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ABSTRACT

In line with Federal Law number 14.026/2020, the Complementary Law number 168/2021 was established with the purpose of creating the water and sewage microregions of the state of Paraíba: Alto Piranhas, Borborema, Espinharas, and Litoral. However, despite the technical study conducted at the moment of creating these delimitations, the microregions may present problems related to both coverage and economic-financial performance of the services provided. In this sense, the present study aims to carry out a comparative cluster analysis of the municipalities of the state of Paraíba based on social, financial, and coverage indicators of water supply and sanitary sewage services and assess the technical capacity of the water and sewage microregions. To this end, cluster analyses were applied along with spatial data analysis techniques using Geographic Information Systems (GIS) and the Moran's index. In general, clusters with worse economic-financial performance and coverage were found to be concentrated in the Borborema microregion. This microregion also presented one of the worst situations in terms of water stress, with high water consumption and high dependence on dams. The Litoral microregion, in turn, had the best patterns of financial performance, with clusters that coincide with regions presenting better performance in water supply in urban areas and good affordability.

Keywords: Sanitation regionalization; Water and sewage microregions; Cluster analysis.

RESUMO

Em consonância com a Lei Federal nº14.026/2020, estabeleceu-se a Lei Complementar nº 168/2021, que cria as microrregiões de água e esgoto do estado da Paraíba: Alto Piranhas, Borborema, Espinharas e Litoral. Entretanto, apesar do estudo técnico elaborado, as regionais delimitadas podem apresentar problemáticas tanto relacionadas à cobertura dos serviços prestados quanto ao desempenho econômico-financeiro. Nesse sentido, o estudo objetiva realizar uma análise comparativa de agrupamento entre os municípios do estado da Paraíba, a partir de indicadores sociais, financeiros e de atendimento dos serviços de abastecimento de água e esgotamento sanitário, relacionando com as microrregiões de água e esgoto do estado, além de uma avaliação da capacidade técnica das regionais. Para tanto, foram aplicadas análises de clusters em conjunto com técnicas de análise espacial de dados, a partir do uso de Sistemas de Informações Geográficas (SIG) e da determinação do Índice de Moran. De maneira geral, nota-se a ocorrência de clusters com piores desempenho econômico-financeiro e de atendimento dos serviços concentrados na regional Borborema. Além disso, a microrregião apresenta uma das maiores situações de estresse hídrico, com grande consumo de água e alta dependência dos açudes. O Litoral, por sua vez, possui os melhores padrões de desempenho financeiro, com clusters de áreas que coincidem com regiões de melhor desempenho no abastecimento de água nas zonas urbanas e boa capacidade de pagamento.

Palavras-chave: Regionalização do saneamento; Microrregiões de água e esgoto; *Cluster analysis*.

INTRODUCTION

One of the United Nations Sustainable Development Goals (UN SDGs) is the achievement of universal access to adequate and equitable sanitation and hygiene and the end of open defecation by the year 2030. According to the latest World Health Organization (WHO) report, 2 billion people still lack access to potable water and 3.6 billion lack safe sewage services. The data also inform that 494 million people practice open defecation, and 92% of these people live in rural areas (WHO/UNICEF, 2021). Thus, to meet the goals set by the UN until 2030, it is necessary that investments in sanitation become a global priority in the coming years.

In Brazil, data from the National Sanitation Information System (SNIS) show that 84.0% of the Brazilian population has access to treated water supply, indicating that almost 35 million people do not have access to potable water. Statistics also show that only 55.0% of the population has access to sewage network, meaning that almost 100 million inhabitants do not have access to this service (SNIS, 2020).

According to the SNIS (2020), the Northeast is one of the regions of Brazil most affected by the problem of water shortages and lack of sewage network. In this region, treated water is available for about 74.0% of the population and effluent collection for only 30.3%. This reality compromises the health and quality of life of the population.

Inequalities in access to sanitation services are also present in different sectors of the same municipality. Within the urban space, there are groups that are more vulnerable and needy, living in the outskirts of the city and negatively affected by inefficient government actions to provide adequate basic sanitation. Unequal access is also observed in rural areas. According to the National Rural Sanitation Program (NRSP), about 14.2% of the Brazilian population lives in rural areas; 28.7% of these people do not have water supply by networks, wells or springs, and 69.3% live in areas with poor sanitary sewage service coverage or none at all (Brasil, 2019).

Federal Law number 14.026/2020, which updated the legal framework for basic sanitation, has as its main objective to ensure the universalization of water supply and sewage services in Brazil in view of the important deficits and serious negative impacts that the absence of these services causes on public health, education, the environment, and economic and social development. Thus, the law allows the states to establish Microregions of Basic Sanitation so that the state and the municipalities that compose the microregions may organize, plan, execute, and operate the water supply and sewage services in a joint and integrated manner (FUNDACE, 2021).

Paraíba is one of the Brazilian states that have a law approved for the regionalization of basic sanitation services. In this state, water supply and sewage collection services are available for 82.98% and 38.21% of the population, respectively. The Complementary Law number 168/2021 established the water and sewage microregions of Paraíba and their respective governance structures, namely: Alto Piranhas with 38 municipalities; Borborema with 84 municipalities; Espinharas with 46 municipalities; and Litoral with 55 municipalities.

The study for the division of Paraíba into four microregions was based on information such as levels of water supply and sewage service coverage in each municipality, the existing demand, costs to provide the service, and estimated investments necessary for universalization. Population projection data and demographic, economic and socioeconomic indicators of the municipalities were

also analyzed (FUNDACE, 2021).

The present study aims to perform a comparative cluster analysis of the municipalities of Paraíba based on the calculation of social, financial and coverage indicators of water supply and sanitary sewage services in the water and sewage microregions of Paraíba. An assessment of the technical capacity of the microregions established in the Complementary Law number 168/2021, based on the water supply-demand ratio, was also carried out because this analysis was not included in the technical study. To this end, in addition to calculating the indicators, cluster analyses were performed in conjunction with spatial data analysis techniques using Geographic Information Systems (GIS) and determination of the Moran's index.

This work can contribute with information from the microregions of the state of Paraíba that was ignored in the process of definition of blocks by the Foundation for Research and Development of Administration, Accounting and Economics (Fundace) and the State Government and which is unknown to the population. The methodology and analyses presented here can assist in the decision making of water supply and sewage service providers in the municipalities in order to achieve the universalization goals established by Federal Law number 14.026/2020 and, consequently, overcome the existing challenges in sanitation management.

REGIONAL MANAGEMENT AND DEVELOPMENT IN THE CURRENT SANITATION SCENARIO

Management in regional development is essential to make progress towards equitable access to basic sanitation services, such as water supply and sewage, in different areas of a region, state or municipality. Adequate management in the pursuit of regional development, in addition to contributing to sanitation, brings improvements in public health, education and in the quality of life of the population. According to the World Health Organization (WHO), for every dollar invested in sanitation, four dollars return in the form of reduced health care costs with the treatment of diseases related to inadequate sanitation conditions (WHO, 2017).

Sanitation and wastewater management face several challenges yet to be overcome, such as disparities in access, adoption of inadequate infrastructures to meet the demands, and lack of financial and technical resources to implement improvements in services. In addition to strategic planning,

management to solve the current problems needs to promote the participation and engagement of the population and monitor and evaluate the progress of the goals set (Neves-Silva *et al.*, 2016; Souza *et al.*, 2019).

Regional development in the context of sanitation must seek policies and investments to improve the conditions of a given region, with the reduction of disparities through partnerships, implementation of technological innovations, sustainability, and conservation of the environment (Cruz *et al.*, 2020; Marrara *et al.*, 2022).

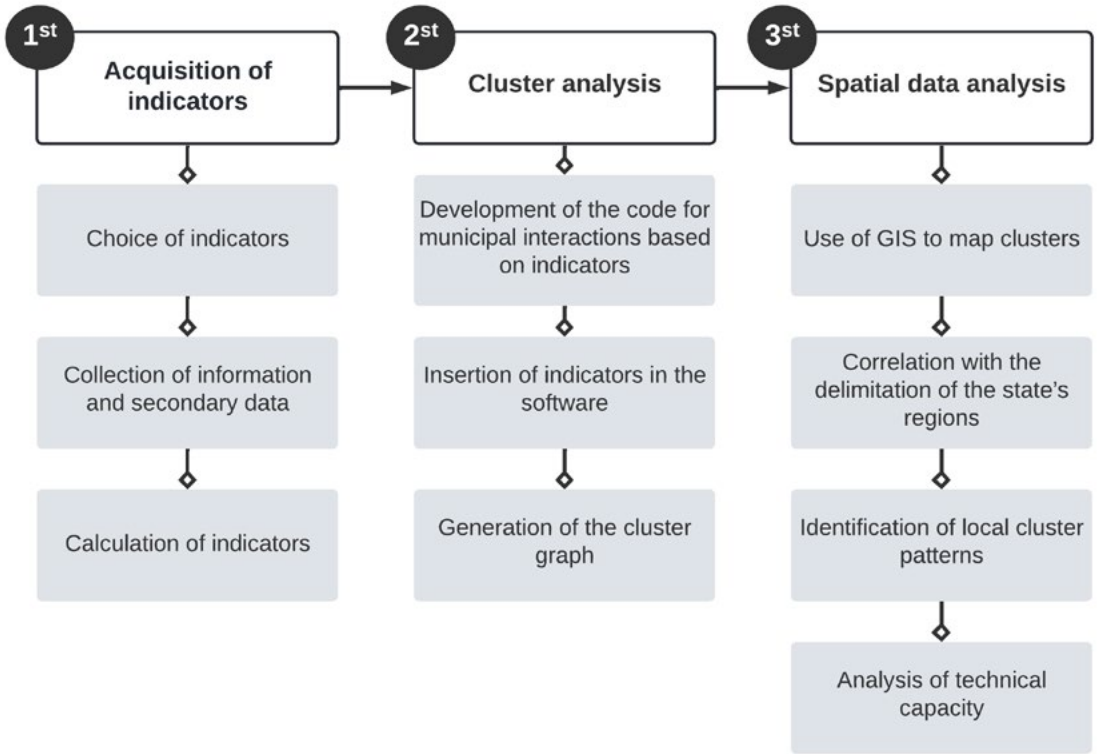
Although the regionalization proposed by Federal Law number 14.020/2020 can be adopted as an instrument of regional development and has been provided for in the Brazilian legal system for some time, it should occur in a planned and technical manner, in environmental, economic, social and human projections. In the case of the state of Paraíba, the municipal blocks created by Fundace standardized the procedure without working on the content along with state technicians and without paying attention to important internal details, such as the compatibility between deficit and surplus municipalities as a measure to diffuse and minimize inequalities (Silva *et al.*, 2022).

The process of regionalization of Paraíba will certainly result in disparities between more favored and less favored regions in terms of both economic performance and coverage of water and sewage services. It is likely that inequalities in access will increase because the socioeconomic profiles and technical feasibility in each municipality and microregion were not evaluated. There are uncertainties regarding sanitation in rural areas and traditional communities and, also, there was no debate between the state government and the population about the definition of the blocks. It is important to highlight that another flaw was the construction of blocks without considering environmental issues (Barreto *et al.*, 2021; Pequeno *et al.*, 2023, Silva *et al.*, 2022).

METHODOLOGY

To achieve the proposed objective, the methodological procedures were based on three stages presented in the flowchart in Figure 1 and detailed later.

Figure 1 | Synthesis flowchart of the stages of the methodological procedures



Source: The authors (2022).

ACQUISITION OF INDICATORS

Considering the technical study that deals with the water and sewage microregions of Paraíba (FUNDACE, 2021), we chose to work with financial, social and coverage indicators of water supply and sewage services, as shown in Box 1. We highlight that, due to the low participation of the municipalities of Paraíba in the declaration of data in the SNIS, coverage data were obtained from the databases of the National Water and Basic Sanitation Agency (ANA) and the Brazilian Institute of Geography and Statistics (IBGE).

In order to carry out a cluster analysis, which classifies the elements of a group into subsets of smaller quantities through recognition of similar characteristics, it was necessary to select

and organize the indicators into different sets (Landeiro; Bacaro, 2015; Stockemer, 2019). According to Barreto *et al.* (2021), the technical study compares the four microregions in several aspects as if they were homogeneous in relation to the analyzed data, so that peculiarities of each municipality such as coverage in urban and rural areas are not considered. Thus, the municipal indicators were allocated into three sets:

- Urban water supply and sewage service coverage (IND_1 and IND_2);
- Rural water supply and sewage service coverage (IND_3 and IND_4);
- Financial performance and affordability (IND_5 and IND_6).

Box 1 | Indicators used in the cluster analysis

	Indicator	Description	Equation	Source
Coverage	IND_1 - Urban water supply coverage	Proportion of the urban population that has regular and adequate access to water supply services by distribution network	$\frac{\text{Urban population covered by water supply network}}{\text{Total urban population}} \cdot 100$	ANA (2021)
Coverage	IND_2 - Urban sewage network coverage	Proportion of the urban population that has access to sewage networks, indicating the reach of the infrastructure	$\frac{\text{Urban population covered by sewage network}}{\text{Total urban population}} \cdot 100$	ANA (2013)
Coverage	IND_3 - Rural water supply coverage	Proportion of the rural population that has regular and adequate access to water supply services by network, springs, wells or cisterns	$\frac{\text{Rural households covered by water supply network, springs, wells or cisterns}}{\text{Total rural households}} \cdot 100$	IBGE (2011)
Coverage	IND_4 - Rural sewage network or septic tank coverage	Proportion of the rural population that has access to sewage network or septic tanks, indicating the reach of the infrastructure in these areas	$\frac{\text{Rural households covered by sewage network or septic tanks}}{\text{Total rural households}} \cdot 100$	IBGE (2011)
Financial	IND_5 - Financial performance	Financial metric that evaluates revenues generated by water supply and sewage treatment services	$\frac{\text{Direct operating revenue from water, exported water and sewage}}{\text{Total expenses with services}} \cdot 100$	SNIS (Mean from 2015 to 2020)
Social	IND_6 - MHDI income	Measurement of the standard of living and economic well-being of the population in a given area based on variables such as mean income	-	PNUD (2017)

Source: The authors (2022).

CLUSTER ANALYSIS

The K-means clustering method was used for the situational analysis of the municipalities of the state, as in the studies carried out by Rodrigues *et al.* (2018), Heinz *et al.* (2021), and Pintanel *et al.* (2021). This methodology groups the municipalities based on the indicators used within multiple groups, previously defined, so that the variation within the cluster is minimized by the sum of the squares of the Euclidean distances between the items and their centroids.

The RStudio computer software was chosen to carry out the abovementioned analysis. The programming code developed for the clustering is shown in Figure 2, in which the databases were implemented through the "data" function. Then, the clusters were elaborated through the "kmeans" function, which analyzes the data and presents the clusters in the form of a list.

Before the the clustering analysis, the "fviz_nbclust" function was used to build the graph of the optimal number of clusters, to define the number of clusters to be used in the clustering process. Through the analysis of this graph and with the objective that the number of clusters was identical to the number of microregions, the chosen number of clusters to be generated by the software was four.

Figure 2 | Code used in RStudio for clustering

```
library(FactoMineR)
library(factoextra)
library(cluster)
library(xlsx)
library(tidyverse)

urbano<-data.frame(Planilha_urbano, row.names = 1)
urbano2<-Planilha_urbano[,-1]
urbano_scale<-scale(urbano2)
fviz_nbclust(urbano_scale, kmeans, method = "wss")
set.seed(123)
km.urb <- kmeans(urbano_scale, 4, nstart = 50)
fviz_cluster(km.urb, data = urbano2, ellipse.type = "euclid")
dd <- cbind(urbano, cluster = km.urb$cluster)
head(dd)
write.csv(dd, "C:/Users/ayrto/Downloads/neww.csv")

```

Source: The authors (2022).

After dividing the clusters for each of the sets studied (coverage in the urban area, coverage in the rural area, and economic and financial sustainability), the "fviz_cluster" function was used to create a graphic representation of the allocation of municipalities to each cluster with the Euclidean ellipse, to allow the visualization of the position of each municipality within the framework and the comparison of the municipalities in relation to the whole. The municipalities are identified in the results for each cluster.

Finally, spreadsheets were generated for each of the sets, using the "write.csv' function. In Excel, we used the "MEAN" function to calculate the mean and the "DESVPAD.P" function to calculate the standard deviation for the indicators of each cluster.

SPATIAL DATA ANALYSIS

The clusters generated in the cluster analysis made it possible to map the municipalities clustered for each of the sets of indicators and thus detect the correlation between the clusters and the delimitation of water and sewage microregions of the state of Paraíba. Geographic Information Systems (GIS) were used to this end, in the QGIS 3.22 software, using shapefiles made provided by the Executive Water Management Agency of the State of Paraíba (AESA).

In order to better understand the local spatial behavior of the criteria coverage, financial capacity, and technical capacity of the water supply and sewage services used in the technical study of the water and sewage microregions of Paraíba, the local Moran's index was calculated for each of the municipalities of the state using the same indicators previously selected, according to the studies of Barros *et al.* (2018), Barreto *et al.* (2019), Cruz *et al.* (2020), Cima *et al.* (2021), and Sotero-Martins *et al.* (2021).

The Moran's index measures the strength of spatial autocorrelation between data from an area of analysis and neighboring values. It allows us to measure how much the value of an indicator in a given region is dependent on the values of that indicator in neighboring regions. According to Anselin (2020), this methodology allows the identification of regional or local spatial association patterns, detection of atypical situations, and visualization of clusters of municipalities with similar values.

The spatial statistics software GeoDa 1.20 was used to perform the calculations of the local Moran's index and generate the scatter plots that allow a better visualization of the patterns. The Queen contiguity neighborhood criterion was used in this work.

Finally, in order to evaluate the technical capacity of the microregions to supply water, data on the following parameters were obtained from AESA and ANA: capacity and location of reservoirs, current percentage of volume, mean annual rainfall rates (isohyets), and consumptive uses of water. The data were processed in Excel software spreadsheets and were spatially evaluated using the QGIS 3.22 software.

RESULTS AND DISCUSSION

Clusters were generated to categorize the sets of indicators, as shown in Box 2. The means and standard deviations used for each of the clusters generated in each set are shown in Table 1.

Box 2 | Clusters generated for each of the sets of indicators

Set/Clusters	1	2	3	4
Urban service coverage	High access to water supply and medium access to sewage	High access to water supply and low access to sewage	Low access to water supply	High access to water supply and sewage
Rural service coverage	Medium access to water supply and medium access to sewage	Medium access to water supply and high access to sewage	Low access to water supply and sewage	High access to water supply and medium access to sewage
Financial performance and affordability	Medium financial performance and low affordability	Poor financial performance and medium affordability	Medium financial performance and high affordability	High financial performance and high affordability

Source: The authors (2022).

Table 1 | Means and standard deviations used to generate clusters for each of the sets of indicators

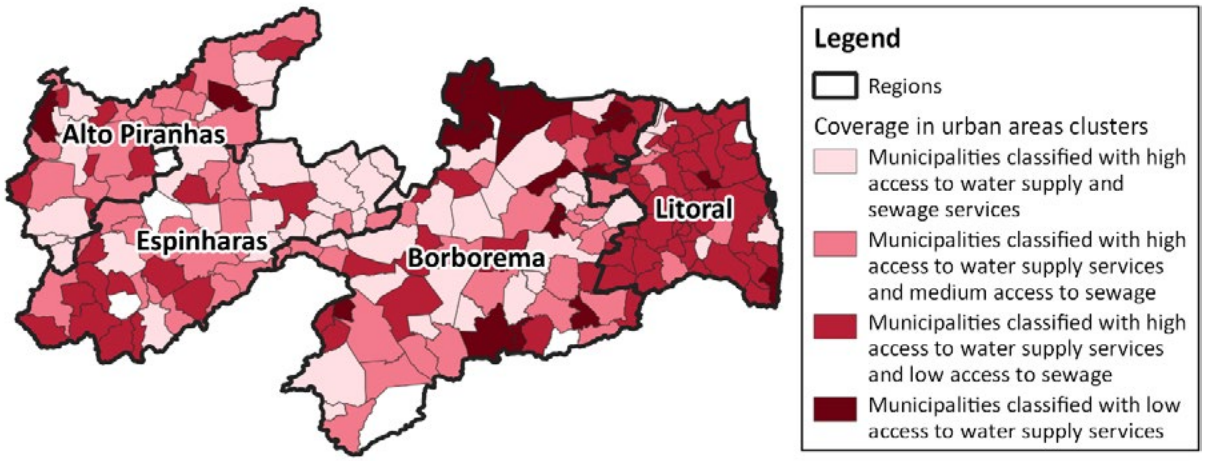
Set	Indicators	Cluster	1	2	3	4
Urban service coverage	Water supply coverage	Mean	93.45	91.47	2.77	97.16
		Standard deviation	11.42	14.43	8.95	6.37
	Sewage collection network or septic tank coverage	Mean	46.50	10.48	39.38	78.84
		Standard deviation	10.61	8.92	31.24	9.30
Rural service coverage	Water supply coverage	Mean	46.59	51.45	49.52	47.73
		Standard deviation	12.58	19.20	10.31	12.14
	Sewage collection network or septic tank coverage	Mean	22.79	58.05	2.95	4.19
		Standard deviation	6.66	13.35	2.69	4.75
Financial performance and affordability	Financial performance (%)	Mean	63.29	83.21	16.09	70.36
		Standard deviation	31.02	24.68	20.94	47.06
	MHDI Income	Mean	0.76	0.75	0.75	0.73
		Standard deviation	0.02	0.015	0.02	0.03

Source: The authors (2022).

CURRENT PANORAMA OF WATER SUPPLY AND SEWAGE SERVICES

The current situation of water supply and sewage services was spatialized in the map in Figure 3, divided by microregions, according to the cluster methodology.

Figure 3 | Map of the current sanitation panorama according to clusters of access to water supply and sewage in urban areas



Source: The authors (2022).

According to Figure 3, the Litoral microregion presented the best situation regarding access to services: 73% of the municipalities in this region were allocated to cluster 3; 11% to cluster 4; and only 4% and 11% were listed in the categories 1 and 2, respectively.

The Espinharas microregion had the largest number of municipalities in cluster 4, which corresponded to 35% of the municipalities allocated to this microregion, classified in the category of high access to water supply and sewage. None of the municipalities in this micrregion were classified with low access to water supply.

The Alto Piranhas microregion had the highest number of municipalities classified with high access to water supply services and medium access to sewage, corresponding to 42%, followed by Espinharas and Borborema with 35% and 27%, respectively. Alto Piranhas was also the second with the largest number of municipalities categorized in cluster 4, with 24%, behind only Borborema.

The Borborema microregion stood out with the worst urban coverage, with 20% of its municipalities allocated in cluster 3, which corresponded to 92% of all municipalities in this category. Due to the large number of municipalities placed in this microregion in relation to the other microregions, this was also the second microregion with the largest number of municipalities classified in the cluster of order 4.

The Litoral microregion stood out for having the highest percentage of population above 50,000 inhabitants, according to data from the National Demographic Census 2022, as well as the highest rate of urbanization. Furthermore, the Litoral microregion has two of the four municipalities of Paraíba considered large according to the National Confederation of Municipalities (CNM, 2018), for having a population of more than 100,000 inhabitants. This is a factor that favors the microregion in relation to the others in terms of public investments in the sanitation sector (Barreto *et al.*, 2021).

Throughout history, small municipalities have been neglected in the development of public policies, while priority has been generally given to larger urban centers, with greater political power and greater economic dynamism (Dunder; Zanirato, 2023; Mtika *et al.*, 2020; Pequeno *et al.*, 2023). These aspects influence the provision of water supply and sewage services in the microregions, since they interfere with the resources and infrastructure of existing systems and the investments made in the sector in urban and rural areas (Barreto *et al.*, 2021).

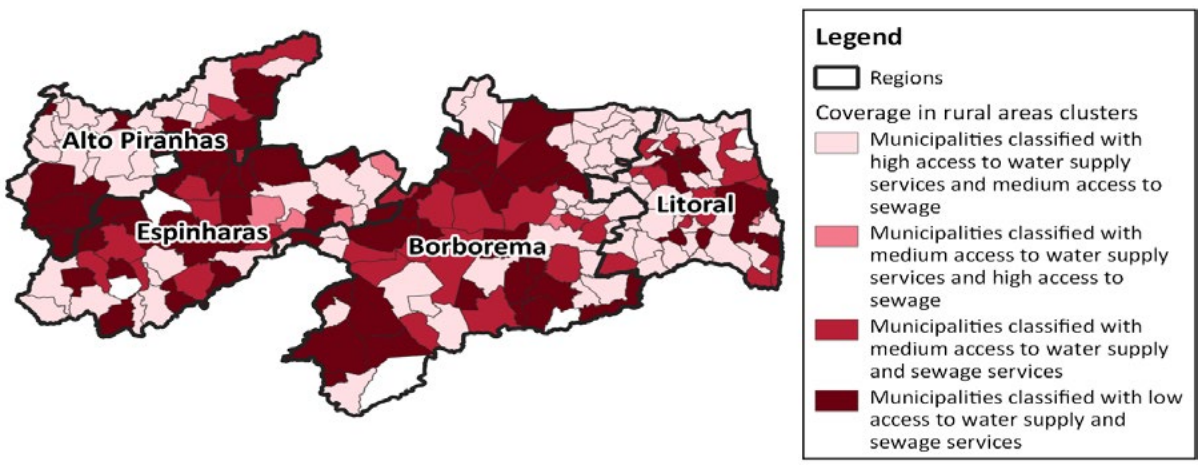
The regionalization of water supply and sewage services in Paraíba proposed by Complementary Law number 168 shows a process that lacked proper analysis of the technical document formulated and delivered and approved by the Chamber of Deputies, as state Pequeno *et al*. (2023) (Pequeno *et al.*, 2023). This gap clearly demonstrates fundamental flaws in regional management and development. In order to align the strategies implemented with the real needs of the population, partnerships and collaborations between the various stakeholders need to be created and the local community needs to be actively involved in decision-making (Baracho, 2018).

The map in Figure 4 shows the current scenario of access to water supply and sewage in the rural area.

The data extracted from the map in Figure 4 indicated that Litoral had 58% of its municipalities located in cluster 4, the category of high access to water supply and medium access to sewage, then Alto Piranhas had 55%, Borborema had 43%, and Espinharas had 26% of the municipalities in this category.

Espinharas had most municipalities (46%) categorized in cluster 3, followed by Borborema and Alto Piranhas with 35% and 32%, respectively. Litoral appeared with 16% of the municipalities with low access to services in the rural area.

Figure 4 | Map of the current sanitation panorama according to clusters of access to water supply and sewage in rural areas



Source: The authors (2022).

A small number of municipalities were allocated to cluster 2. Espinharas had 9% of its municipalities in this category. Litoral led the ranking regarding the municipalities categorized in cluster 1, with medium access to water supply and medium access to sewage, followed by Borborema and Espinharas, with 20%, 18% and 15%, respectively. Alto Piranhas appeared with only 8% of its municipalities in this classification.

In the rural context, the Borborema microregion stood out in terms of percentage of municipalities with low access to services, followed by Espinharas, Alto Piranhas and, finally, Litoral. Due to the large number of municipalities of Borborema in relation to the other microregions, Borborema was also the second one with the highest number of municipalities classified with high and medium coverage of services, behind Litoral.

Federal Law number 14,026/2020 and Complementary State Law number 168/2021 have gaps regarding the universalization of access to water supply and sewage services in rural areas. Besides that, there is a need for improvements in the acquisition and dissemination of data on water supply solutions used in rural areas. Thus, there are clear structural weaknesses in the sector; a stronger integration of policies, programs and management initiatives aimed at rural development is sorely needed (Santos; Mendes, 2023).

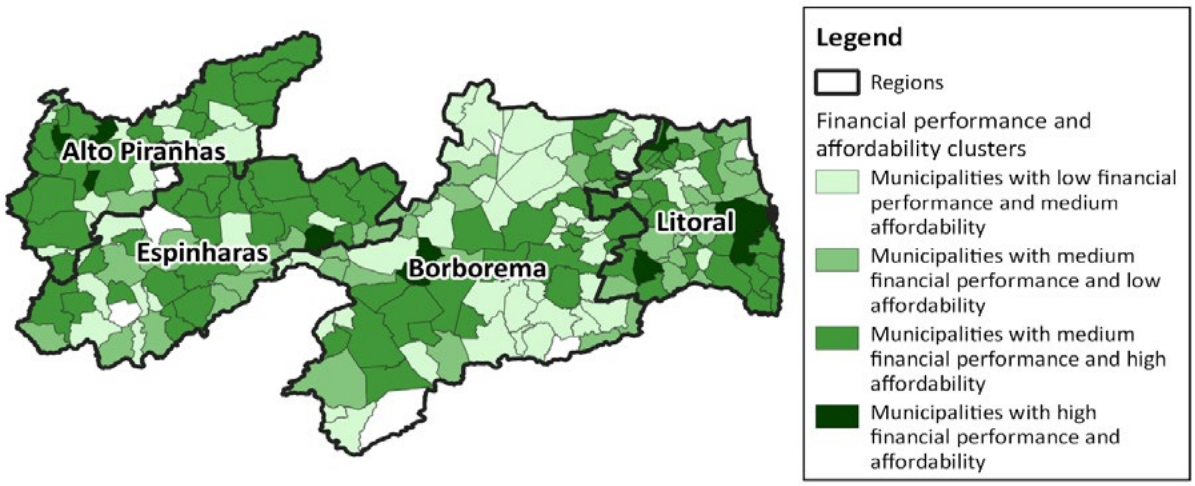
FINANCIAL PERFORMANCE AND AFFORDABILITY

Regarding the current situation of financial performance and affordability, Figure 5 shows the spatialization of data, by region, according to the cluster methodology.

The Borborema microregion had 19% of the municipalities classified in cluster 1, behind Litoral and Espinharas with 31% and 24%, respectively. Alto Piranhas appeared with 8% of municipalities in this category. Borborema stood out with the worst performance, with 49% of its municipalities classified in cluster 2, with low financial performance and medium affordability, which corresponds to 61.2% of the municipalities of the state in this category.

Litoral, on the other hand, stood out with the best performance, containing 45.5% of the total number of municipalities of the state with high financial performance and high affordability (cluster 4), and 27.5% of the municipalities of the state that had medium financial performance and high affordability (cluster 3).

Figure 5 | Map of financial performance and affordability of municipalities, by regions, according to the cluster methodology



Source: The authors (2022).

As pointed out by Barreto *et al.* (2021) in their research, only Litoral has a surplus in finances, being, therefore, the only one microregion with the ability to cover its own expenses and expand services through revenues from direct operations. In addition, this region is able to obtain indirect revenues more easily, since it is the only one of the four microregions that has financial sustainability (Pequeno *et al.*, 2023).

Regionalization could collaborate with the universalization process if the blocks of municipalities were composed of surplus and deficit municipalities, allowing the implementation of cross-subsidization, in order to promote the economic-financial balance necessary for the expansion of services in poorer municipalities (CRUZ *et al.*, 2020). Therefore, the blocks formed by poorer municipalities, namely, Alto Piranhas, Borborema and Espinharas, are not expected to attract investments.

Barreto *et al.* (2021) called attention to inequalities in access to services that may increase among municipalities and microregions because cross-subsidization, which is a way to guarantee access to sanitation services for the poorest regions, will not be feasible, ultimately preventing the universal access to services for a large part of the population of Paraíba.

IDENTIFICATION OF PATTERNS

As described in the methodological stage, Moran's statistics were calculated to verify the spatial relationship of the indicators used. All variables used showed a direct statistically significant spatial correlation with positive Moran's values (Table 2).

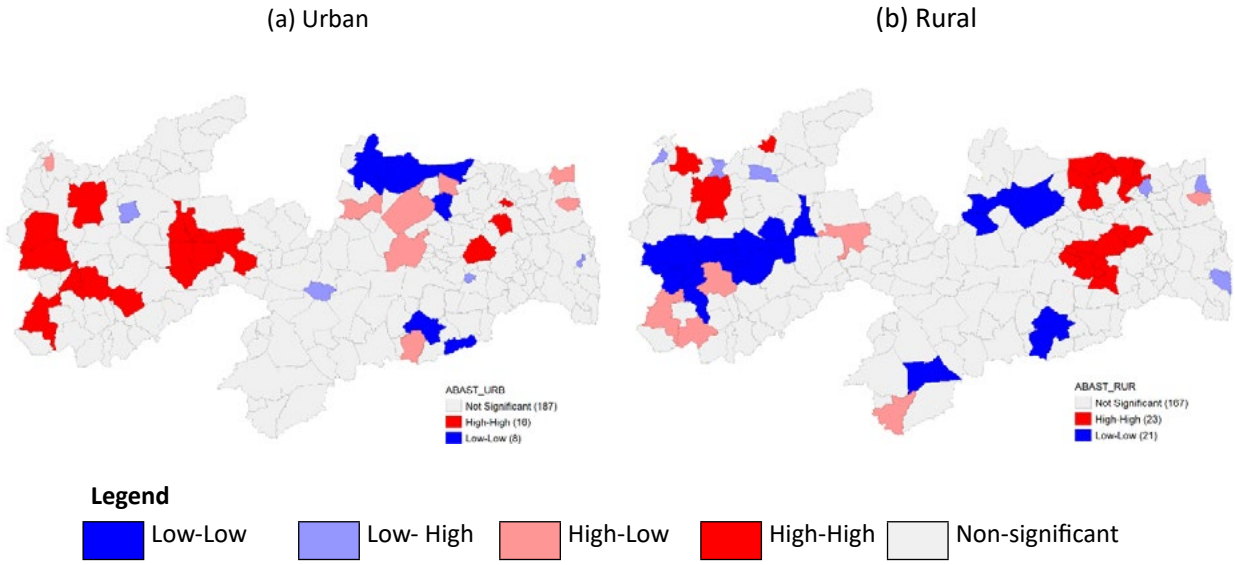
Table 2 | Global Moran's I statistics for the indicators used

Indicator	Global Moran's I statistics	p-value
IND_1 - Urban water supply service coverage	0.224	0.001
IND_2 - Urban sewage network service coverage	0.257	0.001
IND_3 - Rural water supply service coverage	0.228	0.001
IND_4 - Rural sewage network or septic tank service coverage	0.092	0.001
IND_5 - Financial performance	0.212	0.001

Source: The authors (2022).

Moran's scatter plots with the graphical representation of the results obtained, built to identify the occurrence of local patterns and atypical values within the water and sewage microregions and their possible causes, are presented in Figures 6 to 8. In Figure 6, which presents the spatial analysis for water supply indicators in urban and rural areas, the polygons represented in red (High-High) indicate municipalities with high supply coverage surrounded by other municipalities that also have good coverage. The municipalities in blue (Low-Low) have low coverage and are surrounded by municipalities with the same pattern. The municipalities in light blue (Low-High) and pink (High-Low), on the other hand, have low or high coverage but neighboring municipalities with different patterns, showing outlier municipalities. Finally, gray polygons did not present significant spatial autocorrelation (p values < 0.05).

Figure 6 | Moran scatter plot of water supply coverage in urban (a) and rural (b) areas



Source: The authors (2022).

As seen in Figure 6, the results indicate the presence of a strong spatial correlation for water supply coverage in some specific points of the state, in addition to the presence of outlier municipalities. When the indicator of the urban zone was analyzed, the formation of Low-Low clusters was identified in the municipalities of Brejo, Curimataú, and Seridó Paraibano (Picuí, Cuité, Araruna, Nova Floresta, Casserengue, Baraúna, Umbuzeiro, and Barra de Santana), all located in the Borborema region. These microregions of the state have low coverage in urban areas due to the collapse of their supply systems in recent years caused by the low water input in their springs and poor management of water resources during the drought period that began in 2012, as pointed out by Rêgo *et al*. (2015).

In the Sertão Paraibano (semiarid region of Paraíba), the formation of High-High clusters was identified near the reservoirs Engenheiro Ávidos, São Gonçalo, and Coremas-Mãe d'Água, which supply most of the region. These reservoirs have recovered their water volumes in the last rainfall cycles, increasing their water security when compared to other reservoirs in the state. In the Litoral microregion, the formation of High-High clusters was observed in the municipalities of Alagoa Grande, Cuité de Mamanguape, and Duas Estradas.

Some outlier municipalities were also observed in all microregions. Performances below and above the local means were especially observed, respectively, in the municipalities of São Domingos and Alcantil, which have local water supply providers. Similarly, the municipality of Sousa had a notable good performance and has a local water supply provider, in both indicators.

Marked dependence of the state's urban supply systems on the availability of water and rainfall rates and water levels in dams is noticeable, especially in the Alto Piranhas, Espinharas and Borborema regions. On the other hand, greater water security is found in the municipalities of the Litoral microregion because they are supplied through deep tubular wells and mostly perennial rivers.

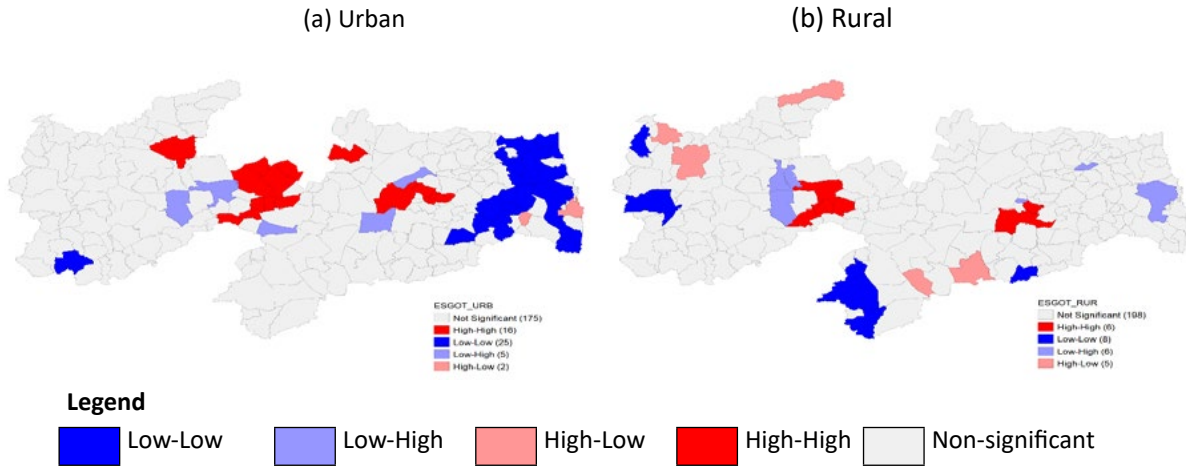
For the indicator rural water supply coverage, different results were found. High-High clusters were formed in municipalities of the Brejo Paraibano between the Borborema and Litoral microregions (Solânea, Araruna, Riachão, Caiçara, Logradouro, Alagoa Grande, Alagoinha, Alagoa Nova, Ingá, Massaranduba, among others), indicating a good coverage of adequate water supply in rural areas. The pattern observed in the results coincides with the advance of the programs "One Million Cisterns" and "One Earth + Two Waters" in the region, through the construction of cisterns to collect rainwater.

In the microregions Alto Piranhas and Espinharas, more specifically in the Vale do Piancó region, there was the formation of Low-Low clusters that indicate a pattern of low coverage of adequate water supply in rural areas. In these municipalities, there is still a strong dependence on water tank cars to supply the built tanks, which makes the supply semi-adequate according to IBGE.

An important lack of access to sewage services was also identified in urban areas (Figure 7a) through the formation of a large Low-Low cluster that encompasses municipalities of the Litoral microregion. The municipalities of João Pessoa and São Miguel do Taipu are outlier municipalities because they have good coverage rates. In the Espinharas and Borborema microregions, there is a High-High pattern near the neighboring municipalities Patos and Campina Grande and there are outlier municipalities with performance below the local mean.

A close analysis of the municipalities served by CAGEPA (Patos, Alhandra, Monteiro, João Pessoa, Bayeux, Campina Grande, among others) shows that there is a greater investment in larger municipalities that have better performance when compared to neighboring municipalities, since the former offer a greater financial return.

Figure 7 | Moran scatter plot of sewage coverage in urban (a) and rural (b) areas



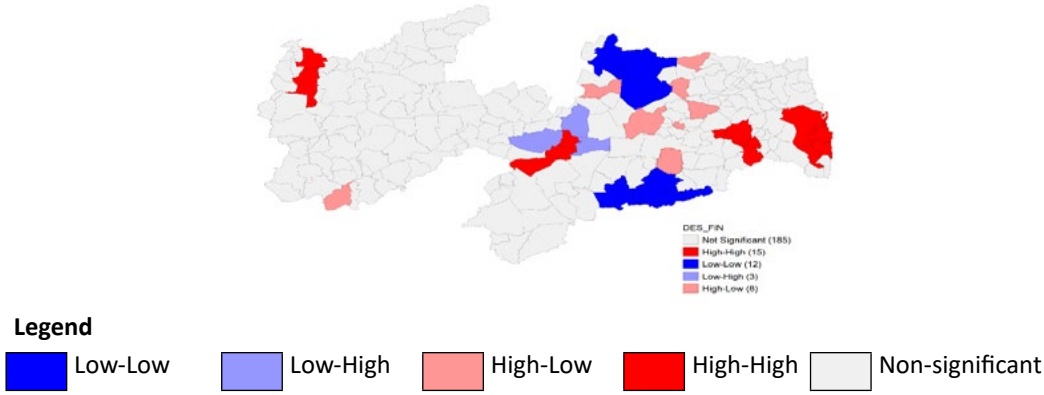
Source: The authors (2022).

Similarly to urban areas, the analysis of sewage service coverage in rural areas showed in Figure 7b indicated the formation of High-High clusters near the neighboring municipalities of Patos and Campina Grande, and Low-Low clusters near Monteiro and São José de Piranhas. Also, the existence of outlier municipalities with performance below the local mean was observed in Espinharas and Litoral, and above the local mean in Borborema and Alto Piranhas.

The economic-financial performance of water supply and sewage services of the municipalities is extremely important to maintain the capacity to invest, maintain and expand the access to sanitation. The map shown in Figure 8 indicates the existence of positive patterns of financial performance in two areas of the Litoral microregion (covering the municipalities of João Pessoa, Santa Rita, Bayeux, Alhandra, Conde, Cabedelo, Itabaiana, São José dos Ramos, and Gurinhém), one area of Alto Piranhas (in the municipalities of Uiraúna and São João do Rio do Peixe,) and another of Borborema (São José dos Cordeiros, Parari and Santo André). The four areas coincide with regions with better performance in water supply in urban areas and good affordability, due to the higher revenue provided by the high coverage of the service and the lower expenses with investments.

On the other hand, Low-Low clusters were observed in Borborema, near the municipalities of Brejo, Curimataú and Seridó Paraibano, which had their supply systems collapsed during the drought period. The low coverage rates of sanitation services associated with the lower population's ability to afford the service in these regions can also be cited as a cause for the negative pattern.

Figure 8 | Moran scatter plot of the indicator financial performance of water supply and sewage services



Source: The authors (2022).

The results confirm the studies carried out by Rodrigues, Venson and Camara (2019), which state that close sites usually have the same characteristics, including low coverage and financial capacity of sanitation services, pointing to the possible existence of spatial dependence in the provision of water and sewage services. Thus, the potential benefits intended by Law number 14.026/2020 may not be fully effective to achieve regionalization. This is due to the fact that the new groups tend to be composed of municipalities with similar features, characterized by a significant need for expansion of services and limited financial capacity. This scenario is in line with the study of Cruz *et al.* (2020).

ANALYSIS OF TECHNICAL CAPACITY

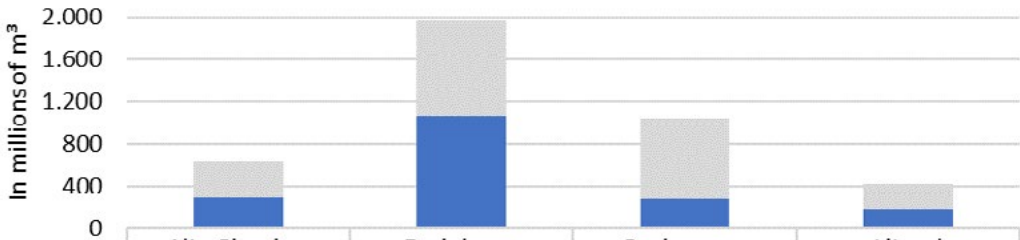
In view of the different scenarios of water availability in the microregions of Paraíba, some of the microregions may face problems of water supply – worsened by the difficulty of transposition of water among microregions – due to the possibility of the presence of different service providers after the consolidation of the regionalization process. However, the evaluation of the technical capacity of the regions with respect to the water supply-demand ratio was not included in the technical study conducted by FUNDACE (2021).

The data records from the monitoring of reservoirs of the state of Paraíba provided by AESA (2022) allowed carrying out a comparison of the water storage capacity of each of the microregions, as well as an analysis of the current situation of the reservoirs in terms of percentage of volume, shown in Figure

9. It is observed that, despite having the largest population among the microregions, Litoral had the lowest installed capacity. This is due to the fact that the region has a good productivity of wells and the presence of perennial rivers used to supply the population, so that there is no need to build reservoirs.

Noteworthy is the large concentration of water storage capacity in the Espinharas microregion, due to the Coremas-Mãe d'Água dam, which is responsible for more than 60% of the total storage capacity, and the low capacity observed in Alto Piranhas, which, despite having the smallest population, has the largest irrigated area in the state. The Borborema microregion has the worst quantitative water security situation, with low storage capacity, the second largest population of the four microregions, and the lowest volume currently stored.

Figure 9 | Storage capacity and current volume in reservoirs monitored by AESA per water and sewage microregion of Paraíba

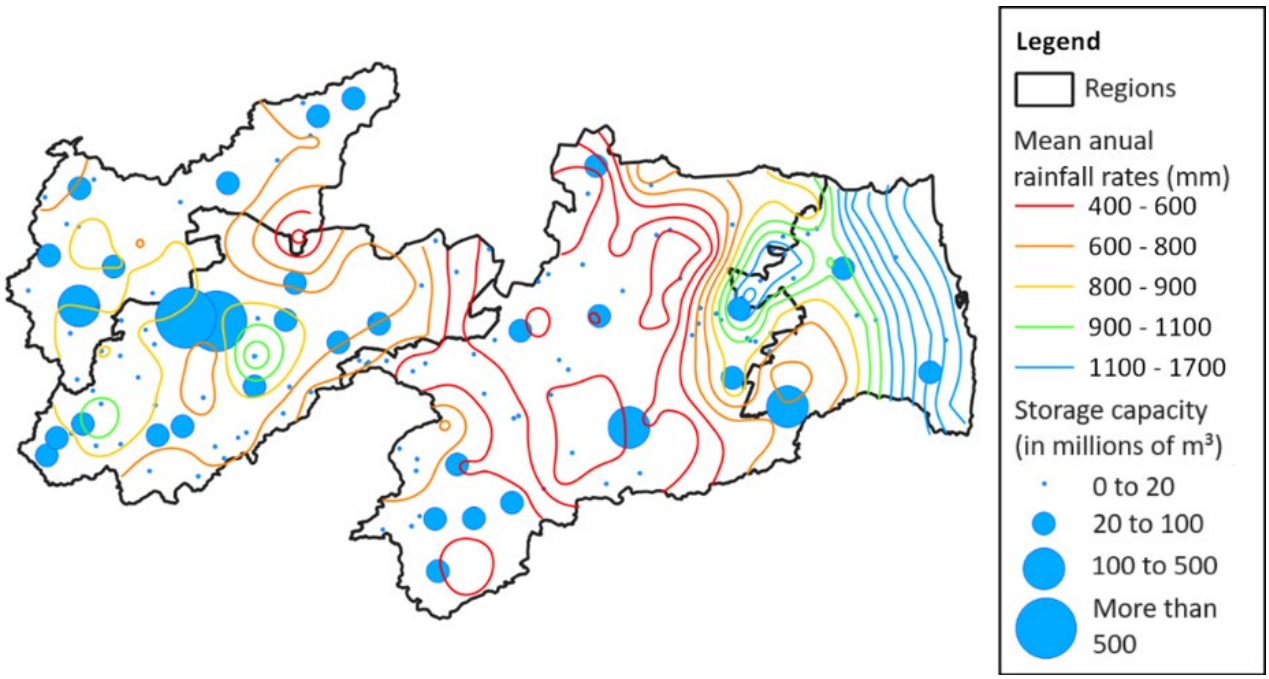


	Alto Piranhas	Espinharas	Borborema	Litoral
Maximum capacity	343.861.075,00	906.262.893,00	763.048.085,00	241.284.584,00
Current volume	285.645.360,00	1.064.766.969,00	279.892.403,00	182.474.675,00

Source: The authors (2022), based on EFSA data (2022).

In relation to the current volume stored in dams, the low percentages recorded still reflect the consequences of the drought period lived in the state since 2012. It is worth noting that part of the recovery observed is due to the Northern and Eastern axes of the São Francisco River Integration Project (PISF), which benefits several reservoirs in all regions of the state. There was an improvement in the amount of water currently reserved (50% of the total capacity on average) in the reservoirs located in the Sertão Paraibano (semiarid region of Paraíba), while a slow recovery (27%) is seen in Borborema due to unfavorable climatic conditions to maintain the stored volume. Figure 10 shows the distribution of water reservoirs in the state and their recharge capacity as a function of the mean annual rainfall.

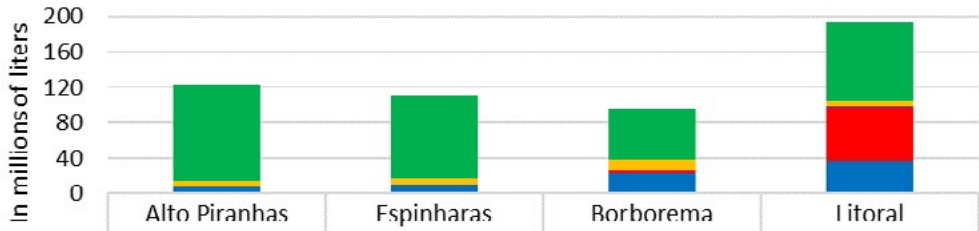
Figure 10 | Map of water storage and recharge capacity in the reservoirs of the state per water and sewage microregion of Paraíba



Source: The authors (2022), based on AESA data (2021).

Higher rainfall rates are recorded in Litoral and near the large reservoirs of the Espinharas microregion, ensuring better water recharge capacity in these regions. In the Alto Piranhas and Borborema microregions, lower rainfall rates are seen, posing a difficulty for the recharge of dams there. It is important to mention that there are areas with high rainfall rates near the municipality of Areia, part of the Litoral microregion, which could collaborate with a better distribution of water resources within the territory, taking into account the arrangement of the population and the productive areas of the state, but which were not considered in the Technical Study of Regionalization of Basic Sanitation (FUNDACE, 2021). Mean annual water consumption figures in each water and sewage microregion of Paraíba according to the type of use in the last 20 years can be observed in Figure 11.

Figure 11 | Mean annual water consumption per water and sewage microregion of Paraíba



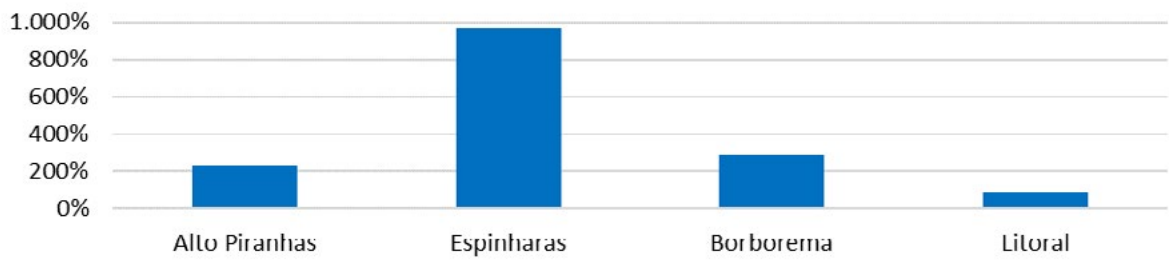
	Alto Piranhas	Espinharas	Borborema	Litoral
Irrigation	107.563.619,52	92.817.701,28	58.316.686,56	88.045.043,04
Animal consumption	5.708.962,08	6.799.476,96	11.214.516,96	6.579.040,32
Mining	7.884,00	34.374,24	91.454,40	376.539,84
Industry	429.204,96	436.458,24	2.486.298,24	60.773.025,60
Human consumption	9.163.100,16	10.145.761,92	24.079.628,16	37.231.086,24

Source: The authors (2022), based on data from ANA (2022).

It appears that the pressure caused by human consumption on the water balance of the microregions is small. Despite being the microregions with the lowest population, Alto Piranhas and Espinharas have high water consumption due to the large agricultural production. Borborema has the lowest consumption when compared to the other microregions, even though it has the second largest population. Litoral has the highest consumption among the four microregions, due to the number of industries installed.

The situation of the microregions in terms of quantitative water security was analyzed based on the relationship between the current levels stored in dams and the mean annual water demand of the last 20 years shown in Figure 12, without considering the evaporated portion. It was noted that Espinharas has the best current situation due to its large-capacity dams. Conversely, Litoral has the worst supply/demand ratio when considering only the superficial water stored, which is enough for less than a year of demand. However, this microregion is favored by the existence of underground and perennial springs. The Alto Piranhas and Borborema microregions, on the other hand, live the situation of greater water stress, with great water consumption and high dependence on dams.

Figure 12 | Relationship between current storage and mean annual water demand per water and sewage microregion of Paraíba



Source: The authors (2022).

CONCLUSION

Correlations among water and sewage microregions of Paraíba were investigated through a comparative cluster analysis of the municipalities of the state using social, financial and coverage indicators of water supply and sewage services.

The Borborema microregion showed the worst economic-financial performance and coverage in urban and rural areas, while the Litoral microregion had a higher occurrence of municipalities with clusters of high and medium coverage, high and medium economic-financial performance and high affordability.

Based on the evaluation of the technical capacity of the established microregions, with respect to the water supply-demand ratio, the Borborema microregion presented one of the worst situations in terms of water stress, with great water consumption and high dependence on dams. In turn, Espinharas had the best current situation due to the presence of dams of large storage capacity.

Regarding the identification of spatial patterns, Borborema presented regions of low urban service coverage due to the collapse of supply systems in recent years. Litoral, in turn, had the best patterns of financial performance, with clusters that coincide with regions presenting high performance in urban water supply and good affordability.

The present study can be replicated to other states to analyze the current panorama of microregions regarding coverage and financial performance of water and sewage services. Additional data can also be included, focusing on the analysis of the economic and financial sustainability of municipalities in a broader sense. Likewise, it is recommended that such study be developed using social indicators.

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