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Sustainability indicators applied to water resources management: a systematic review

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Abstract: Several methods emerge each year with the aim of measuring which are the most appropriate measures to promote sustainable development policies. Therefore, it becomes necessary to have consistent information on the progress of countries, states and municipalities towards sustainable development, so that one can guide the establishment of coherent public policies, in search of economic growth combined with sustainable policies. Indicators are one of the tools available in the planning and management of projects that assist in the decision-making process and in the monitoring of these decisions towards the sustainable use and management of water and natural resources. The objective of this study is to map and gather information regarding the use of sustainability indicators applied to water resource management. Twenty-three studies were analyzed addressing different methodologies that employed environmental and sustainability indicators in the analysis of water resource management policies and actions, focusing on the "prosperity assessment" system, due to its holistic and integrative nature and its adherence to the UN 2030 Agenda.

Key words: review; sustainable development; environmental indicators

1 Introduction

The management of socio-environmental systems can rely on sustainability assessment methods based on indexes and indicators, which assist in decision-making by enabling diagnostic and prognostic studies of scenarios of interest (Castro et al., 2017). However, studies point to a gap in the actions to assess these efforts, making it difficult to establish mechanisms for improvement and advances in the decision-making process aimed at sustainable development (Ferreira et al., 2017).

Therefore, it is necessary to have consistent information on the progress of countries, states and municipalities towards sustainable development, in order to guide the establishment of coherent public policies, in search of economic growth combined with sustainable policies. Therefore, it is essential to create evaluation models to guide decision-making and their insertion in the environmental management process within the principles of sustainable development (Ferreira et al., 2017).

Indicators are one of the tools available in project planning and management that assist the decision-making process and the monitoring of these decisions on the path to the sustainable use and management of water and natural resources (Pires et al., 2020). Sustainability indicators perform many functions: they can lead to better decisions and more effective actions by simplifying, clarifying and providing aggregated information for management policy (Ramos et al., 2013).

The objective of this study is to map and gather information regarding the use of the sustainability indicators methodology applied to water resources management. It is important to verify which sustainability indicators are already

used for water resources management analysis; the degree of importance of the sustainability indicators methodology and whether this methodology is applied worldwide or only at the regional level.

2 Methodology

The work was developed by carrying out a systematic review of the literature based on secondary data according to the following steps: (1) elaboration of the research question; (2) literature search; (3) selection of articles; (4) data extraction; (5) evaluation of the methodology of the selected works; (6) data synthesis; (7) evaluation of the evidence; and (8) writing and publishing the results.

The research questions raised to carry out the systematic review of this work were the following: What are the sustainability indicators used to analyze water resource management? How important is the sustainability indicator methodology? Is this methodology applied globally and nationally?

The criteria for defining the research questions followed the "PICOC" evaluation strategy. In this strategy, the following are observed: the selected articles (population); the methods and techniques used (intervention); the form of intervention of the work (comparison); the methods used and their results obtained (results); and the practical application of the methodology (context). The strategy evaluated the evaluation context of this work by analyzing five spheres of analysis, as shown in Figure 1.

Figure 1. "PICOC" evaluation strategy

Population	Articles that work with sustainability indicators
Intervention	Method used in the management of Water Resources
Comparison	Comparison of techniques used
Outcome	What methodologies have already been used
Context	Practical application of the methodology related to Water Resources management

After this analysis, the thesaurus was defined. The thesaurus used in this review was "sustainability indicators" and "water resources". It was designed to include works that addressed the use of the sustainability indicator methodology and works on water resources, thus combining the methodology with the studied theme. The databases chosen for the review were the "Scopus" and "Web of Science" databases, and works published between 2000 and 2021 were analyzed. For each database, the same record of the search strategy used was maintained, using the same thesaurus, the same search date and analysis of the results. The flow of the selection of works is represented in Figure 2.

When the thesaurus was first used in the search databases, 259 papers were selected based on the specific word chosen. Soon after, 110 duplicate papers were eliminated, totaling 149 papers for analysis of abstracts and titles. This was followed by analysis of the titles and abstracts of the papers, and 45 papers that presented content related to the theme proposed by this systematic review were selected. The 45 articles were read and analyzed according to the eligibility criteria. From them we chose articles with access to the full text, which were not systematic reviews and with texts in English or Portuguese. As a result, 22 articles were excluded, resulting in a total of 23 full articles, in which the methodology and results obtained from the use of environmental indicators related to water resource management were evaluated. That makes up this review.

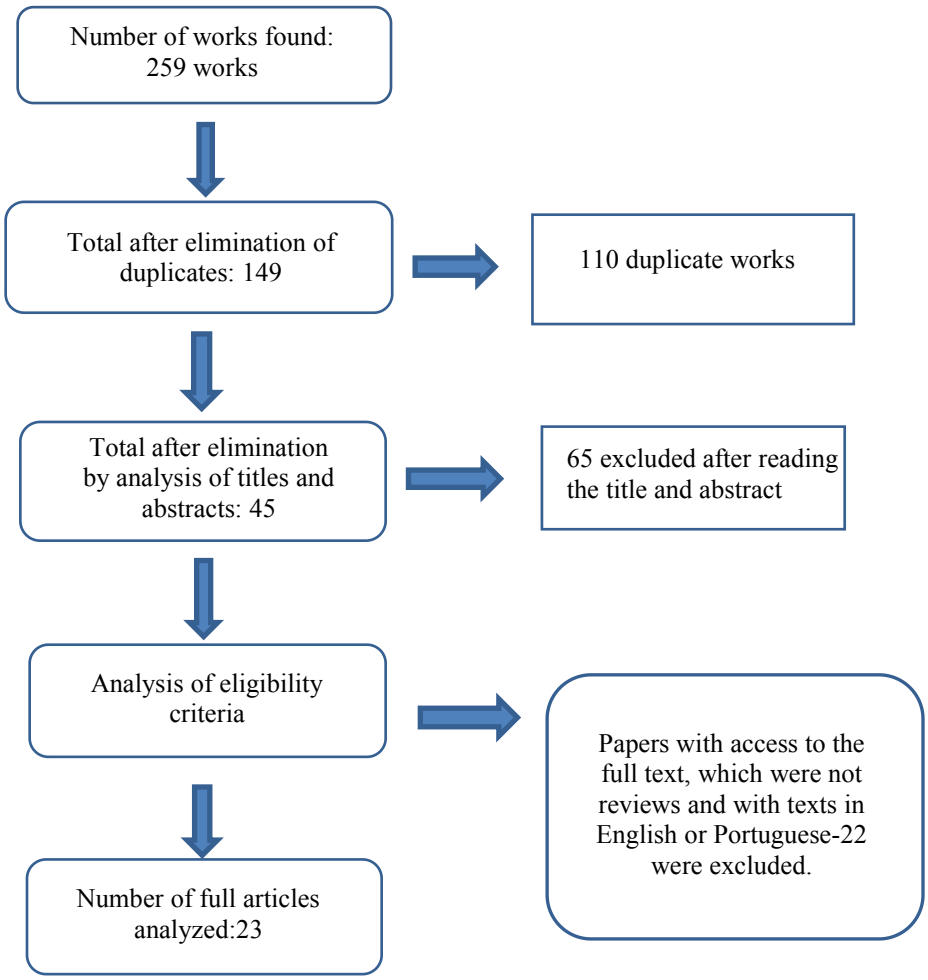


Figure 2. Selection flow of the papers analyzed

3 Results

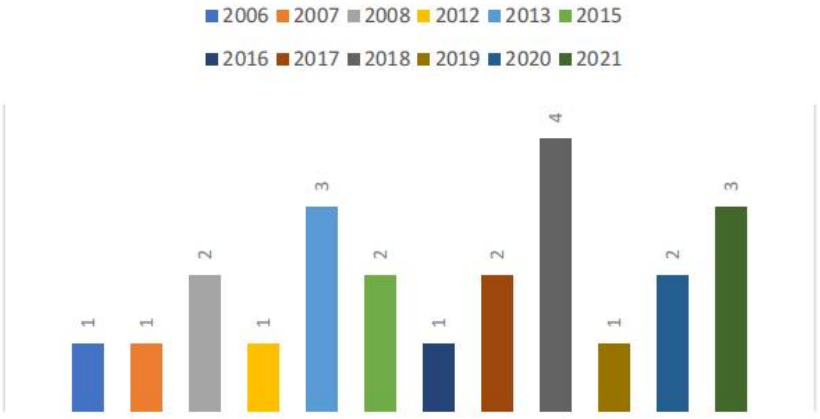
Table 1 presents the place of publication and details of the 23 articles analyzed, containing: title, authors, countries, year of publication, type of publication carrier, publication carrier, document type and corresponding quartile.

Table 1. Detailed table of articles studied

	Authors	Country	Year	Type of vehicle	Vehicle	Quartile
1	Tien-Duc et al.	China and Vietnam	2021	Magazine	Journal of Hydrology	Q1
2	Araujo et al.	Brazil	2015	Magazine	Electronic Journal of Management, Education and Environmental Technology	-
3	Ognianik et al.	Ukraine	2006	Symposium	Seventh IAHS Scientific Assembly at Foz do Iguaçu, Brazil, April 2005	-

4	Sarita-Rengifo et al.	Colombia	2019	Magazine	Engineering and Competitiveness	-
5	Cezare et al.	Brazil	2007	Magazine	Environmental Sanitary Engineering	Q3
6	Passos Okawa et al.	Brazil	2021	Magazine	Environmental Sanitary Engineering	Q3
7	Ioris et al.	Scotland	2008	Magazine	Journal of Environmental Management	Q1
8	Van Cauwenbergh et al.	Belgium, Netherlands and Spain	2008	Magazine	Environmental Geology	Not found(not continued)
9	Ramos et al.	Mexico	2013	Congress	Proceedings of the ASME 2013 International Mechanical Engineering Congress &Exposition	-
10	Shilling et al.	USA	2013	Congress	World Environmental and Water Resources Congress 2013	-
11	Corrêa, M.A. and Teixeira, B.A.N.	Brazil	2013	Magazine	Journal of Urban and Environmental Engineering	Q3
12	Amirhamzeh et al.	Iran and Greece	2012	Magazine	Recent Advances in Electrical and Electronic Engineering	Q4
13	Castro et al.	Castro et al.	2017	Magazine	International Journal of Sustainable Building Technology and Urban Development	Q4
14	Wu, H. and Leong, C.	Singapore	2016	Magazine	Water Policy	Q2
15	Koop, S.H.A. and van Leeuwen, C.J	Netherlands	2015	Magazine	Water Resource Management	Q1
16	Masud et al.	Bangladesh and Belgium	2018	Magazine	Ecological Indicators	Q1
17	Kefayati et al.	Iran	2018	Magazine	Water and Environment Journal	Q3
18	Dias et al.	Brazil	2018	Magazine	Applied Ecology and Environmental Research	Q3
19	Pouya et al.	Turkey	2020	Magazine	Urban Challenge	Q1
20	Bui et al.	Japan and Vietnam	2019	Magazine	Journal of Environmental Management	Q1
21	Bui et al.	Japan, Vietnam and China	2018	Magazine	Ecological Indicators	Q1
22	Ayra et al.	Peru	2021	Magazine	Chemical Engineering Transactions	Q3
23	Ferreira et al.	Brazil and Canada	2017	Magazine	International Journal of Sustainability Policy and Practice	Q3

Analyzing the selected works, it was observed that most of the articles were published in 2018 (4 publications), followed by the years 2013 and 2021, both with 3 publications. Two publications were found from the years 2008, 2015, 2017 and 2020. In the other years, only 1 published work was found. In this analysis, it can be observed that the discussions and use of this methodology are recent, with several works published on the subject mainly in the last five years.



Graph 1. Number of works published per year

Of the 23 studies analyzed, seven were from Brazil, which was the country most represented in the studies analyzed. Three studies were published from Vietnam, followed by two publications from each of the following countries: China, Belgium, the Netherlands, Japan and Iran. The remaining studies were characterized by a wide range of origins. This shows that the use of environmental indicators is widespread and can be applied to different realities in different countries.

Most of the papers were published in Q1 and Q3 quartile journals, with seven Q1 journals and seven Q3 journals. Two papers were published in Q4 quartile journals and one in a Q2 quartile journal. This analysis indicates the high quality of the papers analyzed, resulting in greater reliability of the data collected.

The intervention table was set up, describing the main objective of each work and the method used, in order to systematize the objectives related to the different realities investigated (Table 2).

Table 2 . Intervention table of the works studied

	Authors	Year	Description	Method used
1	Tien-Duc et al.	2021	It presents a new concept that integrates the index overlay method and a physically based numerical method to predict groundwater sustainability under various climatic conditions and anthropogenic activities.	The DRASTIC index overlay method was modified with an analytical hierarchy process theory and employed to create groundwater vulnerability maps for the Pingtung Plain groundwater basin in southern Taiwan. The MODFLOW physical model was used to predict the dynamics of a basin-scale groundwater system.
2	Araujo et al.	2015	It analyzes the use of socio-environmental indicators and their applicability in the upper reaches of the Mundaú river basin in the state of Pernambuco.	The research began with a bibliographical survey.This was followed by data analysis and interpretation based on Prescott Allen's Sustainability Barometer (VAN BELLEN, 2005). The methodology, combined with a systemic vision, produced a vulnerability diagram based on the analysis of three dimensions: environmental, economic and social.

3	Ognianik et al.	2006	It describes the Ukrainian hydroeconomic complex in the context of sustainable development.	Criteria were established such as: provision of renewable sources of water resources of satisfactory quality (Ig), efficiency of water resources use (Ie), and the water resources risk index (Id). These were used to determine sustainable development of water resources use in the country.
4	Sarita-Rengifo et al.	2019	It presents the structure of the final environmental sustainability index that allows the analysis of the components of water and soil resources in small properties through indicators.	The technique used to construct the index included: selection of components, indicators and sub-indicators, their respective weights, their measurement and the robustness analysis of the final index. Data collection was carried out using three methods: survey form, observation and knowledge dialogue in 6 smallholdings located in the Centella hydrographic micro-basin.
5	Cezare et al.	2007	This article aimed to contribute to the discussion on the Evaluation of the Sustainable Development Strategy of the Municipality of Santo André, in the context of the protection of water resources.	Guidelines and actions coordinated by the local government were consulted. The Bellagio Principles were used for the qualitative analysis of the results obtained. Ten principles were selected to serve as guidelines for evaluating and improving the selection, use, interpretation and communication of indicators.
6	Passos Okawa et al.	2021	The objective of this article was to establish sustainability indicators for the source area of the municipality of Paranavaí, in the state of Paraná, Brazil.	The methods used were cognitive mapping and "measuring attractiveness by a categorical-based evaluation technique" (MACBETH), applied during a decision-making conference with the participation of several stakeholders directly affected by and strongly interested in the topic. At the end of the decision-making conference, 14 indicators were defined and their weights established.
7	Ioris et al.	2008	It reports on the formulation and application of a framework of indicators for water resources management at basin level, designedIt discusses water management in the Andarax river basin (Almeria, Spain), defining management as multi-objective, multi-participzant and the problem of long-term decision-making.te the environmental, economic and social aspects of sustainability.	The framework of nine indicators was applied to the River Dee and River Sinos catchments in Scotland and Brazil, respectively. The selection of indicators involved input from water management professionals in both countries, and a pilot exercise in Scotland. The use of some proxy indicators was necessary in both basins due to insufficient data availability.

8	Van Cauwenbergh et al.	2008	It discusses water management in the Andarax river basin (Almeria, Spain), defining management as multi-objective, multi-stakeholder and the problem of long-term decision-making.	The method presented created a decision support system (DSS). The DSS is closely linked to sustainability indicators and is designed through public participation in the process. The successive multi-criteria analysis of the performance indicators makes it possible to classify the different management alternatives according to the multiple objectives formulated by the different participating sectors.
9	Ramos et al.	2013	It analyzes the water demands of the Southern California region and the Baja California region in Mexico, both of which depend on the Colorado River.	Sustainable water supply indicators were calculated to assess and compare their sustainability performance. A selection of indicators was defined that can directly measure the efficiency of the system and its social, economic and environmental impact.
10	Shilling et al.	2013	Describes the development of a framework for quantifying water resource sustainability using indicators, "The California Water Sustainability Indicators Framework"	The structure created includes: 1) a logical hierarchy of goals and objectives for organizing the indicators; 2) the definition of a set of suitable indicators; 3) an analytical measurement method for calculating sustainability in relation to the defined targets. The framework also includes the "Water footprint" as the index to be defined for the locations analyzed.
11	Corrêa, M.A. and Teixeira, B.A.N.	2013	It describes a tool consisting of a set of sustainability indicators for water resource management called CISGRH, to meet the specific needs of the Tietê-Jacaré River Basin Committee (CBHTJ).	The method used consists of first setting up the CISGRH structure, which emerged through consecutive consultation processes. The objective of implementing the CISGRH was to diagnose the current conditions of water resources and their management, as well as to assess future conditions evidenced by trends and interventions carried out by the committee.
12	Amirhamzeh et al.	2012	It brings scenario assessment into water resources planning and management with the aim of increasing the efficiency and sustainability of systems and reducing likely conflicts.	In this article, to apply different approaches to operating the Karkheh reservoir system, two scenarios are applied. The scenarios are analyzed and compared on two scales, seasonal and annual, and the best scenario is selected.
13	Castro et al.	2017	It discusses the Watershed Sustainability Index (WSI), which allows integrated analysis of social, economic and environmental issues that can affect sustainability in a watershed.	The Watershed Sustainability Index (WSI) method is subdivided into four categories: hydrology, environment, life and policy, each of which is analyzed through a three-tier indicator system, namely for pressure, state and response.
14	Wu, H. and Leong, C.	2016	It investigates the use of indicators for the integrated assessment of two large river basins, the Yellow River basin in China and the Ganges River basin in India.	The method employed was to develop a framework, a set of tailored indicators were selected and categorized into three domains: environmental performance, social well-being and economic development. This framework provided policy makers with a holistic review of river sustainability.

15	Koop, S.H.A. and van Leeuwen, C.J.	2015	It proposes an internationally standardized indicator framework for urban Integrated Water Resources Management (IWRM), the "City Blueprint®"	The method presented is based on the City Blueprint Framework (CBF). A distinction was made between trends and pressures and IWRM performances. Only performance-oriented indicators were selected from the CBF. By analyzing correlations and variances, the performance-oriented indicators were reorganized in order to establish a proportional contribution of all indicators and categories to the overall score, i.e. the Blue City Index®.
16	Masud et al.	2018	Analyzes the water resources management practice of the southwest coast of Bangladesh, called "Tidal River Management (TRM)"	The study identifies sustainability indicators of TRM considering ecosystem services. The conceptual framework is followed by the construction of a Sustainability Index of Tidal River Management (SITRM). It also involves trade-off analysis, livelihood analysis and SWOT (strengths, weaknesses, opportunities and threats) analysis.
17	Kefayati et al.	2018	A practical approach is developed to assess the sustainability of river basins subject to an inter-basin water transfer project.	The proposed approach used 15 sustainability indicators (SI) covering three main criteria: economic, social and environmental, and aggregated them into eight different types of sustainability indices for a more robust result. Two scenarios were considered in the source and receiving basins. In addition, multivariate principal component analysis (PCA) was applied to determine the leading and non-leading indicators for the two river basins.
18	Dias et al.	2018	It presents the application of sustainability indicators in river basins in a state in the Northeast of Brazil.	Twelve sustainability indices and three indicators focused on socioeconomic, hydrological and institutional issues were defined and calculated for six river basin regions, both quantitatively and qualitatively. Partial scales for all indices related the calculated values to performance levels (very high, high, medium, low and very low).
19	Pouya et al.	2020	It describes the management of water resources in Turkey. The indicators were classified according to their importance in the resilience of water resources.	The analytical hierarchy process was used to weight the sustainability factors in water resources and river basin planning. Considering the different opinions that experts may have, two groups of interviewees (academics and professionals) were chosen to evaluate the factors.
20	Bui et al.	2019	It proposes a groundwater sustainability assessment framework, which is developed from a regular sustainability assessment approach and analytical hierarchy process (AHP).	The method establishes the three main pillars (environmental, social and economic) of the sustainability concept. The AHP concept was used to create the main sustainability components of a hierarchy. Three main aspects of sustainability were proposed (quantity, quality and management) and therefore its twelve environmental sustainability indicators were selected.

21	Bui et al.	2018	It analyzes groundwater management in the city of Hanoi, the capital of Vietnam, which has a serious problem with the degradation of the quality of its groundwater.	The work used an analytical hierarchy process (AHP) approach, which was used to generate the main components of this structure. After analyzing the main problems encountered in Hanoi, 3 main aspects were proposed (quantity, quality and management) and appropriately 13 sustainability indicators for this target area were selected .
22	Ayra et al.	2021	It analyzes the situation of the Yanacocha lagoon, determining scenarios for the lagoon's water sustainability until 2030 to supply the population.	Precipitation and temperature parameters were estimated for the Yanacocha micro-basin for the period 1970 to 2019. In addition, water sustainability scenarios were estimated based on water supply and demand related to sustainability indicators and the level of water culture of the inhabitants.
23	Ferreira et al.	2017	It proposes a new method for analyzing sustainability indicators applied to water management called Prosperity Assessment, which has been applied in two research areas, in Canada and Brazil.	The paper proposes a new method that combines Berke's SSA (socio-environmental systems) terminology with Ostrom's sustainability principles in a semi-empirical "prosperity assessment method". After establishing the components for each sustainability principle using common test parameters, the perception data was validated with official data sources.

4 Discussion

The methodologies and techniques used were diverse in relation to the sustainability indicators used to analyze water resources management. It can be seen that there is no standardization that would allow for an in-depth comparative analysis. It is believed that this is due to the fact that the use of environmental indicators for analysis considers multiple actors and the different environmental realities of each area analyzed, focusing on the different problems found in these locations.

However, a diversity of approaches and works is observed, highlighting the high degree of importance of the sustainability indicators methodology and its broad applicability, since works from the most diverse countries around the world are analyzed, corroborating the consolidation of the method as an effective tool in the analysis of the different scenarios in the works on water resources management.

The methodology called "prosperity assessment", proposed by Ferreira et al. (2017), presents the assessment proposal in a broad approach, considering that the adequate functioning of social and ecological systems would occur in seven dimensions, translated into seven principles of sustainability. For each of the seven dimensions, a set of components and three tests of common interest were established, thus totaling forty-nine parameters to be evaluated. This methodology provides attribution to each component, and these components observe important characteristics for the sustainable, integrated, decentralized and participatory management of water resources. Thus, it is observed that the "prosperity assessment" methodology is an integrated environmental assessment instrument, with participatory water management as its axis, which can be applied on a regional scale, having been tested for river basin committees of state (MACHADO, 2018; MAFORT, 2019; BARRETO, 2020; SOARES, 2021) and federal (FERREIRA, 2022) rivers. The "prosperity assessment" includes subcomponents associated with indicators of driving forces, pressure, impact, status and response, thus satisfying the sustainability criteria necessary for the multidimensional assessment of integrated water resource management, which must encompass the environmental, economic, social and institutional dimensions, as described by Pires et al. (2017).

5 Final considerations

There are numerous methods that can be applied to assess the quality of an indicator or a set of indicators to support public policies. Studies that combine more than one assessment method can also be carried out, expanding the possibilities for analyzing studies related to water resource management. The studies surveyed in this review show the application of different methods, such as: comparative analyses; data collection involving experts; selection or creation of analysis structures; bottom-up approaches, among others. All of these methods can contribute to improving the selection of criteria in different ways, according to the objectives and data to be collected and also taking into account the reality and area of the study to be conducted.

Additional studies addressing the criteria and methodologies used are necessary in order to analyze their applications for a variety of purposes. The "Prosperity Assessment" method is an appropriate assessment tool, given its holistic and integrative nature, with the aim of producing results that can guide decision-making processes in accordance with the sustainable development goals established in the 2030 Agenda.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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