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Legal Basis for Water Resources Management in Brazil: Case Study of the Rio Grande Basin

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Abstract**—**The water crisis, a major problem of the 21st century, occurs mainly due to poor management. The central issue that should govern the management is the integration of the various aspects that interfere with the use of water resources and their protection, supported by legal basis. A watershed is a unit of water interacting with the physical, biotic, social, economic and cultural variables. The Brazilian law recognized river basin as the territorial management unit. Based on the diagnosis of the current situation of the water resources of the Rio Grande Basin, a discussion informed in the Brazilian legal basis was made to propose measures to fight or mitigate damages and environmental degradation in the Basin. To manage water resources more efficiently, conserve water and optimize their multiple uses, the integration of acquired scientific knowledge and management is essential. Moreover, it is necessary to monitor compliance with environmental legislation.

Keywords**—**Conservation of soil and water, river basin, sustainability, water governance.

I. Introduction

INTEGRATED water resources management can be defined as the promoter of the development and coordinated management of water, land and related resources, with the aim of maximizing social welfare and economic growth, ensuring the sustainability of ecosystems [1]. The Brazilian water resources policy defines the basin as a territorial planning unit and, given its complexity, the approach must be systemic and integrated.

The effectiveness of water management requires a well-developed and reliable set of data to feed into a decision support system at the national level. However, data quality varies among the Brazilian states [2].

The first step in the management of a river basin is to assess or diagnose the situation. The situation assessment helps to understand the present and future conditions of the river basin and assists in the identification and prioritization of the main problems [1]. In the Brazilian law, this first step is included in the basin plan.

The diagnosis of the Rio Grande Basin (BHRG) was based on the DPSIR (Driving Forces-Pressures-States-Impacts-Responses) methodology to analyze the situation and determine the capacity of the indicators to change the state of the water [3]. However, some data are not available for the two areas. Given data failure, 33 indicators have results both for São Paulo and Minas Gerais [3]. Often, a small number of variables contain the essential information. The decision on which variables are relevant can be made through an exploratory analysis [4].

The principal component analysis and the hierarchical clustering analysis are complementary multivariate statistical techniques widely accepted in environmental studies [4].

Understanding the reality of the BHRG, characterizing the water management units and points that require more significant attention from decision makers complement the situation diagnosis and may assist in the construction of the basin plan. It is expected that the exploratory analysis of the diagnostic data point out the main problems in the BHRG, the similarities, and divergences between the states and the management units. In this sense, the intention is to explore the diagnostic data based on multivariate statistics to understand the actual situation of the basin and to point out the main aggravating factors impacting the effectiveness of the water resources policy.

II. Materials and Methods

A. Characterization of the Study Area

The BHRG is located in the southeast region of Brazil and has 143400 km² divided between the States of São Paulo (40% of the total area) and Minas Gerais (60% of the total area) [3]. The Basin belongs to the Paraná Hydrographic Region, one of the most important in terms of economy and use of water resources in Brazil [5]. The Basin is divided into 14 water management units, with eight units in the State of Minas Gerais and six units in the State of São Paulo (Fig. 1). The relief of the Basin is predominantly flat, being smooth undulating in some regions. Latosols and acrisols are the main types of soil of the region. The predominant biome is the savanna, and the regional biodiversity is very rich and diversified. The presence of palm swamps (*veredas*), very typical of the area, consists of typical formations of tablelands, composed of herbaceous and shrubby flowering plants and grass between native and savanna forest patches [3].

Although much of the Basin area is intended for agricultural purposes, the industry is also relevant to the region, especially the manufacturing industry [3]. It is important to highlight the issue of water conflicts in the BHRG and water management units. Most of the conflicts reported in the BHRG are related to environmental sanitation (sewage and solid waste), diffuse pollution due to agricultural activities and soil erosion.

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Fig. 1 BHRG and water management units [3]

B. Exploratory Analysis of Data

For this work, we use the set of social, economic, and environmental indicators published in the BHRG water resources situation diagnosis. Diagnostic developers used the DPSIR methodology to determine the status of the indicators and the ability to change the condition of BHRG's water resources [3]. Subsequently, we selected the indicators with results available for the two states: Minas Gerais and São Paulo. The dataset was submitted to exploratory analysis based on multivariate statistics, using the clustering analysis and the principal component analysis (PCA) techniques [9]. The clustering analysis and PCA were applied after standardization of data to avoid classification errors due to the significant differences in data dimensioning [6].

C. Water Resource Policy at the BHRG

In Brazil, the National Water Resource Policy (PNRH) corresponds to Law No. 9,733 of January 8, 1997 [7]. However, its application in the Brazilian states occurred variously. In the case of the BHRG, the state water laws were created at different times and with some differences from the federal law. The State of São Paulo was a pioneer in the creation of the state law on water resources, even before the federal law came into force. According to the National Water Agency – ANA [8]:

> "The State of São Paulo pioneered the institutionalization of a Water Resource Policy in Brazil, by publishing State Law No. 7,663 of 1991. At the federal level, the PNRH was established by Law No. 9,433 of 1997, which also established the National Water Resource Management System (SINGREH), in compliance with the provisions of the Federal Constitution of 1988 (Article 21, item XIX). In the state of Minas Gerais, the State Policy for Water Resources was established by State Law No. 13,199 of 1999, which also provides for the State Water Resource Management System and was regulated by Decree No. 41,578 of 2001" [2, p. 3].

The instruments for water resource management provided for in Federal Law 9,733/1997 are: a) water resource plans; b) the organization of bodies of water into classes, according to the prevailing uses of water; c) granting rights to use water resources; d) charging for the use of water resources; e) information system on water resources [7].

The diagnosis of the water situation is a mandatory requirement for creation of the integrated water resource plan for a Brazilian river basin.

In the State of São Paulo, basin plans are not characterized as management instruments. Regardless of that, they should be developed and updated by the basin committees. The same happens with the organization of water bodies in classes, but it is part of the plans. Unlike the federal law, São Paulo considers infractions, penalties, and apportionment of the costs of works as management instruments [8].

In the State of Minas Gerais, the management instruments provided for in state policy are the following: a) state water resource plan; b) master plans for water resources in river basins; c) state water resource information system; d) organization of water bodies into classes, according to their prevailing uses; e) granting rights to use water resources; f) charge for the use of water resources; g) compensation to municipalities for the exploitation and restriction on the use of water resources; h) apportionment of the costs of works of multiple uses, of common or collective interest; i) penalties

[5].

It is widely known that there are differences between the current state laws governing the BHRG, but the heterogeneity goes far beyond the legal basis. There are socioeconomic, cultural, and environmental differences, among others. Understanding its characteristics and the main factors that interfere with its management is the object of this study.

III. Results and Discussion

The objective of this study was to make an exploratory analysis of data presented in the diagnosis of the water resource situation of the BHRG, supported by the current legislation, to identify the particularities of the states and respective water management units. The assumption made based on the problem was that the exploratory analysis would make it easier to understand the reality of the basin, indicate the areas requiring more attention from decision makers, and promote new discussions, including on the effectiveness of the water resource policy. For this type of approach, it is necessary to have an integrated and systemic view of the unit of work. Water management is often an involuntary response to the country's culture, legal system, political system, and territorial organization [2]. In this way, an exploratory analysis of the diagnostic data can facilitate the understanding of the managers, indicating the variables responsible for the more significant variations of the data, without considerable loss of information [4].

Of the 33 indicators [6] included in the diagnosis, only 14 were selected by PCA. For this analysis, we considered the principal components 1 and 2 (PC1 and PC2), with an eigenvalue greater than 1 and responsible for synthesizing a cumulative variance of data of 82.79%, being 70% the minimum recommended [9] (as shown in Fig. 2 and Table I). The indicators selected, the units, actual values for each State and correspondence in the DPSIR matrix can be observed in Table II. The differences between the states are clear. Considering the DPSIR, the PCA did not select state indicators, which refer to water quality and availability. Also, the analysis divided the management units into seven groups (Fig. 3).

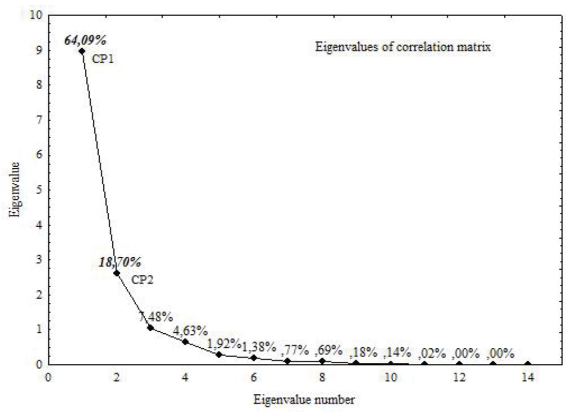

Fig. 2 Eigenvalues of the correlation matrix; Cumulative variance of PC1 and PC2

TABLE I
Cumulative Eigenvalues

Value Number	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative (%)
1	*8.971955*	*64.08539*	*8.97196*	*64.0854*
2	*2.617469*	*18.69621*	*11.98942*	*82.7816*
3	1.047732	7.48380	12.63716	90.2654
4	0.647643	4.62602	13.28480	94.8414
5	0.268641	1.91887	13.55344	96.8103
6	0.193844	1.38460	13.74728	98.1949
7	0.107835	0.77025	13.85512	98.9651
8	0.096252	0.68751	13.95137	99.6527
9	0.025433	0.18166	13.97680	99.8343
10	0.019262	0.13758	13.99607	99.9719
11	0.003415	0.02440	13.99948	99.9963
12	0.000512	0.00366	13.99999	100.0000
13	0.000007	0.00005	14.00000	100.0000

TABLE II
Description of Indicators

Indicator	Unit	Minas Gerais	São Paulo	DPSIR
Total Population **(Pop_Tot)**	No. of inhabitants	3.714.345	4.907.529	Driving Force
Estimated amount of treated water consumed per year **(Agua_Tratada)**	10^6 m³/year	122.57	3717.34	Driving Force
Number of agricultural establishments **(Est.Agro)**	Number	25074	19144	Driving Force
Number of heads of animals reared **(Ani_Criados)**	No.	26.889.845	67.978.645	Driving Force
Proportion of the area occupied by agriculture **(Agricult)**	%	22.06	57.34	Driving Force
Estimated amount of domestic sewage produced per year **(Qtde_Esg)**	10^6 m³/year	183.69	237.66	Pressure
Estimated amount of solid waste produced per year **(Qtde_RS)**	10^3 ton/year	987.93	1218.17	Pressure
Municipal Human Development Index **(IDHM)**	Dimensionless	0.763	0.788	Pressure
Annual amount of hospitalizations due to waterborne diseases **(Doencas_V.H)**	No. per year	6567	10715	Impact
Proportion of municipalities with landfill **(aterro)**	%	19.51	47.53	Response
Proportion of wells monitored against total wells of the monitoring network **(Poços_Monit)**	%	0	26.26	Response
Number of PNRH instruments implemented against the total of 5 instruments **(PNRH)**	No.	1	3	Response
Number of fluviometers installed **(Qtde_Flu)**	No.	6	41	Response
Proportion of the area with native vegetation **(Veg_Nat)**	%	3.44	3.48	Response

t: ton, No.: number/amount

It is possible to observe in Table III the value of the eigenvectors and their associations (positive or negative), which defined the direction of the arrows. CP1 refers to the positive associations with the Driving Force, Pressure, and Impact indicators. CP2 refers to the negative associations with the Response indicators and the proportion of cultivated area

(Driving Force indicator). The proportion of native vegetation preserved had a negative association in both components, being more significant in CP2.

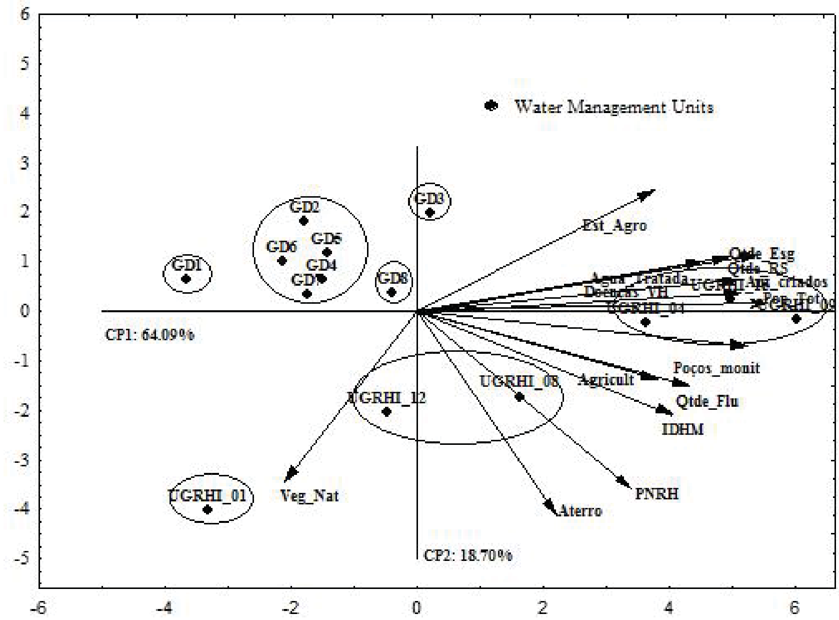

Fig. 3 PCA (CP1 X CP2)

TABLE III
EIGENVECTORS OF THE CORRELATION MATRIX

	First Principal Component	Second Principal Component
Agricult	0,228685	-0,183935
Qtde_Esg	0,319253	0,143222
Qtde_RS	0,318952	0,144264
IDHM	0,240929	-0,263825
Doenças_V.H	0,308350	0,081235
Aterro	0,131473	-0,522928
Poços_Monit	0,311125	-0,091078
PNRH	0,201374	-0,450119
Est_Agro	0,237167	0,310975
Ani_Criados	0,306601	0,042930
Agua_Tratada	0,319247	0,143269
Qtde_Flu	0,257929	-0,203126
Veg_Nat	-0,122729	-0,430746
Pop_Tot	0,320199	0,135675

It is possible to infer the heterogeneity between the states of Minas Gerais and São Paulo from this analysis. Also, we found deficiencies in environmental sanitation due to urbanization and agricultural activities, impacting the health of the population by CP1 and infrastructure problems, especially for water monitoring, which are related to regional development and implementation of water management instruments.

GD1 is the management unit with the lowest proportion of cultivated area and lower HDI of the BHRG, besides having the smaller total population of the area. Additionally, it has the second largest area of native vegetation preserved in the Minas Gerais area. These characteristics differentiated the unit from the others; contrary to the attributes of GD1, GD8 has the largest cultivated area and highest HDI of the area. Of the Minas Gerais management units, GD3 is the one that most closely resembles the management units of the São Paulo area. It has the second highest proportion of cultivated area and HDI of the Minas Gerais area because it is the unit that generates the most solid waste and sanitary sewage. However, GD2, GD4, GD5, GD6, and GD7 have similar developmental characteristics, approaching GD1 because they have cultivated area and HDI lower than GD3 and GD8. Also, this group contains, in general, management units with higher proportions of native vegetation preserved. It is worth mentioning, for example, that the proportion of native vegetation preserved in the BHRG is small.

Regarding the management units of the São Paulo area, we will start by highlighting UGHRI_01, differentiated from all other management units by having the highest proportion of native vegetation preserved, the smallest population and lowest proportion of cultivated area of the BHRG. Of this area, this unit has the lowest HDI value. UGHRI_12 is similar to UGRHI_08 because it has a large proportion of cultivated area (Figs. 3 and 4). Next, the group consisting of UGHRI_04, UGHRI_09, and UGHRI_15 stands out for the more significant generation of solid waste and sanitary sewage and, consequently, the higher number of people hospitalized with waterborne diseases in the BHRG.

The single-linkage hierarchical clustering analysis confirmed the groups discretized in the PCA and their characteristics (Figs. 4 and 5). This method is based on the minimum distance, the nearest neighbor rule [7].

The proportion of cultivated area in the management units influences the Municipal Human Development Index (HDI); where agriculture predominates, in general, human development is higher and the management units are better structured, especially regarding water monitoring and environmental sanitation. Also, the implementation of the management instruments provided for in the water resource policy is generally more significant in the more advanced management units (with higher HDI and cultivated area). However, even in the more developed regions, the number of hospitalizations for waterborne diseases is very high. That is, the water sanitation and monitoring infrastructure are precarious. A small proportion of surface water in the BHRG was monitored, only 14.97%. Groundwater is only monitored in the São Paulo area and was considered insufficient by the diagnosis [3]. That is, from the diagnostic data, the actual situation of water availability and quality could not be defined. In spite of that, the strong impact of water on the health of the population allows us to infer that potability may be inadequate.

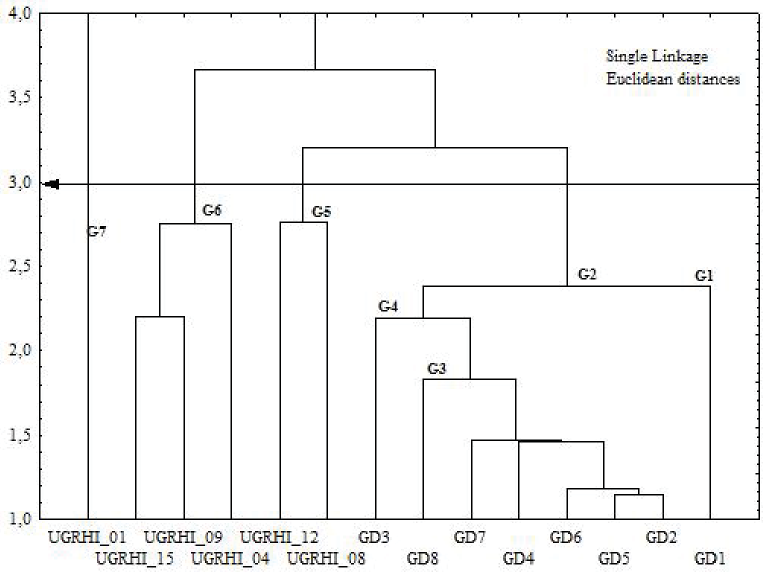

Fig. 4 Single-linkage clustering analysis of the water management units

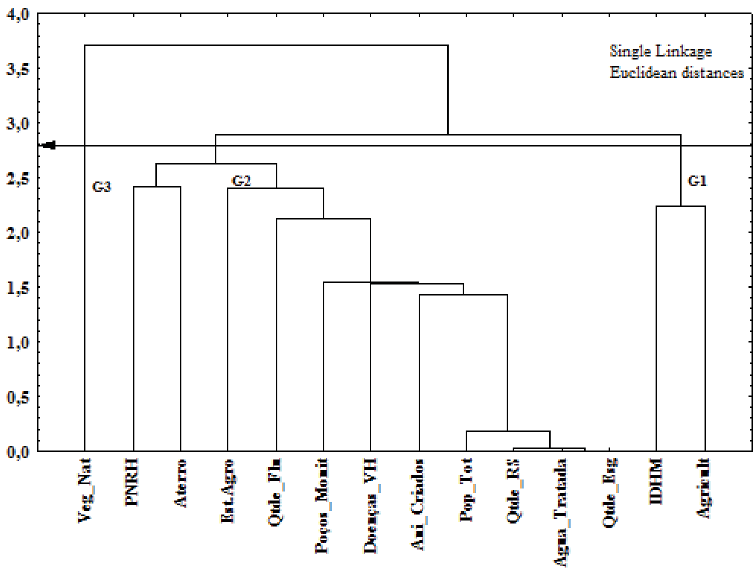

Fig. 5 Single-linkage clustering analysis of the indicators

Given the above, we can infer the lack of coordination between public policies. There is no integration between development policies and water resource policies. This concern must be present at the highest levels of the federal government and state governments and be placed as a priority on the agenda of the state and national water councils [2]. The development brings with urban expansion, agricultural expansion, industrialization, hydropower plants and, consequently, increased demand for water.

Reference [2] established ten rules for effective river basin planning: (1) to understand the whole system; (2) plan and act, even without full knowledge; (3) prioritize issues that require current attention and adopt a stepwise approach; (4) adaptation should be allowed, should anything change; (5) accept the interactivity of the planning; (6) elaboration of thematic and consistent plans; (7) addressing issues at the appropriate scale, tailoring local plans to the basin plan; (8) stimulate the actors involved with a view to strengthening institutional relations; (9) focus on the implementation of the basin plan and, finally, (10) select the methods and approach needed to meet the needs of the basin.

The author makes clear that working with water issues is complex, iterative, and multidisciplinary. Also, it is essential to know the reality of the system and to understand its heterogeneity. The Rio Grande Basin is interstate. The states of Minas Gerais and São Paulo depend on the water resource of the Rio Grande Basin in economic, social and environmental aspects. However, regional development and water legislation are different in the states of Minas Gerais and São Paulo. Therefore, considering the dynamics of the basin, it is necessary to foresee changes and how to adapt to them.

As explained above, an effective management of water resources requires a strong set of data to feed into a decision support system at the national level. However, the quality of hydrological data varies between the Brazilian states [2] and can be observed in this work. While the water resource legislation in São Paulo was established in 1991, in Minas Gerais it only occurred in 1999.

> "First, the São Paulo legislation established in the early 1990s (Law 7,663/91), and its consequent regulations, has led to the availability of Basin Committees established for more than 10 years in all its Water Resource Management Units (UGRHIs), while in the Minas Gerais area this process is in the consolidation phase. As a result, the 22 UGRHIs of São Paulo have already developed at least one complete diagnosis of the water resource situation, and 15 of them already have basin plans [8, pp. 3].

The assessment of the effectiveness of water governance should consider structural problems that need understanding and mitigation. It is clear that there are flaws both in the policies and their applications and in the infrastructure of the municipalities in the BHRG. For the policies and their applicability, the flaws occur from the understanding the reality of the basin to the capacity of the decision makers.

Efficient planning, considering the multiple uses provided in the legislation, requires data at least on availability, demand, and quality.

According to [10] compliance with legislation and water monitoring capacity is varied among the Brazilian states. Compliance with laws is a significant challenge and is greatly influenced by cultural factors.

> "The vast number of small users of water and the lack of a culture of compliance with the rules contribute to the problem, as do limited use, high costs and maintenance issues" [2, pp. 86].

In Brazil, the remediation culture is perpetuated. First, the problems occur, and then you run after alternatives to solve them. "Preventing pollution means reducing or eliminating contaminants at the source before they can pollute water resources - this is almost always the cheapest, easiest, and most effective way to protect water quality" [10, pp. 19]. Due to the low quality of the water of the Brazilian rivers, the cost for treatment of the water and sewage is high.

> "According to the National Sanitation Plan (PLANSAB), the amount of financial resources required by 2033 by water and sewage services may account for 5.2% of GDP. Without forecasted funding and firm long-term commitments, the water resource policy cannot be successfully implemented [2, pp. 71]."

There are many gaps in the path for the successful implementation of water resource policies and basin plans: policy, administration, financing, capacity building, objective, responsibility, information, and planning. There are several plans in Brazil, but they are weak because their planning is flawed.

Water resource plans are important tools in identifying gaps, implementing strategies, building consensus among stakeholders, guiding and measuring progress in achieving targets [2]. The integration between the water resource policy and territorial organization encompasses a series of issues, making coordination difficult. Also, many problems are not addressed because there is a lack of studies on the interaction between these areas. The spatial planning cycle requires greater coordination and cohesion, greater attention to time and more integration of sectoral policies. Likewise, it is important to coordinate and integrate other policies in sectors that affect water, such as agriculture, forestry, energy, sanitation, and tourism [11]

Research shows that to be successful in implementing the water resource policy at the BHRG, a great deal must be rethought. Legislation must be complied with, but to do so, appropriate means are needed to implement it. Our work complements the diagnosis of the water resource situation, but we believe that, in order to elaborate an efficient plan that is consistent with the reality of the basin, adequate water monitoring is essential. The ability to monitor and enforce legislation must be one of the fundamental considerations for correct allocation of water, including the granting of water use rights [2]. In the BHRG, for example, the ability to monitor and enforce the law varies. We can verify this by observing the monitoring indicators and the implementation of the management instruments in the water management units.

> *"The integrated management of water resources is essential for establishing instruments and mechanisms to avoid and resolve conflicts of use, enabling everyone to enjoy sustainable water resources"* [3, pp. 48].

The National Pact for Water Management and other programs are good opportunities to promote integration among sectors, such as energy, agriculture, regional integration, and sanitation, all of which are essential priorities for economic and development policies [2].

Given this, it is possible to state that the BHRG has made progress on water issues, but for the implementation of the water resource policy and the basin plan to succeed, it is necessary to focus on severe and recurrent problems. Through this study, we verified that the main issues are water monitoring and poor environmental sanitation. These issues mainly originate in the urban and agricultural expansion occurring in the basin. The small proportion of native vegetation also stands out. It is worth mentioning that native vegetation, especially Permanent Preservation Areas, plays a fundamental role in maintaining water quality and availability. Also, it is necessary to strengthen local actors, especially state and municipal water resources managers. The awareness of the user population through environmental education is an essential tool. It is necessary to participate and integrate the society in the context of the basin.

IV. Conclusions

The development of this work allows us to visualize the heterogeneity in the BHRG. Not only between the States of São Paulo and Minas Gerais, but also among the water management units.

In general, the management units with the highest proportion of cultivated areas showed better values of Municipal HDI and tended to be more structured regarding water and sanitation monitoring. However, the poor infrastructure of this segment has impaired water quality and threatened the health of the population. The implementation of water management instruments in the BHRG is strongly correlated with sanitation and monitoring issues. Agricultural activities and urbanization are especially responsible for the high generation of solid waste and sanitary sewage in the basin.

Given this, we reinforce that there are no consistent links between public policies in the BHRG. Development must be linked to responsibilities to the environment. Everything that happens in the river basin has a downstream impact, making it a natural integrator of multiple uses of water.

PC1 and PC2 explained 82.79% of the data variation, discretized the states of Minas Gerais and São Paulo and highlighted the main characteristics of the water management units. The clustering analysis confirmed the PCA.

Given the relevance of the theme and its multidisciplinary character, it is necessary for decision makers to acknowledge the importance of the water resource policies and to link them to other development policies. Only then, we believe in the possibility of success in the implementation of water resource policies, as well as the basin plans.

This work complements the diagnosis of the water resource situation, highlighting the particularities of each management unit and the main problems that must be mitigated for proper management of water in the BHRG. Although we have essential management instruments provided for in the legislation, in practice, it is difficult to use them. If the diagnosis of the water situation in a river basin is a mandatory requirement for elaboration of a management plan, we believe that, to be successful, it is necessary to analyze the BHRG as a complex system. It is necessary to align development with water issues, sensitize decision makers and the population to the theme, have a multidisciplinary and capable team to assist in the management, and have a systemic and integrated vision.

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