# ANALYSIS OF WATER LOSS INDICATORS AND THEIR RELATIONSHIP WITH SOCIOECONOMIC INEQUALITY IN THE STATE OF RIO DE JANEIRO

# ANÁLISIS DE LOS INDICADORES DE PÉRDIDA DE AGUA Y SU RELACIÓN CON LA DESIGUALDAD SOCIOECONÓMICA EN EL ESTADO DE RÍO DE JANEIRO

# ANÁLISE DOS INDICADORES DE PERDAS DE ÁGUA E SUA RELAÇÃO COM A DESIGUALDADE SOCIOECONÔMICA NO ESTADO DO RIO DE JANEIRO

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## ABSTRACT
This article presents a sociotechnical analysis of water losses in distribution systems, investigating the correlation between structural inefficiencies and social inequalities. The study draws on data from SINISA (2023) and the Brazilian Institute of Geography and Statistics (IBGE) Demographic Census (2022) to outline a framework ranging from the national scale to a case study in the State of Rio de Janeiro. The results indicate that Brazil loses approximately 40% of the potable water produced, with the State of Rio de Janeiro exhibiting loss rates exceeding 50%, the worst performance in the Southeast region. Spatial analysis revealed a strong correlation between low-income areas, such as the Baixada Fluminense, and high levels of both physical and non-revenue water losses, in contrast to high-income areas such as Niterói, which demonstrate greater operational efficiency. It is concluded that inadequate infrastructure is not merely a technical issue, but rather a component of water injustice that perpetuates historical exclusions and hinders the achievement of the Sustainable Development Goals (SDGs) 6, 10, and 11.

**Keywords:** Water Losses. Water Justice. Basic Sanitation. Distribution Networks. Rio de Janeiro.

## RESUMO
Este artigo apresenta uma análise sociotécnica das perdas de água na distribuição, investigando a correlação entre ineficiências estruturais e desigualdades sociais. O estudo utiliza dados do SINISA (2023) e do Censo Demográfico do IBGE (2022) para traçar um panorama que vai da escala nacional a um estudo de caso no Estado do Rio de Janeiro. Os resultados demonstram que o Brasil perde cerca de 40% da água potável produzida,

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com o Rio de Janeiro apresentando índices superiores a 50%, o pior desempenho da região Sudeste. A análise espacial revelou uma forte correlação entre áreas de baixa renda, como a Baixada Fluminense, e altos índices de perdas físicas e de faturamento, contrastando com áreas de alta renda, como Niterói, que possuem maior eficiência. Conclui-se que a infraestrutura precária não é apenas um problema técnico, mas compõe o panorama de injustiça hídrica que perpetua exclusões históricas e dificulta o cumprimento dos Objetivos de Desenvolvimento Sustentável (ODS) 6, 10 e 11.

**Palavras-chave:** Perdas de Água. Justiça Hídrica. Saneamento Básico. Redes de Distribuição. Rio de Janeiro.

**RESUMEN**

Este artículo presenta un análisis sociotécnico de las pérdidas de agua en los sistemas de distribución, investigando la correlación entre las ineficiencias estructurales y las desigualdades sociales. El estudio se basa en datos del SINISA (2023) y del Censo Demográfico del Instituto Brasileño de Geografía y Estadística (IBGE) (2022) para delinear un marco que abarca desde la escala nacional hasta un estudio de caso en el estado de Río de Janeiro. Los resultados indican que Brasil pierde aproximadamente el 40% del agua potable producida, y que el estado de Río de Janeiro presenta tasas de pérdida superiores al 50%, el peor desempeño de la región Sudeste. El análisis espacial reveló una fuerte correlación entre las zonas de bajos ingresos, como la Baixada Fluminense, y los altos niveles de pérdidas de agua, tanto físicas como no contabilizadas, en contraste con las zonas de altos ingresos como Niterói, que demuestra una mayor eficiencia operativa. Se concluye que la infraestructura inadecuada no es un mero problema técnico, sino un componente de la injusticia hídrica que perpetúa exclusiones históricas y obstaculiza el logro de los Objetivos de Desarrollo Sostenible (ODS) 6, 10 y 11.

**Palabras clave:** Pérdidas de Agua. Justicia Hídrica. Saneamiento Básico. Redes de Distribución. Río de Janeiro.

## 1 INTRODUCTION

Brazil loses about 40% of the drinking water produced and distributed for consumption annually (Trata Brasil, 2024), which shows a critical scenario in the management of water resources. This statistic makes explicit one of the greatest structural inefficiencies among developing countries and directly compromises the fulfillment of Sustainable Development Goal 6 (SDG 6), which seeks to ensure the availability and sustainable management of water and basic sanitation for all (UN, 2015).

According to the International Water Association (IWA, 2022), the high rate of non-revenue water, known by the term Non-Revenue Water, generates impacts that go beyond financial loss. The structural flaw translates into intermittent supply and high tariffs that disproportionately penalize the poorest, since the operating costs of losses are often passed on to the final consumer (Trata Brasil, 2024), while the precariousness of supply is concentrated in lower-income areas (Britto et al., 2011). This dynamic deepens social disparities, contradicting SDG 10, which focuses on reducing inequalities within countries, in addition to making it difficult to maintain resilient urban infrastructure, which directly hurts the premises of SDG 11, whose objective is to make cities and local communities inclusive and sustainable.

The precariousness of distribution networks, especially in peripheral urban areas, reflects social and racial inequalities rooted in the country's historical formation (Santos et al., 2021; Mota et al., 2021). This socio-technical dimension of supply shows that the problems of water loss and lack are not merely technical, but cross issues of equity, public management and the human right to water.

In the State of Rio de Janeiro, municipalities such as São Gonçalo and Duque de Caxias illustrate this phenomenon well. Despite having formal network coverage above 80%, they suffer from low per capita consumption rates and high loss rates (IBGE, 2022; SINISA, 2024). This contradiction suggests that the problem lies in the degraded infrastructure, associated with social vulnerability and the absence of redistributive policies.

Given this scenario, this article analyzes water losses from a social justice perspective. The objective is to investigate the correlation between structural deficiencies that cause physical losses and social inequalities in the territory. To this end, the research adopts a scale approach, starting with a macroscopic analysis of national data and funneling to a regional cut in the State of Rio de Janeiro. It is proposed here that the technical project transcends its specific function and shows itself as a strategic tool for the promotion of water justice and, concomitantly, for the advancement of the Sustainable Development Goals.

## 2 THEORETICAL FOUNDATION

### 2.1 WATER LOSSES: DEFINITIONS, TYPOLOGIES AND INDICATORS

The efficiency of supply systems is commonly measured by the Non-Revenue Water (NRW) index. For the purposes of national standardization and regulation, this article adopts the nomenclature established by the National Sanitation Information System, SINISA. The water goes through different processes from the moment of its capture until it reaches the final consumer, so the schematization of this movement, known as Water Balance, helps to identify problems along the network. This balance divides the volume of water made available into authorized consumption and unauthorized consumption, the latter being our research focus, as it corresponds to what we call losses, which also covers two subcategories.

The first subcategory of unauthorised consumption refers to apparent losses, technically referred to as commercial losses. These correspond to the volume of water that, although effectively consumed, is not billed by the service provider due to factors such as water meter failure, registration errors or irregularities in the network, impacting the financial sustainability of the system without necessarily representing waste of the natural resource.

On the other hand, the second category is composed of real losses, or physical losses. Unlike the apparent ones, these represent the volume of treated water that is extracted from the system before reaching the final consumer, resulting from infrastructure failures, such as leaks in pipelines, overflows in reservoirs and pipe ruptures. The control of these losses requires a rigorous technical approach, since high indicators of real losses suggest obsolescence of the infrastructure, while high apparent losses point to inefficiencies in commercial management. In the Brazilian scenario, where the average distribution loss exceeds 37% (SINISA, 2024), it is imperative to analyze these two typologies not only as operational failures, but as symptoms of network engineering that needs a strategic review.

### 2.2 THE MATERIALITY OF THE NETWORK

The incidence of real losses is directly linked to design decisions and the quality of the materials used at the time of network construction, usually associated with unbridled urban expansion. The choice between different classes of materials, such as PVC or cast iron, and the definition of pressure classes, influence the durability and resilience of the system (Bezerra; Macêdo, 2018).

In the specific context of the State of Rio de Janeiro, a spatial phenomenon related to the historical occupation of the territory is observed. The oldest networks, dating from the nineteenth and early twentieth centuries, are concentrated where the settlement was consolidated, such as the Center and the South Zone of the capital (Koifman, 2013). However, despite their advanced age, these systems have historically had project revisits and preventive maintenance that other regions do not receive. On the other hand, the expansion of the network to the Baixada Fluminense and the West Zone occurred late and unevenly, consolidating a pattern of center-periphery segregation in infrastructure (Britto; Quintslr, 2017), often characterized by technical improvisations to meet a repressed demand without proper hydraulic planning (Marques, 2018).

In peripheral regions, the critical factor goes beyond the age of the pipe, but the operational regime to which it is subjected. The intermittency in the supply generates water hammers, a phenomenon caused by a sudden change in the flow of water, which subjects the network to cycles of pressure loading and unloading, damaging the system, and is even capable of causing the rupture of the pipes and their accessories. According to Tsutiya (2006), this oscillation accelerates the fatigue of the materials, causing frequent ruptures even in pipes that are not necessarily old. That said, it is observed that the project engineering in these locations faces a double challenge: the precariousness of the original installation and the operational stress caused by the lack of water itself.

## 2.3 WATER JUSTICE AND THE SOCIO-TECHNICAL DIMENSION

The concept of water justice arises from the expansion of environmental justice, recognizing that the impacts of lack of water or precarious access fall disproportionately on the poorest, blackest, and peripheral groups (Fracalanza, 2015; Tonel et al., 2021). The human right to water, recognized by the UN, is continuously violated not by natural scarcity, but by institutional inefficiencies and inequality of investments (Roth et al., 2018).

In Brazil, water injustice is aggravated by uneven urbanization. Supply networks are concentrated in central and higher-income areas, while peripheries and informal communities face chronic shortages and low quality of services (Fracalanza, et al, 2022). Authors such as Santos, et al. (2021) and Mota, et al. (2021) argue that inequality in access reflects power relations and racial and economic hierarchies. In addition, Gouveia, et al (2023) created the term "hydroracial scarcity" to describe how unequal access to water in metropolitan eastern Rio de Janeiro reflects historical inequalities based on race and class. Thus, water infrastructure becomes an instrument of social domination, where engineering, instead of promoting equity, reproduces historical exclusions.

The context of vulnerability is aggravated by the way in which loss management is carried out. To compensate for the rates of physical losses, many operators increase the pressure at times of lower consumption or carry out selective rationing, penalizing the network peaks, precisely where the most vulnerable populations live (Britto et al., 2011). Thus, the struggle for loss reduction transcends the technical goal; It is a necessary condition for the guarantee of human rights and for the correction of historical injustices in the urban fabric.

## 2.4 AGENDA 2023: ENGINEERING AND SOCIAL EQUITY

Overcoming the scenario of hydro-racial scarcity and infrastructural precariousness dialogues directly with the 2030 Agenda of the United Nations. Although water resources engineering is traditionally associated with goals in the operational sphere, it plays a key role in meeting the Sustainable Development Goals (SDGs).

SDG 6, referring to Drinking Water and Sanitation, establishes in its goal 6.1, the universalization of equitable access. However, it is in goal 6.4 that network engineering comes into the spotlight, as it requires a substantial increase in efficiency in the use of water. In the context of Brazil, reducing physical losses is not limited to a measure of saving resources or the supply of treated water, but is the only solution to ensure the water availability necessary to universalize access and quality monitoring in the peripheries (UN, 2015).

At the same time, loss management is intrinsically linked to SDG 10, which refers to the reduction of inequalities. As previously discussed, the inefficiency of the systems disproportionately penalizes peripheral populations, either by high tariffs or by intermittency in supply. In this way, investments focused on the modernization of networks in low-income areas act as redistributive policies, in line with goal 10.2, which aims to empower and promote the social and economic inclusion of all citizens.

In addition, resilience in the infrastructure of distribution networks is central to SDG 11, which deals with the creation of sustainable cities and communities. Target 11.5 seeks to reduce the number of people affected by disasters and economic vulnerability. Fragile distribution networks, subject to constant disruptions and unable to provide adequate pressure for supply, compromise health security within the state. Thus, the replacement of obsolete and low-quality materials, together with the technological control of pressures, transcend technique, characterizing themselves as fundamental requirements for the construction of inclusive and resilient cities.

# 3 METHODOLOGY

## 3.1 DELIMITATION OF RESEARCH AND DATA SOURCES

The present study was based on the analysis of secondary data from the report of the National Basic Sanitation Information System (SINISA), referring to the "Technical Water Management" module with base year 2023, published in 2024. The time frame chosen is justified by the fact that it is the most recent data set available at the time of the research. In addition, this database has national coverage and standardized collection forms, as detailed in the Glossary of Information - Water Supply (SINISA, 2024), facilitating the observation of how the indicators behave throughout the national territory.

In addition, for the socioeconomic characterization of Brazil and the State of Rio de Janeiro, information was extracted from the Brazilian Institute of Geography and Statistics (IBGE), through the IBGE Automatic Recovery System (SIDRA), focusing on the most recent Demographic Census, referring to 2022. The option for the Census is due to its universal coverage and availability of data at the municipal level, which is the smallest unit of analysis of the survey.

## 3.2 ANALYSIS STRATEGY AND SPATIAL SCALES

The data analysis was structured under a multiscale approach, starting from the macroscopic dimension to a regional approach. On the macro scale, the national panorama was used, with the analysis of the overall efficiency of the Brazilian federative units, using choropleth maps to identify patterns of inequality in the performance of the indicators. On the micro scale, a regional case study was carried out with a focus on the State of Rio de Janeiro, where the technique of comparative cartography was adopted, confronting the spatial distribution of water losses with indicators of social vulnerability.

## 3.3 SELECTION OF INDICATORS

To diagnose the efficiency of the distribution systems, four main indicators were selected from the "Water Indices (AGI)" group of SINISA, following technical criteria to demonstrate the dimensions of apparent losses and actual losses, as shown in Table 1.

**Table 1**

*Selected Water Loss Indicators*

| Indicator Code | Indicator Name | Type of Loss | Unit |
|---|---|---|---|
| IAG2012 | Water billing losses | Apparent (Commercial) | % |
| IAG2013 | Total water losses in | Total (Actual + | % |

| | | | |
|---|---|---|---|
| | distribution | Apparent) | |
| IAG2014 | Total linear losses | Intensity of loss | m³/km/day |
| IAG2015 | Total water losses per connection | Intensity of loss | l/link/day |

Source: SINISA (2024).

Although all indicators were considered in the exploratory phase of the data, the visualization strategy prioritized those with greater adherence to the sociotechnical hypotheses of the study. To introduce the national panorama and the case study, the indicator of total water losses in distribution (IAG2013) was adopted. The choice of this percentage indicator is justified by its ability to summarize the overall efficiency of the Brazilian water distribution system, facilitating the initial comparison between the federative units and municipalities of Rio de Janeiro.

For the technical analysis of the infrastructure in the State of Rio de Janeiro, it was decided to use two indicators, the linear total losses (IAG2014) and the total water losses per connection (IAG2015). These indices are able to bring a more robust metric to diagnose the physical state of the network and the level of operational stress, since they quantify the intensity of the loss.

Finally, a final analysis of economic correlation was made using the specific indicator of losses in water billing (IAG2012). This variable was selected for its sensitivity to commercial loss and delinquency, helping to test the hypothesis that the difficulty in invoicing is spatially correlated to regions with lower purchasing power.

For the socioeconomic analysis, we opted for the use of the median monthly household income per capita (2022 Census). The choice of the median to the detriment of the mean is justified by the history of great inequality in the state chosen for analysis. The use of the average would cause distortion due to the extreme values centralized in some regions, so the median offers a more robust representation of the economic vulnerability of the typical citizen of each municipality.

## 3.4 DATA PROCESSING AND PROCESSING

The data were processed and analyzed using geoprocessing techniques in the Geographic Information System software QGIS (version 3.40.11). The first stage consisted of the integration of the databases. The cartographic databases, obtained from the IBGE itself, were joined to the tabular data from SINISA and the Demographic Census. To ensure the correct association of the information, this junction was performed using two primary keys, according to the level of aggregation of the analysis: the municipal code (7-digit

IBGE), for the analyses at the municipal level, and the code of the federation unit (IBGE of 2 digits), for the analyses and comparisons at the state level.

For the spatial analysis, thematic maps of the choropleth type were generated, which allow the visualization of the geographic distribution of each variable of interest. This technique was chosen because it favors the visual identification of patterns and hotspots by associating specific ranges of indicator values to a color scale (Archer; Bliss, 2010; Martinelli, 2014). The investigation was carried out at two levels: at the national level, for all Brazilian states, and at the regional level, with a detailed focus on the municipalities of the State of Rio de Janeiro.

## 4 RESULTS AND DISCUSSIONS

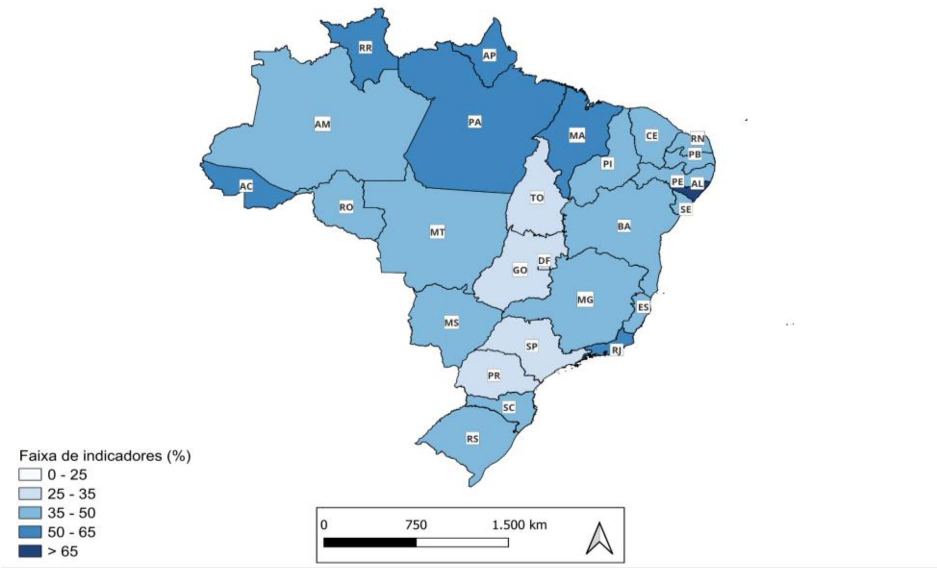
### 4.1 NATIONAL PANORAMA

The macroscopic analysis of the efficiency of water distribution in Brazil, based on the percentage indicator of total losses (IAG2013), reveals a worrying scenario for all regions of the country. As illustrated in Figure 1, only four states have total loss rates below 35%, namely Tocantins, Goiás (including the Federal District), São Paulo and Paraná. Meanwhile, the state with the most worrying data is Alagoas, which has a total loss rate of approximately 70%.

The State of Rio de Janeiro, in turn, stands out negatively in the context of the Southeast Region. While São Paulo is the state with the lowest rate of total losses, below 35%, Rio de Janeiro has rates above 50%. This data justifies the choice of the state as a case study: RJ represents an anomaly in the economically richest region of the country, indicating that the availability of financial and water resources does not guarantee efficiency in the management of this natural resource.

**Figure 1**

*Spatial distribution of the index of total water losses in distribution (IAG2013) by Federation Units*



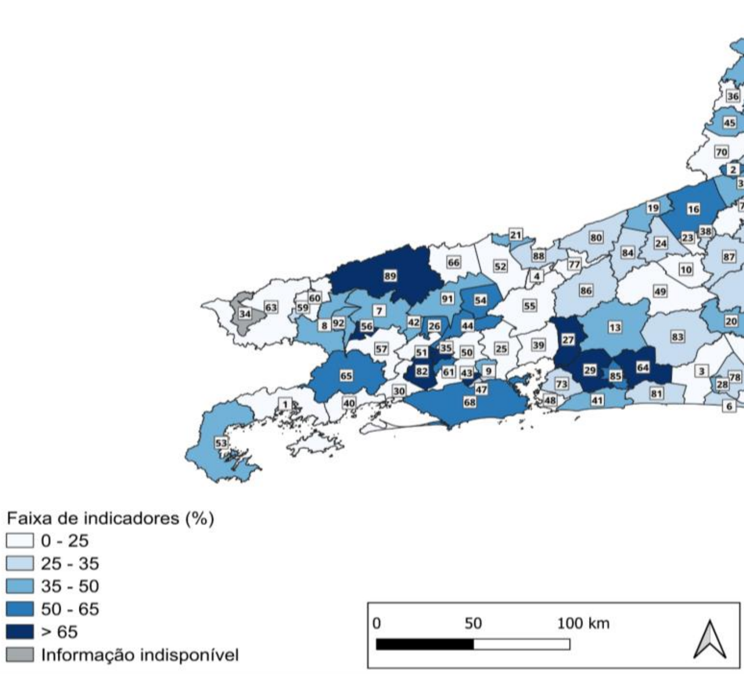

Source: Authors' elaboration based on SINISA data (Reference year: 2023).

While the State of Rio de Janeiro is the federative unit with the worst score in the IAG2013 index of the Southeast Region, this loss is not uniform throughout the territory, which indicates that a study with pertinent results needs to consider the parametric variability throughout the municipalities that compose it.

Figure 2 presents the panorama of total losses in the state. Of the 92 municipalities that make up RJ, 20 have a loss rate calculated above 50%; Itaboraí and Guapimirim are the municipalities in the most critical situation, with rates of 85.6% and 87.98%, respectively. Itatiaia did not have the indicator calculated by the responsible entity, despite the data collection having been carried out in the municipality (SINISA, 2024).

**Figure 2**

*Spatial distribution of the distribution loss index - IAG2013 by municipalities in Rio de Janeiro*



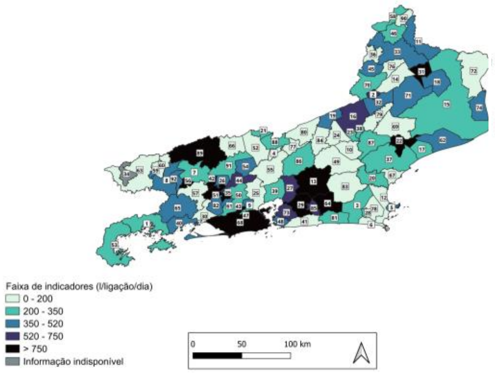

Source: Authors' elaboration based on SINISA data (Reference year: 2023).
Note: Identification of the municipalities: 1. Angra dos Reis; 2. Aperibé; 3. Araruama; 4. Areal; 5. Armação dos Búzios; 6. Arraial do Cabo; 7. Barra do Piraí; 8. Barra Mansa; 9. Belford Roxo; 10. Bom Jardim; 11. Bom Jesus do Itabapoana; 12. Cabo Frio; 13. Cachoeiras de Macacu; 14. Cambuci; 15. Campos dos Goytacazes; 16. Cantagalo; 17. Carapebus; 18. Cardoso Moreira; 19. Carmo; 20. Casimiro de Abreu; 21. Comendador Levy Gasparian; 22. Conceição de Macabu; 23. Cordeiro; 24. Duas Barras; 25. Duque de Caxias; 26. Engenheiro Paulo de Frontin; 27. Guapimirim; 28. Iguaba Grande; 29. Itaboraí; 30. Itaguaí; 31. Italva; 32. Itaocara; 33. Itaperuna; 34. Itatiaia; 35. Japeri; 36. Laje do Muriaé; 37. Macaé; 38. Macuco; 39. Magé; 40. Mangaratiba; 41. Maricá; 42. Mendes; 43. Mesquita; 44. Miguel Pereira; 45. Miracema; 46. Natividade; 47. Nilópolis; 48. Niterói; 49. Nova Friburgo; 50. Nova Iguaçu; 51. Paracambi; 52. Paraíba do Sul; 53. Paraty; 54. Paty do Alferes; 55. Petrópolis; 56. Pinheiral; 57. Piraí; 58. Porciúncula; 59. Porto Real; 60. Quatis; 61. Queimados; 62. Quissamã; 63. Resende; 64. Rio Bonito; 65. Rio Claro; 66. Rio das Flores; 67. Rio das Ostras; 68. Rio de Janeiro; 69. Santa Maria Madalena; 70. Santo Antônio de Pádua; 71. São Fidélis; 72. São Francisco de Itabapoana; 73. São Gonçalo; 74. São João da Barra; 75. São João de Meriti; 76. São José de Ubá; 77. São José do Vale do Rio Preto; 78. São Pedro da Aldeia; 79. São Sebastião do Alto; 80. Sapucaia; 81. Saquarema; 82. Seropédica; 83. Silva Jardim; 84. Sumidouro; 85. Tanguá; 86. Teresópolis; 87. Trajano de Moraes; 88. Três Rios; 89. Valença; 90. Varre-Sai; 91. Vassouras; 92. Volta Redonda.

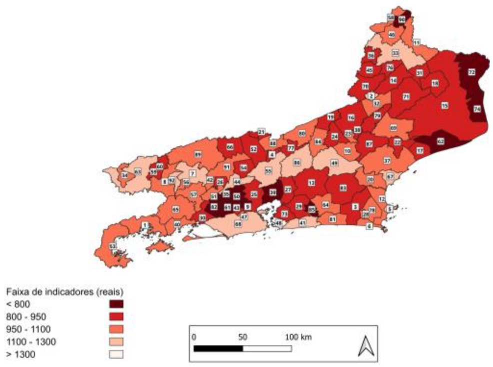
Figure 3 presents, side by side, the distribution of losses per connection and the median monthly per capita income of the municipalities. The spatial overlap between infrastructure performance (Map A) and income (Map B) reveals some worrying patterns in the state's sanitary engineering.

**Figure 3**

*Comparative analysis. (A) Loss Ratio per Connection (IAG2015) in L/lig./day; (B) Median monthly household income per capita (IBGE)*

(A) (B)






Source: Authors' elaboration based on data from SINISA (Reference year: 2023) and IBGE (2022 Census).

There is a concentration of municipalities in the Baixada Fluminense where the average household income per capita does not reach 60% of the minimum wage in force in the year of the 2022 Census (R$ 1212.00). Municipalities with a high population density, such as Belford Roxo and Queimados, operate with a critical median income stagnant at R$ 700.00. In these locations, physical losses reach levels of 691.58 l/call/day and 515.81 l/call/day, respectively. In Duque de Caxias and São Gonçalo, with median incomes of R$ 800.00 and R$ 909.00, the losses reach even more alarming levels, with 669.12 and 900.25 liters per day per connection point. These data indicate that where the population has less ability to pay, the waste of water for consumption wasted in the system itself is significant.

The detailed analysis reveals significant anomalies that go beyond the regional trend and show a lack of absolute operational efficiency in peripheral regions. The most extreme case was the municipality of São João da Barra, with a very worrying socio-technical distortion. With a median income of R$ 733.33, SINISA records a loss of 1414.12 liters per connection/day, being the second largest waste of water in the state. This volume suggests an infrastructure with many disruptions, where the volume lost exceeds the volume consumed. A similar scenario occurs in Nilópolis and Guapimirim, with median incomes ranging between R$ 860.00 and R$ 1,000.00, the systems operate with losses of 1,245.63 and 1,119.77 liters per connection, respectively. Such volumes indicate that the network in these areas loses many resources, an amount more than ten times greater than the municipality with the lowest expenditure, São Sebastião do Alto, with its 69.57 liters lost per connection.

The complexity of the socio-technical scenario reaches its critical point in the direct comparison between the two main powers of the Metropolitan Region: Rio de Janeiro and Niterói. The capital, with a median income of R$1,212.00, registers an alarming loss rate of 1,292.59 liters per connection/day, positioning itself among the worst performances in the state. On the other hand, Niterói, the city with the highest median income in the sample, with R$2000.00, has a much lower volume of losses, in the order of 361.63 liters per connection/day. This disparity between neighboring cities shows that political centrality and the size of the municipality do not guarantee efficiency. The technical abyss reveals that there is a tendency for water security in the state to be linked to the high concentration of income, however, the capital, despite its economic protagonism, faces an operational collapse comparable to or greater than that of the peripheral areas, possibly aggravated by the obsolescence of old networks and many ruptures along the distribution network.

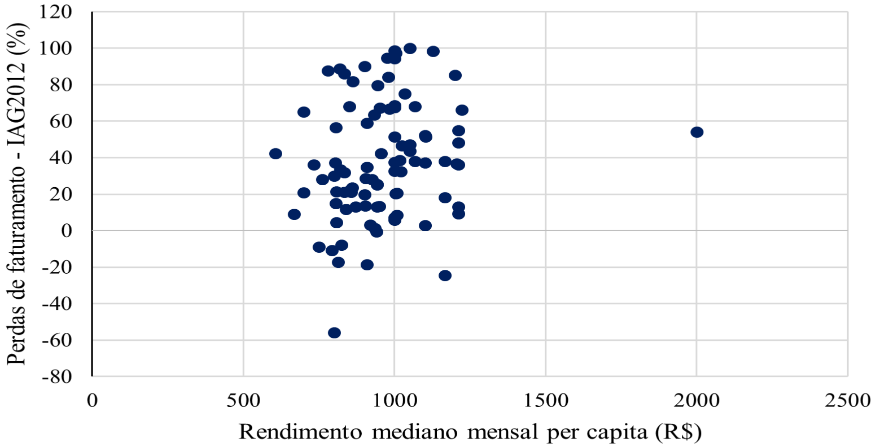
It is noteworthy that the complementary analysis of the linear loss index (IAG2014) corroborated this diagnosis.

## 4.2 ECONOMIC CORRELATION AND COMMERCIAL MANAGEMENT

To approach the economic dimension independently, graph 1 presents a dispersion analysis, which crosses the revenue loss index (IAG2012) with the average municipal income.

**Figure 4**

*Correlation between median monthly income per capita (X-axis) and revenue losses - IAG2012 (Y-axis)*




Source: Authors' elaboration based on data from SINISA (Reference year: 2023) and IBGE (2022 Census).

The data show that the inability to convert the volume of water made available into revenue is not random, being territorially concentrated in areas where social vulnerability is intrinsic. The median per capita income was below the minimum wage in the reference year of the 2022 Census for 85 of the 92 municipalities that make up RJ. Meanwhile, the rate of losses in revenue was above 40% in 31 municipalities.

The most critical pattern is observed in the axis of the Baixada Fluminense and Leste Metropolitano. Municipalities such as Nilópolis, Belford Roxo and Duque de Caxias have revenue loss rates of 84.07%, 65.20% and 56.61%, respectively. These indices indicate that, in these locations, the provision of the service occurs in a context of technical and commercial informality.

There are significant anomalies in the interior of the state, which suggests administrative inefficiency in small systems as well. Municipalities such as Cordeiro and Saquarema record revenue losses of more than 90% (98.75% and 94.31%, respectively), which points to charging models disconnected from the actual volume consumed and penalizes the financial sustainability of sanitation.

Finally, 8 municipalities presented negative percentages in the IAG2012 index, indicating the possibility that the volume of water billed is higher than that produced. There is a scenario of authorized consumption in which some service providers do not bill the entire volume consumed, as in the case of water trucks, for example. Negative values may also be influenced by the existence of a minimum tariff base or errors in the voluntary completion of data by concessionaires (SINISA, 2023).

### 4.3 SUMMARY: RELATIONSHIP WITH THE 2030 AGENDA

The integrated analysis of the indicators used reveals that the current engineering of water distribution networks in Rio de Janeiro operates out of step with the 2030 Agenda. The existence of a high correlation between physical losses and low-income areas (Figure 3) shows the non-compliance with SDG 6, since inefficiency prevents real universal access to treated water (UN, 2015). Together, the selective degradation of infrastructure in peripheries perpetuates the territorial inequality combated by SDG 10, while the lack of quality of systems in the face of intermittent supply compromises the urban resilience recommended by SDG 11. The data indicate, therefore, that water insecurity in these locations is connected with design and management decisions that reproduce patterns of exclusion.

## 5 CONCLUSION

The sociotechnical analysis of the water distribution networks in the State of Rio de Janeiro allowed to show that infrastructural inefficiency does not occur randomly, but reflects patterns of socio-spatial segregation as a material reflection of historical patterns. The study demonstrated a direct correlation between municipalities with lower economic capacity and greater social vulnerability, such as those in the Baixada Fluminense. In these places, the obsolescence of the infrastructure and the operational stress of the networks result in alarming rates of physical losses of the natural resource, applying a disproportionate impact to the population.

The disparity observed between the capital and the neighboring city with the highest per capita income, Niterói, reinforces that the availability of financial resources and political centrality influence the quality of sanitary engineering. The same municipality may present considerable anomalies in the per capita income of the population and, concomitantly, in the year of implementation of its water distribution network. In this context, it is essential to prioritize a management capable of solving historical deficiencies in the pipes, allowing access to drinking water for the entire population, without power relations being the determining factor.

It is concluded that the reduction of water losses transcends the technical challenge of maintenance, it constitutes an urgent measure of social justice and equity. To achieve the Sustainable Development Goals of the 2030 Agenda (SDGs 6, 10 and 11), it is imperative that public policies and engineering projects prioritize the modernization of networks in peripheral territories, transforming infrastructure into an instrument of inclusion and nonperpetuation of existing hydro-social inequalities. As a limitation, this study was based on voluntary data delivered by the concessionaires to SINISA, which may imply omission of information in certain locations. It is suggested to revisit the data through field measurements in critical areas to validate the impact of intermittent distribution in peripheral pipes, subsidizing public sanitation policies that prioritize technical equity.

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