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Assessment of resilience using sustainability indicators in municipalities in the Baixo Pardo/Grande River Basin.

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SUMMARY
Population growth has created challenges in the urban environment for basic sanitation, health, education and urban mobility services. In this context, the use of indicators for the management of urban services stands out as a tool for analyzing quality of life, which motivated the proposal of 128 indicators by NBR ISO 37120:2021. The aim of this research was to assess the resilience of the Baixo Pardo/Grande Water Resources Management Unit (UGHRI 12) using sustainability indicators. The method consisted of selecting indicators with information available on a digital basis, standardizing indicators (scale 0 and 1) to assess local and regional sustainability and, finally, analyzing the potential for urban resilience based on sustainable development indicators. Thirteen indicators were selected in advance and, to identify sustainability, the arithmetic mean of the standardized values was calculated. So far, the main results show that the majority of municipalities (75.0%) have an overall score between 0.50 and 0.65, one (8.3%) is above 0.70 and two (16.7%) are below 0.50, which means that they may face the greatest challenge in tackling resilience associated with sustainability, which negates the central hypothesis. So far, the SDG with the most information available in a digital database has been SDG 6. The main contribution was to point out the local and regional scenario for achieving sustainability, in order to highlight the weak points in this river basin.

KEYWORDS: Indicators. River Basin. Sustainability.

1 INTRODUCTION

Approximately 8 billion people currently inhabit Earth, and this number is expected to reach 9.7 billion by 2050 (United Nations, 2022), causing challenges for urban environments. These challenges impose greater demands on basic sanitation, health, education and urban mobility services and infrastructures.

The 2030 Agenda contains 17 Sustainable Development Goals (SDGs) in the social, environmental, economic and institutional dimensions, and was proposed by the 193 member countries of the United Nations (UN) in order to minimize urban challenges. The aim of this Agenda is to guide countries in their actions towards a more sustainable and resilient world by 2030 (Brazil, 2024).

The climate change scenario points towards an increase in the frequency and intensity of extreme events, requiring adaptation, mitigation and resilience measures in urban areas (Sotto et.al, 2019, p.70). Resilience is the ability to prepare for, respond to and recover quickly from climate challenges, including preventative measures (efficient drainage systems), solid infrastructure and monitoring technology (Curitiba, 2023).

In addition to the SDGs, other methods help managers to plan and design improvements in cities. For example, the Environmental Health Indicator (ISA) and the Sustainable City Development Index (IDSC). The first was drawn up by the São Paulo State Sanitation Council (CONESAN) in 1999 (CONESAN, 1999) and consists of basic sanitation, vector control and socio-economic indicators. The second was developed by the Sustainable Cities Institute (ICS) and consists of 260 indicators aligned with sustainable development. These instruments have been used in national studies, as observed by Montenegro et al. (2001), Dias et al. (2004), Batista (2005), Lins et al. (2017), Lupepsa et al. (2018), Rocha (2019), Lima (2019), Kobren et al. (2019), Alvares (2020), Ferro, Ventura and Rezende (2020), Rezende (2020), Scolari, Medeiros and Passini (2023).

In addition to these tools, there is ABNT NBR ISO 37120 "Sustainable cities and communities - Indicators for urban services and quality of life", which consists of 128 indicators and aims to measure urban services and quality of life. It is the first Brazilian standard that relates the provision of services in the urban environment to quality of life, sustainable development and the business environment (ABNT, 2021). An indicator is a quantitative, qualitative or descriptive measure (ABNT, 2021) used to assess the performance of an objective and the achievement of targets (UFRPE, n.d., p.2), allowing the distance between a society's current situation and its development objectives to be measured (Guimarães and Feichas, 2009, p.309).

The indicators regard education, the economy, energy, the environment, governance, finance, health, sports and leisure, transport, urban planning, telecommunications and innovations. These indicators are directly linked to the 17 (SDGs) and help municipalities achieve the 2030 Agenda.

This Standard was drawn up by the Special Statute Commission on Sustainable Cities and Communities in order to track and monitor the progress of cities' performance based on indicators, grouped into core indicators, supporting indicators and profile indicators (Brazil, 2021). Essential indicators are considered indispensable for directing and evaluating the performance management of urban services and quality of life (Brazil, 2021).

In the recent decades, the progress of sustainable development in the three axes (economic, environmental and social) has been related to the difficulties encountered in each location, especially infrastructure, resources and social engagement (Couto et. al, 2023, p.5). The indicators set out in the Standard help medium- and long-term planning, seeking to achieve the goals of the 2030 Agenda. That way, it brings public managers and cities closer to the heart of sustainability, since there was a lack of clarity about the useful indicators for this aspect.

Indicators for sustainable development have been developed mainly on an international scale, with the SDGs standing out. However, at a regional or local level, the application of indicators is diverse and there is no standard on the best systems to apply (Vieira, 2019, p.46).

The aforementioned indicators are important tools used to identify and recognize problems and to formulate, implement and evaluate policies (Guimarães and Feichas, 2019, p.310), but there are many challenges in using them. These challenges are the absence and quality of data (De Fátima Martins and Cândido, 2015, p.146), outdated data, high cost of monitoring and restrictions on data access (Andries et. al, 2022, p.19) and the difficulty of analyzing data stemming from different sources and methodologies (Braga et. al, 2004, p.9).

In this context, resilience is understood as the ability to cope with intense climatic phenomena without collapsing (Siebert, 2012, p.14).

The central hypothesis of this research is that "Resilience can be analyzed by sustainability indicators, and the more prepared a municipality is to face extreme climate events (drought and heavy rainfall), the more resilient it is. Thus, it is estimated that the majority of the municipalities in UGRHI 12 have a score higher than 0.70 and tend towards climate resilience through sustainability more quickly than other municipalities". The guiding question is: How can the sustainability indicators of NBR ISO 37120 measure urban resilience and indicate the challenges to be met on a regional scale (river basin)?

2 OBJECTIVE

The objective was to assess resilience using sustainability indicators in municipalities in the Baixo Pardo/Grande River Basin.

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3 METHODOLOGY

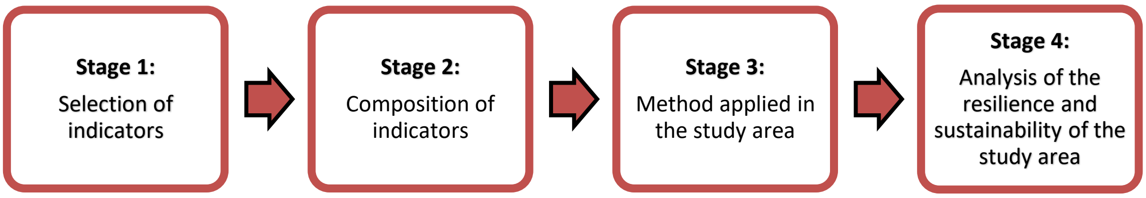
The methodological procedures were based on documentary and statistical data collection, data handling and a case study. Documentary and statistical data collection involves the use of instruments and techniques selected from statistical and census data available on digital platforms. Subsequently, the data was tabulated, i.e. organized in a spreadsheet for ease of use (Marconi and Lakatos, 2003).

Next, a case study was carried out, as it is a linear and interactive method, based on documentary sources (Yin, 2009). Figure 1 shows the methodological stages of the research.

The study area was the Baixo Pardo/Grande River Basin, located in the state of São Paulo (Water Resources Management Unit - UGRHI 12). It is composed of 12 municipalities (Altair, Barretos, Bebedouro, Colina, Colômbia, Guaraci, Icém, Jaborandi, Morro Agudo, Orlandia, Terra Roxa and Viradouro). The drainage area is 7177 Km² and comprises the Pardo and Grande Rivers (São Paulo, 2024).

Thus, 83.3% of the municipalities in UGRHI 12 have fewer than 30,000 inhabitants (Table 1). It should be clarified that the municipalities have been identified by the code M1 to M12, as the aim is to understand how close or far the municipalities are from this Standard and from climate resilience.

Figure 1 – Methodological stages of the research



Source: Own authorship, 2024.

Table 1 – Population characterization according to IBGE

Municipality	Total population	Population size
Altair	3451	small
Barretos	122485	large
Bebedouro	76373	medium
Colina	18486	small
Colômbia	6629	small
Guaraci	10350	small
Icém	7819	small
Jaborandi	9275	small
Morro Agudo	27933	small
Orlandia	38319	small
Terra Roxa	7904	small
Viradouro	17414	small

Source: Own authorship, based on IBGE (2022).

3.1 Selection of indicators

Initially, all the essential, support and profile indicators contained in sections 5 to 23 of the aforementioned Standard were analyzed, totaling 128 indicators. In this article, the use of essential indicators was adopted as a priority and, in the case of unavailable data, indicators from the other groups were used. Therefore, the exclusion of indicators was based on the absence of data for any group of indicators.

Next, a search was carried out in databases (Brazilian Institute of Geography and Statistics - IBGE, National Sanitation Information System - SNIS, websites of city halls and municipal councils) in order to identify the availability of information to compose the indicators proposed in NBR ISO 37120. For existing indicators, a value of 1 (one) is assigned and for absence 0 (zero). In this NBR, the indicators have been organized by SDG, 26 of which are general and not specifically connected to any SDG, such as 16. 5 (essential), 5.7, 5.8, (support), 5.9.1, 5.9.2, 5.9.3, 7.8, 9.5.1, 9.5.2, 12.5.1 to 12.5.6, 13.4.1 to 13.4.6, 19.8.1, 19.8.2, 21.5.1 to 21.5.3 (profile).

In the current phase of the research, it considered the SDGs directly related to this article, highlighting SDG 3 (Health and well-being), SDG 4 (Quality education), SDG 5 (Gender equality), SDG 6 (Clean water and sanitation), SDG 8 (Decent work and economic growth), SDG 10 (Reducing inequalities), SDG 11 (Sustainable cities and communities) and SDG 14 (Life by water). Once the indicators had been selected, they were put together by SDG in the spreadsheet. This stage took around 30% of the time to complete.

3.2 Composition of indicators

The greatest difficulty in composing a joint index or indicator is to combine information from different sources, produced at different scales with different spatial and temporal distribution (Braga, 2004).

To do this, the normalization method as developed by the OECD (2008) was used. Normalization is a statistical method used to treat numerical values in different units and scales, without altering the proper proportions between the values and leaving them expressed in a unified or standardized way. The analysis scale for standardization was 0.0 to 1.0, as shown in Equation 1 (Witten and Frank, 2002).

$$X' = (X - X_{min}) / (X_{max} - X_{min}) \qquad \text{(Equation 1)}$$

X' = normalized value
X = original value
X min = minimum value of the data set
X max = maximum value of the data set

After normalization, the final score for each municipality will be calculated as the arithmetic mean of the selected indicators. This stage took around 20% of the time to complete.

3.3 Method applied in the study area

The available indicators were applied to the twelve municipalities of the Baixo Pardo/Grande river basin, located in the state of São Paulo. The closer the value is to 1 means that the municipality is at a very advanced level of development or implementation of the indicator, while values close to 0 indicate the opposite. Intermediate values indicate that they lie between these interpretations, depending on the normalization calculation.

For that reason, generating and analyzing the results was the most delicate and time-consuming phase of the research (35% of the total).

3.4 Analysis of resilience and sustainability in the study area

There is a relationship between urban resilience and sustainability, which is why data collection and the calculation of Notes 1 and 2 have made it possible to analyze this relationship. Finally, it is estimated that around 15% of the time dedicated to the research was spent observing this relationship.

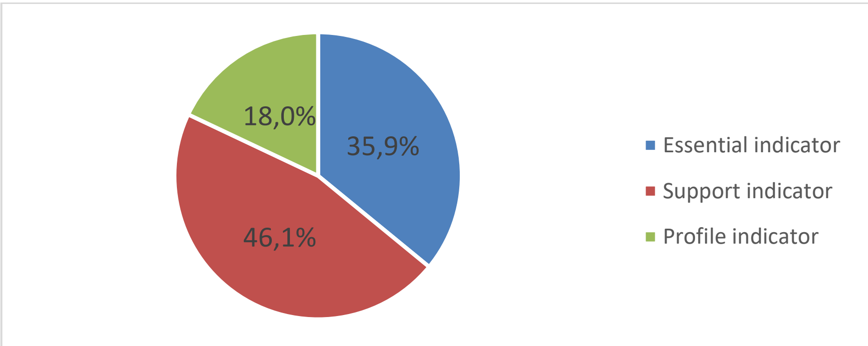
4 RESULTS

4.1 Indicators selected based on the availability of information

Of the 128 indicators listed by NBR ISO 37120, around 46% are classified as support indicators, followed by 36% in the essential class and 18% as profile indicators (Figure 2).

The most easily accessible indicators are in the support and essential groups.

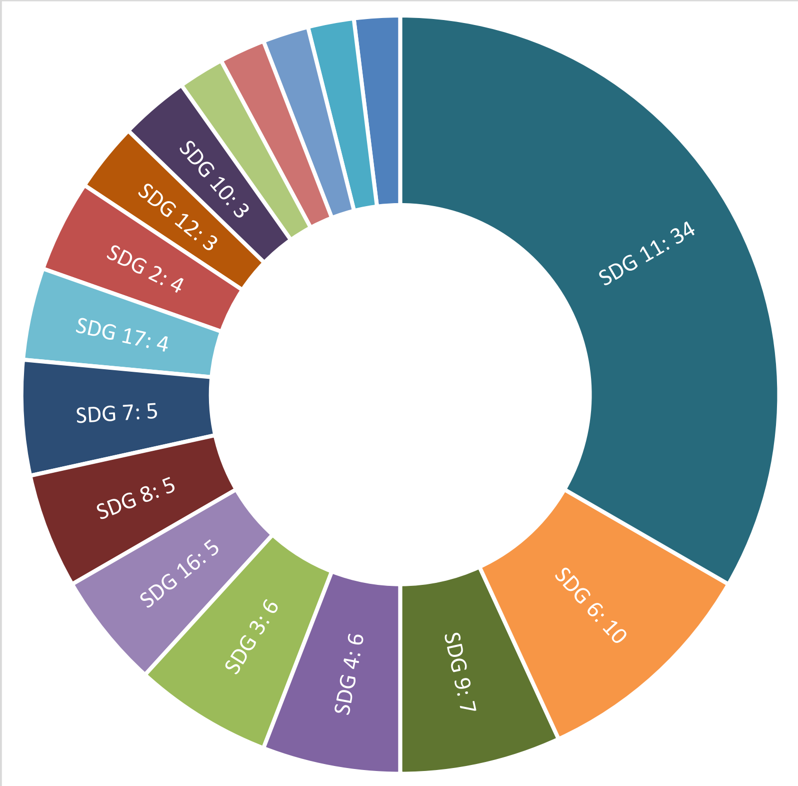
Figure 2 – Classification of the 128 indicators by groups according to NBR 37120:2021



Source: Own authorship, 2024.

Figure 3 illustrates the representativeness of the indicators in relation to the SDGs, excluding the 26 indicators not connected to any goal (102 indicators were considered). The SDG with the highest representation was SDG 11, with 34 indicators (33.3% of the total). The most representative ones were SDG 6 (10%), 9 (9%), 4 and 3 (both 6%). The others have accounted for less than 5% of each objective.

Figure 3 – Representativeness of the 128 indicators by SDG and not classified by group by NBR 37120



NOTE: SDG: 1(Eradication of poverty), 2(Zero hunger and Sustainable agriculture), 3(Health and well-being), 4(Quality Education), 5(Gender equality), 6(Clean water and sanitation), 7(Clean and affordable energy), 8(Decent work and economic growth), 9(Industry, innovation and infrastructure), 10(Reducing inequalities), 11(Sustainable cities and communities), 12(Responsible consumption and production), 13(Action against global climate change), 14(Life on water), 15(Life on land), 16(Peace, justice and effective institutions) e 17 (Partnerships and means of implementation).
Source: Own authorship (2024), based on ABNT (2021).

Indicators were found for SDG 3 (Health and well-being), 4 (Quality education), 5 (Gender equality), 6 (Clean water and sanitation), 8 (Decent work and economic growth), 10 (Reducing inequalities), 11 (Sustainable cities and communities) and 14 (Life in water).

Table 2 – Description of the selected indicators

SDG	Indicators			Description
	Order	Essential	Support	
3	1	11.2		Number of hospital beds per 100,000 inhabitants
	2	11.3		Number of doctors per 100,000 inhabitants
4	3	6.4		The student / teacher relationship in primary education
5	4	10.1		Percentage of women elected in relation to the total number of elected city officials
6	5	22.1		Percentage of the city's population served by sewage collection and disposal system
	6	22.2		Percentage of the city's sewage that receives centralized treatment
	7	22.3		Percentage of the city's population with access to improved sanitation
	8	23.1		Percentage of the city's population with a drinking water supply service
	9	23.3		Total domestic water consumption per capita (liters/day)
8	10	5.1		City unemployment rate (%)
10	11		13.3	Gini coeficiente of inequality
11	12	16.1		Percentage of the city's population with regular solid waste collection (household)
14	13	16.2		Total municipal solid waste collection per capita (ton/per capita)

Source: Own authorship, 2024.

4.2 Use of standardized indicators in UGRHI 12

Chart 1 shows the data collected and Chart 2 illustrates the data after normalization.

Of the 128 indicators, 13 (10%) were found in digital databases. Of this group, only 8% were supportive and the rest (92%) were essential. Despite representing a small quantity in relation to the total, the analyses were carried out normally.

The closer it is to 1, the more resilient and Sustainable the municipality is. Therefore, as municipalities M1 e M11 (16,7%) obtained a Score 1 (average of the indicators per municipality) of less than 0.50, they have presented challenges in terms of resilience and sustainability. The others (83%) scored between 0.50 and 1.00, and it can be seen that they are making progress in terms of resilience and sustainability.

Score 2 (arithmetic average of municipalities by indicator) is shown in Chart 2 and Figure 4. This score made it possible to verify that five indicators (40%) need attention, as they showed results below 0.50. In this case, the indicators have indicated the presence of challenges to achieve resilience and sustainability.

The main sectors which have presented challenges in relation to sustainable development were Health and well-being (SDG 3), Gender equality (SDG 5), Clear water and sanitation (SDG 6), Reducing inequalities (SDG 10) and Life in water (SDG 14).

The most critical indicator was 23.3 on daily per capita water consumption. This indicator represents the amount of water that each individual consumes on a daily basis. Water consumption has a direct impact on basic sanitation services, as municipalities need to increase the productivity of water treatment plants and, consequently, sewage treatment.

In addition, water consumption should be conscious, avoiding waste, and reusing when possible.

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Chart 1 – Standardized indicators (input data) by municipality (M1 a M12)

SDG	Indicators	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	Xmín	Xmáx
3	E 11.2	0,00	0,04	0,02	0,03	0,03	0,00	0,00	0,03	0,01	0,02	0,04	0,03	0,00	0,04
	E 11.3	0,03	0,08	0,04	0,01	0,02	0,04	0,02	0,02	0,01	0,02	0,00	0,01	0,00	0,08
4	E 6.4	12,56	18,35	14,65	16,76	17,95	17,01	15,50	15,89	18,01	16,55	14,96	15,34	12,56	18,35
5	E 10.1	18,18	5,26	30,77	7,69	18,18	0,00	36,36	0,00	8,33	9,09	9,09	18,18	0,00	36,36
6	E 22.1	86,60	45,00	100,00	100,00	100,00	100,00	100,00	100,00	0,00	100,00	100,00	86,60	0,00	100,00
	E 22.2	100,00	100,00	96,13	100,00	99,99	100,00	90,96	100,00	98,91	89,73	100,00	98,57	89,73	100,00
	E 22.3	99,29	100,00	100,00	96,13	100,00	99,58	100,00	93,41	100,00	98,99	91,87	100,00	91,87	100,00
	E 23.1	98,57	100,00	100,00	96,13	100,00	99,99	100,00	90,96	100,00	98,91	89,73	100,00	89,73	100,00
	E 23.3	142,55	203,04	203,25	215,32	164,66	214,02	155,37	162,39	491,90	183,42	168,33	196,92	142,55	491,90
8	E 5.1	69,39	56,07	42,22	49,94	17,41	63,59	77,91	80,54	61,03	45,64	74,68	68,07	17,41	80,54
10	A 13.3	0,42	0,49	0,51	0,46	0,41	0,42	0,45	0,64	0,46	0,50	0,45	0,41	0,41	0,64
11	E 16.1	0,00	96,95	95,29	93,39	96,42	83,47	100,00	96,94	95,85	97,42	95,32	97,07	0,00	100,00
14	E 16.2	0,00	0,28	0,25	0,37	0,16	0,58	0,18	0,35	0,28	0,34	0,22	0,23	0,00	0,58

OBS: E: essential A: support. Source: Own authorship, 2024.

Chart 2 – Standardized indicators, Score 1 and Score 2

SDG	Indicators	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	Score 2
3	E 11.2	0,00	1,00	0,46	0,76	0,80	0,00	0,00	0,61	0,34	0,56	0,90	0,63	0,51
	E 11.3	0,39	1,00	0,46	0,14	0,19	0,51	0,23	0,15	0,13	0,26	0,00	0,03	0,29
4	E 6.4	0,00	1,00	0,36	0,73	0,93	0,77	0,51	0,58	0,94	0,69	0,42	0,48	0,62
5	E 10.1	0,50	0,14	0,85	0,21	0,50	0,00	1,00	0,00	0,23	0,25	0,25	0,50	0,37
6	E 22.1	0,87	0,45	1,00	1,00	1,00	1,00	1,00	1,00	0,00	1,00	1,00	0,87	0,85
	E 22.2	1,00	1,00	0,62	1,00	1,00	1,00	0,12	1,00	0,89	0,00	1,00	0,86	0,79
	E 22.3	0,91	1,00	1,00	0,52	1,00	0,95	1,00	0,19	1,00	0,88	0,00	1,00	0,79
	E 23.1	0,86	1,00	1,00	0,62	1,00	1,00	1,00	0,12	1,00	0,89	0,00	1,00	0,79
	E 23.3	0,00	0,17	0,17	0,21	0,06	0,20	0,04	0,06	1,00	0,12	0,07	0,16	0,19
8	E 5.1	0,82	0,61	0,39	0,52	0,00	0,73	0,96	1,00	0,69	0,45	0,91	0,80	0,66
10	A 13.3	0,08	0,37	0,45	0,24	0,01	0,06	0,19	1,00	0,25	0,43	0,20	0,00	0,27
11	E 16.1	0,00	0,97	0,95	0,93	0,96	0,83	1,00	0,97	0,96	0,97	0,95	0,97	0,87
14	E 16.2	0,00	0,48	0,43	0,64	0,28	1,00	0,31	0,60	0,48	0,59	0,38	0,40	0,47
	Score 1	0,42	0,71	0,63	0,58	0,60	0,62	0,57	0,56	0,61	0,54	0,47	0,59	

Source: Own authorship, 2024.

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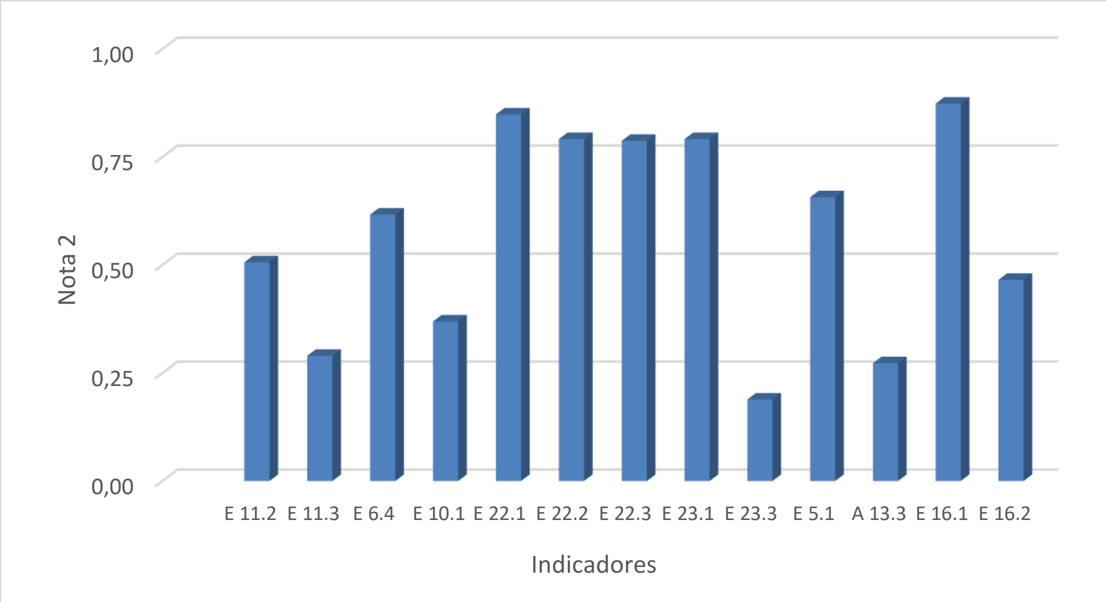
Figure 4 – Score 2, obtained by the arithmetic mean of each indicator



E 11.2: Number of hospital beds per 100,000 inhabitants; E 11.3: Number of doctors per 100,000 inhabitants; E 6.4: Student/teacher ratio in primary school; E 10.1: Percentage of women elected in relation to the total number of elected city officials; E 22.1: Percentage of the city's population served by sewage collection and disposal systems; E 22.2: Percentage of the city's sewage that receives centralized treatment; E 22.3: Percentage of city's population with access to improved sanitation; E 23.1: Percentage of the city's population with drinking water supply service; E 23.3: Total domestic water consumption per capita (liters/day); E 5.1: City unemployment rate (%); A 13.3: Gini coefficient of inequality; E 16.1: Percentage of city population with regular solid waste collection (household); E 16.2: Total municipal solid waste collection per capita (ton/per capita).

Source: Own authorship, 2024.

4.3 Analysis of the resilience and sustainability of the study area

A resilient municipality is one that has planning and infrastructure capable of withstanding and recovering from extreme or adverse climatic events. It is, therefore, a municipality that cares about promoting the quality of life of its population, through public policies which ensure these premises.

SDG 11 has 34 indicators in the norm, two of which will be considered for this analysis, as they have so far been identified on a digital basis. Of the 13 SDGs selected, SDG 6 stands out with five (38.5%) indicators with easy access to data for all municipalities.

This research aimed to analyze the indicators in the Basin and also made it possible to cover the indicators locally. Unfortunately, only two municipalities (16.7%), out of the 12 components of UGRHI 12, are further away from resilience and sustainability as they achieve an overall score below 0.50. Nine of them (75.0%), despite not reaching the maximum score (1.00), had scores ranging from 0.50 to 0.65, denoting that they were a little closer to resilience and sustainability, and only one (8.3%) had a score above 0.70. In general, all of them need improvements in the services analyzed, such as in the area of health, basic sanitation services (water supply, sanitary sewage, rainwater and solid waste), the reduction of inequalities with the generation and promotion of new jobs.

More than half of the indicators (54%) obtained a Score 2 (arithmetic means of each indicator) above 0.50. Therefore, sectors such as health, gender equality (women occupying electoral positions), daily water consumption per capita and inequality among the population must receive attention and improvements.

Health and well-being are directly related to the quality and efficiency of basic sanitation services. However, when extreme weather changes occur (drought or heavy rains), there is interference in these services and the population is affected by a lack of water, the possibility of contamination in water catchments and, consequently, the generation of water-borne diseases and harm to health promotion.

On a regional scale, the data shows that the Baixo Pardo/Grande Basin River needs urgent preventive planning to improve these indicators so that the population does not suffer from the variation in extreme climatic events. In other words, public policies can help prevent water safety while respecting the dynamics that exist between environmental and urban ecosystems.

5 CONCLUSION

The assessment of resilience using sustainability indicators was limited because the description of the indicators is different from the digital database. This required evaluating the information and adjusting the interpretation of the data, increasing the estimated time of the research. Another contributing factor was the absence and obsolescence of information, which led to a slight lag of 1 to 2 years in data collection for this evaluation.

The sustainability indicators supported the research using the method proposed in this article. However, the central hypothesis was not observed for 100% of the municipalities in the basin under study, as only one municipality achieved an overall score above 0.70. This way, the result illustrates that regional engagement by basin committee can be an alternative to institutionalize a set of public policies which are tangible and feasible to the reality of this Basin, consequently making it more inclusive, safe resilient and sustainable.

This research selected 13 indicators, whose information was identified on a digital basis. In future research, it is recommended that the other indicators be updated and included in the methodology for self-assessment, for both municipalities and the basin itself. In addition, the recording and monitoring of results over time shows the collective performance and effort of municipalities towards climate resilience in the urban environment. For this reason, this research can serve as a tool for managing water resources, sustainability and resilience at a regional level.

The biggest challenge for public managers is to keep the information database up to date and relevant to the local reality, as well as to implement mechanisms like this (indicators, measurement method) as a self-assessment tool for achieving the SDGs by 2030, in addition to involving the population as a whole in enlightening debates about what is planned for the future of cities. Popular participation and the engagement of society become allies in local decision-making, and show that shared management is one of the alternatives for the evolution of cities as technological, fair, supportive and equitable cities.

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