

Avaliação da aplicação de modelos de sustentabilidade nas Bacias Hidrográficas dos Rios Piracicaba, Capivari e Jundiáí

Evaluation on applying sustainability models in the Piracicaba, Capivari and Jundiáí Rivers watersheds

Evaluación de la aplicación de modelos de sustentabilidad en las cuencas de los ríos Piracicaba, Capivari y Jundiáí

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Resumo: A degradação do meio ambiente e os impactos nos recursos hídricos aumentaram após a Primeira Revolução Industrial, junto a isso a falta de ações para mitigar os efeitos negativos. Neste contexto, em 2015, a Organização das Nações Unidas propõe os 17 Objetivos de Desenvolvimento Sustentável (ODS) que compõem a Agenda 2030. Trata-se de uma estratégia global para lidar com os impactos ambientais e equilibrar as três dimensões da sustentabilidade: social, ambiental e econômica. Sendo a água um recurso indispensável à vida, foi fundado em 1993 no Estado de São Paulo, o Comitê das Bacias Hidrográficas dos Rios Piracicaba, Capivari e Jundiáí (Bacias PCJ) e, com um time especializado, tem cada vez mais empregado esforços para atender aos ODS. Deste modo, o objetivo geral deste trabalho foi avaliar modelos de sustentabilidade para as Bacias PCJ. A metodologia deste estudo utiliza dados qualitativos, sendo a pesquisa caracterizada por métodos descritivos e fundamentada na revisão bibliográfica de sustentabilidade sobre Bacias PCJ, modelos e indicadores de sustentabilidade. Os resultados obtidos mostram que os relatórios das Bacias PCJ utilizam o modelo Força-Motriz, Pressão, Estado, Impacto e Resposta (FPEIR). Complementar ao modelo FPEIR, nesta pesquisa o modelo de Gibson é usado para avaliar a sustentabilidade, sendo mais amplo que os tradicionalmente aplicados para esse fim. Conclui-se ser relevante a proposição da articulação do modelo de Gibson associado ao modelo FPEIR e aos indicadores de recursos hídricos, pois apresenta-se como uma relevante ferramenta para aplicação nas avaliações das Bacias PCJ.

Palavras-chave: Sustentabilidade, Recursos Hídricos, Indicadores.

Abstract: *The degradation of the environment and the impacts on water resources increased after the First Industrial*

Revolution, together with the lack of actions to mitigate the negative effects. In this context, in 2015, the United Nations proposed the 17 Sustainable Development Goals (SDG) that make up the 2030 Agenda. It is a global strategy to deal with environmental impacts and balance the three dimensions of sustainability: social, environmental and economic. Since water is an indispensable resource for life, the Piracicaba, Capivari and Jundiá River Basins Committee (PCJ Basins) was founded in 1993 in the State of São Paulo and, with a specialized team, has increasingly employed efforts to meet to the SDG. Thus, the general objective of this work was to evaluate sustainability models for the PCJ Basins. The methodology of this study uses qualitative data, the research being characterized by descriptive methods and based on the bibliographic review of sustainability on PCJ Basins, models and sustainability indicators. The results obtained show that the PCJ Basin reports use the Driving Force, Pressure, State, Impact and Response (DPSIR) model. Complementary to the DPSIR model, in this research the Gibson model is used to assess sustainability, being broader than those traditionally applied for this purpose. It is concluded that the proposition of articulating the Gibson model associated with the DPSIR model and the water resources indicators is relevant, as it presents itself as a relevant tool for application in the assessments of the PCJ Basins.

Keywords: Sustainability, Water Resources, Indicators.

Resumen: *La degradación ambiental y los impactos sobre los recursos hídricos aumentaron después de la Primera Revolución Industrial, junto con la falta de acciones para mitigar los efectos negativos. En este contexto, en 2015 Naciones Unidas propuso los 17 Objetivos de Desarrollo Sostenible (ODS) que conforman la Agenda 2030. Se trata de una estrategia global para hacer frente a los impactos ambientales y equilibrar las tres dimensiones de la sostenibilidad: social, ambiental y económica. Dado que el agua es un recurso esencial para la vida, el Comité de las Cuencas de los Ríos Piracicaba, Capivari y Jundiá (Cuencas PCJ) fue fundado en 1993 en el Estado de São Paulo y, con un equipo especializado, se ha esforzado cada vez más para cumplir con los ODS. Así, el objetivo general de este trabajo fue evaluar modelos de sostenibilidad para las Cuencas PCJ. La metodología de este estudio utiliza datos cualitativos, caracterizándose la investigación por métodos descriptivos y con base en la revisión bibliográfica de sustentabilidad sobre Cuencas PCJ, modelos e indicadores de sustentabilidad. Los resultados obtenidos muestran que los informes de la Cuenca PCJ utilizan el modelo de Fuerza Impulsora, Presión, Estado, Impacto y Respuesta (FPEIR). Complementario al modelo FPEIR, en esta investigación se utiliza el modelo de Gibson para evaluar la sustentabilidad, siendo más amplio que los tradicionalmente aplicados para este fin. Se concluye que es relevante la propuesta de articular el modelo Gibson asociado al modelo FPEIR y los indicadores de recursos hídricos, pues se presenta como una herramienta relevante para su aplicación en las evaluaciones de las Cuencas PCJ.*

Palabras clave: Sustentabilidad, Recursos Hídricos, Indicadores.

Introduction

For centuries, human activity has affected ecosystems and environmental resources. After the Industrial Revolution in England in the 18th century, these impacts intensified. Currently, environmental conditions are changing due to pollution, deforestation, and water scarcity, along with technological advances, population growth, and a lack of public awareness.

According to Hawken, Lovins, and Lovins (2007), the process of mass production and consumption, along with its resulting factors such as spatial concentration, accelerated industrialization, agricultural modernization, climate change, depletion of productive resources, exponential population growth, increasing urbanization, water scarcity, and soil, water, and air pollution, forms the main areas of concern regarding human pressure on the global environmental crisis.

The improper use of natural resources led, in September 2015, to a meeting of more than 150 world leaders in New York, USA, at the headquarters of the United Nations (UN), where they proposed a new sustainability agenda: the 2030 Agenda. This agenda includes the 17 Sustainable Development

Goals (SDGs), which countries aim to achieve by 2030 in order to mitigate and adapt to different impacts and geographic realities. These goals seek to balance the three dimensions of sustainable development: social, economic, and environmental. Goal number 6 of the 2030 Agenda aims to ensure the availability and sustainable management of water and sanitation for the population (UN-BR, 2019).

Considering water as an essential resource for survival, a specialized team established the Committee of the Piracicaba, Capivari, and Jundiaí River Basins (CBH-PCJ) in 1993 and has increasingly made efforts to meet the SDGs. This committee is defined as “a forum in which a group of people gathers to discuss a common interest the use of water in the basin” (Brasil, 2011, p. 11).

To understand the network of river basins and the impacts on agricultural, industrial, and domestic activities, researchers use models to represent various phenomena that occur in the environment. Thus, a model can be considered a representation of reality, helping to understand the processes involved in that reality.

Among the existing models, the Gibson Model examines sustainability through a perspective composed of eight pillars, using a set of ecosystem-based elements that relate to social issues, such as equity, justice, and civility. The Gibson Model enables a perception of sustainability that considers, with relevance, the interconnections between objectives, issues, actions, effects, and results (Gibson, 2006).

In this context, this research aims to evaluate the application of sustainability models in the context of the Piracicaba, Capivari, and Jundiaí River Basins.

Theoretical elements of the research

Definition and historical context of sustainability

Industrial advances have caused unprecedented environmental degradation. In response to this situation, the 1972 Stockholm Conference highlighted the need to relearn how to live on the planet while considering both socioeconomic development and the environment.

According to the World Commission on Environment and Development, the publication of the report *Our Common Future*, known as the Brundtland Report, defined the concept of sustainable development “as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (CMMAD, 1988, p. 46). In this context, sustainability occurs when activities preserve natural resources for future generations. From a more rigorous perspective, however, Mikhailova (2004) argues that every activity must undergo a thorough evaluation to determine all its positive and negative environmental impacts.

Only 20 years after the United Nations Conference on Environment and Development (Rio-92) did policies related to sustainable development begin to represent a central issue.

Diamond (2005) states that these concepts are relatively new and became established as social, political, cultural, economic, and institutional concerns only after society began to perceive signs of climate change, natural resource depletion, and shifts in the pace of civilizations. Thus, Menezes, Dias, and Gomes (2010) argue that there is a gap between sustainable and responsible management practices and the cultural and social practices that should support them.

Sustainable development requires the integration of three key areas environmental, economic, and social, considering the factors proposed by Mikhailova (2004):

Conservation of natural resources and the environment: to preserve natural and environmental resources for future generations, society must adopt economically viable solutions aimed at reducing

resource consumption, conserving natural habitats, and preventing pollution.

Economic growth and equity: currently interconnected global economic systems require integrated management to promote responsible long-term growth while ensuring that no community or nation is left behind.

Social development: people have essential needs such as water, sanitation, food, energy, employment, and healthcare services. While addressing these needs, global society must ensure that labor rights, as well as social and cultural diversity, are respected and that all individuals are prepared to participate in and shape their own futures.

Additionally, Barbosa (2007) emphasizes the importance of considering the following elements to promote sustainable development: social equality, environmental protection, and economic growth. Based on these three pillars, Elkington (2004) established the principles of the Triple Bottom Line (TBL) model, which considers not only economic value but also social and environmental value. Thus, to measure sustainability levels, indicators from the three dimensions are used, including social, environmental, and economic measures, as follows.

Social measures: average household income, relative poverty, unemployment rate, female participation in the labor force, average commuting time, violent crimes per capita, life expectancy, and percentage of the population with a degree.

Environmental measures: concentration of nitrogen oxides and sulfur dioxide, general pollutants, excess nutrients, electricity and fossil fuel consumption, hazardous and solid waste management, and changes in land use or vegetation cover.

Economic measures: employment growth, distribution of employment by sector, establishment sizes, personal income, cost of underemployment, business turnover rate, percentage of companies in each sector, and revenue by sector.

The broad scope of sustainability presents challenges such as integrating the three pillars social, environmental, and economic, as well as institutional issues including awareness, social participation, environmental education, and the assessment of the impacts of actions in both the present and the future (Saraiva et al., 2019; Sartori, Latrônico, and Campos, 2014).

Indicators

Waas et al. (2014) define an indicator as an operational representation of a system attribute, which may take the form of a quantitative or qualitative variable with a comparable reference level. Additionally, Meadows (1998) argues that indicators form part of the information flow used to understand the world, plan actions, and support decision-making. In this way, indicators enable the monitoring and partial control of complex systems that are socially relevant.

According to Jannuzzi (2014, p. 141), “sensitivity and specificity are properties that researchers must also evaluate when selecting indicators for the development of monitoring and evaluation systems for public programs”.

Researchers apply indicators to track complex systems, using them as signals of events and as data that reveal system characteristics or show what is occurring within the system. These indicators may consist of a single variable or a function of variables (Siena, 2002). These measures must remain socially relevant, measurable, based on reliable data, easy to understand, and easily accessible to the public. The correct selection of indicators represents an important step for ensuring the effectiveness

of any subsequent application.

According to Slimane (2012) and Sartori, Latrônico, and Campos (2014), sustainability approaches at regional and national scales do not necessarily follow the same structure, particularly when considering mechanisms of geographic transfer. Sartori, Latrônico, and Campos (2014) state that when researchers develop and apply sustainability indicators, they must incorporate regional specificities; otherwise, the indicators may become ineffective or compromise decision-making processes. For environmental indicators, certain characteristics are desirable (Table 1).

Table 1 - Expected Characteristics of Environmental Indicators

| Characteristics | Description |
|---------------------------------|------------------------------------------------------------------------------------------------------|
| Political relevance and utility | Represents environmental conditions, pressures on the environment, and associated societal responses |
| | Remains simple, easy to interpret, and capable of reflecting temporal trends |
| | Reflects environmental changes |
| | Is affected by human activities |
| | Provides a basis for international comparison |
| | Applies at the national level |
| | Applies at the regional level with national relevance |
| | Allows the determination of reference levels for comparison |
| Analytical clarity | Relies on theoretical, technical, and/or scientific foundations |
| | Follows rules and/or agreements with international validity |
| | Connects to economic models |
| | Connects to forecasting and information systems |
| Measurement and data | Remains available with an appropriate cost-benefit ratio |
| | Is documented with quality |
| | Provides up-to-date data at regular intervals |

| |
|----------------------------------------------------|
| Uses data collected through established procedures |
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Source: Silva *et al.* (2020, p. 7).

The Organization for Economic Cooperation and Development (OECD, 2008) proposes criteria for selecting indicators and emphasizes that they must guide decision-making. An indicator should be as precise as possible and describe the phenomenon under analysis in terms of input, output, or process.

According to Meadows (1998), sustainability indicators should go beyond environmental indicators by providing information about the future and the limits of the biophysical environment. Due to the importance of sustainable development indicators, researchers must avoid biases that could fail to identify systemic trends.

Decision-makers must consider the strengths and weaknesses of indicators to prevent superficial or extreme reactions in the decision-making process. According to Silva *et al.* (2020, p. 7), examples of biases to avoid include:

- i. excessive aggregation of factors, which may obscure messages;
- ii. measurement bias, when focus lies more on measurable aspects than on important aspects;
- iii. incorrect conceptual basis, if indicator use follows a false model;
- iv. falsification, which involves deliberate alteration of results;
- v. alienation, if an indicator diverts attention or alters the true condition;
- vi. overconfidence, when an indicator generates positive thinking about the subject under study despite existing problems;
- vii. incompleteness, when indicators fail to reflect all system characteristics.

Meadows (1998) highlights that selecting indicators is a rational process of identifying characteristics to prevent the occurrence and effects of such biases. Desirable characteristics of indicators include clarity in value and content, persuasiveness, political relevance, feasibility, sufficiency, and democratic applicability (Silva *et al.*, 2020).

The United Nations (UN, 2007) applied selection criteria for sustainable development indicator systems, as shown in Table 2.

Table 2 - Selection Criteria for Sustainable Development Indicator Systems

| Criteria | Description |
|-------------------|------------------------------------------------------------|
| Context | National scale |
| Relevance | Capable of assessing sustainable development progress |
| Number | Limited (open and adaptable) |
| Specificity | Broad coverage in terms of Agenda 21 aspects |
| | Broad coverage in terms of sustainable development aspects |
| Comprehensibility | Clear and unambiguous |

| | |
|---------------------|-----------------------------------------------------------------------------|
| Concept | Based on a conceptual framework |
| | Capable of capturing relevant phenomena |
| | Does not distort results |
| Consensus | Represents international consensus |
| Government capacity | Allows monitoring, data collection, analysis, synthesis, and interpretation |
| Data | Cost-effective measurement |
| | High quality |

Source: Silva *et al.* (2020, p. 8).

According to Booyesen (2002) and Singh et al. (2012), researchers should select indicators based on their ability to measure a relevant aspect of the problem both over time and across contexts, using either absolute or relative terms. Indicators may involve input and output data, but they must remain simple and clear in content, purposeful, methodologically sound, comparable, and focused.

Silva et al. (2020) emphasize that indicator selection should follow specific criteria: political relevance, data reliability, managerial relevance, and availability with an appropriate cost-benefit ratio.

Sustainability Assessment Models

The importance of statistical and mathematical models in representing natural phenomena lies primarily in their ability to support decision-making. The following three sustainability assessment models are presented: Gibson, PER, and FPEIR.

Gibson Model

The Gibson Model establishes eight criteria, laws, or principles to evaluate sustainability, functioning as an integrated and dynamic process that addresses systemic characteristics as well as environmental, social, and economic dimensions. The model uses a set of ecosystem-based elements guided by these eight criteria to assess sustainability (Gibson, 2006):

1. Socio-ecological system integrity: Researchers build human-ecological relationships to preserve and restore the long-term integrity of socio-ecological and biophysical systems (carrying capacity). They also protect life-support functions that are irreplaceable for ecological and human well-being.
2. Sufficient resources for subsistence and access to opportunities: This criterion emphasizes that all communities must have enough to live a decent life and access opportunities for improvement without compromising the future of current and successive generations.
3. Intragenerational equity: Researchers ensure that all individuals have sufficient effective choices to meet essential needs such as education, health, esteem, and social recognition.

4. Intergenerational equity: Decision-makers preserve or create opportunities for future generations to live inclusive, sustainable, and dignified lives.
5. Maintenance of natural resources and efficiency: The model provides a broad foundation to guarantee sustainable livelihoods for everyone, while reducing threats to the integrity of socio-ecological systems over the long term, minimizing waste generation, and lowering material and energy consumption.
6. Socio-environmental civility and democratic governance: This criterion motivates individuals, communities, and collective decision-making bodies to consider and promote sustainability requirements through an open, well-informed process. It encourages mutual awareness, collective responsibility, and more integrated practices across administrative, market, habitual, and personal decisions.
7. Precaution and adaptation: The model addresses uncertainty by avoiding actions with potential risks that could compromise ecosystem sustainability. Researchers aim to reduce severe and irreversible harm to natural resources, implementing adaptive and preventive management that fosters continuous learning.
8. Integration of current and long-term conditions: The model extends beyond biophysical aspects to consider growth and quality of life in environmental decision-making.

From this perspective, sustainability assessment seeks more than balance among social, environmental, and economic criteria. Sugahara et al. (2021, p. 303) reinforce that “sustainability assessment is a dynamic, integrated process that encompasses systemic aspects in addition to social, environmental, and economic dimensions”. The authors also highlight that by mitigating risks through precaution and adaptation, it becomes possible to address issues related to the integrity of ecological systems (Sugahara et al., 2021).

Pressure-State-Response (PSR) Method

The Pressure-State-Response (PSR) model was developed by the Organization for Economic Cooperation and Development (OECD, 1993). Researchers use this model to create sustainable development indicators related to environmental issues, such as water resources. The PSR method relies on analyzing environmental problems through a causal framework, answering the following questions:

- Why is it happening? (Pressure)
- What is happening to the environment? (State)
- How does society respond? (Response)

After the 1992 Earth Summit (ECO-92) in Rio de Janeiro, the United Nations Commission on Sustainable Development began promoting the production and use of sustainable development indicators.

According to OECD (1993), environmental indicators can be organized within the PSR framework and divided into three categories:

Pressure: Researchers define pressures on ecosystems, which can be measured using parameters such as technological efficiency, contaminant emissions, land-use interventions, and environmental impacts. Water-related indicators in this category include water production volume, water consumption volume, multiple water uses, urban and rural sanitation, erosion, and contaminated areas.

State: Researchers assess the quality of the environment in a specific spatial and temporal context. Water-related indicators for this category include surface, groundwater, and coastal water quality; water availability; sanitation system deficits; and floods and droughts.

Response: Researchers evaluate societal responses to environmental concerns and changes, including adherence to programs or implementation of measures that benefit the environment. Water-related indicators in this category include improvements and expansions of sanitation systems, remediation of contaminated areas, monitoring and regulation of water use, and restoration of degraded areas.

Carvalho and Bracellos (2009) note that the main advantage of the PSR method lies in its ability to provide a comprehensive view of the multiple components of specific environmental problems, supporting the diagnosis and formulation of effective public policies. The PSR model goes beyond merely identifying environmental degradation; it reveals causes and impacts, enabling interventions and action planning to mitigate negative environmental trends.

Driving Force-Pressure-State-Impact-Response (DPSIR) Method

The Driving Forces-Pressure-State-Impact-Response (DPSIR) method applies to watershed management. Soares et al. (2011) emphasize that the integrated environmental assessment model assigns values to human activities.

Driving Force indicators capture human influences and activities which, when combined with environmental conditions, generate changes in the environment. Pressure indicators describe variables that directly cause (or may cause) environmental problems. State indicators represent environmental quality, reflecting the current condition of the ecosystem. Impact indicators describe the effects of changes in state. Response indicators reflect society's efforts to address environmental problems through policies, laws, clean technologies, and other measures.

Driving Force indicators cover aspects related to human activity, including the Annual Geometric Growth Rate, Population Density, and the São Paulo Social Responsibility Index.

Impact indicators express problems arising from the state of water resources. Researchers measure parameters such as waterborne diseases, bathing water restrictions, damage to aquatic life, conflicts in water use, and costs associated with water supply interruptions.

It is important to note that Pressure, State, and Response indicators have already been described within the PSR method.

Methodological Elements of the Research

This study proposes an evaluation-based analysis of natural resources. Researchers employ descriptive and bibliographic methods. According to Gil (2010), the primary objective of descriptive research is to describe the characteristics of a specific phenomenon or population and to establish relationships among variables.

The study applies bibliographic and documentary research techniques. Gil (2010) explains that bibliographic research develops from pre-existing material, primarily composed of scientific articles and books. The study also employs documentary research, which, according to Gil (2010, p. 45), “uses materials that have not yet received analytical treatment or that can still be reworked according to the research objectives”.

For data collection, the study obtained information through a bibliographic review and secondary data from the following sources: Summary Report: Water Resources Plan of the Piracicaba, Capivari, and Jundiaí River Basins, 2020–2035 (PCJ Committees, 2020) and Piracicaba, Capivari, and Jundiaí River Basins Committees – Water Resources Status Report 2020, Base Year 2019 (PCJ Committees, 2021).

Case Study – PCJ River Basins

River basins are key elements for understanding and analyzing the hydrological cycle. Collischonn and Dornelles (2015) define them as natural catchment areas for rainfall-generated water flows, where tributaries converge toward a single point, known as the outlet.

In 2018, the PCJ River Basin Agency became the first water agency to sign the United Nations Global Compact (PCJ River Basin Agency, 2020). By taking the lead in this commitment, the agency aimed to mobilize the international community toward adopting widely recognized human rights and environmental values, increasing both the visibility and efficiency of its work regarding the Sustainable Development Goals of the 2030 Agenda (Brazil, 2019).

According to the PCJ Basins Plan 2020–2035 (PCJ Committees, 2020), the estimated area of the PCJ Basins is 15,320 km², with the Piracicaba River Basin covering 12,655 km², the Capivari River Basin 1,568 km², and the Jundiaí River Basin 1,154 km². These basins span 76 municipalities, 5 in the state of Minas Gerais and 71 in the state of São Paulo.

The Piracicaba River Basin contains the largest share of the population (66.99%), followed by the Jundiaí River Basin (16.55%) and the Capivari River Basin (16.45%). The basins divide into seven sub-basins: five belong to the Piracicaba (Atibaia, Camanducaia, Corumbataí, Jaguari, and Piracicaba), along with the Capivari and Jundiaí sub-basins. The Piracicaba and Capivari sub-basins are the least sustainable due to the highest water withdrawal volumes and the greatest population concentration (PCJ Committees, 2020).

Land use in the PCJ Basins is distributed as follows: natural grasslands (25.30%), native forests (20.35%), sugarcane plantations (19.02%), and urbanized areas (12.11%) (PCJ Committees, 2020).

The PCJ Basins occupy an economically important region with high Human Development Index (HDI) and Gross Domestic Product (GDP) levels. The main economic activities include agriculture, industry, commerce, and services, with industrial growth standing out.

The presence and actions of the PCJ River Basin Agency are crucial for promoting sustainable management across economic, environmental, and social dimensions. The agency mitigates the risk of potential water crises that could compromise sustainable development not only in the PCJ Basins but also in the São Paulo Metropolitan Region, considering the transposition of PCJ Basin waters to the Cantareira System (PCJ Committees, 2020).

Results and Discussion

Sustainability Assessment Models – PCJ River Basins

Studies on the sustainability assessment of river basins play a crucial role in water resources management. In this context, Sugahara et al. (2021) analyzed the Water Resources Management Programs of the PCJ River Basin Plan using Gibson's sustainability principles assessment model.

Since 1994, the PCJ River Basin Committees have produced annual Water Resources Status Reports to evaluate basin sustainability. From 2007, they organized these reports using a set of indicators structured within the DPSIR framework (Driving Forces, Pressures, State, Impact, and Response) (PCJ Committees, 2021).

The DPSIR model remains one of the most widely applied methods for systematizing environmental issues. Historically, both PCJ River Basins studies and international research have employed it. This model offers significant advantages: it enables the collection and aggregation of information to support decision-making and provides a broader perspective compared to the PER method. DPSIR includes more sustainability dimensions and allows for the identification of issues within each category, guiding targeted societal responses in river basin management.

Nevertheless, the DPSIR approach presents a limitation: the Driving Forces category contains fewer indicators than the State category. This imbalance justifies the development of additional indicators to better capture Driving Forces related to sustainable water use and management in the basin context.

According to the World Water Assessment Programme (WWAP, 2006), Driving Forces indicators are essential, as they assess the underlying factors and root causes that influence economic development, social conditions, and environmental status. Consequently, indicator developers should focus on capturing Driving Forces that inform water management and use strategies.

Gibson's sustainability model complements the DPSIR approach by providing a multidimensional assessment framework. It proposes eight criteria to evaluate sustainability within specific contexts. This model offers advantages beyond traditional sustainability dimensions (environmental, social, and economic), incorporating equity, civility, intergenerational integration, and justice (Gibson, 2006). Hence, Gibson's model provides a more comprehensive framework compared to conventional sustainability assessment methods.

Pires et al. (2017) highlight water use and management indicators aligned with water resource criteria. However, most indicators neglect broader sustainability dimensions, suggesting that

conventional water management indicators often reflect a limited perspective that overlooks multidimensional aspects.

Table 3 illustrates the correspondence between DPSIR indicators and Gibson’s eight criteria, offering valuable guidance for river basin management and informing future research directions.

Table 3 - Relationships Among Gibson’s Sustainability Criteria, the DPSIR Method, and the PCJ River Basin Plan Indicators

| Gibson’s Sustainability Assessment Criteria | DPSIR Categories | Indicators |
|----------------------------------------------------------------|-------------------------|---------------------------------------------------------------------------|
| Socio-ecological System Integrity | State | Surface Water Quality |
| | State | Surface Water Availability; Groundwater Availability |
| | Driving Forces | Population Growth Rate (PGR); Population Density |
| | Pressure | Volume of Water Consumed |
| | Pressure | Contaminated Areas |
| | Impact | Fish Mortality Complaints |
| Adequate Resources for Livelihoods and Access to Opportunities | State | Surface Water Quality |
| | State | Surface Water Availability; Groundwater Availability |
| | Pressure | Water Produced vs. Water Consumed |
| | Impact | Fish Mortality Complaints |
| | Driving Forces | São Paulo Social Responsibility Index |
| | Driving Forces | Population Growth Rate (PGR); Population Density |
| Intragenerational Equity | Driving Forces | São Paulo Social Responsibility Index |
| | State | Surface and Groundwater Quality |
| | Driving Forces | Population; Population Density |
| | State | Urban Water Service Index; Connection Loss Index; Distribution Loss Index |
| | State | Groundwater Availability; Surface Water Availability |
| Intergenerational Equity | Impact | Contaminated Areas; Flash Floods; Floods and Inundations |
| | Impact | Waterborne Diseases |
| | Driving Forces | São Paulo Social Responsibility Index |
| | Driving Forces | Population Growth Rate (PGR); Population Growth |
| | State | Surface Water Quality |

| | State | Surface Water Availability; Groundwater Availability |
|--------------------------------------------------------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| Natural Resource Maintenance and Efficiency | Response | Urban Water Service Index; Connection Loss Index; Distribution Loss Index; Spatial Coverage Index of Monitoring (IAEM); Hydrometric Network Density |
| | Response | Remediated Contaminated Areas |
| | Response | Reservoirs for Buffering and Linear Parks |
| Socio-environmental Civility and Democratic Governance | | No indicators were investigated for this criterion |
| Precaution and Adaptation | Impact | Contaminated Areas; Flash Floods; Floods and Inundations; Waterborne Diseases |
| | State | Surface and Groundwater Quality |
| | State | Surface Water Availability; Groundwater Availability |
| | State | Water Produced vs. Water Consumed |
| | Response | Remediated Contaminated Areas |
| | Impact | Flash Floods; Floods and Inundations |
| Integration of Current and Long-term Conditions | | All investigated indicators collectively provide a perspective aligned with this criterion |

Source: Prepared by the authors based on Chaves et al. (2020).

Integrating Gibson’s model with the DPSIR method provides a novel, transversal, and multidimensional perspective on sustainability assessment, offering insights that differ from using the PER, DPSIR, Triple Bottom Line, or Gibson models in isolation.

In agreement, Carvalho, Carvalho, and Curi (2011) argue that integrating these approaches for sustainability assessment in cities within a sub-basin employs a multicriteria evaluation model, using indicators that encompass demographic, social, environmental, and economic dimensions.

Final Considerations

By integrating the DPSIR method and water resource indicators, we propose the use of Gibson’s model, which proves to be a useful and relevant tool for sustainability assessments in the PCJ River Basins. Since Gibson’s model explicitly addresses sustainability criteria and embraces multidimensionality, it becomes a powerful framework for evaluating, managing, and implementing actions aimed at addressing the actual challenges faced by municipalities and river basins. Applying Gibson’s model allows for continuous monitoring beyond water resources, capturing the real conditions of the basins and ensuring sustainability not only in the present but also for future generations through effective, safe, and feasible measures.

In today’s challenging context, Gibson’s sustainability assessment model stands out for providing

an integrated evaluation that involves civil society participation. Moreover, the model consists of a set of criteria that overcome the limitations of conventional sustainability assessments by weighing social, environmental, and economic dimensions of the sustainability tripod in an integrated manner without overlapping, achieving greater cohesion between ecological and social systems.

Gibson's model also enables the identification and resolution of gaps present in the traditional DPSIR approach, such as the lack of ecosystem interconnections and the absence of long-term, sustainability-oriented planning.

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