Integrated Water Resource Management (IWRM): assessment and applicability of tools in the Brazilian context

Gestión integrada de los recursos hídricos (GIRH): evaluación y aplicabilidad de las herramientas en el contexto brasileño

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ABSTRACT

Integrated Water Resources Management (IWRM) is a central concept in water governance, promoting cooperation and articulation in fragmented systems. This study identifies and analyses tools used in water resources managing in Brazil, through a methodological proposal based on integrated management concepts. The research was carried out online using search keys and included academic works and institutional initiatives, both private and public. The study identified 60 tools and assessed their applicability, considering the relevant focus and context within different categories of IWRM. The majority of identified tools are technical ones and designed for water quality assessment and monitoring. A smaller number of tools were related to user registration, land use and occupation assessment, communication, and information dissemination. This study demonstrates the use of the water management tools and it provides an overview of the potential benefits associated with their application to improve local, regional, and national water governance.

KEYWORDS: Integrated Water Resource Management (IWRM), Water governance, GWP ToolBox, Decision Support Systems, Brazil.

RESUMEN

La Gestión Integrada de los Recursos Hídricos (GIRH) es un concepto central en la gobernanza del agua, que promueve la cooperación y articulación en sistemas fragmentados. Este estudio analiza las herramientas utilizadas en la gestión hídrica en Brasil, a través de una propuesta metodológica basada en conceptos de gestión integrada. La investigación se realizó utilizando descriptores e incluyó trabajos académicos e iniciativas institucionales privadas y públicas. Como resultado se identificaron 60 herramientas y se evaluó su aplicabilidad, considerando el enfoque y el contexto de diferentes categorías de la GIRH. La mayoría de las herramientas identificadas son diseñadas para la evaluación de la calidad del agua. Pocas herramientas estaban relacionadas con el registro de usuarios, la evaluación del uso del suelo y la comunicación. Este estudio proporciona una visión general de los beneficios de su aplicación para mejorar la gobernanza local, regional y nacional del agua.

PALABRAS CLAVE: Gestión integrada de los recursos hídricos (GIRH), Gobernanza del agua, Caja de herramientas de la GWP, Sistemas de Soporte a la Decisión, Brasil.

Gestão Integrada de Recursos Hídricos (GIRH): avaliação e aplicabilidade de ferramentas no contexto brasileiro

RESUMO

A Gestão Integrada de Recursos Hídricos (GIRH) é um conceito central na governança da água, promovendo a cooperação e articulação em sistemas fragmentados. Este estudo identifica e analisa ferramentas utilizadas na gestão da água no Brasil, por meio de proposta metodológica baseada nos conceitos de gestão integrada. A pesquisa foi realizada usando descritores, incluindo trabalhos acadêmicos e iniciativas institucionais privadas e públicas. O estudo identificou 60 ferramentas e avaliou sua aplicabilidade, considerando o foco e o contexto das diferentes categorias da GIRH. A maioria das ferramentas identificadas são técnicas e concebidas para avaliação e monitoramento da qualidade da água. Um número menor de ferramentas é relacionado ao cadastro de usuários, avaliação do uso e ocupação do solo e comunicação. Este estudo demonstra o uso das ferramentas para gestão de água e fornece uma visão geral dos benefícios potenciais da sua aplicação para melhorar a governança hídrica local, regional e nacional.

PALAVRAS-CHAVE: Gestão Integrada de Recursos Hídricos (GIRH), Governança da água, GWP ToolBox, Sistemas de Apoio à Decisão, Brasil.

Gestion intégrée des ressources en eau (GIRE): évaluation et applicabilité des outils dans le contexte brésilien

RÉSUMÉ

La gestion intégrée des ressources en eau (GIRE) est un concept central de la gouvernance de l'eau, favorisant la coopération dans des systèmes de gestion fragmentés. Cette étude analyse les outils utilisés dans pour la gestion de l’eau au Brésil, à travers une méthodologie basée sur des concepts de gestion intégrée. L’étude a été réalisée sur internet en utilisant des descripteurs, comprenant des travaux académiques et des rapports liés à des initiatives privées et publiques. La recherche a identifié 60 outils et évalué leur applicabilité en tenant compte du contexte des différentes catégories de GIRE. La majorité des outils sont conçus pour l'évaluation de la qualité de l'eau. Les autres sont liés au recensement des utilisateurs, à l'aménagement du territoire et à la diffusion de l'information. Cette étude démontre l'utilisation d'outils et les avantages potentiels de leur application pour améliorer la gouvernance de l'eau aux niveaux local, régional et national.

MOTS-CLÉS: Gestion intégrée des ressources en eau (GIRE), La gouvernance de l'eau, GWP ToolBox, Systèmes d'aide à la décision, Brésil.

Gestione integrata delle risorse idriche (GIRI): valutazione e applicabilità degli strumenti nel contesto brasiliano

SOMMARIO

La gestione integrata delle risorse idriche (GIRI) è un concetto centrale nella governance dell’acqua, poiché promuove la cooperazione in sistemi frammentati. Questo studio identifica e analizza gli strumenti utilizzati nella gestione dell'acqua in Brasile, attraverso una proposta metodologica basata su concetti di gestione integrata. La ricerca è stata effettuata online utilizzando parole chiavi e ha incluso lavori accademici e iniziative istituzionali, sia private che pubbliche. Lo studio ha identificato 60 strumenti e ne ha valutato l'applicabilità, considerando il focus e il contesto rilevanti all'interno delle diverse categorie della GIRI. La maggior parte degli strumenti identificati sono progettati per la valutazione della qualità dell'acqua. Un numero minore di strumenti riguardava la registrazione degli utenti, la valutazione dell’uso del territorio e la diffusione delle informazioni. Questo studio dimostra l’uso di questi strumenti e dei potenziali benefici associati alla loro applicazione per migliorare la governance idrica a livello locale, regionale e nazionale.

PAROLE CHIAVE: Gestione integrata delle risorse idriche (GIRI), governance dell'acqua, GWP ToolBox, Sistemi di supporto alle decisioni, Brasile.

Introduction

The water crisis in the 21st century is much more about management and governance failure than a real problem of water scarcity[1]. However, it can be also argued that the water crisis stems from real problems of availability and increased demand, combined with sectoral management and crisis response processes[2].

To face this crisis, it is necessary to overcome the old sector-oriented agenda and the river basin must be considered for the adoption of an integrated and systemic approach to water management: the integrated water resources management - IWRM[3]. IWRM was defined by the Global Water Partnership (GWP) as a process, which promotes the coordinated development and integrated management of water, land and other related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems[4].

This is the most adopted IWRM definition which is responsible for its dissemination worldwide and quickly becoming a kind of flagship of water programmes as an attempted response to several sources of fragmentation in water governance systems[5]. The emergence of IWRM concept implied the establishment of multi-disciplinary teams at various levels (local, regional, national and international) to communicate different perspectives on water resources, building consensus on the conservation of water resources and the maintenance of ecosystem functioning[6]. IWRM emergence also provided a necessary resource framework, such as similar concepts and also management beyond water, as parts of the framework and management practices[7].

IWRM has been widely adopted, standing out as a holistic and participatory approach that involves users, planners and policy makers at all levels[8]. Often, but incorrectly, the terms water governance and IWRM are used almost interchangeably. It is a fact that there is a direct relationship between good governance and IWRM. The key principles of good governance touch the issues of responsibility, participation and transparency[9]. Therefore, the IWRM, based on good governance, must be understood as the decision-making processes that involve public, social and private actors, with a focus on participation as a structuring axis. The points of convergence of these two concepts seem to focus on issues related to equity and protection of interests[10]. Thus, the IWRM is a core concept in water policy and governance and can be considered a way to facilitate cooperation, joint responsibility and integration within fragmented water governance systems[11]. The effective implementation of IWRM, aligned with the principles of good governance, ensures responsible and transparent decision-making processes involving diverse stakeholders in water management[12].

Gallego-Ayala[13] conducted a study with the objective to identify the main trends in IWRM research during the 2000–2011 period, considering twelve years of the initial spread of this definition and the efforts to make it an operating concept. The trends and thematic dominance in research topics identified by him suggested that the scientific community had given more attention to integration itself rather than to water resources management. Scientists and policy makers agreed that the ecological, socioeconomic and physical aspects of water management need to be addressed together. This has led to the development of an increasing number of tools to support the decision-making process in water management and assist managers in strategic planning tasks dealing with the water system in an integrated manner[14]. Tools development were also mainstreamed as national strategies for dynamic planning of water resources management[15]. Tools can here be defined as a set of "concepts that helps the user to select a suitable mix and sequence of processes or steps that work in a given situation, context and country", aiming to promote IWRM[16].

Gallego-Ayala[17] also identified trends in the research methodologies within the IWRM field, trying to classify them in subject categories. This effort can suggest tools categorization concerning IWRM, aligned to the GWP previous efforts to identify and group more than 50 tools in a logical box structure[18]. The tools library available for public in 2000 by the GWP (GWP Toolbox)

1 Rogers; Llamas; Cortina, 2005. Gleick, 2000.
2 Somlyódy; Varis, 2006. Van Ginkel et al., 2018.
3 Falkenmark, 1997. Molle, 2009.
4 GWP, 2000.
5 Biswas, 2008. Lubell; Edelenbos, 2013.
6 Al Radif, 1999.
7 Grigg, 1999.
8 Jazi, 2021.
9 Allan; Rieu-Clarke, 2010.
10 Allan; Rieu-Clarke, 2010.
11 Edelenbos; Teisman, 2013. Lubell; Edelenbos, 2013.
12 Nagata et al., 2022.
13 Gallego-Ayala, 2013.
14 De Kok et al., 2009. Giupponi; Sgobbi, 2013.
15 Ouamane; Sekkour; Athmani, 2022.
16 Jazi, 2021.
17 Gallego-Ayala, 2013.
18 GWP, 2018.

contains a set of knowledge and practices inspired by the principles of IWRM, organized hierarchically in three parts: A) Enabling Environment, which encompasses policies, legislative structure and financing, which favours the management of water resources; B) Institutional Arrangements, which assist in the construction of an organizational structure, as well as in institutional training; and C) Management Instruments, which assist in the decision-making process for the management of water resources.

The GWP Toolbox has been then used in national and international experiences: The study by Bielsa and Cazcarro[19] analyzed integrated management in the Ebro River basin in Spain and showed some gaps between theory and practice that deserve mention. In another study, Domingues[20] assessed integration in the management of the Rio Doce River basin and concluded that the process of management of the referred basin can be perceived as an improvement in water resources management. This author recommended the use of IWRM tools in studies involving other Brazilian basins, to demonstrate the diversity of cases in Brazil. The GWP ToolBox was also addressed in the study conducted by Zamignan[21], who analyzed case studies in South America from the perspective of IWRM, in order to identify contributions to the development of capabilities aimed to overcome the challenges inherent in water management. Finally, Saito[22] highlighted the prioritization of the GWP Toolbox to support knowledge management by GWP-South America in their strategic planning for the next years.

Therefore, the present study aimed to identify, characterize and analyze the tools currently used in the planning and management of water resources in river basins in an IWRM framework. The present study has a narrower focus on IWRM Tools compared to the study by Gallego-Ayala[23], but also with a wider scope beyond the scientific community to encompass agencies, research institutes, universities, non-governmental organizations (NGOs), companies, among others. The tools were identified through a systematic search using the web search engine, which made it possible to find the tools developed in articles, dissertations, theses, software, applications or posted on web pages.

[19] Bielsa; Cazcarro, 2015.
[20] Domingues, 2011.
[21] Zamignan, 2018.
[22] Saito, 2019.
[23] Gallego-Ayala, 2013.

Materials and Methods

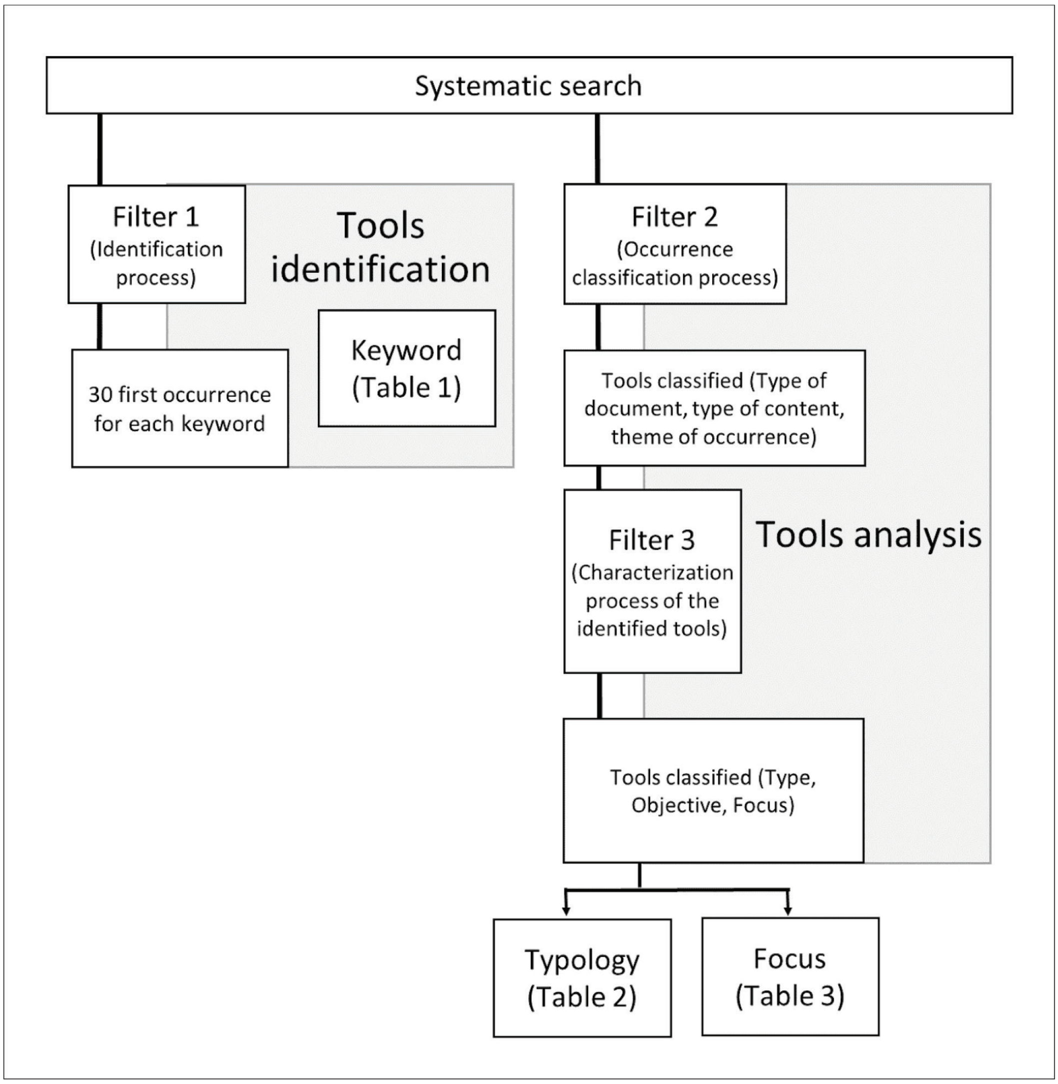
IWRM Tools encompass techniques, instruments, indicators, applications, protocols, methodologies and softwares that guide the decision-making process and allow access to data on water resources and the river basin. These tools were also considered instruments that allow the assessment of current and future scenarios in water resource planning and management were considered IWRM instruments.

The proposed methodology for identification and analysis of water resources planning and management tools was organized in two parts: I) Identification of Tools; and II) Analysis of the Tools. The steps of the methodology are shown below in Figure 1. The subsequent sections will provide a comprehensive overview of the steps involved in the identification and analysis of the tools.

Tools identification

The tools were identified through a systematic search carried out using the Google™ search engine, making it possible to identify the tools developed by agencies, research institutes, universities, non-governmental organizations (NGOs), companies, among others, presented in articles, dissertations, theses, software, applications or published on web pages. The Google™ search engine was selected with the purpose of identifying common and applicable tools and not just theoretical-scientific studies, covering several existing tools. Table 1 column C presents Filter 1 (Identification Process) that consists of a keyword database created specifically for each category of application of the tools, based on the tools established in Item C - Management Instruments (8 categories) of the GWP Toolbox. The choice of this filter 1 is based on the objective of the study, focused on the characterization of instrumental tools representatives of the efforts for seeking IWRM implementation. The sample size considered in this study was the first 30 occurrences presented for each keyword used. The choice of a sample of 30 occurrences for each keyword in this study was based on the premise that this number is sufficient to capture a representative variety of contexts and usages associated with each term. Additionally, this quantity was determined as an appropriate balance between the scope of the analysis and the need to ensure a meaningful sampling, allowing for a comprehensive understanding of the nuances and patterns associated with each keyword used.

Figure 1. Steps of the research methodology



Source: authors.

Tools analysis

All occurrences found from Filter 1 (Identification Process) were classified into categories, in Filter 2 (Occurrence Classification Process): *Type of document*, which indicated whether the referred document was a scientific article, end of course paper, dissertation, thesis, web page, among others; *Type of content*, which classified the document into methodology, concept, software, model, application, tool, among others; and *Theme of the occurrence*, which indicated the theme of the document, such as solid waste, water resources, among others. From this second filter, all occurrences that were not considered as tools, and whose objectives were not consistent with the theme, were discarded from the analysis.

The identified tools from Filter 2 (Occurrence Classification Process) were analyzed from the categories of Filter 3 (Characterization Process of the Identified Tools), to describe the tools as to: *Type*, which indicated whether the tool was an indicator, methodology, or a computational tool, among others; *Objective*, the purpose for which the tool was built and applied; and *Focus*, indicating the main theme of application of the tool. The present article will focus on the results about *Type* and *Focus*.

After this characterization, the identified tools were analyzed to assess whether the tool met the scope of a given category of tools, that is, whether it could be used in the context considered to achieve the desired objective. Characterization and analysis of the selected tools was carried out through documentary research,

Table 1. GWP Toolbox Structure - Management Instruments, and keywords for tools searching (based on GWP Toolbox 1.0, before the end of 2021 when the GWP Toolbox 2.0 was launched)

(A) Categories	(B) Subcategories	(C) Keywords
C1 - Understanding Water Endowment	C1.01 Demand and supply	WR demand
		WR supply
	C1.02 Data collection	WR data collection
	C1.03 Monitoring and evaluation systems	WR database
		WR information Systems
C2 - Assessment Instruments	C2.01 Risk assessment	WR risk assessment
	C2.02 Vulnerability assessment	WR vulnerability assessment
	C2.03 Social assessment	WR social assessment
	C2.04 Ecosystem assessment	WR ecosystems assessment
	C2.05 Environmental impact assessment	WR environmental assessment
	C2.06 Economic assessment	WR economic assessment
C3 - Modelling and Decision-Making	C3.01 Geographic information system	WR modeling systems
	C3.02 Stakeholder analysis	WR stakeholder analysis
	C3.03 Shared vision planning	WR shared Management
	C3.04 Decision support systems	WR support decision making
C4 - Planning for IWRM	C4.01 National IWRM plans	Integrated WR Management
	C4.02 Basin management plans	Watershed Management
	C4.03 Groundwater management plans	Groundwater Management
	C4.04 Coastal zone management plans	Coastal zone management
	C4.05 Integrated urban water management plans	Urban Water Management
	C4.06 Integrated disaster risk management plans	Water risk disaster management
	C4.07 National adaptation plans	WR Adaptation Plans
C5 - Communication	C5.01 Communication channels	WR communication channels
	C5.02 Consensus building	WR consensus Building
	C5.03 Conflict management	WR conflict management
C6 - Efficiency in Water Management	C6.01 Demand Efficiency	WR demand efficiency
	C6.02 Supply efficiency	WR supply efficiency
	C6.03 Recycle and reuse	WR recycling and reuse
C7 - Economic Instruments	C7.01 Pricing for water and water services	WR services pricing
	C7.02 Water markets	WR markets
	C7.03 Tradable pollution permits	WR tradable pollution
	C7.04 Pollution charges	WR pollution charges
	C7.05 Subsidies	WR subsidies
	C7.06 Payments for environmental services	Payments for environmental water services
C8 - Promoting Social Change	C8.01 Youth education	WR Education
	C8.02 Raising public awareness	WR awareness
	C8.03 Water footprint	Water footprint
	C8.04 Virtual water	Virtual water

Source: authors. WR = Water resources.

using mainly texts and articles from the institutions and authors who developed the identified tools. Articles and documents from other authors and institutions that addressed the investigated tool were also used, when available, considering the necessary information to characterize each of the selected tools.

The GWP ToolBox structure (category and subcategory) was used for both the characterization and analysis of the tools so that it was possible to understand how the applications of the identified tools were related to a systemic hierarchical IWRM framework and how they could meet the principles of IWRM. The cross-cutting analysis with GWP Toolbox helped to establish search categories and subcategories for existing tools that subsidize IWRM. These categories and subcategories were studied and analyzed to support the definition of identification patterns (specific keywords) according to the theme addressed in each category. This was done with the purpose of finding, through a systematic search, the tools that are being developed and implemented for the planning and integrated management of water resources in river basins. The GWP Toolbox Management Instruments were grouped into eight categories, according to their objectives (Table 1, columns A and B).

Results and Discussion

Sixty (60) tools used in different application contexts for the management of water resources in Brazil were identified. These tools were characterized by Type, Name, Objective and Application Focus. Most of the tools found in this study were identified as Computational tool, followed by tools characterized as Indicators, Methodology, Information System, Web Platform and Application (Table 2). This characterization of the tools by Type sought to describe the model used in the elaboration of the tool and are essential to provide a comprehensive understanding of each type of tool, allowing for more accurate classification and deeper analysis of their distinctive characteristics. The typologies used to characterize the tools are in Table 2.

Concerning the application focus, the identified tools are mostly aimed at monitoring and evaluating water quality and, to a lesser extent, there were also tools focused on themes such as Groundwater, Hydrological Data, Assessment of Aquatic Ecosystems, Environmental Education, River Basin Management, Management of Land Use and Occupation, Water Supply, Irrigation, Assessment of Grants and Charging for the use of water, Payment for Environmental Services, Communication, among others (Table 3).

Table 2. Qualitative and quantitative analysis on the typology of the identified tools

Typology	Amount (n)	Tools
Computational tool	21	2, 7, 9, 10, 11, 12, 14, 16, 17, 21, 26, 27, 28, 29, 30, 31, 32, 33, 46, 47, 52
Indicators	18	18, 19, 20, 22, 23, 24, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 57, 59
Methodology	10	8, 34, 48, 49, 50, 51, 55, 56, 58, 60
Information system	9	1, 3, 4, 6, 13, 15, 35, 53, 54
Web platform	1	5
App	1	25
Total	**60**	**60**

Source: authors.

GWP[24] defined management tools as specific methods that allow decision makers to make informed decisions and adapt their actions to specific scenarios. Thus, tools can support water management and they can also express the adoption of principles on Water governance. Frameworks and analytical tools can foster awareness and build commitment within the participatory process of water resources management supporting the assessment of current water resources conditions and the development of solutions[25]. OECD has developed twelve principles on water governance, in a bottom-up process, involving a diversity of stakeholders, that provides a menu of options building on the diversity of legal, administrative and organizational systems and considers that there is no single solution to all water challenges worldwide[26]. The OECD Principles on Water Governance are based on three main dimensions of Effectiveness, Efficiency, and Trust and Engagement, providing a framework for understanding whether water governance systems are performing optimally and help to adjust them, when necessary[27]. These principles are somehow present in GWP Toolbox.

The identified tools were of a technical nature, as they were designed to monitor the quality of water resources, whether surface or underground, and they

[24] GWP, 2018.
[25] Borden; Goodwin, 2022.
[26] OECD, 2015.
[27] Akhmouch; Correia, 2016. Keller; Hartmann, 2020.

Table 3. Quali-quantitative analysis on the Application Focus of the identified tools

Application Focus	Amount (n)	Tools
Water quality	12	2, 3, 12, 16, 24, 25, 27, 36, 54, 56, 59, 60
Groundwater	4	1, 6, 15, 26
Aquatic ecosystems assessment	4	18, 23, 28, 45
Hydrological data	4	9, 13, 14, 29
Environmental education	4	51, 55, 57, 58
Watershed management	4	4, 31, 37, 47
Decision making process	4	34, 39, 40, 41
Water supply	3	17, 22, 35
Payment for environmental services	3	49, 50, 52
Municipal management water resources	3	42, 43, 44
Grant and charging	3	11, 21, 48
Water risk assessment	2	19, 20
Irrigation	2	7, 33
Environmental impact assessment	2	32, 53
Land use and occupation	1	8
Communication and information	1	5
User registration	1	10
Recycling and reuse	1	46
Coastal management	1	30
Water bodies classification	1	38
Total	**60**	**60**

Source: authors.

provided hydrological data. Some tools were intended for environmental applications, focused on the assessment of the quality of ecosystems and environmental impact. Tools for the assessment of water resources management instruments, such as grant and charging, were also found.

Tools related to the theme of environmental education and awareness were identified, but no specific tools were found connected to the training of managers and the participation of the community and other users. Only one tool was found for the processes of communication and dissemination of information among water users of the river basin, for the analysis of land use and occupation and for the registration of water users. It is important to note that identifying tools addressing these aspects, such as training for managers, community participation, and effective communication among water users, is essential in the context of IWRM. These aspects play a fundamental role in fostering sustainable water governance and enhancing the overall effectiveness of water resource management strategies.

Graphics 1 provides a clear and concise visualization of the distribution of tools identified and analyzed in each of the eight Toolbox GWP categories. Of the 60 identified tools, all met the category C1- Understanding Water Endowment; 33 tools met the category C2-Assessment Instruments; 59 tools met the category C3-Modeling and Decision-Making; 56 tools met the category C4-Planning for IWRM; 11 tools met the category C5-Communication; 53 tools met the category C6-Efficiency in Water Management, 8 tools met the category C7-Economic Instruments, and 21 tools met the category C8-Promoting Social Change. Only for subcategories C4.07-National Adaptation Plans and C7.03-Marketable pollution licenses there was no identified tool.

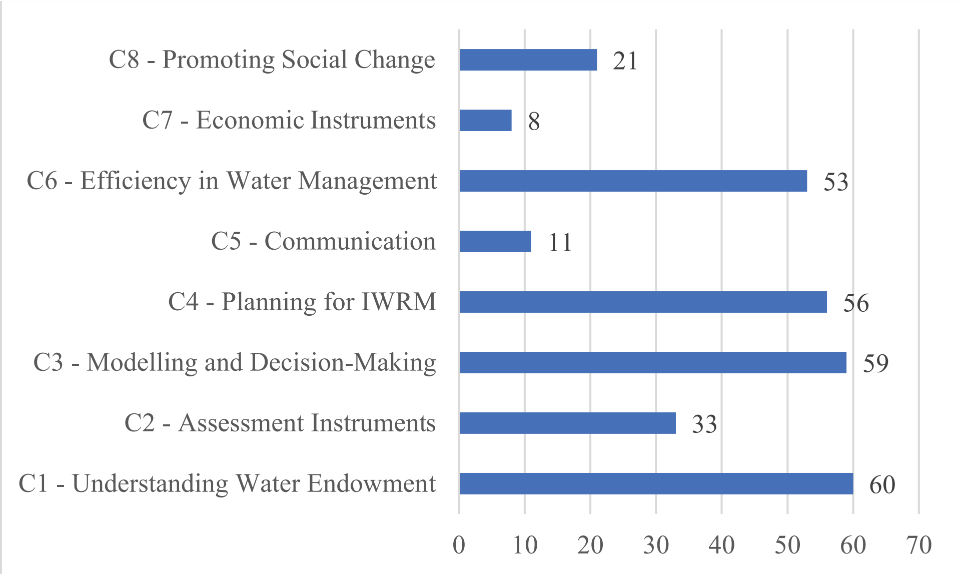
Most of the identified tools (35 %) were classified as Decision Support Systems (DSS). The DSS is an Information System that supports decision-making activities, which analyzes many variables, so that stands are taken on specific issues[28]. Decision Support Systems can be understood as ways of processing data into information, aggregating several databases of different natures and using models to build and analyze scenarios, with the purpose of subsidizing an appropriate decision making[29].

The results demonstrate that the identified tools meet most GWP ToolBox's analysis categories and, therefore, IWRM principles, and they can support best practices for water management at the local, regional or national level, supporting good water governance. Depending on the context of application and the needs diagnosed by users, the community or the technical team, some tools can be selected and used to support the decision-making process in the referred context. Thus, users must carefully evaluate each case and select the most suitable tools for IWRM.

Maps 1 shows the results of the geographic analysis of the number of tools identified in the study reveals different patterns among the federative units. The states of São Paulo and Rio de Janeiro stand out with the highest numbers, suggesting a significant concentration of activities related to the study and research of water resources management tools. Minas Gerais and Paraná also show significant participation. On the

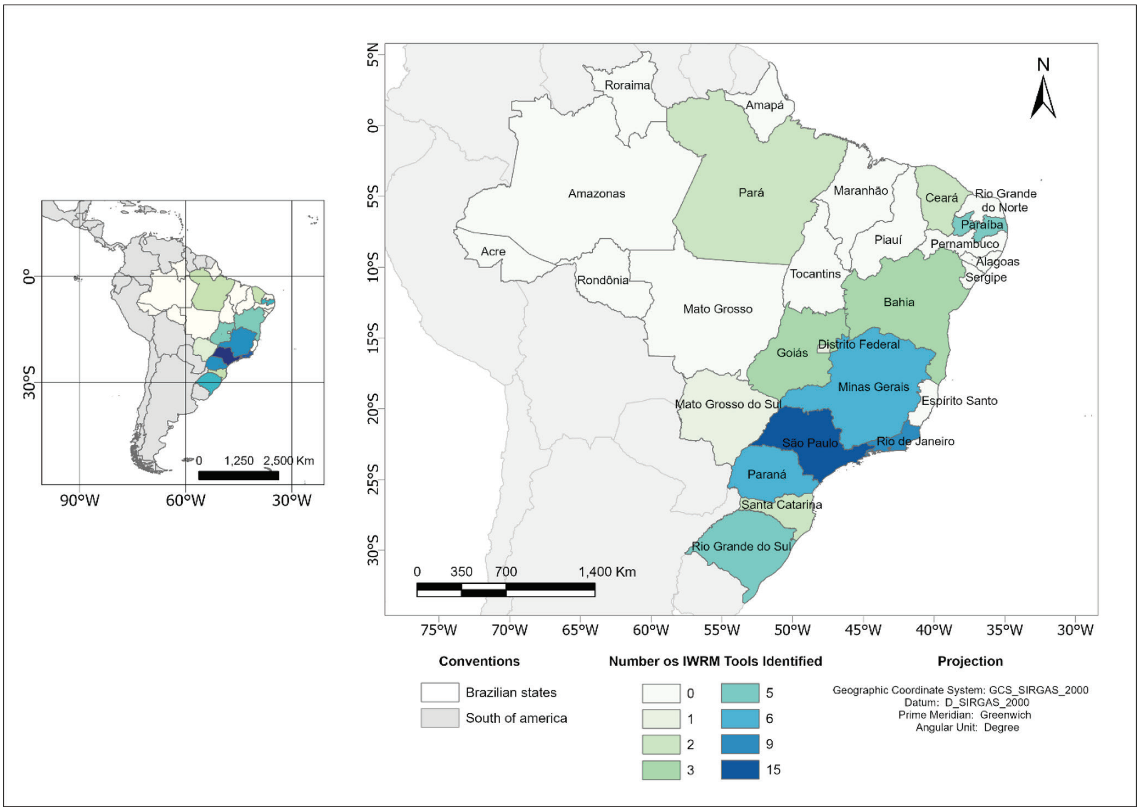
[28] Jannuzzi; Falsarella; Sugahara, 2014.
[29] Porto; Porto, 2008.

Graphics 1. Distribution of identified tools by GWP Toolbox categories



Source: authors.

Maps 1. Geographic distribution of the identified tools in Brazil



Source: authors.

other hand, some federative units, such as Rondônia, Acre, and Amazonas, did not present identified tools, indicating possible gaps in these locations. Detailed analysis by federative unit is essential to understand local contexts.

These results may reflect that, in Brazil, many states have already instituted their water resources policies, creating, for example, watershed committees, boards aimed at participatory and decentralized water resources management through the implementation of technical management tools, conflict negotiation, and the promotion of multiple water uses in the watershed[30]. Thus, water resources management tools are in different stages and levels of institutionalization and implementation. In 1991, São Paulo became the first state to approve its water resources law, preceding the implementation of the Federal Water Policy, which took place in 1997[31]. Therefore, these results may reflect the presence of watershed committees, concentrated in the Southeast and South regions of the country[32], as well as the number of universities and research centers focused on water resources. These elements highlight the influence of state policies and the presence of academic institutions in the observed results.

Contrary to popular belief, water crises are more related to governance failures than to water shortages or technical shortcomings[33]. The integrated management approach challenges conventional and fragmented water development and management systems, emphasizing coordinated decision making across different sectors and scales[34]. That's why integrated management demands a look beyond the tools itself in its traditional, common-sense meaning (corresponding to the Management Instruments-Tools C), encompassing the enabling environment (Tools A) and institutional arrangements (Tools B) as it can be seen in GWP Toolbox. An institutional reform and its arrangements can contribute more to the improvement of the water sector than the development of new technologies or infrastructure[35]. This can also be interpreted not as a disregard for management tools, but as a concern for their proper and integrated use of the current level of instruments, technologies, and infrastructure. Management tools, in turn, are how concrete planning and action ensures that an enabling environment and institutional arrangements are used to facilitate the implementation of IWRM.

In this sense, the integrated management approach challenges conventional and fragmented water planning and management systems, emphasizing coordinated decision making between sectors and scales[36]. Thus, according to the purpose of GWP Toolbox emergence, for an effective integrated management of water resources, it is essential that both institutional policies and arrangements and management tools are implemented consistently within a structured framework. This framework should also integrate different systems and processes, such as landscape-water[37] and coastal management-freshwater[38], and also articulate different scales of analysis[39].

The structure of the GWP ToolBox also encompasses an integrated assessment, considering a wide array from market instruments, demand and supply to communication channels between users, public awareness, water reuse and social assessment. Thus, all the tools that were identified and analyzed from the integrated approach of the GWP ToolBox can contribute to better water governance, helping to overcome the economic, social and environmental challenges related to water and achieving water security. The concept of water security has been adopted by the Global Water Partnership since the beginning of this century. The definition originally referring to safe, sufficient and accessible access to water, guaranteeing a healthy and productive life for people, sustaining livelihood and human well-being, and the environmental protection, was then expanded to encompass the protection against water-borne pollution and water-related disasters, and develop water management in a climate of peace and political stability[40].

Despite the different contexts, focuses and objectives, the identified tools did not meet some categories considered in IWRM, showing possible gaps in the construction, use and application of the tools. Through the identification and analysis of the current tools used in the management of water resources in Brazil, the present study shows how these tools are being developed and used in practical applications and provides an overview of the needs and possibilities of using these instruments in the search and construction of an integrated approach to water management.

The category of analysis *Understanding Water Endowment* (C1) of the GWP Toolbox[41], under the IWRM approach, comprises the endowment of water and its uses from social, environmental and economic perspectives, considering the holistic view of water resources. By relating environmental and socioeconomic aspects to water demand and supply, these tools help to

[30] ANA, 2021.
[31] Cerezini; Barbosa; Hanai, 2017.
[32] ANA, 2021.
[33] GWP, 2018.
[34] Galvez; Rojas, 2019.
[35] Koudstaal; Rijsberman; Savenije, 1992.
[36] GWP, 2018.
[37] Saito; Laques, 2021.
[38] Michels-Brito; Ferreira; Saito, 2023.
[39] Steinke et al., 2022.
[40] UN-Water, 2013.
[41] GWP, 2018.

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understand possible variations and responses related to water resources in different scenarios, conditions, geographic and time scales, considering the quantity and quality of surface and groundwater.

The balance between water demand and supply is crucial to ensure water security and avoid social conflicts over water supply, such as the one that happened in Correntina (Bahia), when people came into conflict with agribusiness sector and governmental authorities blaming the former for excessive water withdraw and the latter for the lack of regulation leading to unavailability of water for human consumption[42]. Likewise, restrictions imposed on consumption such as a rotation (alternation of water service on and off) in the regions, due to water supply interruption in Distrito Federal during the period of water rationing in 2018, highlight the importance of the theme[43].

Nevertheless, water security and environmental justice should be understood together, because the apparently democratic alternation of water service by rationing water distribution in moments of crisis hides social inequalities and different levels of capabilities to store water to face those days without water in the alternation calendar. IWRM and water security concept is a new arena of struggle for water rights[44].

Thus, the assessment of management practices, of the performance of policies and the results obtained regarding the achievement of sustainability objectives, through monitoring and assessment systems, shows that it is possible to make processes more efficient and help to redesign policies and programs aimed to an integrated water resource management[45].

Assessment Instruments (C2) are tools that, in addition to assisting in the assessment of scenarios associated with water use and management, also help in the analysis of scenarios in other sectors that may directly or indirectly impact the water resources sector. The assessment of risks in water endowment must consider the systemic analysis of the economic, social and environmental dimensions between competitive uses, to allow greater adaptability of the water management system[46]. Fresh water plays a critical role in maintaining the health of the ecosystem and in supporting human and economic development, so it is especially important to develop tools to assess water vulnerability and risks. In consequence, numerous efforts have been made in recent decades to develop water vulnerability indicators and indices to identify the main factors that offer insights into water-related risks and strategies that can be useful in reducing these risks[47].

With the aid of these tools, decisions made in other sectors, such as tourism or health, which may interfere with water management, must integrate the analysis in the planning process, contributing to the integrated water management[48]. Thus, the tools found in this research contribute to the promotion of water security, by enabling the analysis of economic, social, ecosystem and climatic risks. They assist in the adoption of appropriate measures, reducing and managing potential risks and vulnerability scenarios. The identification of risks and vulnerabilities provides subsidies for more efficient planning of development actions and activities.

The identified tools in this study, in the category *Modeling and Decision-Making* (C3), with a model-based methodology, simulate scenarios related to water balance, surface and underground water quality, hydrological data, supply and demand of water, collection and multiple uses of water, and are essential to generate information that provides basis for decision-making. Models are simplified descriptions and representations of reality, which assist in the interpretation of a system, through calculations and forecasts, making it possible to diagnose problems and assess scenarios. The models related to water systems integrate hydrological, ecological, environmental, economic, social, institutional and legal aspects related to water at the river basin level, to provide understanding on the functioning of these systems and simulate different scenarios[49].

However, such models do not consider other aspects that are also key to a better understanding of these different scenarios, such as ecological, environmental, economic, social, cultural, institutional and legal aspects. Many of these identified tools use Geographic Information Systems (GIS) as the methodology base, allowing the integration of spatial and geographic data in the construction of the models. As mentioned in the GWP Toolbox, the priorities of the stakeholders must also be addressed, in addition to technical issues, so that the modeling systems are useful in the search for solutions.

42 Aly Junior, 2019.
43 Brandão; Paviani, 2018.
44 Saito, 2018.
45 GWP, 2018. Ferrer; Gómez, 2023.
46 Silva; Souza-Filho; Aquino, 2017.
47 Gleick, 2015.
48 GWP, 2018.
49 Fan; Collischonn; Rigo, 2013. Almeida; Serra, 2017.

Thus, such tools configure Decision Support Systems (DSS), by allowing the aggregation and processing of different data into accurate information, which will help in the construction and analysis of scenarios, supporting qualified decision-making. DSS can facilitate decision making in complex scenarios, such as water resources management, in addition to promoting dialogue between users and allowing for the discussion and interpretation of pieces of information that reflect different points of view and scenarios[50].

Some DSS are developed to assist in scenario modeling, to solve water system optimization problems to achieve a robust decision policy that should minimize the risk of wrong decisions[51]. Although the various DSS developed for the management of water resources, the need to develop new decision support tools in this field is widely recognized, aiming at obtaining a better understanding of the risks and contributing to the improvement of decision making in water management[52].

Despite tools such as the DSS being very popular in the literature on water resource management, Giupponi and Sgobbi[53] indicate that the priority efforts should not focus on the development of tools, but rather on improving the effectiveness and applicability of legislative and regulatory structures, from integrated water resource management planning, training and capacity building, networking and cooperation, harmonizing transnational data infrastructures and, most importantly, learning from previous experiences and adopting improved protocols for the development of DSS. More, tools are instruments, and behind the choice of variables to combine in a GIS environment, it is necessary to make the correct choices, considering commitment to social justice and the human rights to water[54].

Planning for IWRM (C4) is essential in the integrated water management process, as it refers to the formulation, analysis and presentation of management strategies[55]. The plans for integrated water resource management are among the instruments in the National Water Resources Policy (Brazil, Law nº. 9.433/97), which consist of management actions to regulate the use, conservation, and protection of water resources, to balance economic development and the maintenance of ecosystems. Aiming at integrating the different uses of water, the plans are drawn up for the river basins at states and country levels, with the perspective of implementing the programs and actions in the short, medium, and long terms.

For the development and effective implementation of these plans, it is important to promote the participation of civil society, users, government agencies and the various institutions and stakeholders that are involved in the management of water resources and that are affected by sector decisions. As well emphasized by the GWP Toolbox[56], this process must consider the development of scenarios within the sector itself and also the relationships between other sectors that may have an impact on water resources, such as, for example, agriculture, navigation, tourism, industry and health. These scenarios should be visualized with the help of tools such as the SWOT technique (the Strengths, Weaknesses, Opportunities, and Threats), so that planning efforts could consider multiple uses, stakeholders disputes, and policy focus[57]. Based on the evolution of the water security concept, planning must include not only access to water but also the prevention of waterborne disasters[58].

A very integrated water management planning at basin level should also include river basin revitalization as a broader framework than a simple restoration concept, through careful planning capable of amplifying effects that improves water quantity and quality towards a sustainable use of water and the promotion of water security[59].

In addition to assisting in the construction and preparation of these plans, the identified tools are also useful in the planning process of the actions and projects forecast, as well as in the continuous monitoring of the implementation of these plans, ensuring the necessary adjustments to the dynamic development process. Integrated approaches to water resources planning and management imply the need to consider the social, economic, and environmental aspects of water use[60]. These tools also assist in the assessment of social, economic and environmental dimensions, supporting the development of plans that promote integrated water

50 Porto; Porto, 2008.
51 Pallottino; Sechi; Zuddas, 2005.
52 Mysiak; Giupponi; Rosato, 2005.
53 Giupponi; Sgobbi, 2013.
54 Saito, 2018.
55 Koudstaal; Rijsberman; Savenije, 1992.
56 GWP, 2018.
57 Pinto-Filho; Cunha, 2022. Cacal; Taboada; Mehboob, 2023.
58 Branco; Saito, 2017.
59 Rosa; Morais; Saito, 2021.
60 Giupponi; Sgobbi, 2008.

resources management, in a holistic approach of this system.

The identified tools in the category *Communication* (C5) are important instruments to promote an effective communication between the parties involved in water resource management, supporting the establishment of dialogue channels, consensus building and conflict management, inherent to complex systems, whose priorities and views are usually divergent. Communication between the parties is essential in the implementation of IWRM throughout the planning, management and monitoring process, systematizing and assessing different types of data and scenarios, identifying and solving problems and dealing with divergences, as well as establishing plans and actions[61]. Thus, democratic management must be a basic pillar in building consensus, based on a shared view that contemplates the different viewpoints and arguments of the groups involved, and this is only possible through effective communication[62].

As identified by Olsson and Andersson[63], for the successful use of management tools aimed at communication, some factors are fundamental: awareness and preparation to deal with restrictions related to communication; transparency of the tools and data used and the uncertainties involved; mutual respect between experts and stakeholders and between stakeholder groups involved; a robust institutional network; and sufficient time for dialogues. The use of tools to strengthen communication processes requires the development and use of participatory modeling strategies, based on continuous dialogue between experts and stakeholders, to facilitate water resources management[64].

Communicating information to all the parties involved is a way of contributing to and promoting democratic water management. However, to ensure effective communication, it is important to know the interlocutor and adapt the information so that it is accessible to this audience, to convey the message clearly to establish a meaningful dialogue. Communication is not restricted to providing information, but also exchanging it in a two-way process where feedback processes must be implemented, to allow a significant interaction between stakeholders. Therefore, it is essential to identify the stakeholders and establish platforms or communication channels, as well as a set of principles on effective communication[65].

The identified tools in the category *Efficiency in Water Management* (C6) are intended to analyze the efficiency of the endowment of water resources, granting the right to use, monitoring quality and hydrological data, as well as water reuse in production processes. This category is related to item C1-*Understanding Water Endowment*, and it assists in the management of water demand and supply in different systems, to establish water supply limits and implement management strategies that ensure an efficient use of water resources, in several sectors and levels, from the river basin to water users. The current challenges faced by Brazil regarding the efficient management of water use involve issues related to the quality and quantity of water resources in large cities, rural development and irrigation, hydro energy, water use in the supply and sanitation sector, health and preservation[66]. Thus, the use of these tools provides a better understanding of the multiple needs of water, ensuring water security from the perspective of the IWRM, to meet the needs of all water users in a balanced way, without compromising the needs of future generations.

However, to meet the various needs of water use with equity, from the perspective of IWRM, a change in the technical management model is also necessary, focused on increasing the water supply, in an approach that prioritizes demand management, through more efficient water uses by users[67]. This paradigm shift in water resources management is related to economic instruments (item C7 of GWP ToolBox) and, particularly, to instruments of social change (item C8 of GWP ToolBox). Strategic changes in the management of water demand, supply and (re)use can be highly effective in the overall consumption of water, especially in regions with inadequate water supply[68].

The identified tools in the category *Economic Instruments* (C7) of the GWP ToolBox are capable of assisting in the assessment of pricing for water services through tariffs and charges for the extraction of surface and underground water resources; valuation of ecosystem services provided by water bodies, springs and aquatic environments. These tools support the subsidies for environmentally correct practices for the preservation

[61] Empinotti; Jacobi; Fracalanza, 2016.
[62] Machado, 2003. Cerezini; Barbosa; Hanai, 2017.
[63] Olsson; Andersson, 2007.
[64] Olsson; Andersson, 2007. Berlinck; Saito, 2010.
[65] GWP, 2018.
[66] Tundisi, 2008.
[67] GWP, 2000. UNESCO, 2019.
[68] GWP, 2018.

of river basins and water quality improvement; and other financial incentives for actions that promote the efficient use of the resource. Examples of economic instruments (EIs) include pollution taxes, water markets and tradable licenses, subsidies and payment for environmental services. EIs can be efficient means of promoting integrated water resources management for user sectors, including access to water services, socio-economic benefits, ecosystem protection, improvement in water quality and overall poverty reduction, providing means to manage scarce water resources[69]. Thus, the use of EIs can be a reasonable way to encourage conscious consumption, stimulate the sensible use of water, regulate the excessive extraction of water resources and avoid environmental and ecological damage.

However, as emphasized by GWP[70], such instruments should complement the institutional, regulatory and technical tools used in water management. They are not effective alone, nor do they replace other water governance instruments, such as monitoring, regulation and enforcement of environmental and public health standards, within an appropriate legal and institutional framework. They can also lead to a more environmental injustice situation if it is guided only by economic interests[71]. The use of market-based economic instruments in environmental management, such as charging for the use of water, causes a change in the rational behavior of this resource use in the short term[72].

Additionally, for a long-lasting result and conflict resolutions, the necessary cultural change must be promoted by raising awareness of water conservation, which is supported by environmental education actions[73]. Considering all these, in view of the growing involvement of the private sector in the management of water supply worldwide, it is important to note that water must be perceived as a common use good, and not as a "commodity", considered as a resource available for purchase and sale[74] as economic instruments (EIs) can easily lead to.

The tools used for *Promoting Social Change* (C8), with methodologies based on the concepts of Water Footprint and Virtual Water, include information on water use and demand in different sectors. This dimension helps consumers to comparatively analyze the impacts related to water resources in manufacturing products, goods and services, supporting more adequate consumption choices towards sustainability and pressuring companies to adapt to environmental issues. The tools aimed at teaching, environmental education and research practices to allow the promotion of sensitization and awareness of the community and users, expanding the understanding of water-related problems. These tools are instruments for joint diagnosis, planning and monitoring that promote the creation of shared visions and encourage individuals to become agents of transformation of their reality. These tools are, therefore, important instruments of social change, as they enable the participation of the stakeholders in water planning and management decisions, in the claim of their rights and in the fulfillment of their duties[75].

According to GWP ToolBox[76], education and training are basic pillars for social change, both inside and outside a school environment, because when people learn about water and the impacts caused by human action on water resources, they can become aware of the importance of adopting more sustainable practices, generating positive impacts on local and global water issues. Thus, such tools aimed at increasing public awareness, through educational processes, provide society with essential data and information for building knowledge about the use and management of water, supporting the community in the processes of participation and decision and in social practices of water resource management[77]. Educational processes can assist in scientific literacy, and the domain of knowledge and the ability to reason based on science can mediate conflicts over water use, contributing to strengthen participatory management of resources water resources[78].

An Expert Panel developed in Brazil aiming to identify the most primary challenges and guidelines for water management found out that Knowledge and Education was considered the top challenges, which demanded the following guidelines for action: a) Implementing environmental education at all levels of formal and non-formal education continuously and in an integrated manner; b) Developing engaging educational materials about water resources;

[69] Cantin; Shrubsole; Aït-Ouyahia, 2005.
[70] GWP, 2018.
[71] Santos; Saito, 2006.
[72] Forgiarini et al., 2010.
[73] Santos et al., 2005.
[74] Bakker, 2007.
[75] Jacobi; Francalanza, 2005.
[76] Thalmeinerova et al., 2017. GWP, 2018.
[77] Berlinck; Saito, 2010.
[78] Santos et al., 2005.

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c) Incorporate education as an instrument of water resource policies; d) Creating formative processes directed towards managing authorities, committees, and stakeholders involved in the National Water Resources Management System; and e) Establishing partnerships with universities, educational institutions, and research entities to promote educational activities and capacity-building[79].

The second principle of the Dublin Statement on Water and Sustainable Development says that “Water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels”[80]. Participation requires that stakeholders at all levels of the social structure can have an impact on decisions at different levels of water management[81].

Mostert and collaborators[82] discuss social learning to implement IWRM, address its main components and present some experiences, through a review of the GWP Toolbox. The authors conclude that the social learning approach can be considered the key to the implementation of IWRM, and their approach has several implications for the GWP Toolbox, as a framework for analyzing and promoting collaboration between stakeholders in the search for developing effective solutions for all parties in water management[83]. Participation requires the introduction of new paradigms in knowledge and knowledge sharing related to the empowerment of disfavored groups, the search for new political spaces at the public sphere, and the production of new social practices[84]. Thus, the need to consider integrated approaches and social aspects of water use is highlighted, in addition to the economic and environmental spheres, as only with participation at international, national, regional and local levels it is possible to ensure transparency and responsibility for the political decision-making process in water management[85].

Conclusions

This study allowed the identification, characterization and analysis of tools that can assist in the planning and management of water resources in river basins, providing managers, users and the community with tools that assist in decision-making processes. The identified tools can contribute to the integrated management process, indicating solutions to problems associated to water resources management, through models, techniques and indicators related to economic, educational, political, environmental and social aspects, assisting in the identification of gaps and suggesting ways to build a sustainable water management.

The referred tools meet specific goals, but they can also interrelate and be applied together with tools for different applications, as they are flexible, interdisciplinary instruments that help in the search for complementarity, transversality and integration of dimensions in the analysis of scenarios and in making the right decision. For example, Tool 1-Information Systems (that includes data on groundwater), was identified by its use in the assessment of economic instruments for regulating water use. It also meets the category of promoting social change, by increasing public awareness of access to information, assists in the analysis of water demand and supply, serves as a data collection and monitoring and evaluation system, in addition to providing a communication channel as it is an information system, and finally it can be considered as a decision support system.

The keywords set out in Filter 1, covered all aspects related to water management. Filters 2 and 3 allowed to classify and analyze the tools to specify them, facilitating decision making on the appropriate focus and context for its application, and the final analysis of the categories of C part of the GWP ToolBox allowed an integrated assessment of the possibility of use of the tools. The filters developed were adequate for the classification and characterization of the tools and allowed data systematization and organization.

Most of the identified tools are technical and aimed at assessing the quality of river waters and for hydrological monitoring. Fewer tools were identified aimed for registration of users, assessment of groundwater use and occupation, communication and dissemination of information, among other purposes that contemplate environmental, economic and social aspects of water resources management system and river basins.

The present study provided insight into how the tools can help in the management of water resources from the point of view of integrated approach and demonstrate the diversity of tools available in a country of great complexity with regard to needs, contexts and

79 Cerezini; Hanai, 2023.
80 ICWE, 1992, 4.
81 GWP, 2000.
82 Mostert; Craps; Pahl-Wostl, 2008.
83 Mostert; Craps; Pahl-Wostl, 2008.
84 Santos et al., 2005.
85 Giupponi; Sgobbi, 2008.

natural resources like Brazil. It is hoped that the study can contribute to the integrated management of water resources in Brazil and serve as reference for future studies and assessments on tools for the management of water resources, in support of IWRM themes.

This paper sought to fill the gap in studies that provide the current theoretical and methodological frameworks for the integrated management of river basins, according to a systemic view of sustainable development, to overcome the current management limitations and face the challenges of the complex socio-ecological reality. systems. In this way, the present study offers a valuable contribution, by presenting information on the state of the art of tools that can be applied to the planning and integrated management of water resources.

Finally, the procedures used here can support new methodologies, to help the identification of tools that are being developed and applied in different contexts, both on a local and global scale, to assist in the development and construction of new tools that address the desired aspects of IWRM and support the planning and integrated management of water resources in Brazil.

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