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Papers

# Watershed Sustainability and Composite Index: Application and Challenges

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**Abstract**

The need for efficient water resources management highlights the importance of discussing the watershed sustainability issue. This is a complex subject, which justifies the choice for multidimensional indexes. The aim of this paper is to discuss the assessment of watersheds' sustainability through composite indices to detect this statistical instrument's strengths and weaknesses. This is a descriptive, exploratory, and quantitative research. The literature review on sustainability indices and their application in hydrographic basins guided the selection of a watershed sustainability index (WSI). The dual approach that combines the criteria of the Pressure-State-Response (PER) model with the dimensions of the Hydrology-Environment-Life-Policy model (UNESCO HELP model) guided the selection of the fifteen indicators that were chosen. The WSI was used to assess the degree of sustainability of the Piracicaba, Capivari and Jundiaí river basins during two periods in the 2010s. The analysis of the results detected a minor decrease in the index's value, due to the Hydrology and Politics dimensions that recorded a setback in the second half of the decade under analysis. The result was not worse because of the remarkable improvement recorded in the Life dimension. This compensation is a weakness of the WSI that implicitly promotes the concept of weak sustainability. On the other hand, the selection of indicators guided by the dual approach is particularly interesting and challenging by connecting the PER criteria with the dimensions of sustainability well summarized in the HELP model.

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## INTRODUCTION

Managing water resources based on and guided by up-to-date, summarized evidence benefits from the availability of straightforward, accurate statistical tools. Due to the complexity of such an issue, composite or multidimensional indices are necessary. Academic literature offers several indices that tackle challenges in water management, namely Water Poverty Index (SULLIVAN, 2002), Watershed Sustainability Index (CHAVES; ALIPAZ, 2007), Water Footprint (HOEKSTRA, CHAPAGAIN, 2007), among others.

This paper presents a literature review and an application of the Watershed Sustainability Index (WSI) in the version developed by Chaves and Alipaz in 2007. The chosen index stands out for combining two relevant conceptual benchmarks that guide the choice of the indicators, the PSR (Pression-State-Response) and HELP (Hydrology-Environment-Life-Policy) models. Such an index was applied to the Piracicaba, Capivari and Jundiaí (PCJ) rivers' watersheds throughout two periods during the decade of 2010.

This paper is the result of a research guided by two questions: a) How to measure and assess watershed sustainability?; b) Does the chosen tool meet water resources management's needs for information?

This is an exploratory, descriptive research, with a quantitative approach, whose methodology is described in further detail in section 2, after the literature review on sustainability indicators and indices. The third section presents the results of the PCJ watersheds' sustainability assessment/.

## LITERATURE REVIEW

The development model focused on economic growth has been criticized since the decade of 1970 in the past century, when it was found that it was impossible to ensure economic welfare for all without threatening natural resources. In the 1972 United Nations meeting in Stockholm, the need for a shift in the development paradigm was emphasized, since the traditional one did not ensure neither social equality nor environmental awareness. But only in 1987, the definition of sustainable development arose in the Brundtland Report (BARBIERI, 2020).

Two other events conducted under the aegis of the United Nations are especially relevant while studying sustainability indicators: Rio Conference in 1992, with the development of the "Agenda 21" report, and the New York Summit in 2015, with the development of "Agenda 2030."

In chapter 40 of Agenda 21, "Information for decision-making", it is stressed the need for improving information availability, as well as for reducing inequality regarding data accessibility.

> Indicators of sustainable development need to be developed to provide solid bases for decision-making at all levels and to contribute to a self-regulating sustainability of integrated environment and development systems (UNCED, 1992).

The acknowledgment of indicators as essential elements for decision-making implies that they must be available to all stakeholders, enabling an active participation in developing and monitoring actions toward sustainable development. (BARBOSA; CÂNDIDO, 2018; BELLEN, 2006; MALHEIROS; COUTINHO; PHILIPPI, 2012a; 2012c; VEIGA, 2010).

Agenda 2030 (UN, 2015), in turn, defines the 17 Sustainable Development Goals (SDG) that must guide actions toward a form of development that encompasses economic, social and environmental dimensions. Among natural resources, water is an essential resource for life and societal development, regarding both economy and environment. Water resources management sustainability implies actions related to water resources use and protection, in compliance with the current legislation, as well as the monitoring of such actions. SDG 6 aims to "Ensure access to water and sanitation for all".

The formulation of development policies as well as the monitoring of their results benefits from objective, preferably quantitative tools, namely sustainability indicators (BOULANGER, 2008; 2018; GUIMARÃES; FEICHAS, 2009).

An indicator may be defined as

> … a measure that summarizes important information on a specific phenomenon. The point is that what is actually measured has a meaning greater than just the value related to such a measurement (MALHEIROS; COUTINHO; PHILIPPI Jr, 2012b, p. 35).

Indicators are abstractions of reality and may be incomplete or partial representations of it. Also, they are interpreted according to a set of hypotheses that reflect the values of those choosing the indicators and which determine what must be measured. Thus, the selection of indicators is a crucial stage for the assessment process, since the collected information may influence the formulation of public policies, as actions are conducted when there are differences between the goals and the state of the perceived system (measured by the indicators) (BELL; MORSE, 2008; 2018; JANNUZZI, 2017; MEADOWS, 1998).

In this sense, sustainability indicators are useful tools for measuring complex phenomena such as sustainable development, making it easier to monitor its economic, social and environmental factors, identifying the relations between the parties and favoring the identification of hindrances (MAYNARD; CRUZ; GOMES, 2017). The representation of reality through numeric indicators is beneficial when it gives visibility to relations otherwise invisible (ROTTENBURG; MERRY, 2015, p. 7-8). On the other hand, its capacity to synthesize complex phenomena may suggest a limitation in the use of indicators if this means an oversimplification of reality (WITULSKI; DIAS, 2020).

In short, indicators that work as tools for sustainability assessment must enable the measurement of different dimensions of complex social phenomena, be firmly based on theory, and be sensitive to properly capture shifts in the object of study. They must also be straightforward, in order to convey results to the non-specialized, general public, and be replicable, enabling the construction of historical series, essential for monitoring the evolution of an object of assessment (CARVALHO; BARCELLOS, 2010; GUIMARÃES; FEICHAS, 2009; HARDI; ZDAN, 1997; PINTÉR et al., 2011).

## *Watershed sustainability*

In the academic literature, there are different indices that seek to include the contribution of water resources in sustainable development. According to Silva et al. (2020), the Watershed Sustainability Index (WSI), proposed by Chaves and Alipaz, is the most used index for assessing watershed sustainability. It was chosen for this research due to two reasons: Spatial contour and integrated view.

Regarding the first reason, the contour related to the watershed space is due to the fact that the Federal Act 9,433 from 1997 and the National Environmental Council's Resolution 001 from 1986, which define the Brazilian national policy for water resources, appointed watersheds as territorial units for planning.

> "...[A]mong its goals, we may highlight: The maintenance of quantity and quality of several usages throughout time, the rational, integrated use of water resources aiming at sustainability and at the prevention of critical hydrological events either of natural original or due to anthropogenic interference (LACERDA; CÂNDIDO, 2013, p. 19).

Watershed Committees are collegiate organizations composed of representatives of the executive branch, of water users, and of civil society, which, among other activities, are responsible for the coordinated management of water resources in order to achieve economic and social welfare, and to protect the environment. Such distinct representatives have unequal knowledge and benefit from sustainability assessments that are easily interpretable and replicable.

The second reason which guided the choice for WSI regards the need for an integrated view on physical, biotic and anthropic environments when planning and management of watersheds are defined.

As mentioned in the end of the previous sections, when facing complex phenomena, it is necessary to have information systems, or ordering benchmarks, that provide guidelines for choosing indicators (MEADOWS, 1992). Among such systems or ordering benchmarks that address the environmental and sustainable development issue proposed by Quiroga (2005), we may mention the Pressure-State-Response (PSR) model.

The category of Pressure-State-Response models stems from Canada's National Statistical Agency's report developed by Rapport and Friend in 1979, in order to develop an environmental accounting system based on the Stress-Response Environmental Statistical System, S-RESS). It is a model devised to describe the environmental condition and the dynamic processes (stressing forces) that modifies it, as well as the response dynamics. The authors define the approach that examines the impacts of human activities on the environment as Stress-Response (or Pressure-Response).

The Pressure-Response model inspired some approaches for the selection of environmental indicators adopted by international organizations, namely: The United Nations Environment Programme (UNEP), which in 1995, developed the Pressure-State-Impact-Response (PSIR) approach for the Global Environment Outlook-Cities (GEO-Cities, PNUMA, 2004); the United Nations

Commission on Sustainable Development (CSD), which from 1996 to 2001, used the Driving Force-State-Response (UN, 2007) model; the Organization for Cooperation and Economic Development (OECD, 2003), with the Pressure-State Response (PSR) model, and the European Environment Agency (EEA, 1999) which developed the Driving Forces-Pressure-State-Impact-Response (DPSIR) model.

In brief, the category of Pressure-State-Response models summarizes the causal relations between human actions and natural resources. Thus, it provides guidelines for the selection of Pressure indicators, that is, those that describe the influence of anthropic actions on the environment. Such activities modify the quality and the quantity of natural resources (measured by the State indicators) and elicit reactions that seek to limit human actions' effects (summarized by the Response indicators).

In recent research on the papers available on Biblioteca Digital de Teses e Dissertações (Brazilian Digital Library of theses and dissertation), eleven papers, including theses and dissertations defended throughout the period between 2006 and 2018, which applied the DPSIR method in studies concerning Brazilian watersheds (BRANCHI; FERREIRA, 2020). Vollmer; Regan and Adelmann (2016) reviewed the methodology of 95 indices in an international bibliographic research on academic literature and papers from organizations dedicated to the theme of water management. Out of those, 14 were based on PSR and/or DPSIR models.

Unlike the PSR model, the HELP model proposed by UNESCO's International Hydrological Programme (IHP) and World Meteorological Organization (WMO) (UNESCO, 2001). The HELP model, specifically devised for the integrated management of watersheds, makes it possible to identify indicators related to hydrological (H), environmental (E), life (L) and policy (P) subjects. Thus, it is a model closer to a multidimensional approach for sustainable development (JUWANA et al., 2012).

The joint application of PSR and HELP models becomes particularly interesting in the systematization of sustainability indicators, especially when they are employed to assess sustainable development, since such a concept is usually defined as identifying multiple dimensions.

## *Watershed sustainability assessment indices*

In Chart 1, there is an example of integrated usage of the HELP model to classify indicators and the PSR model in the definition of parameters, inspired by the methodology proposed by Chaves and Alipaz (2007).

**Chart 1 -** Example of Indicators selected for the assessment of watershed sustainability in accordance with the PSR and HELP models.

| | **Pressure** | **State** | **Response** |
|---|---|---|---|
| *Indicators* | *Parameters* | | |
| **Hydrology** | Variation of the availability of water per capita<br>Variation of the watershed water quality Index | Availability of water per capita<br>Watershed water quality annual average | Evolution of water usage efficiency<br>Evolution of sewage treatment |
| **Environment** | Index of anthropic pressure on the watershed | % of the watershed area with natural vegetation | Evolution of the preservation areas in the Watershed |
| **Life** | Variation of the human development Index-Income | Human development Index (HDI) in the watershed | Evolution of the HDI in the watershed |
| **Policy** | Variation of the human development Index-Education | Institutional and legal capacity for the Integrated Management of Water Resources in the watershed | Evolution of expenditure with the Integrated Management of Water Resources in the watershed |

Source: Adapted from Maynard, Cruz and Gomez (2017), p. 212.

The pioneering work of Chaves and Alipaz (2007) assessed the sustainability of São Francisco Verdadeiro River's watershed from 1996 to 2000. According to those authors, the proposed index contributes for water resources planning and management. They also have the potential of guiding water resources management with a sustainable development approach, identifying bottlenecks.

In 2008, WSI was applied to the Panama Canal Watershed (UNESCO, 2008). Since then, such methodology has been applied in several countries, among which: Reventazón river's watershed, in Costa Rica (CATANO et al., 2009); Elqui river's watershed in Chile (CORTÉS et al., 2012); Chhattisgarh river's watershed in India (CHANDNIHA; KANSAL; ANVESH, 2014); Japaratuba river's watershed (MAYNARD; CRUZ; GOMES, 2017), and Piranha-Açu river's watershed in Brazil (COSTA and SILVA et al., 2020). Therefore, such methodology has become relevant in the academic literature. In all papers mentioned here, the sustainability index was applied in only one period, and sometimes the results of different watersheds were compared. This paper assesses the PCJ watersheds' sustainability throughout two periods from the 2010s, aiming to assess that index's capacity to monitor sustainability evolution throughout time.

## METHODOLOGY

This is a descriptive, explanatory, applied research, of the quantitative type. The data employed in the development of sustainability indicators are available in public bases detailed in Chart 2, accessible via the internet. For this reason, the year is not included, except in particular instances.

The index was applied to the Piracicaba, Capivari and Jundiaí rivers' watersheds throughout two periods: 2011-2015 and 2015-2019.

The Pressure, State and Response indicators were calculated for each of the HELP model's four dimensions. For the Hydrology dimension, the variables considered were those related to both water quantity and water quality. In Charts 2a-2d, there are the indicators, their definitions and the source of the data used in the PCJ watersheds' sustainability assessment.

**Chart 2a -** Hydrology: Selected indicators, definition and data source

| | Indicator | Definitions | Sources$^{(*)}$ |
|---|---|---|---|
| **Pressure** | Variation of the availability of water per capita | Variation of the availability of water per capita (m3/hab./year). | ◦ AGÊNCIA PCJ (2021a) |
| | Variation of the watershed water's quality Index. | Variation of the Biochemical Oxygen Demand (BOD. | ◦ CETESB (2021) |
| **State** | Availability of water per capita | Average availability of water per capita (m3/hab./year). | ◦ AGÊNCIA PCJ (2021a) |
| | Annual average of the watershed water's quality Index | Long-term average of the BOD for the Watershed (mg/l). | ◦ CETESB (2021) |
| **Response** | Evolution of the water use efficiency | Variation of the sectorial Gross Added Value quotients' average compared to the water demand volume taken from the same sector (R$/m3). | ◦ ANA (2019a)<br>◦ IBGE (2021) |
| | Evolution of the sewage treatment | Proportion of domestic sewage treated compared to the generated amount – variation. | ◦ CETESB (2021) |

Elaborated by the author (2022).

**Chart 2b -** Environment: Selected indicators, definition and data sources

| | Indicator | Definitions | Sources(*) |
|---|---|---|---|
| **Pressure** | Environmental Pressure Index | Average of the percentual variation of the agricultural area, and of the percentual variation of the urban population. | ◦ IBGE (2021)<br>◦ SEADE (2021a)<br>◦ FJP (2021a) |
| **State** | Percentage of the watershed area with natural vegetation | Percentual of the watershed area with natural vegetation | ◦ AGÊNCIA PCJ (2021b) |
| **Response** | Variation of the protected areas | Variation % of the protected areas throughout the period | ◦ AGÊNCIA PCJ (2021b) |

Elaborated by the author (2022).

**Chart 2c -** Life: Selected indicators, definition and data sources

| | Indicator | Definitions | Sources(*) |
|---|---|---|---|
| **Pressure** | Variation of the watershed's per capita income | Variation of the real municipal per capita GDP | ◦ IBGE (2021) |
| **State** | Human Development Index weighted by the population | Social Responsibility Index weighted by the population | ◦ SEADE (2021b)<br>◦ FJP (2021b) |
| **Response** | Variation of the development index | Variation of the Social Responsibility Index | ◦ SEADE (2021b)<br>◦ FJP (2021b) |

Elaborated by the author (2022).

**Chart 2d -** Policy: Selected indicators, definition and data sources

| | Indicator | Definitions | Sources(*) |
|---|---|---|---|
| **Pressure** | Variation of the education index during the current period, compared to the previous period | Variation of the Social Responsibility Index – Education component | ◦ SEADE (2021b)<br>◦ FJP (2021b) |
| **State** | Institutional capacity of the integrated management of water resources in the watershed | Level of legal, institutional and participative frameworks on management | Subjective assessment of the existence of a Watershed Bureau and of the law enforcement |
| **Response** | Evolution of the expenditure on the integrated management of water resources in the watershed | Expenditure on recovery, conservation and protection policies for riverheads | ◦ AGÊNCIA PCJ (2021b) |

Elaborated by the author (2022).

The selected indicators are almost entirely quantitative, except for the State indicator related to the Policy dimension.

In order to monitor the Pression and Responses elements of each dimension, the variations of the indicators were calculated in the selected periods of time: 2011-2015 and 2015-2019. For the State indicators, values related to the last period of the analyzed period were used. When there lacked information on the chosen year, information on the closest year available was selected.

Most of the time, the selected indicators were available in the mentioned sources, with little additional development. However, the water use efficiency was calculated according to the methodology proposed by Agência Nacional das Águas (ANA, 2019b), the federal agency responsible for the implementation of Brazilian water resources management, for the 6.4.1 indicator. Such an indicator is calculated by dividing the gross added value of a sector by the volume of water demand taken from the same sector. In this case, for water efficiency, the three big sectors' average was used: agriculture, industry and services from each municipality in the PCJ watersheds. Monetary values of the added value were deflated using the implicit deflator of the Gross Domestic Product with prices from 2015.

For devising the index, all indicators were transformed so that a value ranging from 0 to 1 could be assigned to the values observed (Table 1). Such transformation is essential, considering the heterogeneity of the indicators' measurement units.

**Table 1 -** Correspondence between values and scores of the selected indicators

| | | **Values** | | |
|---|---|---|---|---|
| | Pressure | State | Response | **Scores** |
| (H1) Hydrology-Quantity | < -20% | < 1700 | < 0 | 0.00 |
| | [ -20%, -10%) | [1770, 3400) | [0, 5%) | 0.25 |
| | [-10%, 0) | [3400, 5100) | [5%, 10) | 0.50 |
| | [0, +10%) | [5100, 6800) | [10%, 15) | 0.75 |
| | ≥ 10% | ≥ 6800 | ≥ 15% | 1.00 |
| (H2) Hydrology-Quality | ≥ 20% | ≥ 10 | Very weak | 0.00 |
| | [10%, 20%) | [10, 5) | Weak | 0.25 |
| | [0, 10%) | [5, 3) | Medium | 0.50 |
| | [-10%, 0) | [3, 1) | Good | 0.75 |
| | < -10% | < 1 | Great | 1.00 |
| (E) Environment | ≥ 20% | < 5 | < -10% | 0.00 |
| | [10%, 20%) | [5, 10) | [ -10%, 0) | 0.25 |
| | [5%, 10%) | [10, 25) | [0, 10%) | 0.50 |
| | [0, 5%) | [25, 40) | [10%, 20%) | 0.75 |
| | < 0% | ≥ 40 | ≥ 20% | 1.00 |
| (L) Life | < -20% | < 0.5 | < -10% | 0.00 |
| | [ -20%, -10%) | [0.5, 0.6) | [ -10%, 0) | 0.25 |
| | [-10%, 0) | [0.6, 0.75) | [0, 10%) | 0.50 |
| | [0, +10%) | [0.75, 0.9) | [10%, 20%) | 0.75 |
| | ≥ 10% | ≥ 0.9 | ≥ 20% | 1.00 |
| (P) Policy | < -20% | Very weak | < -10% | 0.00 |
| | [ -20%, -10%) | Weak | [ -10%, 0) | 0.25 |
| | [-10%, 0) | Medium | [0, 10%) | 0.50 |
| | [0, +10%) | Good | [10%, 20%) | 0.75 |
| | ≥ 10% | Great | ≥ 20% | 1.00 |

Source: Adapted from Chaves and Alipaz (2007).

The calculation of the sustainability index occurs in two stages. In the first step, the subindices of the HELP dimensions are calculated based on the PER indicators of each dimension with the following formula:

$$Subindex_i = \frac{P_i + E_i + R_i}{3}$$

Considering $Subindex_i$ = H if the dimension is hydrology, E if it is the environment, L if the dimension is life, and P if the dimension is policy.

On the second stage, the sustainability index (Watershed Sustainability Index - WSI) is calculated as the arithmetic average of the subindices:

$$WSI = \frac{H + E + L + P}{4}$$

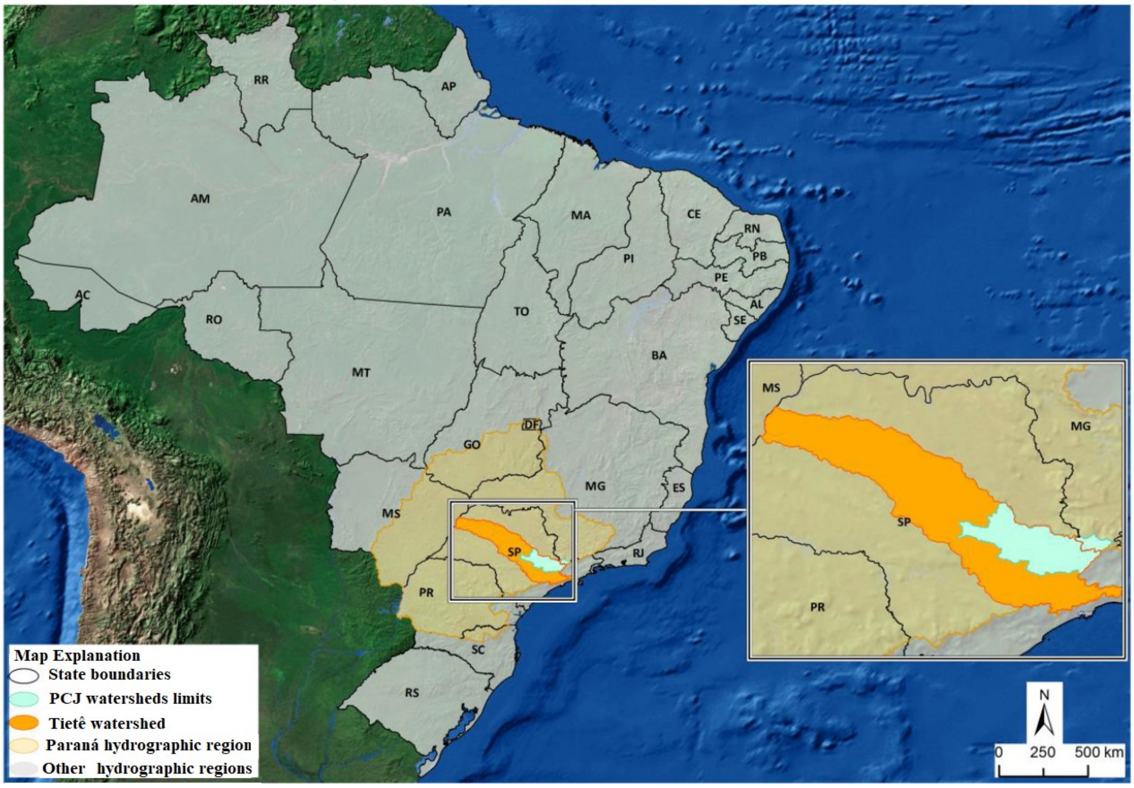
The interpretation of the final result employed in the academic literature is: Low sustainability if WSI < 0.1; medium if 0.5 ≤ WSI ≤ 0.8 and high if WSI > 0.8.

In this methodology, the option of perfect exchangeability between the subindices is implicit. That implies the acceptance of the concept of weak sustainability or compensation between the alterations measured by the subindices, considering the decrease in one dimension is compensated by the increase in other one(s) (NARDO et al., 2005)

## RESULTS AND DISCUSSION

The Piracicaba, Capivari and Jundiaí (PCJ) rivers' watersheds belong to the Tietê river's watershed, in the hydrographic region of the Paraná river, with an area of about 15 thousand km², out of which 92.5% are located in the state of São Paulo and the remainder in Minas Gerais (Figure 1). The area of the PCJ watersheds is mostly assigned to: Rural fields (25%), native forests (20%), sugar cane (19%) and urban areas (12%). There, 44 Conservation Units can be found, out of which 25% have full protection and the remainder are sustainably used (CONSÓRCIO PROFILL-RHAMA, 2020).

**Figure 1** - Location of the PCJ watersheds.



Source: Consórcio Profill-Rhama (2020) p. 41.

Across the PCJ watersheds, there are 76 municipalities, out of which 71 belong to the State of São Paulo. In that area, with a rate of urbanization of 96¨, about 5.8 million people live (CONSÓRCIO PROFILL-RHAMA, 2020). Its main economic activities are agriculture, cattle raising and industry. It is an economically important area, responsible for 7% of the GDP of Brazil. The education, health and income conditions are very high, and virtually all its municipalities have very high rates of Human Development.

According to Relatório Síntese do Plano de Bacia 2020-2035, 94% of the total population have access to water supply, 90% have sewage collection and 83% of the collected sewage is treated (CONSÓRCIO PROFILL-RHAMA, 2020).

According to that report, the PCJ watersheds are always under water stress, with water availability rates under 1000 cubic meters per capita/year. The population growth and the economic activities are pressure factors on the water demand and on its quality.

According to the methodology detailed in the previous section, the indicators, the subindices and the sustainability index (WSI) of the PCJ watersheds were calculated throughout the two periods 2011-2015 and 2015-2019 (Tables 2 and 3).

**Table 2 -** WSI results and their components, PCJ Watersheds, 2011-2015.

| | Values | | | Scores | | | **Index** |
|---|---|---|---|---|---|---|---|
| | Pressure | State | Response | Pressure | State | Response | |
| | **2011-2015** | | | **2011-2015** | | | |
| (H1) Hydrology-Quantity | -5.12 | 1027.92 | -0.37 | 0.50 | 0.00 | 0.00 | **0.417** |
| (H2) Hydrology-Quality | -2.88 | 8.95 | 21.40 | 0.75 | 0.25 | 1.00 | |
| (E) Environment | 0.88 | 12.60 | 0.00 | 0.75 | 0.50 | 0.50 | **0.583** |
| (L) Life | 0.15 | 0.55 | -0.27 | 0.75 | 0.25 | 0.00 | **0.333** |
| (P) Policy | 16.88 | good | > 20% | 1.00 | 1.00 | 1.00 | **1.000** |
| **PCJ watersheds' Sustainability Index (WSI)** | | | | | | | **0.583** |

Source: The author (2022).

**Table 3 -** WSI results and their components, PCJ Watersheds, 2015-2019.

| | Values | | | Scores | | | **Index** |
|---|---|---|---|---|---|---|---|
| | Pressure | State | Response | Pressure | State | Response | |
| | **2015-2019** | | | **2015-2019** | | | |
| (H1) Hydrology-Quantity | -3.97 | 981.06 | 9.32 | 0.50 | 0.00 | 0.50 | **0.333** |
| (H2) Hydrology-Quality | 42.09 | 8.95 | 7.16 | 0.00 | 0.25 | 0.75 | |
| (E) Environment | 2.07 | 22.43 | 0.00 | 0.75 | 0.50 | 0.50 | **0.583** |
| (L) Life | 0.12 | 0.59 | 7.49 | 1.00 | 0.25 | 0.50 | **0.583** |
| (P) Policy | 4.89 | good | >20% | 0.75 | 1.00 | 1.00 | **0.917** |
| **PCJ watersheds' Sustainability Index (WSI)** | | | | | | | **0.604** |

Source: The author (2022).

The PCJ watersheds' WSI shows medium sustainability throughout the decade of 2010, with a moderate improvement in the second half of the decade.

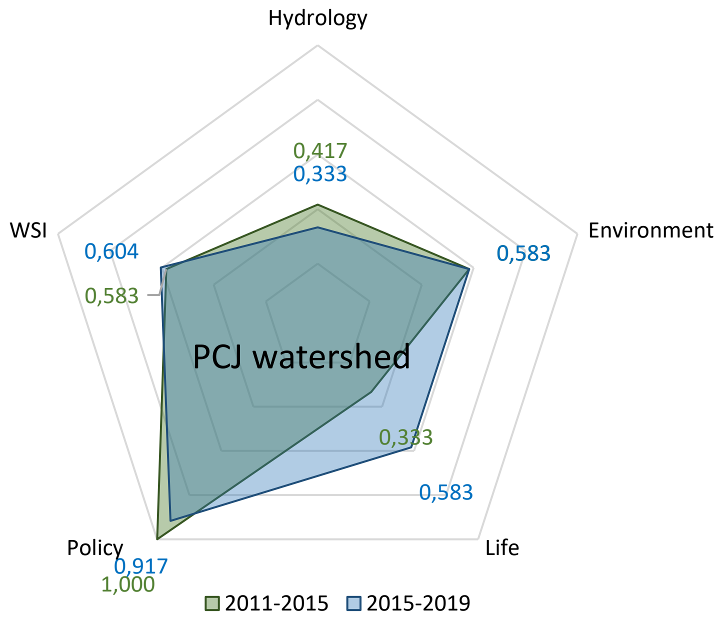
In the first half of the decade, the subindex related to the social dimension (Life) registered the worst contribution to the PCJ watersheds' sustainability. That result can be ascribed to an aggravation of the social responsibility index in the municipalities of that region (Response dimension). The recovery in the following period raised the subindex to medium levels. Such improvement was partially compensated by the variation registered in the Hydrology dimension, especially in the water quality indicators. In this sense, there was an increase in Pressure that caused a decrease in water quality and a less intense response than in the first half of the decade considered. The response indicator is the variation of the sewage proportion that in the 2015-2019 years was not as fast as previously.

The Policy dimension is remarkable for its huge contribution to the PCJ watersheds' sustainability. It should be highlighted that this dimension includes education indicators (Pressure dimension), legal and institutional frameworks (State) and expenditure on restoration, conservation and protection policies for riverbeds (Response). In the second period, there was a slight decrease in that subindex caused by the slowdown in the educational progress registered in the municipal Social Responsibility Index component.

The observed compensation is no surprise since the adoption of a weak approach on sustainability is implicit in the methodology of such an indicator. However, it represents a serious limitation when the WSI is used in a temporal analysis of sustainability. This is even more relevant for years before a new water crisis occurs in those watersheds, when the involution of hydrologic indicators should warn the water resources managers about the aggravation of problems.

Such a limitation may be partially overcome if the global value of the WSI is always followed by the subindices' values, such as in Tables 1 and 20 and in Figure 2. The graphic representation excels in the communication of results for the visualization of a transformation, going beyond the WSI's mere numeric comparison and illustrating which are the most critical dimensions regarding sustainability in the PCJ watersheds.

**Figure 2** - PCJ watersheds' Sustainability Index (WSI), and their components, 2011-2015 and 2015-2019.



Source: The author (2022).

## FINAL CONSIDERATIONS

The development of the WSI sustainability index inspired by the PER and HELP models brings closer the sustainability analysis of the watersheds and the usual dimensions of sustainable development, making analysis, interpretation and results communication easier.

WSI shows typical problems of composite indices and makes it clear that the hypothesis on the weak sustainability in the aggregation by simple average is a clear limitation when that index is used in intertemporal comparisons. Thus, the joint analysis of subindices proves to be necessary. In the case of the PCJ watersheds in the second half of the decade of 2010, there was a smaller unbalance between the HELP dimensions due to the improvement of the Life subindex. The WSI's improvement was not higher due to setbacks registered in the Hydrology and Policy subindices.

Finally, if WSI is used as a tool for guiding an efficient management of water resources, it is urgent to accelerate the availability of official statistics, necessary for its development, particularly georeferenced statistics concerning the HELP model's four dimensions' variables.

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## AUTHORS' CONTRIBUTION

Bruna Angela Branchi conceived the study, collected, analyzed the data and wrote the text.