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Water Efficiency and Management in Sustainable Building Rating Systems: Examining Variation in Criteria Usage

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Abstract: The building sector, due to the significant energy and environmental footprints it creates, needs to adopt sustainable approaches to help prevent global warming and climate change. Sustainable Building (SB) rating systems have been developed around the world as a method to promote sustainability in this sector. Water is one of the most vital natural resources, and is extensively consumed in the building sector. This article examines the coverage of water-related aspects in 11 prominent SB rating systems under the three key sustainability dimensions: environmental, economic, and social, using a comprehensive coverage analysis approach. Findings highlight a wide range of variation between the examined SB rating systems in terms of water attributes being assessed, water assessment criteria used, the optimal number of these criteria, and the weight assigned to them. Results also show that in general, most of the examined systems exhibit low representativeness and comprehensive coverage of major water subcategories and themes related to sustainable buildings. However, some moderate to high comprehensive coverage was found in water attributes that focus on the environmental and social aspects. The results indicate that representative and comprehensive coverage of social-related water attributes are less than that of environment-related water attributes. The results also highlighted the effectiveness of using coverage analysis techniques as a systematic and efficient way to assess comprehensive coverage of water criteria in SB rating systems.

Keywords: water; sustainable building rating systems; sustainable buildings; sustainability; dry regions

1. Introduction

Climate change is one of the biggest challenges the world faces today. It impacts wide ranging problems, including rises in sea level, seasonal disorders, food-insecurity, and increased natural catastrophes, such as flooding, droughts, and wild fires [1,2]. Scientific evidence suggests that the situation is on the verge of irreversible changes in major ecosystems of the planet, leading to adverse consequences [3]. The situation requires a paradigm shift in human activities, particularly in relation to consumption of natural resources. To mitigate the impacts of global warming and climate change, the concept of sustainability and sustainable development needs to be embedded in all human activities [4,5].

The building and construction industry is one of the major emitters of carbon dioxide (CO_2), leading to global warming and climate change [6–8]. The building sector accounts for more than 40% of materials consumption and over one third of total greenhouse gas emissions in the world [9,10].

Buildings contribute towards global warming not only through depleting resources, such as raw materials, water, and energy, but also by producing waste and harmful atmospheric emissions. In the United States, for example, buildings account for 40% of materials use, 38% of CO_2 emissions, and 30% of waste output [11].

Given their associated wide-ranging environmental burdens, countries across the world are moving towards sustainable buildings (SBs) through reducing overall environmental, social, and economic impacts of buildings. A sustainable building is resource-efficient, environmentally responsible, economical to construct and maintain, healthy, and socially responsible throughout its life-cycle. Globally, over the last couple of decades, a large number of SB rating systems have been introduced to assess and measure the performance of buildings and their sustainability. Prominent examples of such SB rating systems include the Building Research Establishment Environmental Assessment Methodology (BREEAM, UK), Leadership in Energy and Environmental Design (LEED, USA), Comprehensive Rating system for Built Environment Efficiency (CASBEE, Japan), Deutsches Gütesiegel Nachhaltiges Bauen (DGNB, Germany), Global Sustainability Assessment System (GSAS, Qatar), Building Environmental Assessment Method (BEAM, Hong Kong), and Green Star (Australia). A typical SB rating system assesses the performance of a building based on several attributes, including energy, water, materials and natural resources, waste, pollution, and health and well-being. Water is one of the most important natural resources considered vital in the area of building sustainability. All of the SB rating systems have adopted water as one of their main sustainability categories.

This article examines how different rating systems assess and incorporate aspects of water efficiency and management in their assessment of sustainable buildings. It investigates the use of water criteria in 11 prominent and widely-used SB rating systems with the help of a structured comprehensive analysis framework. This article is part of an ongoing research project designed to develop a SB rating system that fits Saudi Arabia's local conditions, needs, and sustainability goals. Saudi Arabia, and other countries in the Gulf Cooperation Council (GCC) region, severely suffer from lack of freshwater resources. Indeed, the GCC region is one of the most water scarce regions in the world [12]. Therefore, there is a need to benchmark how water use in buildings is assessed in a sample of prominent and widely-used SB rating systems.

2. SB RATING Systems and Water Significance

2.1. SB Rating Systems and Their Structure

SB rating systems are becoming increasingly popular in the architecture and building industries across the world [13–16]. Over the past three decades or so, tens of SB rating systems (also called green building rating systems) have been developed by various countries worldwide to assess the performance of buildings and their sustainability [15,17,18]. The objective of these systems is to improve the performance of buildings, minimize impact on environment, and set standards for buildings, among others. Typically, an SB rating system assesses or measures the performance of a building based on several attributes, such as energy, water, materials, natural resources, waste, health and well-being, pollution, land use and ecology, design innovation, socio-economic aspects, and building operation and management. While there are similarities among these rating systems, there are also differences. Typically, every country has its own conditions, such as available natural resources, socio-economic development, climate, local regulations, and type of building stock. This necessitates modifications and adjustments in SB rating systems to suit the particular needs and practices of a region. However, many of these systems are currently being used in countries and regions across the world beyond where they were originally designed for [19,20]; this raises the challenge of how to contextualize them for a specific context.

The literature suggests a lack of consensus on a specific definition of sustainable buildings [14,19–22]. However, it is possible to discern general agreement on the procedure to assess and quantify level of sustainability across indicator-based rating systems. As abstracted in Figure 1, SB rating systems are typically composed of a hierarchical structure of nested groups—categories, indicators, and criteria [14–16,23]. Categories are the top-level group representing the major sustainability aspects to be assessed by the rating system. Water, materials and resources, energy, indoor air quality (IAQ), and site and ecology are examples of categories. In some cases, categories may have several subcategories. Each building sustainability category (or its subcategories) is operationalized and quantified using a set of indicators [13,15]. Each SB indicator is composed of one or more measurable variables, usually called criteria. An SB indicator is typically a measurable attribute of a building with a proven contribution towards assessing and evaluating the performance and sustainability of buildings [15,20,24].

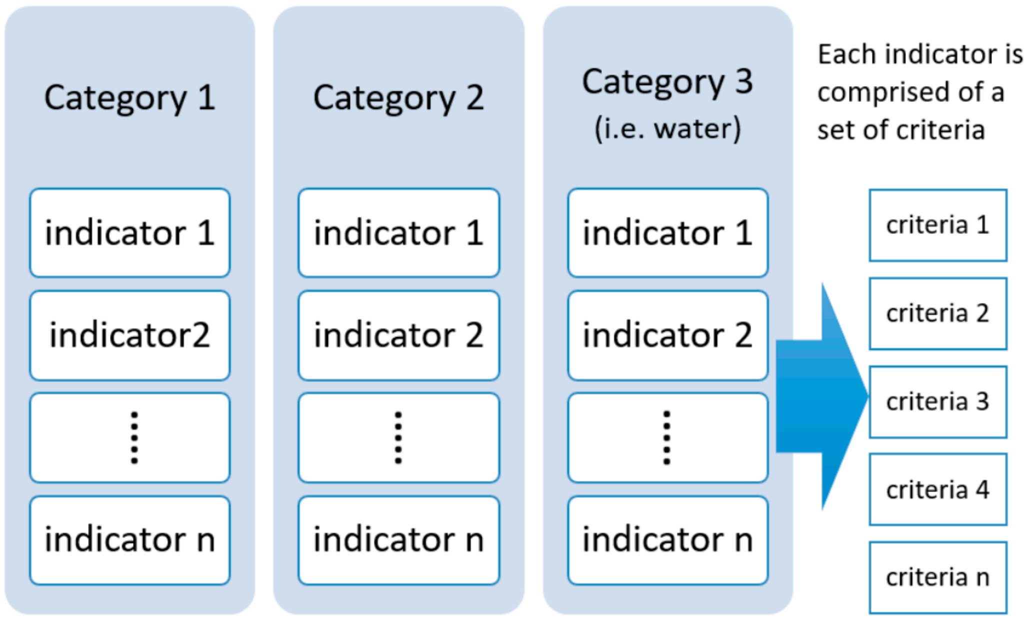

Figure 1. General structure of indicator-based sustainable building (SB) rating systems (source: authors).

The literature suggests that sustainability in buildings is comprised of three core dimensions: environmental, social, and economic [9,25,26]. Therefore, a comprehensive assessment of a building requires the use of a multidimensional rating system that covers all attributes related to these three core dimensions. Using more than one criteria or indicator to assess one sustainability attribute is a practice found in SB research, though it is currently being criticized to be inconsistent and may result in overweighting of some sustainability attributes [20].

All SB rating systems assign weight to SB categories, indicators, and criteria [20,23,27]. Weight is interpreted as the extent of the contribution of the respective category, indicator, or criterion to the sustainability of a building. The overall sustainability score of a building is calculated by aggregating the weights assigned to each criterion, indicator, and category in the rating system.

2.2. Significance of Water in SB Rating Systems

To save water resources in buildings, all of the existing SB rating systems, including the ones examined in this article, incorporate water conservation as one of their main sustainability categories. Water is a basic human need and is, therefore, one of the critical sustainability categories. The availability and quality of water is crucial throughout the life-cycle of buildings. For example, concrete is the backbone of the construction process and water is the essential ingredient to produce cement and concrete. Water is also one of the most commonly used natural resources in buildings during their operational phase. The significance of water is evident from the fact that two of the seventeen United Nation's Sustainable Development Goals (SDGs) directly address it [28]. Sustainability criteria commonly used in rating systems cover different aspects of water efficiency and management, such as water usage, water use reduction, water monitoring, use of efficient fittings, and use of grey and rainwater. Literature suggests that the implementation of water strategies and practices similar to those enforced by such criteria have a significant influence on water conservation, as well as other environmental benefits [29]. The water efficiency of buildings has been extensively examined by researchers, in addition to other parameters, such as energy-savings and carbon-reduction [30–33]. It has also been reported that SB rating systems have a positive impact on water savings [32,34]. Cheng et al. [32], for example, reported that, in Taiwan, the average water-saving rate for 1320 buildings certified with the local SB rating system during 2000–2013 is about 37.6%. These rating systems usually assess the water efficiency performance of sustainable buildings from various environmental and social perspectives, using dedicated criteria and indicators.

The significance of water in different rating systems is generally reflected through the weight assigned to water attributes of buildings in the form of points or credits. Each of the rating systems has its own weighting and aggregating scheme that differs from other systems [20,23]. The weight allocated to water varies among rating systems due to several factors, including climatic conditions, water scarcity and sustainability goals. For example, in the 11 examined systems, the weight assigned to the main "water category" varies between 2.4% in the DGNB rating system to 23.9% in the Pearl Rating System. In addition to the main "water category" that is incorporated in all of the examined systems, water efficiency and management aspects are also assessed under other categories. For example, the LEED rating system incorporates a main water category called "water efficiency—WE", which is assigned a weight of 10% out of the total weight. However, LEED also assesses water under other categories, such as the "sustainable sites—SS" category using the "Rainwater management" indicator. Thus, when evaluating the extent to which a rating system covers water aspects, it is not sufficient to examine the criteria and indicators under the main water category; one needs to examine water-related criteria and indicators of all other categories in the system.

3. Methodology

This article examines the level of coverage of water as a category in SB rating systems. For this purpose, 11 prominent and widely-used SB rating systems were selected for analysis. The comprehensive coverage analysis approach, developed by Al-Qawasmi [20], was adopted to assess water coverage in these systems. In this respect, a Comprehensive List of Water Criteria (CLWC) was compiled from all water criteria used in these SB rating systems. The consolidated list of CLWC provides a comprehensive set of water-related criteria that can serve as a base-case to benchmark coverage of water-related criteria in SB rating systems. The comparative coverage analysis is used to determine the degree of compliance of water criteria in each SB rating system with that of the CLWC; that is, to what degree each of these SB rating system covers water criteria as defined in the CLWC.

3.1. Development of the Comprehensive List of Water Criteria (CLWC)

The CLWC is a consensual list of unique water-related criteria found in the selected 11 SB rating systems. As illustrated in Figure 2, the CLWC is developed as follows. Based on an extensive literature review, 11 widely used SB rating systems from around the world were selected for analysis, as shown in Table 1. Various indicators related to assessing water usage in buildings, and their corresponding criteria, were then identified and tracked in the selected set of SB rating systems. This resulted in identifying a total of 67 water-related indicators that contain 81 criteria. Next, these indicators (and their criteria) were classified or categorized under sets of unique water subcategories and themes. A total of 9 water subcategories composed of 21 unique water themes were identified in the examined 11 systems. The 67 water indicators (and their criteria) were categorized under the 9 identified water subcategories and 21 water themes, as shown in Table 2. Subsequently, the 9 subcategories of CLWC are further divided under the three core sustainability dimensions of buildings (i.e., environmental, social, and economic). However, since none of the water-related criteria are expressed in economic terms or are intended to explicitly assess water from the economic aspects of building sustainability, the economic dimension of sustainably, as related to water, was set aside in our analysis; that is, we organized all water criteria under environmental and social aspects of sustainability based on the main concern or focus of the indicator or criteria. Although some of the water criteria may have an implicit impact on the economic dimension of sustainability, we did not consider this impact, as we focused on the main issue(s) explicitly intended for each criterion. As a result, the water criteria in the CLWC have been grouped under two sustainability dimensions: environmental (which includes all criteria that assess "environmental load") and social (which includes all criteria that assess "building qualities that impact social and health aspects"), as shown in the first column of Table 2.

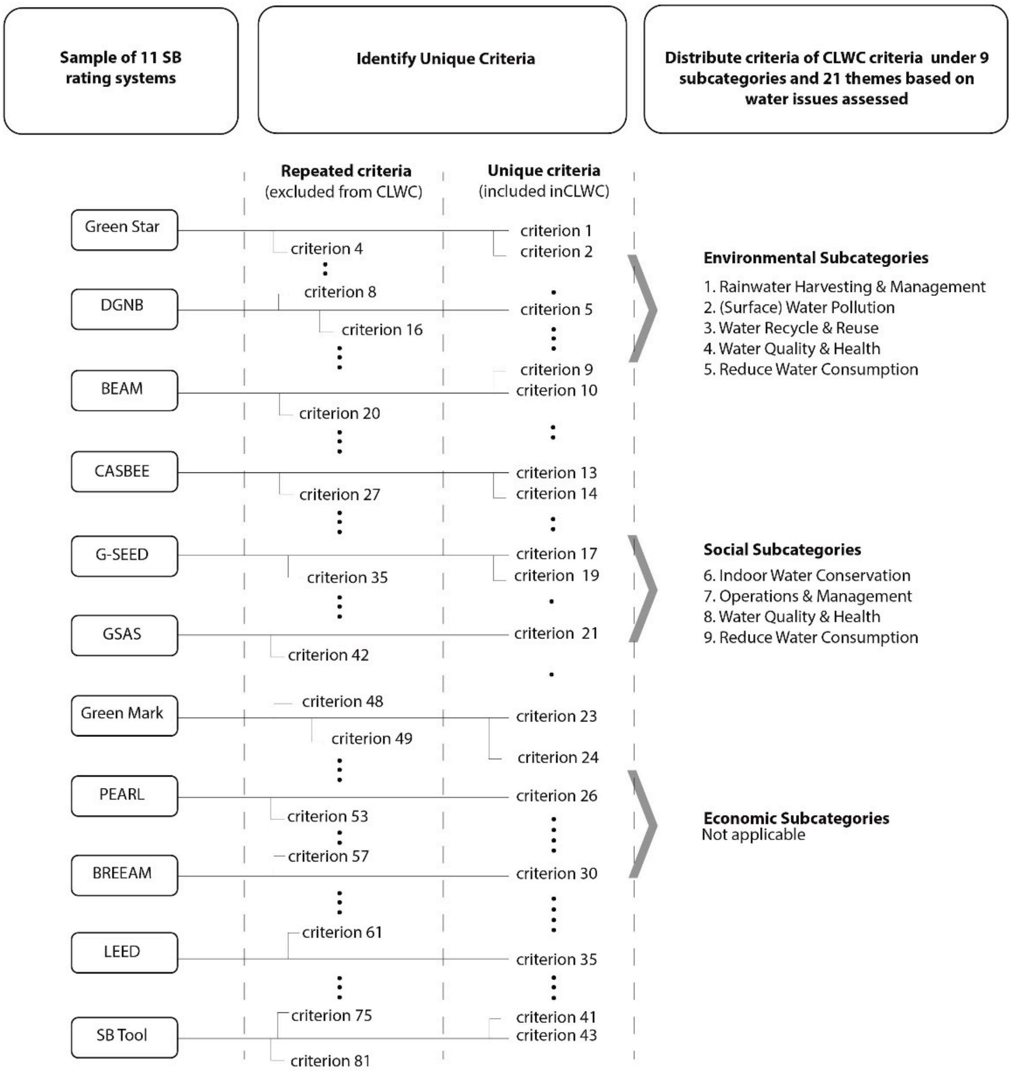

Figure 2. Process of developing the Comprehensive List of Water Criteria (CLWC) (source: authors, adapted from a previous study [20]).

In the compilation of the CLWC, the classification and terminology used in the analyzed 11 SB systems were adopted wherever possible. Two conditions were considered while forming the CLWC. First, only unique water criteria that assess different and distinctive water-related attributes were included in the CLWC. As water criteria are usually defined and measured differently in different rating systems, and to avoid repeating criteria in the CLWC as a result, the uniqueness of a criterion is evaluated at two levels: (1) the operational definition of the criterion, including its intent and unit of measurement; and (2) the unit of analysis (i.e., outside the building, inside the building, component of a building, etc.). A criterion must demonstrate uniqueness at both levels in order to be included in the CLWC. Second, indicators and their criteria usually demonstrate synergies, e.g., they influence two or more of the three dimensions of sustainability (environmental, social, and economic). The decision to assign a specific criterion to a specific environmental, social, or economic sustainability dimension is made based on its main intention(s) as explicitly declared in the documentation of the rating system rather than on any potential synergy effect. Each of the water-related criteria is examined at the level of parameters and variables in order to determine the sustainability dimension it influences the most, and thus to assign it to the pertinent sustainability dimension.

Table 1. Overview of the 11 examined SB Rating Systems.

Code	SB Rating System	Launch Date	Version of the System	Country	No. of Indicators	No. of Water Indicators	No. of Water Criteria
Gstar	Green Star	2003	Ver. 1.0 (2014)	Australia	34	3	4
DGNB	DGNB	2008	Ver. 2012	Germany	141	2	2
BEAM	BEAM	2012	Ver. 1.2	Hong Kong	67	10	11
CASBEE	CASBEE	2004	2014	Japan	101	7	8
GSEED	G-SEED	2002	2013	Korea	54	4	4
GSAS	GSAS	2009	Ver. 2.0 (2013)	Qatar	58	6	7
GMark	Green Mark	2005	4.1	Singapore	22	4	7
Pearl	Pearl Rating System	2010	Ver. 1.0	United Arab Emirates	86	8	12
BREEAM	BREEAM	1990	2014	United Kingdom	52	5	8
LEED	LEED	2000	Ver. 4.0	United States	55	6	8
SBTool	SBTool	2007	2014	International	115	10	10
		Total			785	65	81

3.2. *The Coverage Analysis Approach*

The CLWC was developed to serve as a base-case in order to undertake a comprehensive coverage analysis, in which water criteria in each rating system is examined in comparison with water criteria available in the CLWC as a base-case. The purpose of this analysis is to gauge the level to which the criteria of the CLWC are included (literally or using similar terms) in each SB rating system. In reference to Table 2, the coverage analysis was conducted as follows: the 9 water subcategories and the 21 unique water themes of the CLWC are listed in the second column of the table; then every water criterion in each one of the 11 analyzed systems (shown in the upper row of the table) is compared with corresponding criterion in the CLWC to determine if this criterion is included in the rating system; and finally, each rating system is assessed to determine the level to which a particular system complies with all CLWC conditions.

Table 2. Data of the coverage analysis of the 11 SB rating systems.

SB Dimension		Subcategories and Themes of the CLWC Criteria	Gstar	DGNB	BEAM	CASBEE	GSEED	GSAS	GMark	Pearl	BREEAMM	LEED	SBTool	Total
Environmental Load Aspects	**1**	**Rainwater Harvesting and Management**												
		1. Rainwater harvesting	0	0	0	1	1	0	0	0	0	0	2	4
		2. Reduce rainwater load	0	0	0	1	1	1	0	0	1	0	0	4
		3. Stormwater Management	0	0	0	0	0	0	1	1	0	1	1	4
		Total of subcategory	0	0	0	2	2	1	1	1	1	1	3	12
	2	**(Surface) Water Pollution**												
		4. Potential to contaminate nearby water bodies during operation	1	0	1	0	0	2	0	0	0	0	3	7
		5. Potential to contaminate nearby water bodies during construction	0	0	1	0	0	0	0	0	0	0	0	1
		Total of subcategory	1	0	2	0	0	2	0	0	0	0	3	8
	3	**Water Recycle and Reuse**												
		6. Split grey/potable water system	0	0	0	0	0	0	0	0	0	0	1	1
		7. Grey water use system	0	0	1	1	1	0	0	0	0	0	0	3
		Total of subcategory	0	0	1	1	1	0	0	0	0	0	1	4
	4	**Water Monitoring and Control**												
		8. Indoor water metering	1	0	1	0	0	1	1	1	1	1	0	7
		9. Outdoor water metering	1	0	0	0	0	1	1	1	1	1	0	6
		10. Water monitoring and leak detection	0	0	0	0	0	1	1	1	2	0	0	5
		Total of subcategory	2	0	1	0	0	3	3	3	4	2	0	18
	5	**Outdoor Water Conservation**												
		11. Efficient irrigation systems	0	0	1	0	0	0	1	1	0	1	0	4
		12. Landscape related measures	0	0	0	0	0	0	1	1	0	1	1	4
		13. Outdoor water reduction using other approaches	0	0	0	0	0	0	0	2	0	0	0	2
		Total of subcategory	0	0	1	0	0	0	2	4	0	2	1	10
		Total of all environment-related subcategories	3	0	5	3	3	6	6	8	5	5	8	52
Qualities related to Social and Health Aspects of Building	**1**	**Indoor Water Conservation**												
		14. Water efficient fixtures and fittings	0	0	2	1	1	0	1	2	1	1	0	9
		15. Indoor water reduction using other approaches	0	0	1	1	0	0	0	2	0	1	0	5
		Total of subcategory	0	0	3	2	1	0	1	4	1	2	0	14
	2	**Operations and Management**												
		16. Integrative building design processes to save water	0	1	0	0	0	0	0	0	0	0	0	1
		17. Durability and serviceability	0	0	0	3	0	0	0	0	0	0	0	3
		Total of subcategory	0	1	0	3	0	0	0	0	0	0	0	4
	3	**Water Quality and Health**												
		18. Potable water quality	0	0	1	0	0	0	0	0	0	0	1	2
		19. Biological contamination	0	0	1	0	0	0	0	0	0	0	0	1
		Total of subcategory	0	0	2	0	0	0	0	0	0	0	1	3
	4	**Reduce Water Consumption**												
		20. Potable water demand	1	1	1	0	0	1	0	0	1	0	1	6
		21. Consumption of process water	0	0	0	0	0	0	0	0	1	1	0	2
		Total of subcategory	1	1	1	0	0	1	0	0	2	1	1	8
		Total of all social related subcategories	1	2	6	5	1	1	1	4	3	3	2	29
		Grand Total	4	2	11	8	4	7	7	12	8	8	10	81

3.3. Overview of the Selected SB Rating Systems

An extensive literature review was conducted to select a sample of SB assessment systems in this analysis. The authors used two main criteria to select a SB assessment system to include in the analysis. Firstly, the system should be intended to assess all core dimensions of building sustainability (i.e., environmental, social, and economic). Secondly, the system should be well established and a real-world assessment system. Regarding the first condition, unidimensional assessment systems that focus on a particular sustainability outcome (e.g., health, social, or environmental aspects) were excluded. For example, the WELL Building Standard, though it is becoming a popular assessment system, is excluded from analysis since it focuses mainly on well-being and social aspects of building sustainability. From this perspective, the 11 SB rating systems selected for analysis in the present study are well established and real-world systems in use across a broad range of countries and regions worldwide. Of these, SBTool provides a generic framework and sets of criteria for SB assessment. Table 1 provides a list of examined SB rating systems, along with an overview of their basic features. All of these systems are indicator-based systems developed over the past three decades. The present study attempted to examine the latest versions of these systems where possible. From their documentation, these systems appear to be designed based upon specific rationales and solution-focused approaches aligned with market needs and regional practices instead of any well-established theoretical framework of building sustainability. Typically, these systems include different schemes dealing with certain types and phases of buildings. This article examines schemes of rating systems that are dedicated for new "design and construction". While PEARL and GSAS have been developed for hot desert climates of GCC countries, the rest of the systems are designed for regions with an abundance of freshwater.

4. Coverage Analysis and Results

The coverage analysis examines the extent to which water criteria in the 11 SB rating systems comply with the requirements of the CLWC. Table 2, showing the results of the coverage analysis, is created by assigning each water theme included (literally or using similar terms) in a rating system an integer number "n" that represents the number of criteria provided in that specific theme. For example, the "rainwater harvesting" theme is denoted "0" under "Gstar", "1" under both "CASBEE" and "GSEED", and "2" under "SBTool", suggesting that the "Green Star" rating system has no criteria to assess "rainwater harvesting", while "CASBEE" and "GSEED" have one criterion each, while SBTool has two criteria.

Figure 3 presents the findings of the depth of coverage analysis, where 100% indicates the total number of water criteria provided in any rating system, while the height of the bar segment indicates the percentage of CLWC themes covered by 0, 1, or 2 or more criteria (i.e., n-criteria) in the respective rating systems.

Figure 4a–c shows the representativeness of coverage, where 100% represents the complete coverage of all water themes in CLWC, while the height of the bar-segments corresponds to the percentage of water themes listed in CLWC that are covered in respective rating systems; that is, the percentage of the water themes in each rating system that include criteria relative to the total number of water themes in CLWC.

Figure 5a–c depicts the results of comprehensiveness of coverage, where 100% represents complete coverage of all CLWC subcategories, while the height of the bar-segments corresponds to the percentage of CLWC covered in each rating system; that is, the percentage of water subcategories that are covered or assessed by criteria in each rating system relative to the total number of water subcategories in CLWC.

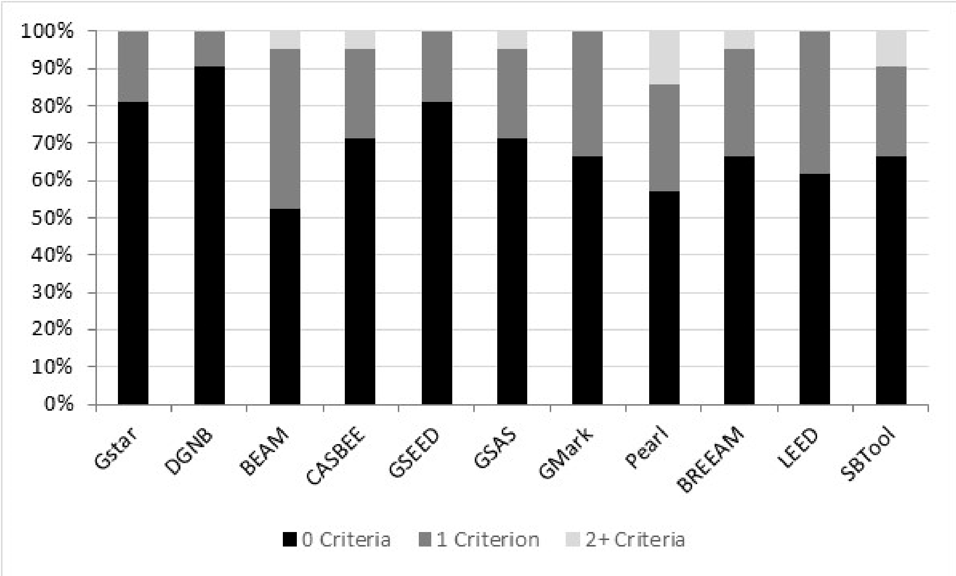

Figure 3. The percentage of CLWC themes covered by 0, 1, and 2+ criteria in each rating system (i.e., depth of coverage).

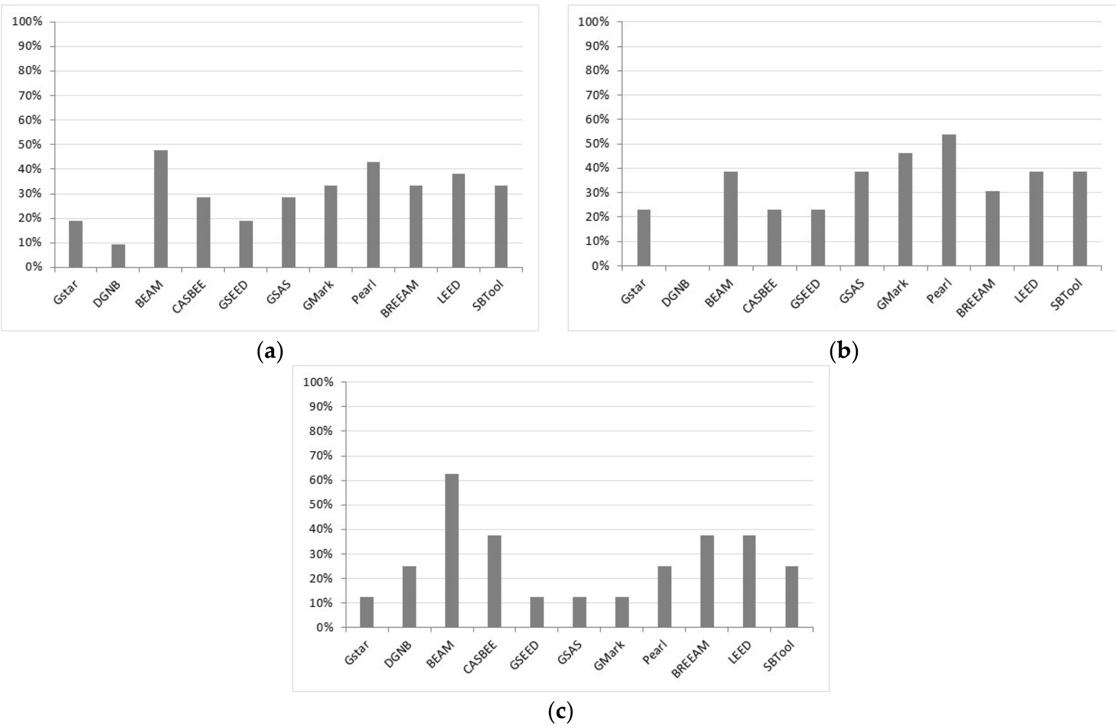

Figure 4. Representativeness of coverage. The percentage of water themes available in a rating system relative to the water themes in the CLWC: (**a**) all water themes; (**b**) environment-related water themes; (**c**) social-related water themes.

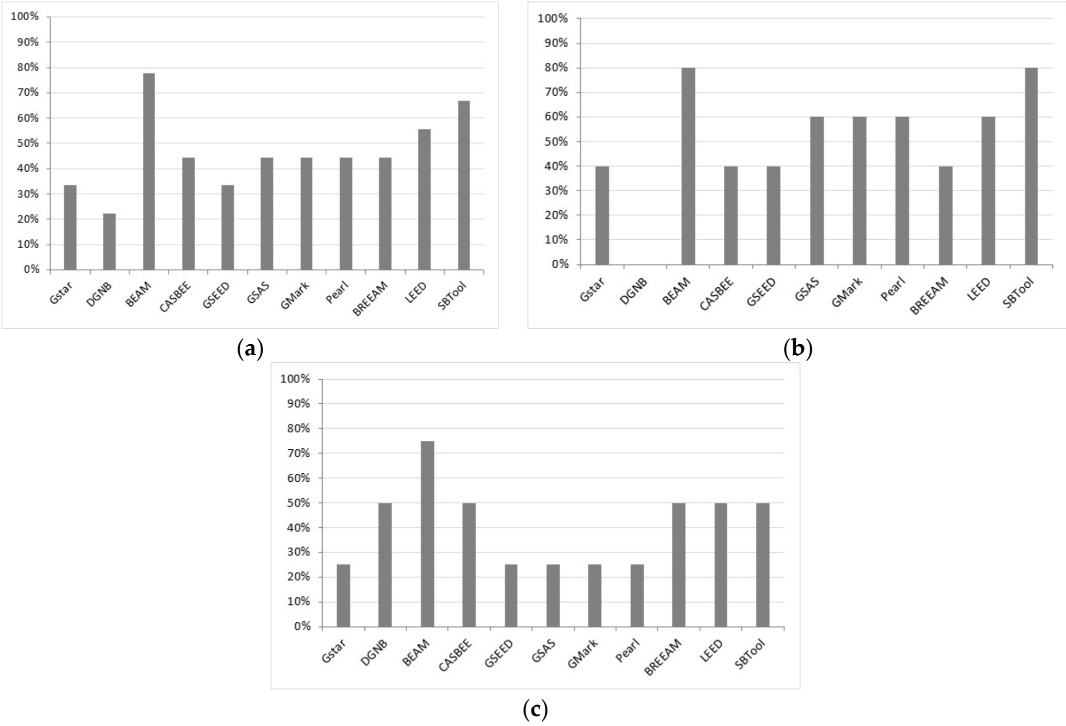

Figure 5. Comprehensiveness of coverage. The percentage of water subcategories available in a rating system relative to water subcategories of the CLWC: (**a**) all water subcategories; (**b**) environment-related subcategories; (**c**) social-related subcategories.

5. Findings and Discussion

The sections below discuss and highlight the results and findings of the study.

5.1. Weight of Water Aspect in SB Systems

Figure 6 demonstrates that the weighting allocated to water-related categories varies from less than 3% (in DGNB) to almost 24% (in PEARL) of the total system weight. Among the studied rating systems, PEARL and GSAS assign the highest weight for water attributes. While the PEARL system, developed by the United Arab Emirates, allocates 23.9% of its total weight to water aspects, the GSAS, developed by Qatar, dedicates 19.6% of its total weight to water. Both of these systems are in the GCC region that severely suffers from lack of freshwater resources. All other systems (9 out of 11) allocate between 10% to 15% of their total weight to water, except DNGB (Germany), which assigns 2.4%, the least weighting assigned to water. While 10% to 15% of system weight assigned to water seems reasonable in systems developed in regions with abundance of freshwater resources, it is on the low side for countries that suffer from lack of freshwater resources.

These results provide an appropriate benchmark regarding water weight in rating systems in countries with a hot and dry environment. Saudi Arabia and other GCC countries, for example, are amongst the top 10 most water-scarce countries in the world, with annual freshwater supply of less than 84 m^3/person [35].

5.2. Number of Water Criteria

The results of the analysis reveal wide variations across the analyzed SB rating systems in terms of the number of criteria used to assess water aspects of sustainable buildings. The number of water-related criteria used in any specific system range from 2 to 12, as shown in Table 1. Although the 11 systems contain a total of 81 water criteria, of which 43 are unique ones, each rating system uses a small number of these criteria, varying between 2 and 12. Such a wide variation in the number of criteria used in different systems makes it challenging to determine the optimal number of criteria to be used in assessing water-related aspects in sustainable buildings. However, as highlighted in the discussion below, it can be argued that using 2 criteria to assess or measure water efficiency and management in SBs, as is the case in DGNB, is insufficient and limits the system's ability to appropriately assess the wide range of water efficiency and management in SBs.

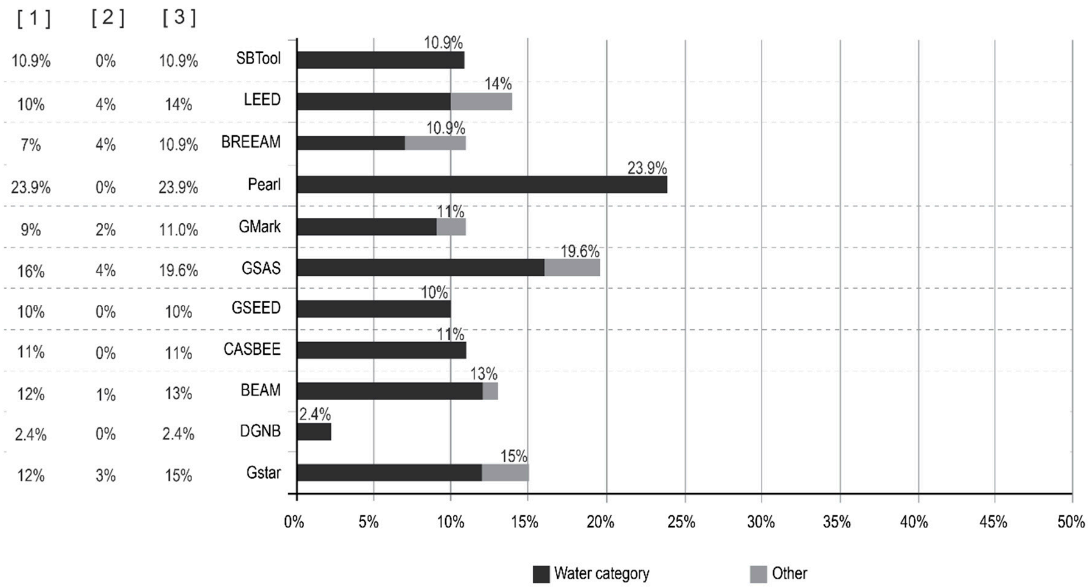

Figure 6. Total weight of the water category as a percentage of the total weight of each SB rating system. [**1**] Weight of water in the main water category, [**2**] weight of water in other categories, [**3**] total weight of water in both main water category and other categories. Note: In CASBEE, all SB categories, including water category, are calculated as load reduction and environmental quality; the reported weights represent the combined effect.

5.3. Frequency of Using Water Criteria

The examined rating systems contain a total of 81 water criteria, of which 53% (43 out of 81) are unique criteria. The analysis reveals that about 40% (17 out of 43) of the unique criteria are used in only one of the total 11 systems. Using a criterion in only one rating system may suggest that all other systems do not regard it as an important attribute towards assessing water efficiency in sustainable buildings. Therefore, it can be argued that a large portion (40%) of unique criteria are not considered as important towards assessing water efficiency in buildings. This result reveals a lack of consensus amongst the examined SB systems regarding a major set of criteria that defines water efficiency practices in sustainable buildings. Only 60% (26 out of 43) of the unique criteria are used in two or more systems. This may suggest that the analyzed rating systems seem to measure or assess different water efficiency practices in SBs, which raises concerns about their reliability and validity.

Indicator-based rating systems are typically built using a hierarchical structure composed of criteria, indicators, subcategories, and categories, and thus should be accordingly evaluated at the different levels of the hierarchy. As discussed below, using the CLWC as a base-case, a three level coverage analysis is undertaken to evaluate the extent to which the criteria used in each rating system covers all water efficiency and management aspects in SBs. The coverage analysis is conducted at three nested levels: the criteria level (discussed in Section 5.4), the level of water themes and issues (discussed in Section 5.5), and the level of water subcategories (discussed in Section 5.6).

5.4. Depth of Coverage

The depth of coverage is used to analyze coverage at the level of water themes and issues and is calculated based on data at the level of criteria (or indicators) of a rating system. Results of the analysis, as shown in Table 2, suggest that while some water themes are measured or assessed with the help of more than one criterion, there are other important water themes that are not covered at all. The number of criteria used to assess a specific water theme represents a gauge of its depth of coverage. "Deep coverage" of a water theme occurs when a rating system includes more than one criterion to assess or measure that specific theme. For example, as shown in Table 2, both the Green Star and BEAM rating systems include one criterion to assess the water theme titled "potential to contaminate nearby water bodies during operation". SB Tool uses three criteria, while the other eight rating systems use no criterion to assess the same theme. The percentage of water themes assessed by zero, one, and two or more criteria in each one of the examined systems is presented in Figure 3.

As highlighted in Figure 3 and Table 2, 52% to 90% of all water themes in BEAM and DGNB, respectively, do not include any water criterion at all, thus indicating a lack of depth of coverage. This is a major concern because it indicates that several critical building water themes are not covered or assessed by those rating systems. Data, for example, shows that 5 (out of 11) systems—Green Star, DGNB, G-SEED, Green Mark, and LEED—do not use deep coverage to assess any water theme. On the other hand, 6 systems display deep coverage by using more than one criterion to assess water themes. While deep coverage helps improve the accuracy of assessment of a particular water theme, it may also have drawbacks in terms of redundancy and possible overweighting of those themes, or it may result into underrepresentation of other themes, as discussed above. Thus, there is a need to balance breadth and depth of coverage to ensure that all water themes in SBs are optimally assessed. This is particularly true when the rating system uses a low number of criteria to assess water efficiency and management in a SB.

5.5. Representativeness of Coverage

The representativeness of coverage analysis is used to describe coverage at the level of water subcategories and is calculated based on data at the level of water themes. In this article, representativeness of coverage of a water subcategory (or set of water subcategories) is defined as the percentage of water themes covered in a rating system relative to all water themes available in the CLWC under that specific water subcategory (or set of subcategories). The representativeness of coverage determines the degree to which the water subcategory in a rating system covers a reasonable percentage of all water themes specified in the CLWC. Data in Table 2 demonstrates the representativeness of coverage in the 11 examined systems.

5.5.1. Representative Coverage across All Water Subcategories

Examining the representativeness of coverage across all water themes reveals that all the rating systems exhibit a lack of or low representative coverage, as each one of them covers 45% or less of the water themes specified in the CLWC, except BEAM, which covers 48%. This indicates that in all rating systems, over 52% of water themes specified in the CLWC goes unmeasured by any criterion, which suggests a lack or low representative coverage. As shown in Figure 4a, 9 of the 11 systems cover under 40% of the 21 unique water themes of CLWC, and 5 of those 9 systems cover below 30% of those water themes. The low representative coverage of water may suggest that most of the examined systems are not comprehensive enough, as they do not assess a large portion of important water themes. Comparing representativeness of coverage of water with other sustainability categories (e.g., material, energy, etc.) in these 11 rating systems, as reported by Al-Qawasmi [20], shows that it is significantly less. Al-Qawasmi [20] reported that representative coverage of various SB categories ranges between 40% to 77% [20]. Rating systems developed for hot arid regions with water scarcity, such as Saudi Arabia, should attempt to attain higher representative coverage that covers all or most of the important water themes in SBs.

5.5.2. Representative Coverage across Core Sustainability Dimensions

Examining the representativeness of coverage across the core sustainability dimension of buildings reveals low representative coverage of both environment- and social-related water themes, except for BEAM, which shows moderate representative coverage of environment-related themes, covering 63% of CLWC water themes. As indicated in Figure 4b, the representative coverage for water themes that focus on environment-related issues ranges between 0% (in DGNB) and 54% (in Pearl). On the other hand, as depicted in Figure 4c, representative coverage of water themes that focus on social-related issues ranges between 13% (as in Green Star, G-SEED, GSAS, and Green Mark) and 63% (in BEAM).

The results also show that water themes focusing on assessing environmental aspects exhibit higher representative coverage compared to those focusing on assessing social aspects. As shown in Table 2, and depicted in Figure 4b,c, the examined systems included 52 environment-related water criteria, covering 32% of the 13 water themes that focus on environmental impact and with less variation among different systems, compared to 29 social-related water criteria, covering about 27% of 8 water themes that focus on social impact. This suggests that there is a greater degree of agreement or consensus on the environment-related water themes compared to the social ones. This can be explained by the fact that SB rating systems are typically focused on environmental aspects, thus, are sometimes called Green building rating systems.

5.6. Comprehensiveness of Coverage

The comprehensiveness of coverage is used to analyze and examine coverage of building water aspects at the level of rating system and calculated at the level of water subcategories. The comprehensiveness of coverage of water aspects in a rating system (or in one core sustainability dimension of the system) is defined as the percentage of water subcategories included in the rating system (or one of its core sustainable dimensions) relative to all water subcategories available in the CLWC (or that specific core dimension in the CLWC). The objective of the comprehensive coverage analysis is to determine the comprehensiveness of the system in capturing all major water efficiency and management aspects of sustainable buildings. The highest level of comprehensive coverage is achieved when a rating system exhibits the full range of water subcategories in the CLWC, whether at the level of the system or one of its core sustainability dimensions. On the other hand, when the system or one of its core dimensions is not covered (i.e., no water subcategories are included) or are covered by an insufficient number of water subcategories, then it exhibits lack of comprehensive coverage. Figure 5a,c shows the comprehensiveness of coverage in the 11 examined systems, and below is a discussion of the findings in this regard.

5.6.1. Comprehensive Coverage across All Water Subcategories

The analysis of the comprehensive coverage across all main water subcategories shows that 73% (8 out of 11) of the systems exhibit low to moderate comprehensive coverage, as each one of them covers between 45% to 78% of all water subcategories specified in the CLWC. Figure 5a shows that BEAM exhibits the most comprehensive coverage followed by SBTool and LEED, covering 78%, 67%, and 56% of the CLWC water subcategories, respectively. DGNB, on the other hand, exhibits the least comprehensive coverage, covering only 22% (2 out of 9) of water subcategories, thus it does not cover important subcategories, such as rainwater harvesting and management, water recycle and reuse, indoor and outdoor water conservation, operations and management, and water quality. A similar argument applies to Green Star and G-SEED, as each of them covers only 33% (3 out of 9) of water subcategories listed in CLWC. It can be argued that 2 criteria (as in DGNB) or 4 criteria (as in Green Star and G-SEED) are too few to capture all water-related aspects in sustainable buildings. An interesting observation is that compared to other systems, some systems have achieved more comprehensive coverage using the same number of criteria or even less. For example, BEAM covers 78% (7 out of 9) of water subcategories using 11 criteria, while Pearl covers only 44% (4 out of 9) of water subcategories with 12 criteria. By the same token, GSAS and Green Mark achieved the same comprehensive coverage as that of PEARL with less criteria; that is, 7 water criteria instead of 12. Thus, it can be argued that the effective use of criteria can be achieved through selecting the appropriate criteria that ensures comprehensive coverage of all, or most, of the important water subcategories and themes rather than by increasing their number.

5.6.2. Comprehensive Coverage across Core Sustainability Dimensions

The analysis of comprehensive coverage across the core sustainability dimension of buildings shows that while six systems reveal high to moderate comprehensive coverage of both environment- and social-related water subcategories, all other systems exhibit low or lack of comprehensive coverage of those two dimensions. As shown in Figure 5b, BEAM and SBTool show high comprehensive coverage of environment-related subcategories, with each of them covering 80% of the relevant CLWC water subcategories. BEAM also shows adequate to high comprehensive coverage of social-related water subcategories, covering 75% of relevant CLWC water subcategories, as illustrated in Figure 5c. On the other hand, as shown in Figure 5b, four of the examined systems (i.e., GSAS, Green Mark, PEARL, and LEED) exhibit moderate comprehensive coverage of environment-related water subcategories, with each of them covering 60% of the environment-related water subcategories of CLWC. All other systems exhibit a lack of, or low comprehensive coverage of both environment- and social-related water subcategories, as each of them covers between 22% to 50% of the relevant water subcategories, except DGNB, which has no criteria in the environment-related subcategories, thus exhibiting absence of comprehensive coverage in this dimension.

The data presented in Figure 5b,c also demonstrates that environment-related water subcategories have higher comprehensive coverage compared to social-related ones. This result indicates that the examined systems lack in their ability to assess social-related attributes of water in sustainable buildings, compared to environment-related attributes. This result is supported by literature that raises concern about these systems for overly focusing on assessing environmental issues.

6. Conclusions

This article used the comprehensive coverage analysis approach to examine the coverage of water efficiency and management aspects in 11 prominent SB rating systems. In this approach a Comprehensive List of Water Criteria (CLWC) is compiled from all of the water criteria available in the examined rating systems, and is used as a base-case to benchmark the coverage of water-related criteria in each of these systems. Three coverage analysis techniques—depth of coverage, representativeness of coverage, and comprehensiveness of coverage—were used.

The results of the analysis indicate a lack of consensus among the examined systems in terms of the used set of building water criteria, the optimal number of criteria, and the water aspects being measured or assessed by these criteria. Of the 81 total available water criteria, the number used by systems ranged between 2 and 12. It is found that 40% of the unique water criteria are used in only one rating system, suggesting inconsistency and significant variation in these systems in terms of the criteria used. Therefore, it is likely that different rating systems would assess or rate the water efficiency in a particular building quite differently. This finding raises doubts regarding the wider applicability of these systems beyond the specific context they are developed in.

The coverage analysis results reveal an unbalanced coverage of water attributes across the examined systems. Results of the representativeness of coverage analysis reveal that the majority of the examined systems (10 out of 11) exhibit a lack of, or a low level of representative coverage, as each one of them exhibits less than 45% of water themes specified in the CLWC. The results also indicate that although deep coverage helps to obtain accuracy in assessment, it may also result in underweighting of other important attributes, especially in cases of systems with fewer criteria. Therefore, there is a need to balance the depth and breadth of coverage to ensure that water attributes are optimally assessed. Results from the comprehensiveness of coverage analysis show that 8 out of the 11 rating systems exhibit a low comprehensive coverage, with each of them exhibiting 45% or lesser degree of water subcategories specified in the CLWC. However, 6 systems (i.e., BEAM, SBTool, GSAS, Green Mark, PEARL, and LEED) demonstrate high to moderate comprehensive coverage of water attributes related to the environmental aspects in sustainable buildings. The results also indicate that the representative and comprehensive coverage of the social-related water subcategories are fewer compared to the environment-related water subcategories.

In addition to identifying some of the water-related coverage problems found in a sample of the widely-used SB rating systems, the results of the study demonstrate the effectiveness of using the coverage analysis techniques as an efficient approach to assess the comprehensive coverage of water criteria in SB rating systems. The approach is also potentially useful for enabling the selection of a representative and comprehensive list of criteria to ensure water efficiency in buildings while developing or designing new SB rating systems. This is particularly important for arid regions, such as GCC, which suffer severely from lack of freshwater resources.

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