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Review

Comparative Analysis of Water Sustainability Indices: A Systematic Review

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Abstract: The achievement of water sustainability necessitates the development and application of comprehensive assessment tools to monitor and evaluate the impact of water resource management. This article presents a comprehensive comparative analysis of various water sustainability indices, emphasizing their underlying principles, methodologies, and potential applications. Our study reveals the diverse landscape of existing indices, illustrating that even indices with similar names can vary significantly in scope and methodology. Via a systematic review of 124 publications, this study provides insights into existing composite indices related to water sustainability, highlighting their specific applications and potential contributions to water resource management and sustainability. The information gathered from the selected papers was synthesized and analyzed thematically to identify common patterns through keyword co-occurrence mapping, SDG mapping, standard review protocols, and cluster analyses. Through a cluster analysis, we identified six distinct clusters of indices, highlighting the need for careful consideration in selecting appropriate ones. Moreover, our analysis of co-occurring keywords underscores the close relationship between sustainable development, water resources, water supply, and water conservation within the context of water-related indices. Notably, these indices address not only sustainable development goal six but also a number of other interconnected goals. It was also found that "sustainability index" is a common name for different nature water indices. This review also identifies research gaps in the existing literature. However, significant limitations exist, including a lack of historical application and future projections for many current water sustainability indicators. Without the ability to track changes over time and project the future, identifying areas of improvement and measuring progress toward long-term water sustainability goals becomes challenging. Furthermore, many indices are complex and designed for watershed or regional levels, limiting their adaptability to different contexts. Despite these challenges, indices remain valuable tools for assessing and managing water resources sustainably, addressing various dimensions of sustainability, and supporting decision-making processes across different sectors and contexts.

Keywords: water sustainability indices; systematic review; SDG6; water resource management; water sustainability; water resource sustainability

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1. Introduction

Water sustainability refers to the ongoing and adaptable condition in which water resources are effectively managed, ensuring harmonious equilibrium between the requirements of humans (such as economic, social, and health needs) and the environment [1]. It involves a comprehensive approach that aims to meet the present demands for water while safeguarding the ability of both natural and human components of water systems to meet the needs of future generations [2]. The concept of water sustainability is particularly important with increasing anthropogenic stress, such as population growth, rapid urbanization, industrial development, and climate change impacts, where the availability and quality of freshwater resources have come under severe strain [3]. This crisis not only threatens human well-being but also jeopardizes ecosystems, agricultural productivity, and economic stability [4–6]. Water sustainability is very complex. Both at the macro- and the micro-level, socioeconomic development, and status have a significant impact on water quality, as highlighted in several studies. For instance, Feng et al. (2021) found that the economic development level of a region has a direct relationship with the quality of its water resources, with a higher economic status associated with better water quality [7]. Similarly, Barman et al. (2022) argued that social and economic factors, such as income level, education, and population density, are closely associated with water quality in urban areas [8]. Attaining water sustainability is an urgent and multifaceted challenge that demands immediate attention and concerted efforts from governments, organizations, and individuals worldwide [9], even more so as it forms an important backbone for sustainable development in general [10]. The importance of water sustainability for human well-being is also reflected in the 17 sustainable development goals established by the United Nations in 2015 as part of the 2030 agenda for sustainable development [11,12]. Sustainable development goal six (SDG6), which focuses on ensuring access to clean water and sanitation for all, has connections with several other SDGs [13], and it is necessary for achieving sustainable development [14]. Thus, to effectively address these sustainability issues pertaining to water quality and quantity and to ensure the long-term sustainability of water resources, it has become imperative to develop comprehensive water-related sustainability assessment tools such as sustainability indices [15]. Morris (2019) stressed the need for the development of indices to monitor and measure progress towards SDG 6 [16]. Such sustainability indices should concern a wide range of factors that impact both water quality and quantity. By utilizing specific indices designed to evaluate the effectiveness of existing policies and identify gaps, decision-makers can refine regulatory frameworks, enhance institutional coordination, and foster collaboration among stakeholders [17]. Additionally, comprehensive assessment tools can shed light on the socio-economic dimensions of water scarcity, including equitable access to water, social implications, and potential conflicts, thereby facilitating the development of strategies that consider the needs and aspirations of all segments of society [18]. Besides tracking changes in the indices over time, water sustainability indices can also be used to assist in decision-making based on evidence [19,20]. This is particularly important in the context of complex and dynamic socio-environmental systems that require integrated and adaptive approaches [21]. While index-based assessment tools may not capture the full system complexity, they are pragmatic approaches for evaluating water management policies, governance frameworks, and institutional capacities [22,23]. These tools have the potential to serve as indispensable aids in evaluating the current state of water resources, understanding the factors contributing to their degradation or improvement, and guiding the formulation of appropriate strategies for sustainable water management. However, with the emerging number of such indicators, there is a need for more systematic reviews [24]. However, the rapid expansion of the available tools and indicators to assess water sustainability has resulted in a proliferation of options, which in turn has led to a state of confusion among users and researchers alike [15,19,24]. Thus, with the increasing awareness of water-related challenges and the complexity of water systems, researchers and organizations need to have a clear picture of the wide array of tools and indicators to measure different aspects of water sustainability, including water quantity, quality, governance, and socio-economic factors. By providing clarity in the selection and utilization of tools and indicators, researchers and practitioners can enhance the effectiveness and comparability of their assessments, ultimately contributing to more informed decision-making and sustainable water management practices [25,26]. Using appropriate tools could enable a more holistic understanding of the complex dynamics surrounding water resource sustainability and pathways to water quality improvement, thereby safeguarding this vital resource for present and future generations [27,28]. As the number of tools and indicators for assessing water sustainability continues to grow, maintaining clarity and discernment regarding their similarities, differences, and strengths becomes paramount to making informed decisions about their utilization [24].

This paper addresses the need for clarity in selecting and utilizing water sustainability assessment tools, focusing on both their methodologies and potential applications. The comparative analysis aims to elucidate the landscape of various water sustainability indices, aiding informed decision-making in water resource management. As the paper delves into a comparative analysis of various water sustainability indices, it underscores two primary focuses: (1) examining these indices and (2) providing insights into how they are referenced, analyzed, and applied. By accurately understanding water sustainability indices and exploring the underlying principles, methodologies, and potential applications, this study seeks to elucidate the landscape of water sustainability assessment tools and contribute to informed decision-making in water resource management.

2. Materials and Methods

The systematic review followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. It comprises 27 sub-items, encompassing well-defined stages in the systematic review process [29]. Within the framework of PRISMA, this systematic review investigates the use of water sustainability indices for sustainable water resource management.

2.1. Eligibility Criteria

The eligibility criteria, delineating the boundaries of the systematic review, were established through a collaborative meeting among the authors. Subsequently, these were used to screen the information collected during the database search stage.

We established the following inclusion criteria: (1) works related to water sustainability indicators: articles had to be dedicated to sustainability indicators specifically related to water. This criterion ensured that the selected papers addressed the assessment and measurement of sustainability aspects within the context of water; (2) articles reporting the comprehensive development/modification and application of indicators dealing with water sustainability. This criterion ensured that the selected papers contributed to the advancement of knowledge in terms of developing or refining indicators used to assess water resource sustainability; (3) papers with full-text access; (4) articles published from inception to 19 May 2023.

The exclusion criteria were: (1) works published in a language other than English; (2) dissertations and proceedings of conferences; (3) books or book chapters; (4) editorial material.

2.2. Information Sources

The Scopus database was used for the literature search and initial data collection. It was selected as the most comprehensive platform for scientific publications and is easy to access through university accounts.

2.3. Search

The keywords were selected through an iterative process by all the authors of the current systematic review. The Boolean strings (also using a wildcard) chosen for the present systematic review were: ((TITLE (index) OR TITLE (indices)) AND (TITLE (water) OR TITLE (river) OR TITLE (lake) OR TITLE (sea)) AND (TITLE (sustainable) OR TITLE (sustainability))). The search focused only on the title.

2.4. Study Selection

The title, abstract, keywords, authors' names and affiliations, journal name, year of publication, DOI, and link of the identified records were exported to an MS Excel spreadsheet and proceeded for the subsequent screening.

The papers were initially assessed based on their titles and abstracts to determine their relevance to the research questions. Papers falling beyond the eligibility criteria were excluded, and papers satisfying the criteria underwent a full-text review. A total of 124 papers were collected at the early stage, and after the screening process, 62 papers were identified as eligible for (Supplementary Materials, S.M.1) inclusion for in-depth review according to the protocol (Table 1).

Table 1. Review variables.

Variable	Value	Explanation
1. Addressed SDGs (directly and indirectly)	1 = SDG 1: No poverty, 2 = SDG 2: zero hunger, 3 = SDG 3: good health and well-being, 4 = SDG 4: quality education, 5 = SDG 5: gender equality, 6 = SDG 6: clean water and sanitation, 7 = SDG 7: affordable and clean energy, 8 = SDG 8: decent work and economic growth, 9 = SDG 9: industry, innovation, and infrastructure, 10 = SDG 10: reduced inequality, 11 = SDG 11: sustainable cities and communities, 12 = SDG 12: responsible consumption and production, 13 = SDG 13: climate action, 14 = SDG 14: life below water, 15 = SDG 15: life on land, 16 = SDG 16: peace, justice, and strong institutions, 17 = SDG 17: partnerships for the goals). Multiple goals can be listed.	Categorizing the index's role in the realization of sustainable development goals, including water-related goals (SDG 6 and 14).
2. Input data time frame	1 = Historical, 2 = historical to present, 3 = present, 4 = historical to future, 5 = current to future, 6 = future, 7 = dummy data	Referring to the specific duration or period over which the data are collected and analyzed.
3. Input data domain	1 = Social; 2 = institutional; 3 = economic; 4 = built/infrastructure; 5 = environmental	Its complexity explains the range of the variable and the index
4. Water data as the input	1 = Water quality, 2 = water quantity/availability (including moisture), 3 = water quality and quantity, 4 = no water-related parameters	Identifying the role of the water quality and quantity in computing the index.
5. Number of variables (raw data or parameters) used as the input	1 = 1–10, 2 = 11–20, 3 = 21–30, 4 = 31–40, 5 = 41–50, 6 = 51–60, 7 = 61 and above	Expressing the difficulty of obtaining a complete set of the data for the calculation.
6. Data sources	1 = Primary data, 2 = secondary data, 3 = primary and secondary data	Expressing the difficulty of data collection for computing the index.
7. Geographical scale/area	0 = Not specified, 1 = rural 2 = urban, 3 = regional/watershed, 4 = national, 5 = transboundary or global, 6 = institutional/business	Expressing the scale for which the index was designed or applied.
8. Projecting future water sustainability	1 = yes, 2 = no	Identifying if the index can elicit future results.
9. Application of the indicator	1 = General sustainability of water resource management; 2 = river water basin management; 3 = water supply; 4 = agriculture; 5 = wastewater management; 6 = water quality; 7 = regional sustainable development; 8 = project evaluation, 9 = water resource conservation; 10 = energy production, 11 = watershed/nature conservation; 12 = flood management; 13 = water security	Explains the application field or sector for which the index was designed or applied.

As per the PRISMA methodology, the review team consisted of two authors to ensure that the measures were implemented to minimize random error and bias in all stages of the review process. Two authors independently reviewed the titles, abstracts, and full texts of the potential inclusions; moreover, both authors evaluated the articles against the inclusion or exclusion criteria set in the eligibility criteria section. Any disagreements on the selection process for a given reference were resolved through a discussion of all the authors of the present systematic review. This section is important to ensure that there was no bias or error in the review.

2.5. Data Items

Qualitative analyses of the selected items were conducted, and the information was extracted using the nine variables listed in Table 1.

2.6. Data Collection

VOS viewer software (version 1.6.19(0)) was used for the bibliometric data analysis to directly identify co-occurring keywords of the articles [30]. Together, the author's keywords and index keywords were taken for analysis. Secondly, all index names were replaced with a single keyword, "index". Co-occurrence was limited to those keywords present at least three times. The same software was used to identify the linkages between different SDGs when treated using different indicators. The minimum co-occurrence was set at one. Additionally, cluster analysis, a statistical technique used to classify objects or cases into groups based on their similarities or dissimilarities, was employed [31]. IBM SPSS Statistics ver. 29 was used to perform the hierarchical cluster analysis using variables with squared Euclidean distances. This method organized the variables listed in Table 1 into a dendrogram. The clusters were based on how closely related they were to each other in terms of their values. The number of clusters was visually determined by examining the dendrogram to identify points where the distances between the clusters were relatively large, with a significant increase in distance, i.e., represented by a longer vertical line, compared to earlier levels. The number was also guided using the empirical method, which is a number of clusters $\approx \sqrt{n/2}$ for a dataset of n points [32].

2.7. Synthesis of the Results

No meta-analysis was conducted, as all the articles included in the present systematic review needed more statistical information to calculate the necessary effect sizes. This is considered a qualitative systematic review [31,33,34], which synthesizes the results, focusing on the empirical trends in the data.

3. Results

3.1. Study Selection

A flowchart of the review process is shown in Figure 1, with the steps and corresponding numbers. Initially, 124 works were identified and subjected to duplicate checks and other screening methods, as reported in the figure, eliminating 50 works in total. Afterward, a full-text review was conducted for 74, in which 12 works were excluded based on the selection criteria (non-English publications, anonymous works, review papers of multiple indices that did not introduce a new index and irrelevant topic indices), and 62 were retained in the final analysis of the systematic review (Supplementary Materials, S.M.1).

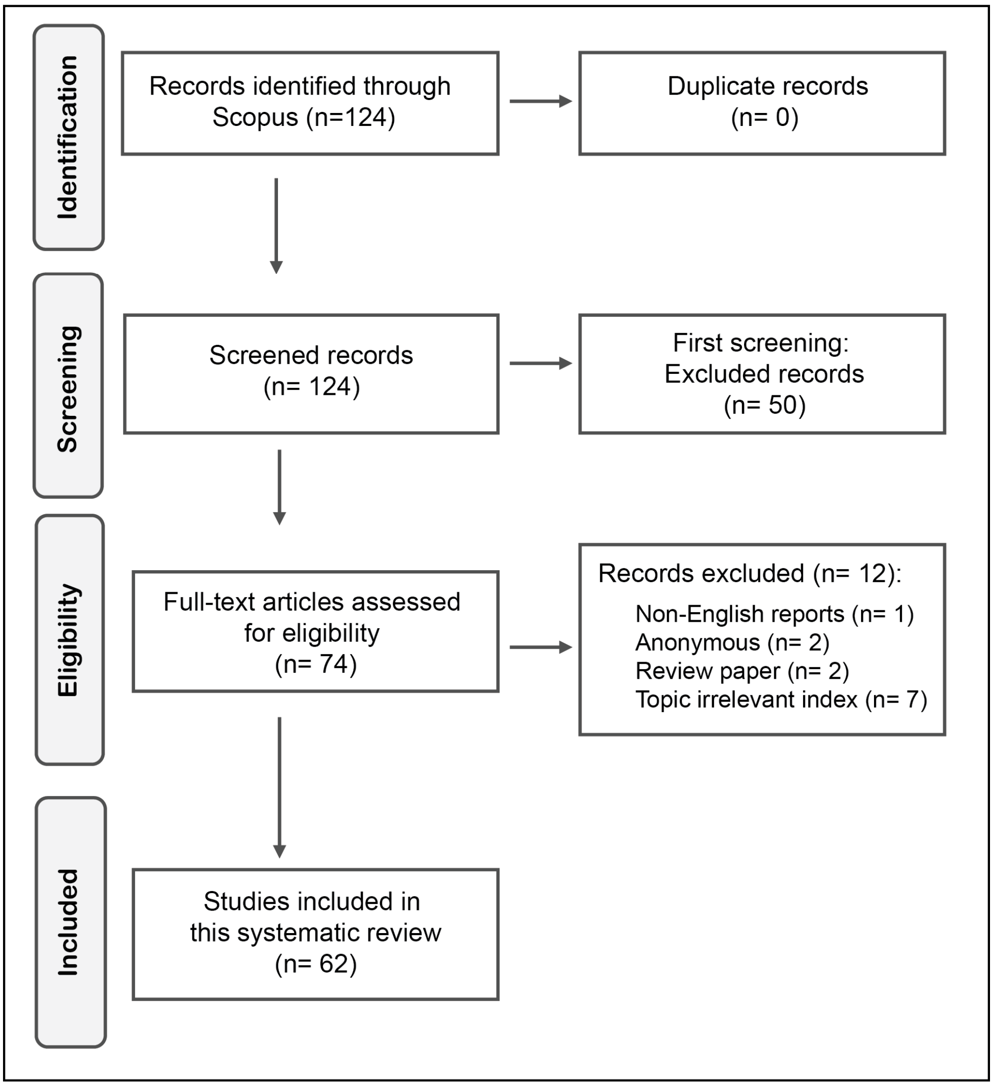

Figure 1. Study selection flow diagram.

3.2. Biometric Network Analysis

In bibliographic VOS viewer software (version 1.6.19), we identified 648 keywords, and after the alternations, the keywords containing the given name of indices, coded as "index" left 629 keywords. Out of those, 59 keywords were used at least three times. Figure 2 shows the interconnections between the 59 most frequently co-occurring keywords. The analysis revealed five distinct sub-groups within the field of water- and sustainability-related indices. The first sub-group revolved around the interconnected themes of sustainability, rural areas, and water supply. The second sub-group focused on the crucial aspects of water quality, availability, water loss, and conservation within the framework of sustainability. The third sub-group encompassed diverse topics, such as decision-making processes, risk assessments, climate change impacts, irrigation practices, river management, and water pollution. The fourth sub-group adopted a more technologically advanced approach by incorporating artificial intelligence, models, statistical analyses, runoff patterns, and quality control methods. Finally, the fifth sub-group focused on integrated water management and water planning, specifically in the context of reservoirs and underground water sources.

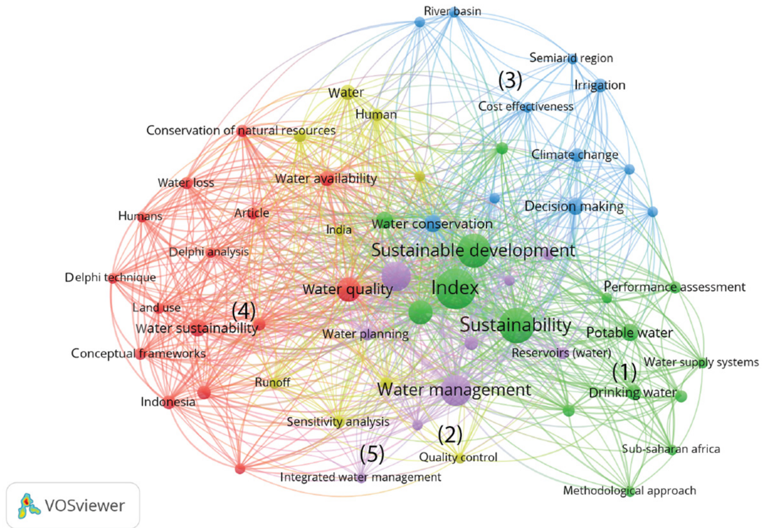

Figure 2. Co-occurring keyword sub-groups. Note: The numbers correspond to each of the five sub-groups.

In SDG mapping, we identified 10 SDGs, for which co-occurrence is presented in Figure 3. While SDG6 was the central goal, there were five identified groups: (1) SDG 1 (no poverty) and SDG2 (zero hunger), (2) SDG 13 (climate action) and SDG7 (affordable and clean energy), (3) SDG 11 (sustainable cities and communities) and SDG 14 (life below water), (4) SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production), and (5) SDG 15 (life on land), denoted in blue, yellow, green, red, and purple colors, respectively. Water-related goals, such as SDG 6 [35] and SDG 14 [36], are particularly notable, emphasizing the significance of water sustainability in the broader context of sustainable development. In all publications, the input data time frame for the research study encompassed different periods, with the largest portion (63% of the reviewed publications) focusing on the present. Additionally, 27% of the data of the reviewed publications spanned from the historical period to the present. A smaller percentage (6% of the reviewed publications) were considered historical to future time frames. Lastly, 3% of the articles comprised dummy data for index calculations, serving as a control or placeholder within the study.

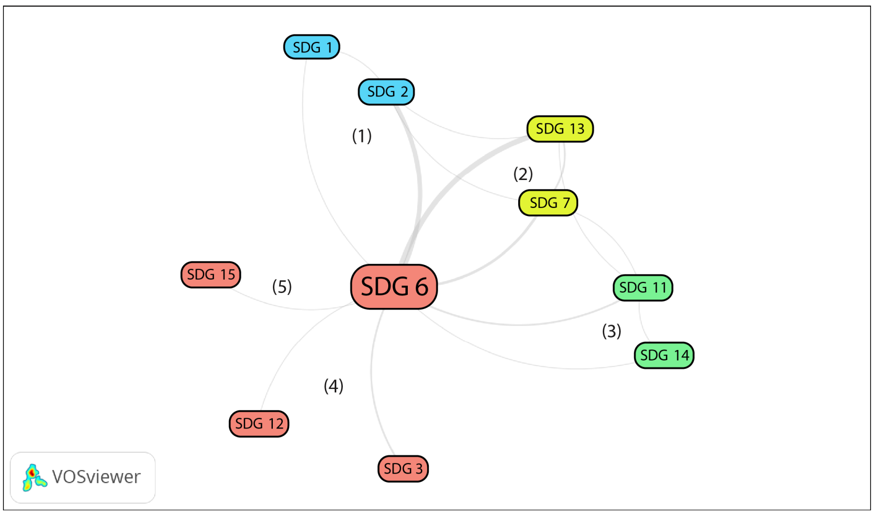

Figure 3. SDG co-occurrence. Note: The colors and numbers in parentheses denote the groups.

The reviewed publications presented indices that were applied globally (Figure 4), with 16% of the publications demonstrating or developing indices in more than one country.

In the majority of the publications, index implementation (71%) focused on regional or watershed scales. Urban areas accounted for 10% of the index application. Similarly, the indices designed or applied at a national scale consisted of 10% of the reviewed publications. Rural areas accounted for 8% of the index application. Lastly, business entities represented 2% of the scale. The data sources comprised a combination of primary and secondary data in seven publications (11% of the reviewed publications), while data in fifty-two publications (84%) was obtained from secondary sources alone. Only three publications (5%) used data derived directly from primary sources (Supplementary Materials, Table S1). Figure 5 presents the domain of the input data. It states that variables from all domains, i.e., social, economic, environmental, institutional, and built/infrastructure, were applied in 44% of the reviewed papers, and in 16%, variables from one domain were applied. Figure 6 describes the representation of different variables from the water data inputs of the indices. It revealed that combined water quality and quantity were largely used, whereas water quality received more attention as a separate parameter.

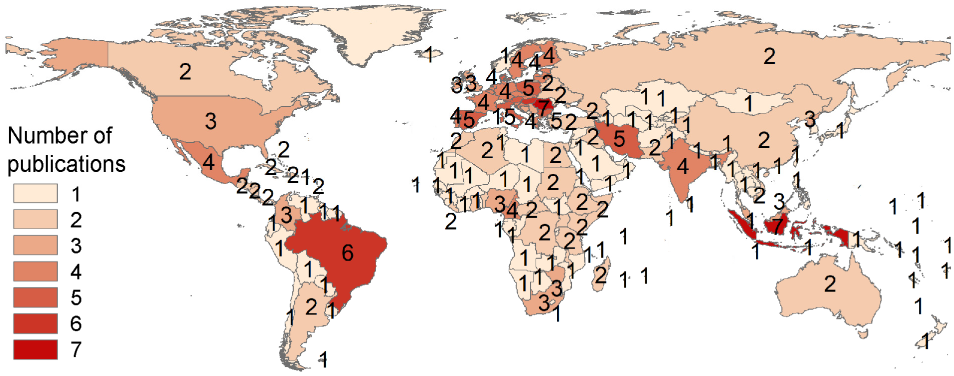

Figure 4. Application per country. Note: The publication count in the legend scale corresponds to the number on the label.

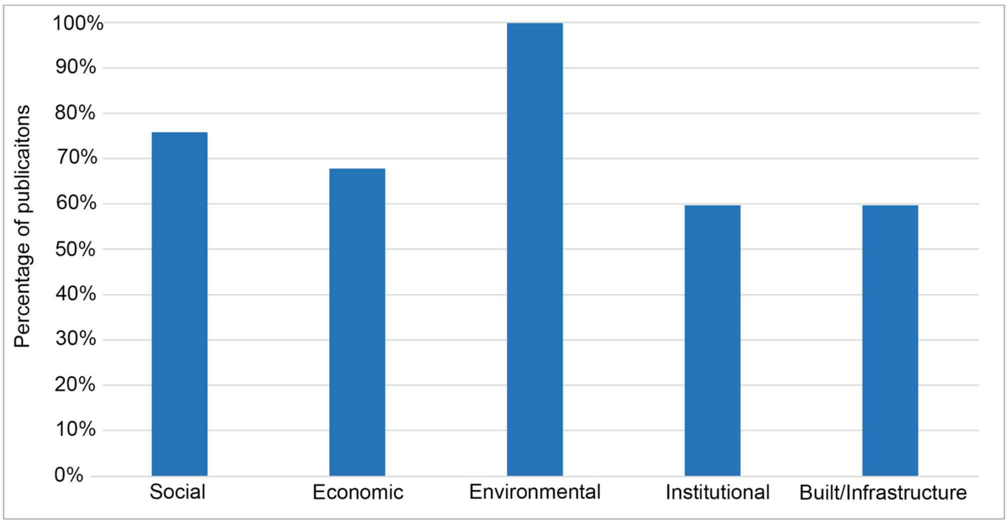

Figure 5. Input data domains.

Figure 7 presents the number ranges of the variables used as the input. The scale for which the index was designed or applied varied across different contexts. The application of indices is presented in Figure 8. It shows that nearly half of the publications conducted research on a general assessment of water resource management, while only 6% of the publications projected future water sustainability. Figure 9 and Table 2 present the six clusters.

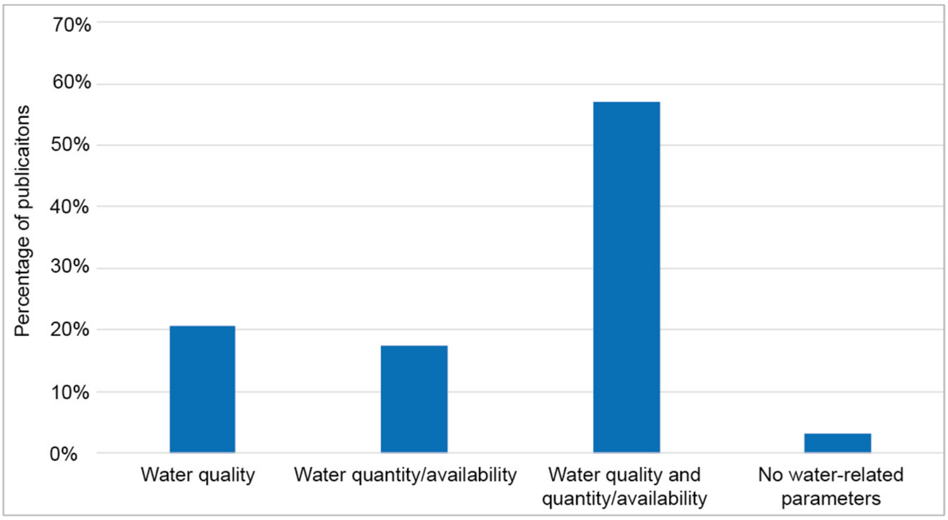

Figure 6. Water data as the input.

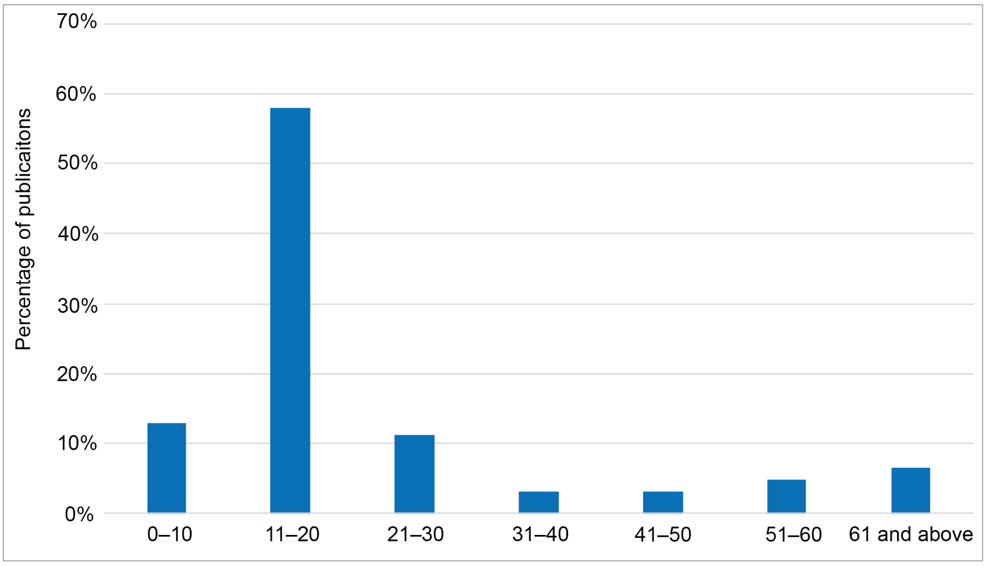

Figure 7. Number of variables used as the input.

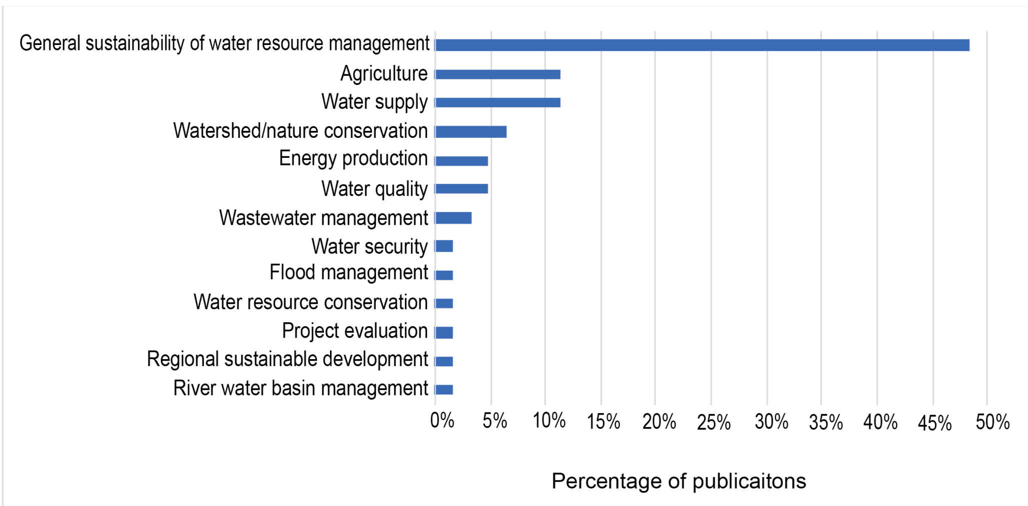

Figure 8. Application of the indicator in the reviewed publications.

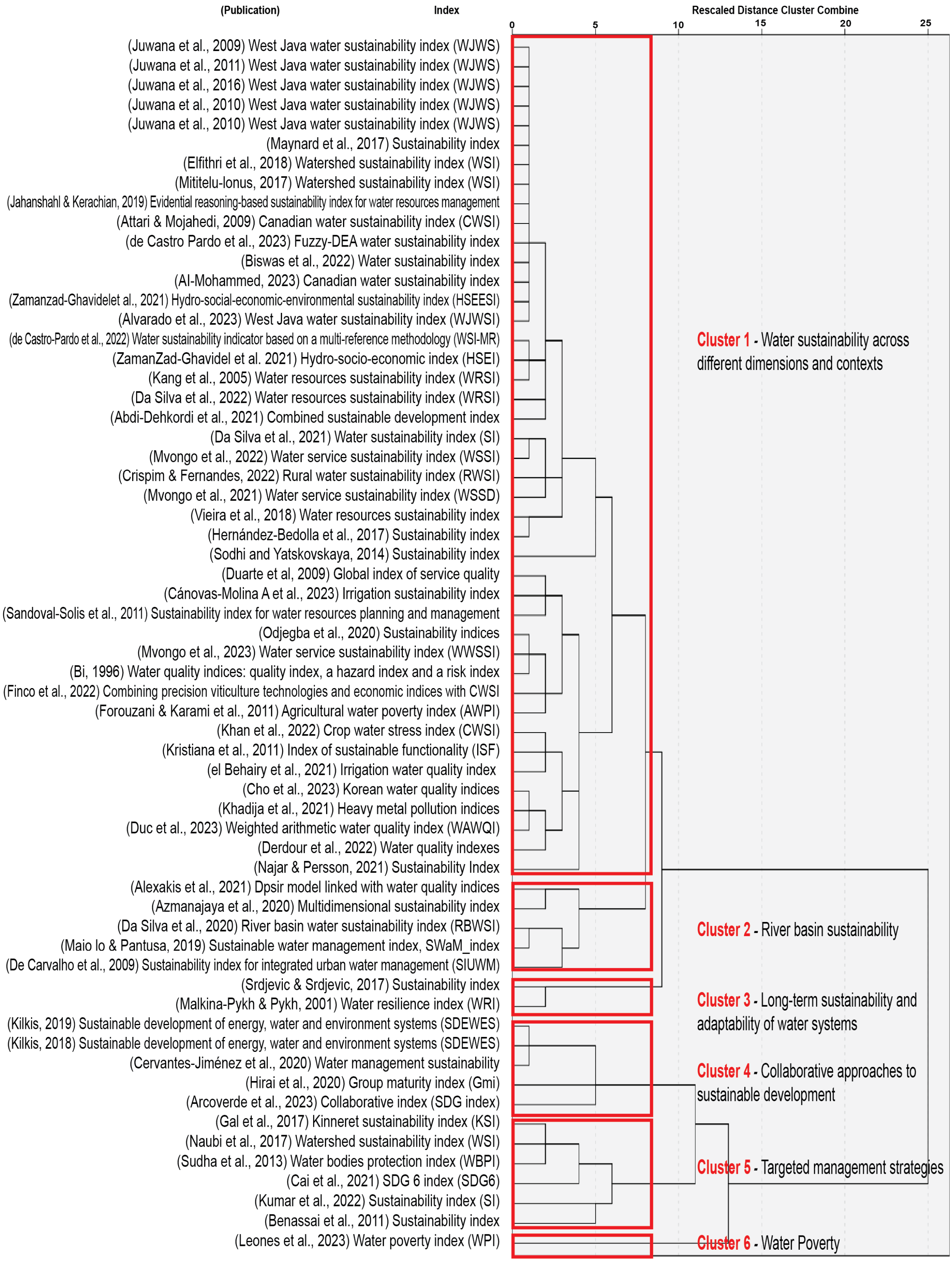

Figure 9. Dendrogram of the cluster analysis [15,37–97]. Note: The list of indices and publications is located in Supplementary Materials Table S2.

Table 2. Clusters.

Cluster	Indices
1	30 Publications, indices: agricultural water poverty index, Canadian water sustainability index, combined sustainable development index, combining precision viticulture technologies, crop water stress index, evidential reasoning-based sustainability index, fuzzy-DEA water sustainability index, global index of service quality, heavy metal pollution indices, hydro-socio-economic index, hydro-social-economic-environmental sustainability index, index of sustainable functionality, irrigation sustainability index, irrigation water quality index, Korean water quality indices, rural water sustainability index, sustainability index for water resources, sustainability index, water resources sustainability index, water service sustainability index, water sustainability index, watershed sustainability index, West Java water sustainability index; water quality indices: quality index, a hazard index, water service sustainability index, and weighted arithmetic water quality index.
2	5 Publications, indices: river basin water sustainability index, sustainable water management index, water quality indices (with the DPSIR model), multidimensional sustainability index, and sustainability index for integrated urban water management.
3	2 Publications, indices: sustainability index and water resilience index.
4	5 Publications, indices: collaborative index (SDG index), group maturity index, sustainable development of energy, water, and environment systems, and water management sustainability index.
5	6 Publications, indices: Kinneret sustainability index, sustainability index, water bodies protection index, watershed sustainability index, and SDG 6 index.
6	1 Publication, index: water poverty index

Note: Different indices may have the same name.

4. Discussion

4.1. Publication Groups Based on Keywords and SDGs Addressed

In the scientific literature, a wide range of composite, indicator-based frameworks for water sustainability have been described. Despite the differences in the details, their core idea is to combine specific and relatively easily available indicators to assess water sustainability in general or specific aspects pertaining to it. Sustainable development, water resources, water supply, sustainability, and water conservation were frequently co-occurring keywords related to the indices, which suggests that these topics are closely linked in the context of sustainability and water-related indices (Figure 2). The presence of these keywords together indicates a focus on addressing water-related challenges while considering the principles of sustainable development and the conservation of water resources. The first sub-group suggests a recognition of the need for sustainable water management practices in rural regions to meet the demand for water while considering environmental and social factors. The second sub-group highlights the importance of maintaining and improving water quality, addressing water scarcity issues, minimizing water loss, and promoting conservation efforts as integral components of sustainable water management. The third sub-group's broad range of keywords indicates an emphasis on understanding the complex dynamics and challenges associated with water resource management. It underscores the necessity of informed decision-making in the face of climate change and the need for effective strategies to address issues related to irrigation, rivers, and water pollution. The fourth sub-group suggests an interest in leveraging cutting-edge technologies and analytical techniques to enhance water management practices, mitigate uncertainties, and improve the overall efficiency and accuracy of water-related processes. The fifth sub-group signifies the recognition of the interconnected nature of water resources and the need for comprehensive strategies that consider the holistic management of both surface and sub-surface water systems.

By encompassing the social, environmental, and economic dimensions of sustainable development, SDG 6 reflects the interconnectedness of water with both planetary and socioeconomic objectives, including interlinkages with all other sustainable development goals [14]. The analysis showed that aside from SDG 6, indices directly or indirectly address a number of different SDGs (Figure 3). The most prominent finding is the strong linkage between SDG 6 and SDG 13 (climate action), SDG 2 (zero hunger), and SDG 7 (affordable and clean energy), and relatively strong links with "SDG 1" (no poverty), SDG 11 (sustainable cities and communities), and SDG 14 (life below water). This indicates the multidimensional nature of the indices related to water sustainability.

4.2. Domains for Holistic Sustainable Development

The indices incorporated variables from multiple domains (Figure 5). These domains encompass social, institutional, economic, built/infrastructure, and environmental aspects, each playing a crucial role in shaping water management strategies and policies. Social factors within water sustainability indices often encompass aspects such as access to clean water, sanitation, and public health. By including social indicators, indices can assess the equity and inclusivity of water resource management, ensuring that the needs of all communities are addressed [98]. Variables related to the social domain were present in 76% of the reviewed papers, making it the second dominant domain in sustainability assessment. Institutional dimensions focus on governance structures, policies, and regulatory frameworks related to water management. Effective institutions and governance mechanisms are essential for ensuring efficient water allocation, enforcing regulations, and promoting stakeholder engagement in decision-making processes [99]. It was found that 60% of the reviewed publications recognized the importance of institutional capital. Economic considerations involve evaluating the cost-effectiveness of water management strategies, assessing the economic value of water resources, and promoting sustainable financing mechanisms for water infrastructure development and maintenance [100,101]. Economic domain-related variables were found in 68% of the reviewed publications. Built/infrastructure factors pertain to the physical infrastructure necessary for water supply, treatment, and distribution [102]. This includes assessing the resilience and efficiency of water infrastructure systems, as well as their capacity to adapt to changing environmental conditions and population growth. Built/infrastructure domain-related variables were identified in 60% of the reviewed papers, which was the same percentage as the institutional domain. Consequently, these two categories of variables were the least represented among the reviewed studies. Environmental aspects within water sustainability indices address the conservation of water resources, protection of aquatic ecosystems, and mitigation of water-related environmental risks such as pollution and habitat degradation. Evaluating environmental indicators helps ensure that water management practices are environmentally sustainable and do not compromise the integrity of ecosystems [103–105]. The environmental domains were found in all the publications, the most frequently used category of variables for water sustainability assessment. Furthermore, it was found that to facilitate the development of integrated and holistic strategies for addressing water-related challenges and advancing the goals of sustainable development, in 44% of the publications, variables from all domains, i.e., social, economic, environmental, institutional, and built/infrastructure, were applied. Examples of indices that apply to all domain indicators include the watershed sustainability index [37], water sustainability index [38], West Java water sustainability index (WJWSI) [39,40], and river basin water sustainability index (RBWSI) [15]. It is apparent that these tools recognize the interconnectedness of sustainability. By covering the domains ranging from social equity and institutional governance to economic viability, built infrastructure, and environmental integrity, these indices underscore the holistic approach required to address water-related challenges effectively. This holistic perspective acknowledges that sustainable water management entails more than just ensuring an adequate supply; it encompasses considerations of environmental health, socio-economic factors, and institutional governance. Therefore, including variables across multiple domains in water sustainability indices reflects a commitment to addressing the complex and interdependent nature of water resource management.

4.3. Indicator Systems and Applications

Furthermore, in the reviewed papers, indices incorporated a diverse range of indicators and metrics to evaluate the various aspects of sustainability. However, the specific metrics employed could vary from one indicator to another, with different ranges of variables applied (Figure 7), but the majority of publications employed indices that combined 11 to 20 variables. For instance, in the majority of reviewed publications, both water quantity/availability and quality were simultaneously considered as input parameters (Figure 6). On the other hand, water quality alone, without considering water quantity, was used as the primary metric in only one-fifth of the reviewed publications, while water quantity alone, without considering water quantity/availability, was utilized in an even lower number of publications. It is worth noting that water quality as a parameter does not consider seasonal changes. Several publications have addressed the seasonal variability in water supply, which may result in changes in water quality [41–43]. This underscores the critical need to incorporate seasonal dynamics into comprehensive water quality assessments, emphasizing their importance in accurately capturing and understanding water quality variations over time. Notably, only a small fraction of the publications with indices such as the group maturity index (GMI) [44] and sustainability index [16] did not incorporate either water quality or quantity/availability as input data. For example, the GMI, in terms of the natural resource domain, monitors the status of resource mapping and the stewardship of resources in urban areas [44]. Thus, there are examples of water sustainability indices that do not have water-related variables as the primary input data but rather elicit information necessary for water sustainability. In terms of complexity, the majority of indices are concentrated within the range of 10–20 variables, which seems to strike a balance between being comprehensive and manageable. These numbers may reflect a practical approach to index development and application, where researchers and practitioners find this range suitable for their specific purposes. It is worth mentioning that the choice of index scale can significantly impact the data requirements and the feasibility of implementation. Higher numbers of indices, while potentially offering a more comprehensive assessment, can pose challenges related to data availability and input requirements. Further research could delve into whether any of the reviewed papers specifically highlight optimal index values or provide a basis for the observed variation in scale choices. Understanding these factors can aid in making informed decisions when developing and applying sustainability indices.

In the analyzed publications, the input data time frames for the research studies varied, covering different periods. The majority of the publications focused on the present, indicating a focus on assessing the current state of water-related issues. This reflects the importance of understanding water resources' present conditions and dynamics and management practices for monitoring and advising decision-makers. One-fourth of the publications spanned from historical periods to the present (Supplementary Materials, Table S1). This suggests that researchers and practitioners recognize the value of incorporating historical data to gain insights into the long-term trends and patterns related to water resources. By considering historical data, it becomes possible to assess changes and developments over time, which is crucial for identifying patterns, evaluating the effectiveness of past interventions, and informing future strategies for the sustainability of the water. However, collecting historical data is challenging. Moreover, the analysis showed that the water sustainability indices revealed a relatively limited application of water sustainability indices for analysis that spanned from historical data to future projections. While historical data provides valuable insights into past trends and patterns, incorporating future projections is crucial for anticipating and preparing for potential challenges and changes in water resources [106].

These revised publications presented indicator systems comprising a diverse range of variables and metrics that captured various dimensions of water resource management, including quantity, quality, accessibility, and ecosystem health. By considering various factors, decision-makers can gain insights into the potential challenges and opportunities that lie ahead and develop proactive strategies to address them [107]. Moreover, the development and refinement of these indicator systems are essential for ensuring the accuracy, reliability, and relevance of sustainability assessments over time. As such, ongoing research and innovation in index systems are crucial in advancing our understanding of water sustainability and supporting informed decision-making processes.

4.4. Indicator Applications for Sustainability

Employed in the reviewed publications, water sustainability indices for various purposes highlighted the versatility and their broad scope in addressing diverse water-related challenges, supporting sustainable water resource management across different sectors and contexts (Figure 8). The sustainable management of water resources, water supply, and agriculture were categories that frequently defied the purpose of the indices. These categories, however, may not align with the overall goals of creating comprehensive sustainability indices because they are narrow in their focus and are not designed to be holistic. Examples of water sustainability indices in the agricultural sector, such as the agricultural water poverty index (AWPI) [86] and crop water stress index (CWSI) [45], emphasize efficient and sustainable water use in irrigation practices, crop production, and agricultural water management. Therefore, while these specialized indices are excellent for their specific applications, they may not be suitable for assessing sustainability comprehensively across all sectors, as they do not encompass the broader range of factors that are relevant to sustainability in their entirety. In this way, the narrow focus of these indices may not align with the overarching goals of creating comprehensive sustainability indices that are designed to capture the complexity and interrelatedness of sustainability issues across various domains.

Moreover, we found that in the majority of the publications, index implementation (71%) focused on regional or watershed scales, while urban areas and national scales accounted for 10% each, and rural areas represented 8% of the index applications. Business entities constituted 2% of the scale. In the overall application, the majority of countries received at least one index application due to global assessment with the sustainable development goal six index [46]. Among the countries reviewed, Brazil, Indonesia, India, Iran, member states of the European Union, and Mexico received a higher number of applications (Figure 4).

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4.5. Six Clusters of Water Sustainability Indices

The cluster analysis helped to group the cases that exhibited similar characteristics across the variables [108], and we were able to understand the relationships and dynamics within water resource management and sustainability further (Figure 9). The analysis revealed six distinct clusters, each characterized by a unique set of indices related to water sustainability. Cluster one encompasses a diverse range of indices, including the agricultural water poverty index [86], the Canadian water sustainability index [42,43], and various others, such as the sustainability index for water resource planning and management [47], reflecting a comprehensive approach to assessing water sustainability across different dimensions and contexts. Cluster two focuses on indices related to river basin sustainability (the river basin water sustainability index [15]), sustainable urban water management (the sustainability index for integrated urban water management, [48]), and a broader spectrum of sustainability (the multidimensional sustainability index [49]), highlighting the significance of integrated approaches in managing water resources. Cluster three consists of indices dedicated to overall sustainability and water resilience, addressing the long-term sustainability and adaptability of water systems (sustainability index [50] and water resilience index [51]). Cluster four emphasizes collaborative approaches to sustainable development, with indices like the collaborative index (SDG index) [52] and group maturity index [44], underscoring the importance of collective action and stakeholder involvement. Cluster five showcases the indices related to specific areas, such as the Kinneret sustainability index [53], water body protection index [54], and watershed sustainability index [55], emphasizing the need for targeted management strategies. Finally, cluster six consists of the water poverty index. The water poverty index (WPI) [56] was originally a metric that links water availability and poverty by measuring the impact of water scarcity on human populations [109], and in the reviewed study by Leones et al. (2023), the index was modified for the sustainability assessment of water ecosystems [56].

4.6. The Common "Sustainability Index" Represents Different Nature Water Indices

In the reviewed publications, we found that "sustainability" became a commonly used element in the name of the indicators. However, it does not imply that the scope or methodology are similar. Publications demonstrated that the "sustainability index" had diverse applications and contexts in which it was used. Some publications focused on water resource planning and management [50], water and wastewater management [57], the responsible use of water by companies [58], rural water management [59], offshore wind farms and aquaculture [60], integrated water resource management [61], and specific river watersheds [62]. Each publication focused on applying a sustainability index within its specific domain. The publications aimed to evaluate and assess sustainability within their respective contexts. Some publications sought to extend or refine the definition of the sustainability indexes [50], evaluate the sustainability of specific sectors or practices [57,59,60], or assess the impacts of climate change on integrated water resource management [61]. The publications employed different methodologies to develop and assess the sustainability indexes. Some publications utilized artificial neural networks (ANNs) for their assessment [58], while others evaluated case studies [57] or proposed specific frameworks [60]. Each publication emphasized specific considerations within its sustainability index. These considerations included factors such as water availability, quality, and conservation [50], resource efficiency and environmental impact [57], the responsible use of water by companies [58], equity and long-term viability in rural areas [59], environmental impacts and the economic viability of offshore sectors [60], climate change impacts on water resource management [61], and the sustainability of specific river watersheds [62]. In the case of the watershed sustainability index (WSI), we also found that different studies showcased variations in methodology and understanding. Elfithri et al. (2018) focused on the Langat River Basin in Malaysia, employing the WSI to analyze the environmental and socio-economic conditions based on the UNESCO-HELP state condition indicators [37]. Mititelu-Ionuş (2017) conducted research in the Motru River basin in Romania, developing a WSI using indicators such as water availability, water quality, land use, and education [63]. The study by Naubi et al. (2017) explored the Skudai River watershed in Malaysia, utilizing the WSI and the Promethee method to rank sub-watersheds based on flood damage and water quality deterioration [63].

4.7. Suggestions for Future Water Sustainability Indices Studies

Through our review, we discerned critical gaps in the current academic understanding of water indices, posing obstacles to long-term water sustainability goals. To overcome these hurdles, we advocate for future studies on water sustainability indices to prioritize key areas. Firstly, integrating historical water quality assessments and projecting future trends is essential for robust index design. Secondly, streamlining index complexity by focusing on pivotal metrics enhances usability. Thirdly, developing comprehensive indices that embrace the interconnectedness of sustainability issues across domains is imperative. Fourthly, crafting adaptable indices applicable to diverse contexts facilitates meaningful cross-regional comparisons, fostering a broader understanding of water challenges.

Embracing these principles in future research is crucial to bridging knowledge gaps and advancing sustainable water resource management.

By adhering to these guidelines, we can collectively propel toward a more resilient and equitable water future, ensuring a legacy of stewardship for generations to come.

5. Conclusions

In order to make informed decisions regarding water sustainability, it is essential to identify specific approaches and tools that can help. In this context, indices serve as valuable empirical assessment tools that can effectively evaluate different domains of sustainability in the context of water challenges. In this article, by examining and comparing different studies related to water sustainability indices, we provided a comparative analysis of various water sustainability indices, focusing on their underlying principles, methodologies, and potential applications. The analysis of co-occurring keywords revealed the close relationship between sustainable development, water resources, water supply, and water conservation in the context of water-related indices. Moreover, these indices demonstrate that they do not only address SDG 6 but also a number of other goals. The cluster analysis demonstrated there is a large diversity of existing indices, with six distinct clusters. This study found that even if indices have the same or similar name, methodologies and scope can vary vastly, and they cannot be categorized as the same index as underlined using the cluster analysis. One significant limitation is the lack of historical applications for many current water sustainability indicators and the lack of projections for the future. Without the ability to make past assessments or track changes over time and project the future, it becomes difficult to identify areas of improvement and measure progress toward water sustainability goals in the long term. Furthermore, many indices are quite complex, with a large number of variables applied and designed for watershed or regional levels, making them less useful in other contexts. An index should be adaptable and applicable to a range of contexts and locations, allowing for meaningful comparisons and assessments across different regions and settings. In conclusion, despite the limitations, the use of indices provides valuable tools for assessing and managing water resources sustainably, addressing various dimensions of sustainability, and supporting decision-making processes in different contexts and sectors.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w16070961/s1, Table S1: Variables' values and their count; Table S2: Indices listed in each reviewed publication; S.M.1. Full list of the reviewed papers.

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