
Zona da Mata	897,057,729.03	10,679,258.68
Rio Doce	1,177,616,442.70	21,807,711.90
Triângulo	1,633.916,404.21	85,995,600.22
Central	19,619,064,989.45	248,342,594.80
MINAS GERAIS	R$24,761,084,840.34	R$397,058,455.86

*Sum of the investments made by different entities (providers, municipality and State) in all the municipalities of each region in each year; **average amount invested in the region, obtained by dividing the total investments and the number of municipalities of each region.

Integrated analysis

An integrated analysis of the data compiled in Table 6 was conducted, resulting in a repetition pattern that shows unfavorable results concentrated in the North and Jequitinhonha-Mucuri regions for water vulnerability, sewage index with and without treatment, total investment, average investment, per capita income and MHDI. On the other hand, the Zona da Mata and Triângulo regions present the best indexes in relation to water vulnerability, sewage index with and without sewage treatment and water supply. The Triângulo Mineiro region also presents high rates of total investment, average investment, per capita income and MHDI.

It is also important to stress that the Sul de Minas and Alto Paranaíba regions present better conditions in the evaluated indexes. An exception of the correlation model was observed in Sul de Minas. Despite the high MHDI values, sanitation indexes do not have the same behavior. A similar conclusion was presented by Souza et al. (2016) for the State of Goiás.

In a study on access to water supply and sewage in the mesoregions of Minas Gerais, Rodrigues et al. (2019b) noticed a relationship between the greatest access deficits and the lowest rates of urbanization and income levels, especially in the north of the State. Oliveira and Ervilha (2019)

Table 6 – Compilation of the values and attributes related to the variables analyzed for the planning regions of Minas Gerais.

Region	WV	WE (%)	TR (%)	WS (%)	AI (R$)	PCI (class)	MHDI
North	Very high, high and average	29,04	24,76	96,85	3,497,769.6	1, 2 and 3	Low, average and high
Northwest	High and average	30.27	34.88	96.53	7,755,130.7	1, 2 and 3	Average and high
Jequitinhonha-Mucuri	Very high, high and average	54.21	18.08	96.70	1,466,942.4	1, 2 and 3	Low, average and high
Midwest	High, average and low	56.73	27.62	96.91	7,467,952.8	1, 2 and 3	Average and high
Central	High, average and low	60.30	14.54	96.74	248,342,594.8	1, 2, 3, 4 and 5	Low, average, high and very high
Rio Doce	Average and low	62.49	16.53	97.36	21,807,711.9	1, 2 and 3	Low, average and high
Mata	Average and low	66.02	11.28	97.54	10,679,258.7	1, 2 and 3	Low, average and high
South	Average and low	66.63	14.99	95.68	5,214,528.5	1, 2 and 3	Average and high
Alto Paranaíba	Average and low	67.45	20.22	98.10	4,830,966.25	1, 2 and 3	Average and high
Triângulo	Average and low	67.67	18.09	99.38	85,995,600.2	1, 2 and 3	Average and high

WV: water vulnerability; NT: sewage without treatment; TR: sewage with treatment; WS: water supply coverage; AI: average investment; PCI: *per capita* incom); MHDI: municipal human development index.

concluded there are significant inequalities between the municipalities of Minas Gerais concerning access to basic sanitation, with the worst rates in the North, Jequitinhonha and Mucuri valleys. Assessing the inequity in access to water, Aleixo et al. (2016) concluded there is an obvious influence of regional (country, state, type of area — urban or rural), socioeconomic (income and schooling), demographic (gender and race) and cultural factors (religion) in access or lack of access to water.

Conclusion

Based on the aforementioned results, the Model of Integrated Territorial Assessment for Environmental Justice Applied to Sanitation proposed in this paper and applied for the State of Minas Gerais allows a systemic and integrated analysis of environmental justice in the sanitation sector.

Principles and practices of environmental justice in access to sanitation were not considered when allocating financial resources in Minas Gerais. It is worth noting that in only 43 – out of the 674 municipalities in Minas Gerais studied by Siqueira et al. (2018) – the quality of investment in sanitation showed high level of efficiency in the allocation, which, in fact, may be related to political determinants (Kresch and Schneider, 2020).

The comparison between the Central and North regions, representing extremes, shows that the Central region received 79.23% of the investment in water supply and sewage in the last 20 years, whereas the North received 0.13%. The Central region has about 2/3 of its territory with average and low water vulnerability, while the North has almost all cities with high and very high vulnerability. In the Central region, 60.3% of the sewage is collected, but not treated, against 29.04% in the North. The lowest income and MHDI rates occur in the municipalities of the North region.

The North and Jequitinhonha-Mucuri planning regions have the highest water vulnerability, as well as the lowest levels of water supply, sewage without treatment and investment. This, associated with the unfavorable socioeconomic results (low income and MHDI), points to a critical situation of the mentioned regions in relation to environmental justice in sanitation, coherent with what is verified in the global scenario (Local Burden of Disease WaSH Collaborators, 2020).

The results show there is inequality between the Minas Gerais regions regarding water supply and sewage, not only because of the natural context, marked by water vulnerability, but also by the socioeconomic status and different concentrations of investments.

Authors' contributions:

Elias, L.G.R.: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Data Curation, Writing — Original Draft, Writing — Review & Editing; Melo, M.C.: Validation, Formal Analysis, Writing — Review & Editing, Supervision; Santos, A. S. P.: Writing — Review & Editing; Maia, L. C.: Writing — Review & Editing.

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